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Gemma Dale
Brodie Reid

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Please be aware that this publication may contain images of Aboriginal and Torres Strait Islander people who are now deceased. Several variations of Aboriginal and Torres Strait Islander terms and spellings may also appear; no disrespect is intended. Please note that the terms 'Indigenous Australians' and 'Aboriginal and Torres Strait Islander peoples' may be used interchangeably in this publication.

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About the authors

Dr Gemma Dale
Lead author

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

Dr Brodie Reid

Dr Brodie Reid teaches secondary science and Years 11 and 12 ATAR Chemistry. He also has many years of experience teaching at the tertiary level and is an author of more than 10 academic publications. He has presented his research internationally, winning several awards along the way.

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

About the cover

Austromuellera trinervia, commonly referred to as Mueller's Silky Oak, is a rainforest tree found in north-eastern Queensland. It is listed as near-threatened under Queensland's *Nature Conservation Act 1992*. The tree reaches a maximum height of 18 metres and typically flowers between November and January.

Austromuellera trinervia

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Contents

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

How to use this resource

Elements in the print book

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

Explore!

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

Quick check

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

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

Did you know?

These are short facts that contain interesting information.

Science as a human endeavour

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

Section questions

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

Hands-on activities

Try this

Classroom activities help explore concepts that are currently being covered.

Making thinking visible

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

Practical skills

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

Investigation

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

End-of-chapter features

Chapter review

Chapter checklist

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

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

Chapter checklists help students check that they have understood the main concepts and learning intentions of the chapter. They come with example questions.

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

Data questions

A Year 9 student with diabetes measures their blood sugar level hourly and the data is plotted in blue in Figure 2.46. 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.

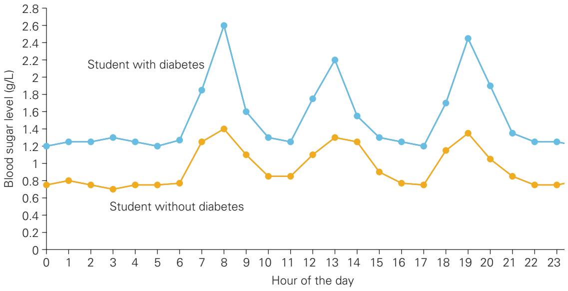
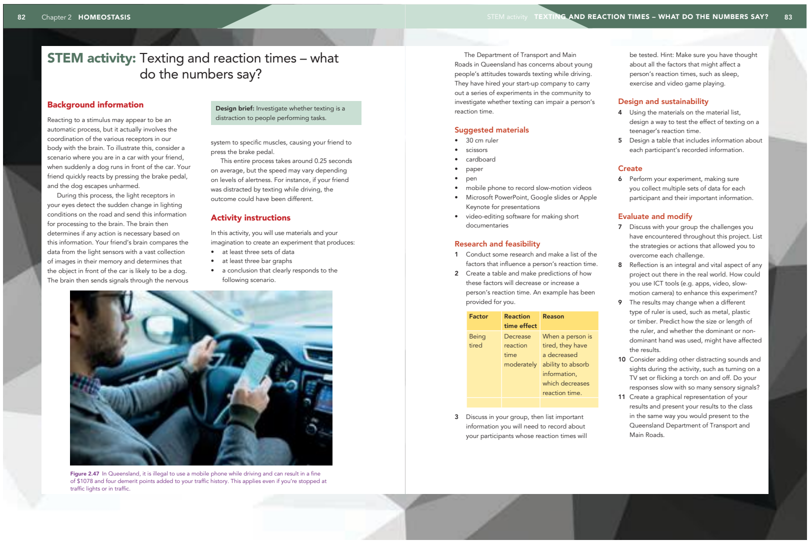


Figure 2.46 Relative blood sugar level over a 24-hour period

Data questions help students apply their understanding, as well as analyse and interpret different forms of data linked to the chapter content.



82 Chapter 2 **HOMEOSTASIS**

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.

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.

Figure 2.47 In Queensland, it is illegal to use a mobile phone while driving and can result in a fine of $1078 and four demerit points added to your traffic history. This applies even if you're stopped at traffic lights or in traffic.

STEM activity **TEXTING AND REACTION TIMES – WHAT DO THE NUMBERS SAY?** 83

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.

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 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 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 times, 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 out there in the real world. How could you use ICT tools (e.g. apps, video, slow-motion camera) to enhance this experiment?

9 The results may change when a different type of ruler is used, such as metal, plastic or timber. 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. Do your responses slow with so many sensory signals?

11 Create a graphical representation of your results and present your results to the class in the same way you would present to the Queensland Department of Transport and Main Roads.

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

Links to the Interactive Textbook

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

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

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

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

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

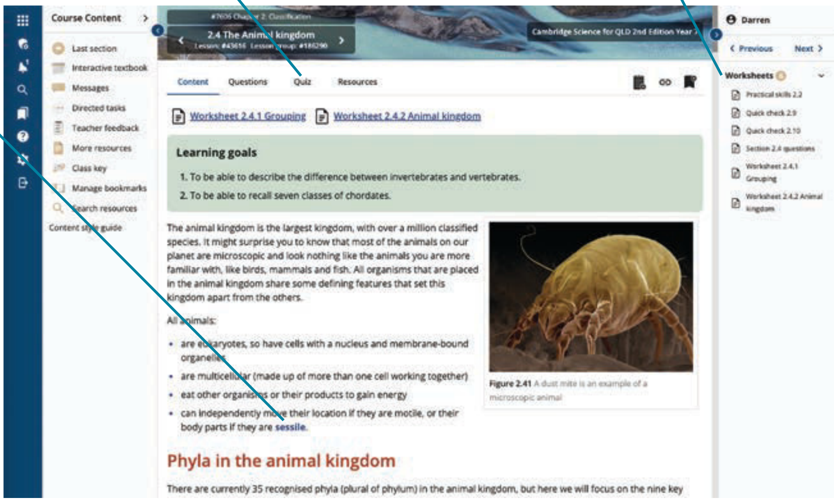
Overview of the Interactive Textbook (ITB)

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

Definitions pop up for key terms in the text.

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

Worksheets are provided as downloadable Word documents.



Worksheet 2.4.1 Grouping Worksheet 2.4.2 Animal kingdom

Learning goals

1. To be able to describe the difference between invertebrates and vertebrates.
2. To be able to recall seven classes of chordates.

The animal kingdom is the largest kingdom, with over a million classified species. It might surprise you to know that most of the animals on our planet are microscopic and look nothing like the animals you are more familiar with, like birds, mammals and fish. All organisms that are placed in the animal kingdom share some defining features that set this kingdom apart from the others.

All animals:

- are eukaryotes, so have cells with a nucleus and membrane-bound organelles
- are multicellular (made up of more than one cell working together)
- eat other organisms or their products to gain energy
- can independently move their location if they are motile, or their body parts if they are sessile.

Figure 2.41 A dust mite is an example of a microscopic animal

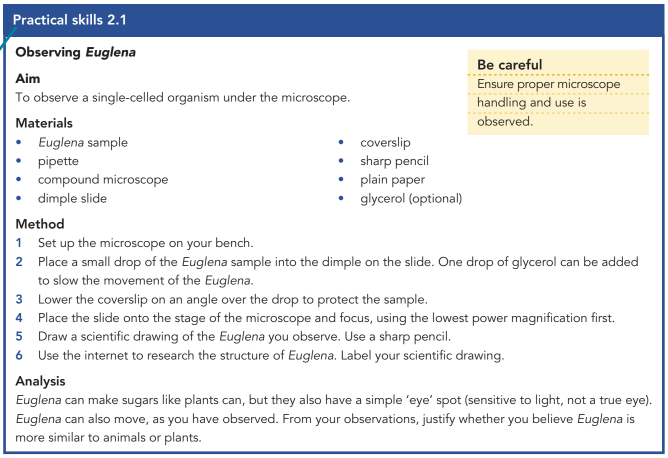
Phyla in the animal kingdom

There are currently 35 recognised phyla (plural of phylum) in the animal kingdom, but here we will focus on the nine key

Videos summarise, clarify or extend student knowledge.

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

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



Practical skills 2.1

Observing *Euglena*

Be careful
Ensure proper microscope handling and use is observed.

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

Materials

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

Method

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

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

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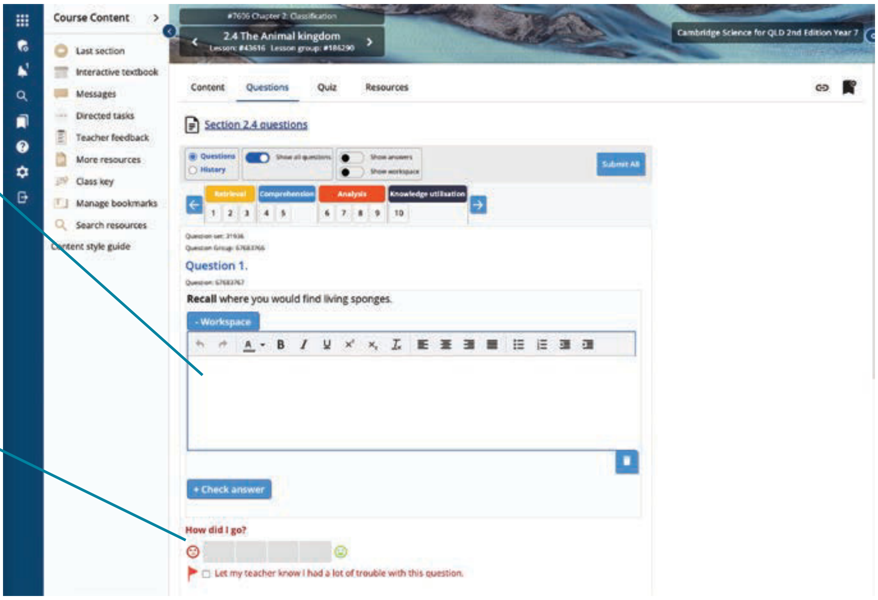
Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

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.



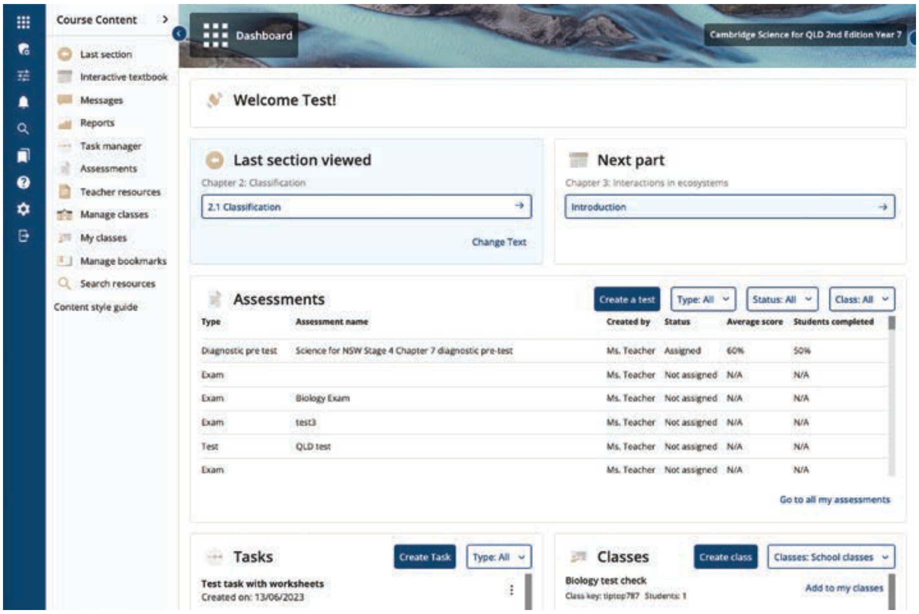
Recall where you would find living sponges.

☐ Let my teacher know I had a lot of trouble with this question.

Overview of the Online Teaching Suite (OTS)

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

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



Welcome Test!

Last section viewed: Chapter 2: Classification – 2.1 Classification

Next part: Chapter 3: Interactions in ecosystems – Introduction

Assessments

Type	Assessment name	Created by	Status	Average score	Students completed
Diagnostic pre test	Science for NSW Stage 4 Chapter 7 diagnostic pre-test	Ms. Teacher	Assigned	60%	50%
Exam		Ms. Teacher	Not assigned	N/A	N/A
Exam	Biology Exam	Ms. Teacher	Not assigned	N/A	N/A
Exam	test3	Ms. Teacher	Not assigned	N/A	N/A
Test	QLD test	Ms. Teacher	Not assigned	N/A	N/A
Exam		Ms. Teacher	Not assigned	N/A	N/A

Test task with worksheets
Created on: 13/06/2023

Biology test check
Class key: tiptop787 Students: 1

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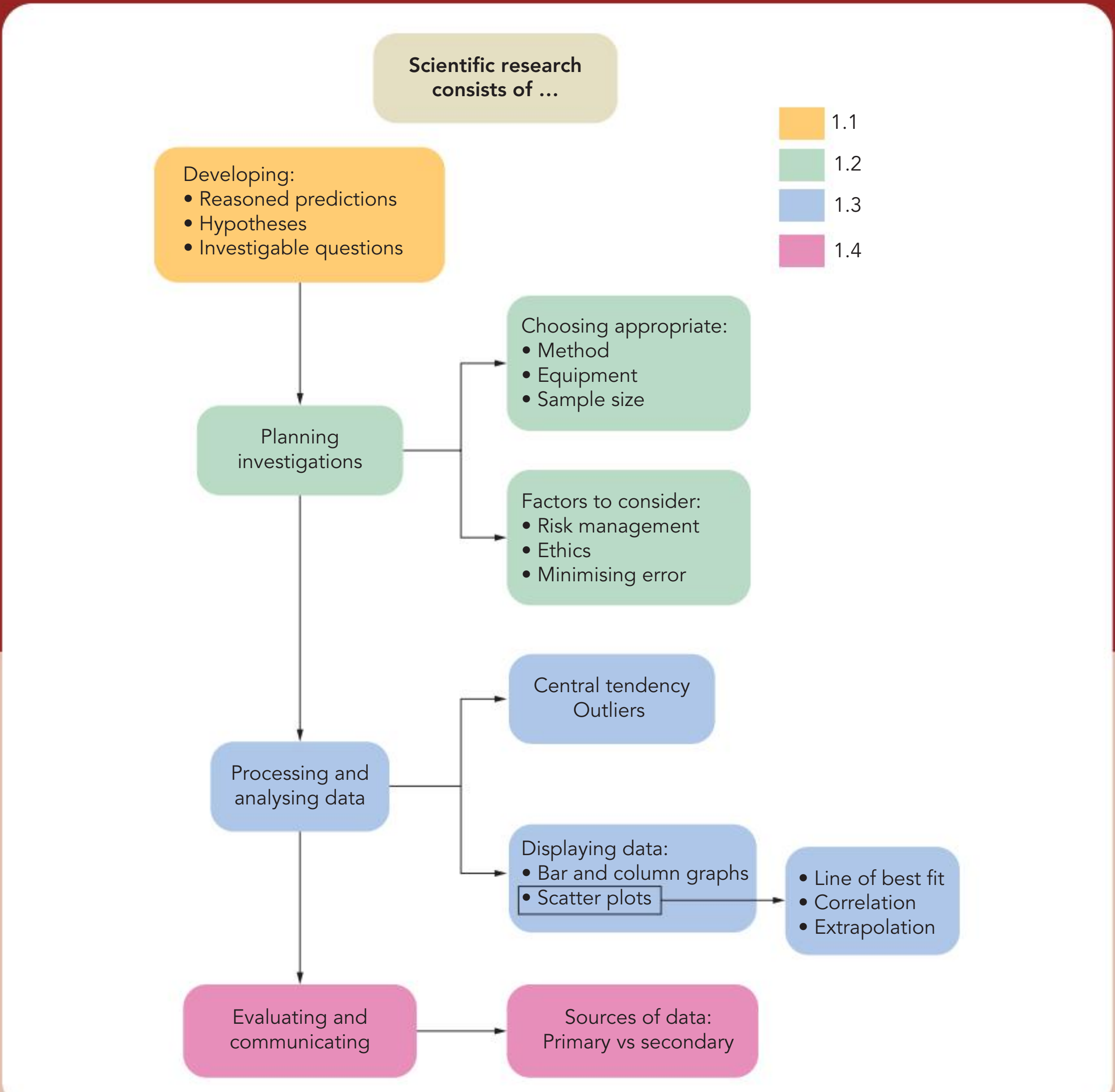
Chapter 1

Science and data

Chapter introduction

In this chapter, you will explore the process of developing hypotheses, reasoned predictions and investigable questions, and how they can be used to expand understanding. You will consider how to plan and conduct valid, reproducible and ethical investigations that test your hypotheses and answer your research questions, as well as assess the validity and reproducibility of other scientists' research.

Concept map



Glossary terms

Confounding variable
Ethics
Extrapolation
Hypothesis
Linear
Mean
Median
Mode
Non-linear
Origin
Outlier
Peer review
Plagiarism
Prediction
Primary data
Random error
Randomised controlled trial
Range
Replicability
Reproducibility
Significant figures
Systematic error
Validity

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1.1 Questioning and predicting

WORKSHEET
Types of data
and variables

Learning goal
To be able to develop investigable questions, reasoned predictions and hypotheses to test relationships and develop explanatory models.

Predictions, hypotheses and research questions are all interconnected parts of the scientific research process. Researchers often start by generating hypotheses, which are explanations for observed events that can be tested. Predictions are then made based on these hypotheses, describing the expected outcomes of experiments or observations. To test these predictions, researchers then develop research questions.

Developing reasoned predictions and hypotheses

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.

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

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

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

Developing investigable questions

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.

Explanatory models can help you answer investigable questions. For example, you may ask: Why do plants grow better at the front of my house than at the back? This is a question that can be answered through investigation. By using scientific ideas, you can construct an explanatory model that explains how and why plants grow. This model can then be used to investigate further questions related to plant growth.

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

Worked example 1.1

Developing reasoned predictions, hypotheses and investigable questions

Figure 1.1 One investigable question that you might ask is: How does the height of a box jump affect my chance of injury?

Raj wants to research the effect of exercise on the human body. He knows that after he exercises at the gym, his heart rate and breathing rate increase.

Raj hypothesises that 'as the intensity of exercise increases, heart rate and breathing rate will also increase'.

Based on this hypothesis, Raj predicts that 'Participants who engage in high-intensity exercise will have higher heart rates and breathing rates than participants who engage in low-intensity exercise or in no exercise at all'.

This hypothesis and prediction can be tested through empirical research, such as measuring heart rate and breathing rate before, during and after different levels of exercise intensity, and comparing the results between participants of different fitness levels.

This leads Raj to developing an investigable question of: How does the intensity of exercise affect heart rate and breathing rate?

In pairs, generate some other investigable questions about the relationships between human body systems and everyday events.

Quick check 1.1

1 What is a hypothesis?
2 What is a prediction?
3 Name three criteria that an investigable question should meet.

Section 1.1 questions

Retrieval

1 **Define** 'prediction'.

Comprehension

2 **Explain** why an investigable question must be specific.

Analysis

3 **Connect** hypotheses, predictions and investigable questions.

Knowledge utilisation

4 **Develop** an investigable question to explore an explanatory model about plant growth.

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1.2 Planning and conducting

WORKSHEET
Planning and conducting

Learning goals

1. To be able to plan and conduct valid, reproducible investigations to answer questions and test hypotheses.
2. To be able to select and use appropriate equipment.

Planning and conducting any experiment is a complex process that requires careful consideration of many factors. Researchers must select appropriate methods and techniques for data collection and analysis, consider risks, minimise sources of bias and **confounding variables**, and ensure that they uphold ethical principles throughout the study.

Choosing an appropriate 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. **Replicability** refers to the ability to repeat an experiment and obtain the same results. A replicable experiment should produce consistent results each time it is performed.

confounding variable
a factor that can affect the outcome of a study, making it difficult to know if the relationship observed is due to the variables being studied or to another factor

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

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

To ensure both validity and replicability in an investigation, researchers must use appropriate research methods and techniques. This includes using reliable and valid measures, selecting appropriate samples, controlling for confounding variables, and using appropriate techniques to analyse the data. Additionally, researchers must clearly document their procedures to ensure that other researchers can replicate their study.

Selecting appropriate equipment and scales

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 (Figure 1.2).

Figure 1.2 Measuring cylinders are less accurate than pipettes.

A data logger is an appropriate instrument for collecting data over time for various purposes, such as monitoring environmental conditions. When using data loggers, it is important to choose the correct scale and select the appropriate range of values that the data logger will measure. For example, if you are monitoring temperature, you might choose a scale that ranges from –5°C to 50°C, which would likely cover the expected range of temperatures in the environment you are monitoring.

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Figure 1.3 Weather stations are systems that measure and record weather conditions such as temperature, humidity, wind speed and direction, and precipitation. They typically consist of a variety of sensors and instruments that are connected to a data logger, which collects and stores the data.

Sample size

It is important to consider sample size in any experiment because it can affect the accuracy and reliability of the results obtained. The amount of data needed to produce a useful sample size depends on several factors, but in general you need a larger sample size to obtain more accurate and reliable results. This is because a larger sample size reduces the effect of random error. However, a larger sample size may not always be necessary or feasible, particularly in cases where the data is highly consistent, or there are experimental or financial limitations.

Figure 1.4 Larger samples better represent the population and provide more accurate results.

Using digital tools

Digital tools have revolutionised the way scientific data is collected, managed and analysed, and 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.

One advantage of digital tools for data collection is that they 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 measurement errors that can occur with traditional data collection methods, as all participants provide data in the same way.

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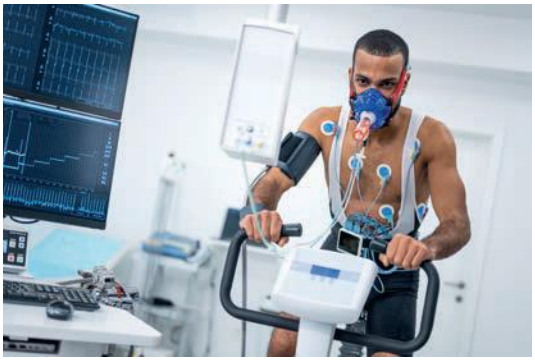


Figure 1.5 Digital tools can ensure that physiological data is recorded accurately.

significant figures the number of digits used to indicate how accurate a measurement or calculation is

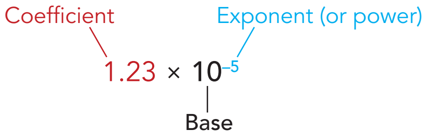
Digital tools can also help data management and analysis, particularly for larger sample sizes. Digital tools can automate data entry, reducing the time and resources required for these tasks, and facilitate complex data analysis, allowing researchers to analyse large amounts of data quickly and efficiently.

Quick check 1.2

1. What does validity mean in an experiment?
2. How can researchers ensure reproducibility in their investigations?
3. What are the advantages of digital tools for data collection and analysis in an experiment?

Recording and presenting data

Scientific notation is a commonly used system in science for writing numbers. It involves writing a number as a coefficient multiplied by a power of 10. For example, the number 0.0000123 can be written in scientific notation as shown in Figure 1.6.



$$1.23 \times 10^{-5}$$

Figure 1.6 Writing 0.0000123 in scientific notation. *Note* that the decimal point has been moved *backwards* five places, so the exponent is –5.

When recording data values, it is important to use appropriate scientific notation to reflect the precision of the measurements. For very small or very large numbers, scientific notation can help to make the values more manageable and easier to read. It also allows us to represent the precision of the measurements concisely.

For example, consider a measurement of 0.0062 grams. This value could be recorded as 6.2×10^{-3} g, which indicates that the measurement is accurate to two **significant figures**. If we were to record the measurement as 0.006 g (i.e. using one significant figure), we would be losing precision and potentially introducing error into our data.

Figure 1.7 You should always use an electronic balance that measures within the parameters of the required mass, and record data to the correct number of significant figures, using correct units.

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 protective equipment, such as gloves, safety glasses and respirators, to prevent exposure to hazardous substances

- implementing safety protocols for handling and disposing of materials
- ensuring that all equipment is properly maintained and calibrated.

In addition, researchers should be familiar with emergency procedures in the event of an accident or exposure and ensure that all individuals involved in the experiment are adequately trained in safety procedures.

Figure 1.8 Personal protective equipment is an important part of risk management.

Minimising error

When 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 instrumentation and procedural errors, as well as **random errors** that occur due to chance.

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.

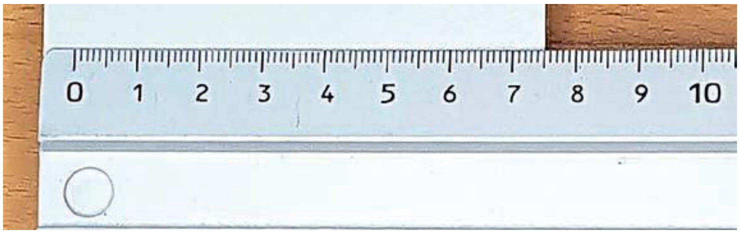


Figure 1.9 What is the systematic error in this picture?

Ethics

Ethics is a critical consideration when planning and conducting scientific experiments because it ensures that the welfare of everyone involved is respected, and that the research is conducted with integrity. Ethics in science experiments involves assessing the potential risks of the research and ensuring that the experiment is carried out in a way that minimises harm. This involves following established ethical guidelines, such as informed consent, confidentiality and the protection of vulnerable populations.

ethics
the study used to guide what is considered to be right or wrong

Ethics in science experiments may also consider animal welfare, environmental impact and potential conflicts of interest.

Animal welfare

The use of animals for scientific purposes has been a controversial issue for many years, with ethical concerns regarding the treatment and care of animals being at the forefront of the debate. When considering an investigation involving animals, researchers must carefully evaluate the potential benefits of the study against the ethical issues that may arise.

random error
an unpredictable error that occurs in different directions each time a measurement is made; caused by external factors that affect the measurement process

systematic error
a consistent and predictable error that occurs in the same direction each time a measurement is made; caused by issues in the measurement system or experimental set-up

One of the key ethical issues involved in the care and use of animals for scientific purposes is animal welfare. Researchers must ensure that animals are treated with respect and that their wellbeing is protected throughout the study. This includes providing appropriate housing, food and water, as well as minimising any pain or distress the animals experience. In addition, researchers must carefully consider the ethical implications of any procedures or treatments that may be carried out on the animals.

Figure 1.10 Wistar rats are a breed of laboratory rats that are widely studied because they have a consistent genetic make-up and are easy to look after. They have a docile and friendly temperament, making them easy to handle and work with. Wistar rats have been used in a wide range of scientific studies, including research on cancer, neuroscience and drug development, and have contributed greatly to our understanding of various biological processes.

Protection of heritage sites and artefacts

In Australia, anyone conducting experiments in the field must be aware of First Nations Australian heritage laws to ensure that the research is conducted in a culturally sensitive and respectful manner. First Nations Australians have a deep connection to the land, and the cultural heritage of many different communities is tied to many sites and artefacts across the country. Therefore, it is essential that researchers understand and respect the cultural significance of these sites.

First Nations Australian heritage laws recognise the importance of protecting and preserving sites and artefacts for cultural and spiritual reasons. These laws require researchers to obtain informed consent from the local First Nations Australian communities before conducting research on or near these sites, and it is the public responsibility of all Australians to report any new sites or artefacts found.

All researchers must respect cultural protocols and traditions and recognise the potential legal and ethical consequences of disturbing heritage sites, which can include legal penalties.

Quick check 1.3

1 What are some examples of protective equipment that researchers might use when handling hazardous materials in experiments?
2 What are some ethical considerations that researchers must consider when conducting experiments involving animals?
3 Why is it important for researchers to be aware of First Nations Australian heritage laws when conducting experiments in the field?

Section 1.2 questions

QUIZ

Retrieval

1 **Recall** why scientific notation is useful.

Comprehension

2 **Explain** why ethics must be considered in any scientific investigation.

Analysis

3 **Critique** the statement: ‘Digital tools might enable more efficient data collection for larger sample sizes’.

Knowledge utilisation

4 **Discuss** the ethical and social issues involved in the care and use of animals for scientific purposes.

1.3 Processing and analysing

Learning goals

1. To be able to select and construct appropriate representations of data.
2. To be able to analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies.

DOC

WORKSHEET
Plotting data

Collecting data from an investigation, experiment or survey is an important part of the scientific process. Once the data is collected, it needs to be recorded in a way so that it is manageable and easy to use. The data must be recorded neatly and accurately to avoid any confusion.

Central tendency

When conducting experiments with multiple trials, there are several values obtained that need to be summarised into one representative value. The three commonly used measures of central tendency are the **mean**, **median** and **mode**. The mean is the average of all the values obtained, and it can be easily calculated by adding up all the values and dividing the total by the number of values. The median is the middle value in a sorted list of all the values, while the mode is the most frequently occurring value. Another useful measure is the **range**, which is the difference between the largest and smallest values in the data set. By calculating and comparing these measures, researchers can gain a better understanding of the overall pattern of the data and draw meaningful conclusions from their experiments.

mean
the average of a set of data, calculated by adding up all the values in the set and dividing by the total number of values

median
the middle value in a set of data when they are arranged in order

mode
the value that appears most frequently in a set of data

range
the difference between the largest and smallest values in a set

Worked example 1.2

Determining measures of central tendency

A scientist caught five fish and measured the length of each. The lengths (cm) of the fish were 20.2, 21.6, 23.4, 20.0 and 22.2. Determine the mean, median, mode and range of the data.

Sample property	Working	Explanation
Mean	Step 1: 20.2 + 21.6 + 23.4 + 20.0 + 22.2 = 107.4 cm	Add up all the values.
	Step 2: 107.4 cm ÷ 5 = 21.5 cm The mean fish length is 21.5 cm.	Then divide the result by the sample size, which in this case is 5 (the number of fish).
Median	Step 1: 20.0, 20.2, 21.6, 22.2, 23.4	Arrange the values in order.
	Step 2: The middle value is 21.6 cm, which is the median length of the fish.	Select the middle value.
Mode	The mode is the value that appears most frequently in the data set. In this case, none of the lengths occur more than once, so there is no mode length to report.	
Range	Step 1: Largest value: 23.4 cm Smallest value: 20.0 cm	Identify the largest and smallest values in the data set.
	Step 2: 23.4 – 20.0 = 3.4 cm The range of fish lengths is 3.4 cm.	Subtract the smallest value from the largest value.

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

Sometimes the data collected may contain one or more values that seem very different from the other observations made. These values are called **outliers** and might be due to faulty procedures or chance errors in collecting the measurements.

If outliers are identified, some decisions need to be made. Should the trial be performed again? Or, if that is not possible, could the outlier values be deleted from the data and an average calculated from the rest? Both options could be acceptable depending on the situation. If outliers are not handled properly, then the mean or average may not be a true representative of the measurements collected.

Displaying and representing data

There are several ways to represent quantitative data (Table 1.2). The most common one is the *x*–*y* scatter plot.

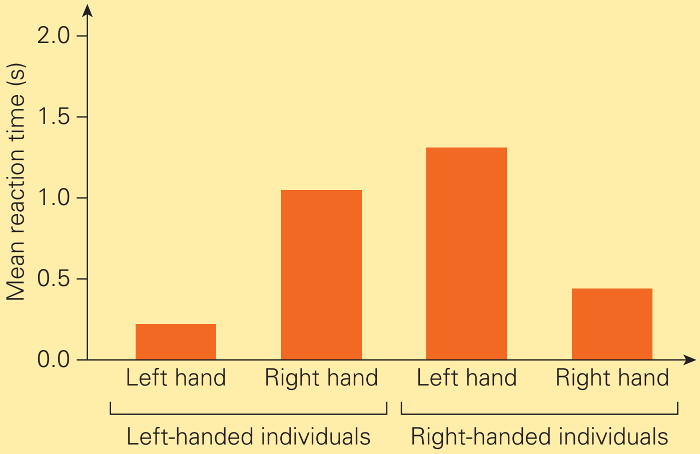
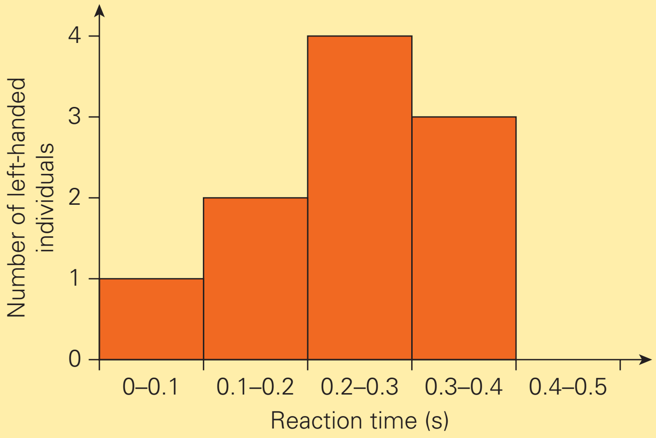
Data representation	Reason for use
Bar graph  	Bar graphs are used for comparing data between different categories or groups. They are suitable for medium-to-large sets of data.
Histogram  	Histograms are used to plot the frequency of continuous data that is divided into intervals. They are suitable for medium-to-large sets of data.

Table 1.2 Different types of graphs for different types of data and variables

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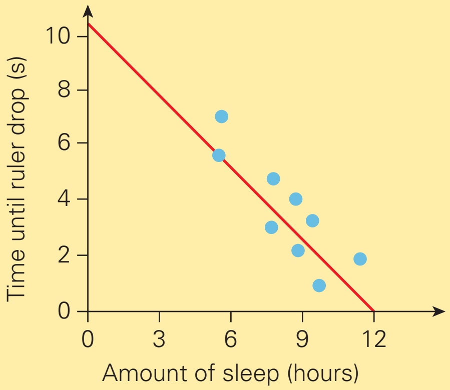
Data representation	Reason for use
x–y scatter plot  	Scatter plots are used to determine the relationship between variables. They are suitable for medium-to-large sets of data.

Table 1.2 *(Continued)*

Figure 1.11 The ability to represent data in a visual form is an important part of many day-to-day tasks in modern culture.

Bar graphs and column graphs

Bar graphs have rectangular bars that are proportional to the values that they represent. A vertical bar graph may be called a column graph. Bar graphs are made up of four parts:

- a title that explains the information being graphed; titles for graphs should be written below the graph
- axes with labels that explain what each side of the graph is showing, including units
- 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.

Usually, the columns are vertical, but they can be horizontal if the categories are difficult to display on the bottom axis.

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

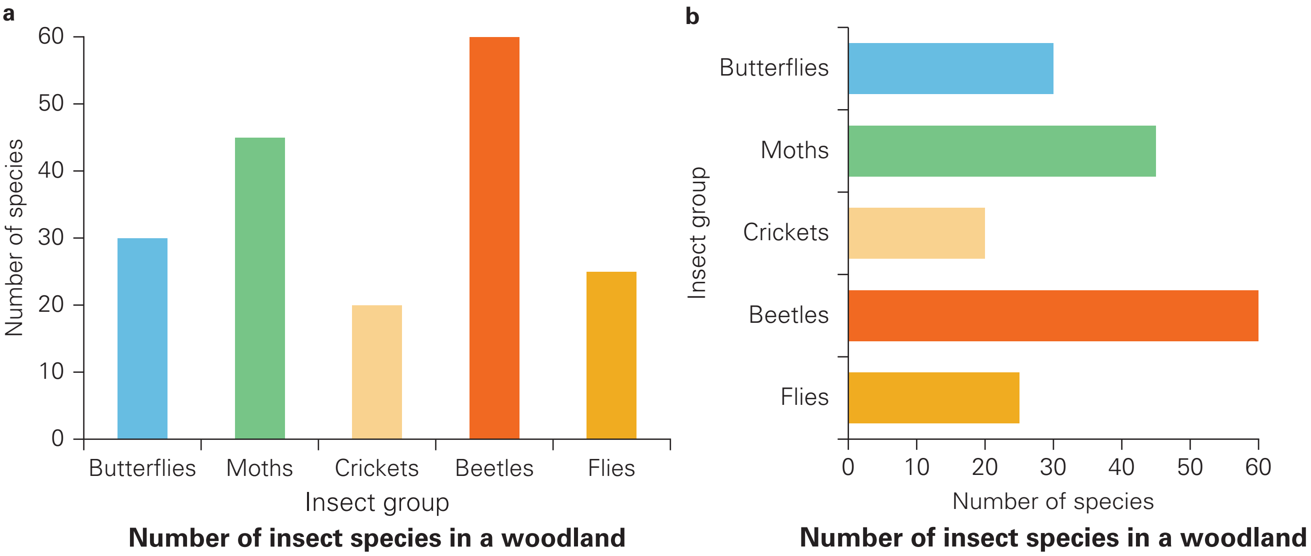


Figure 1.12 Data presented in a **(a)** vertical bar graph (column graph) and **(b)** horizontal bar graph

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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 bar 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, mode, median and range of this data.

Scatter plots

An x–y scatter plot is used to identify the relationship between two variables. The data is displayed on a Cartesian plot where a single point consists of a pair of numbers: one indicates the x-axis value and the other indicates the y-axis value.

This graph can be used for discrete or continuous quantitative data. The graph consists of similar parts to the column graph, but with some additions.

- The x-axis is the bottom horizontal side of the graph. It contains the data from the independent variable. These numbers are changed in an experiment and not affected by the other variables. For example, it could be the time the experiment runs for or the mass of substance used as a reactant.
- The y-axis is the vertical side of the graph and represents the dependent variable. These numbers are a result of changes to the independent variable.

A simple method of remembering this is remembering the acronym DRY MIX.

D **D**ependent variable
R **R**esponds to changes in other variables
Y Is placed on the y-axis.
M The **m**anipulated variable is the one that is deliberately changed.
I **I**ndependent variable
X Is placed on the x-axis.

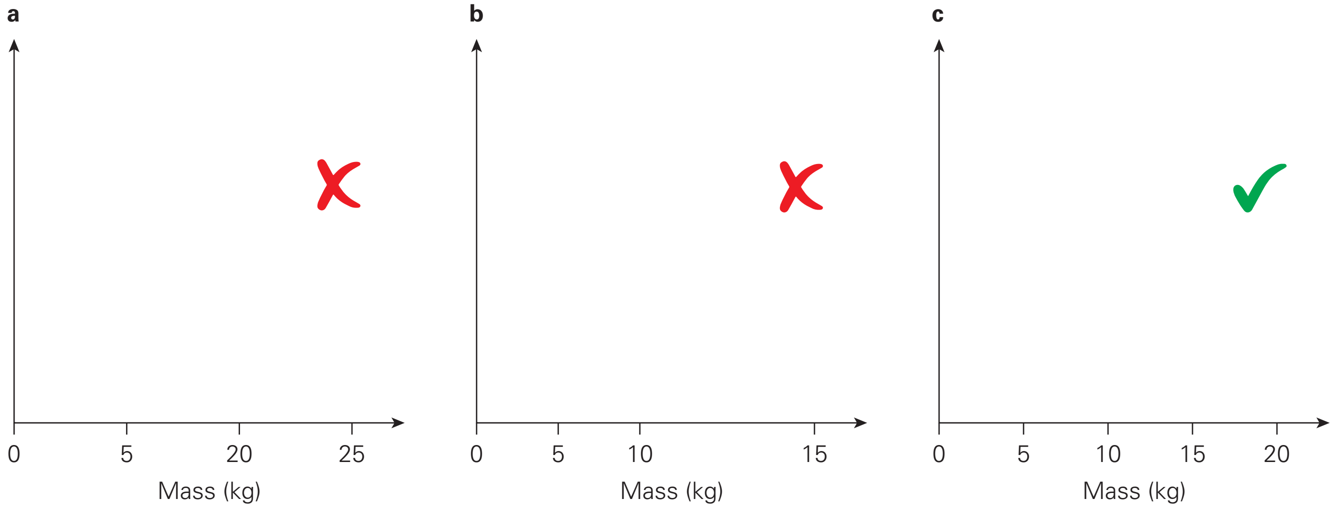

Figure 1.13 Graph **a** does not increase evenly along the x-axis. Graph **b** is not spaced evenly. Graph **c** has the correct spacing and numbering for the x-axis.

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It is important to place the numbers on the *x*-axis and *y*-axis in a way that shows the correct relationship. The numbers on both axes need to increase evenly, and usually start at zero as the corner point (**origin**). Each unit of distance on the line needs to represent the same value of the data. For example, if the first unit of the graph represents 5 kilograms (kg), every increment of the graph also has to be 5 kg (see Figure 1.13).

Points are plotted on the graph by placing a dot or cross at the intersection of the two numbers. If more than one variable is being plotted, you can use different shapes to distinguish the points; for example, squares, stars, closed circles and open circles.

Aim to make the graph as large as possible – at least half a page is a good guide. This will make the data clearer and easier to use when doing your analysis. Also, wherever possible, draw all parts of the graph in pencil only to make it easier to correct any mistakes.

Once the data points are plotted, they can be further analysed in terms of correlation and line of best fit.

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

Table 1.3 shows the results from an investigation into plant height that took place over 25 days. Only the averages are shown.

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 1.3 Mean plant height over time

Plotting the data correctly on a Cartesian plane makes it much easier to analyse (Figure 1.14).

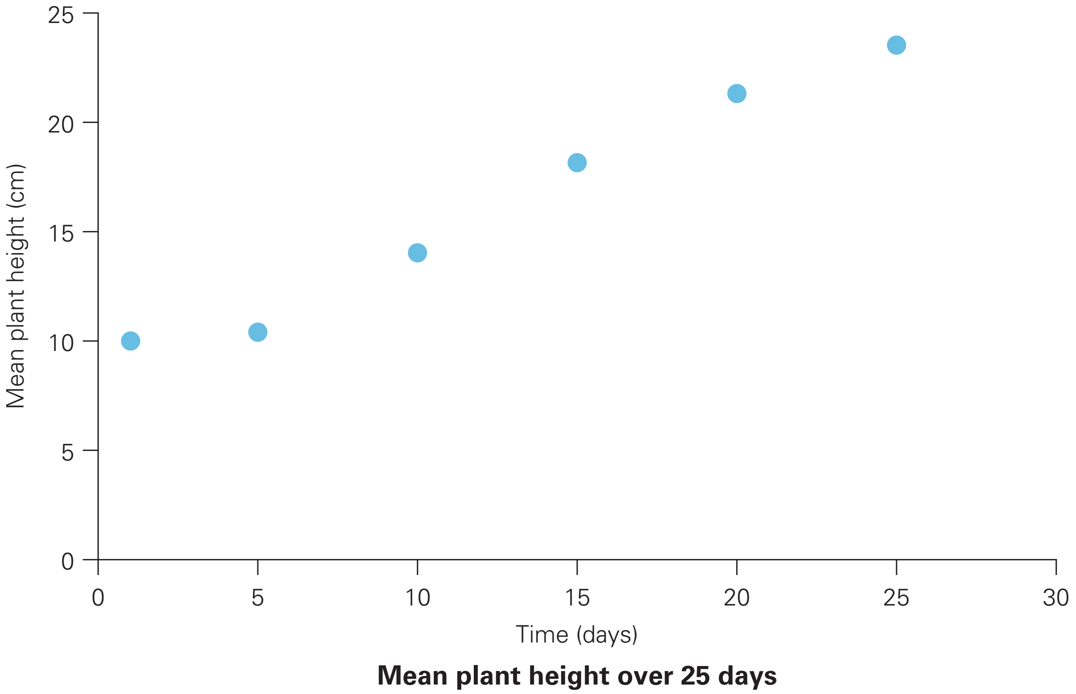

Figure 1.14 A graph of mean plant height against time

Quick check 1.5

A study was undertaken of the effect of the amount of fish food added on plant growth in an aquarium. 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 *x*–*y* scatter plot of this data.

Line of best fit

It may be difficult to see how the variables relate to each other on a scatter plot, 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. A line is drawn so that it goes through the points as accurately as possible. It may touch some, all or even none of the data points. The line is sometimes **linear** (straight) but may also be **non-linear** by adding it in as a curve. Drawing a line of best fit allows scientists to look for a general trend in the data being analysed.

linear
a straight line plotted on a graph

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

There are some general rules for drawing a line of best fit.

- Do not include outliers.
- Make the line as close to as many points as possible (Figure 1.15).

Figure 1.16 is an example of when a non-linear line fits the data points better than a straight line. In these cases, you can use a software program such as Microsoft Excel or a website such as Desmos to find the line of best fit.

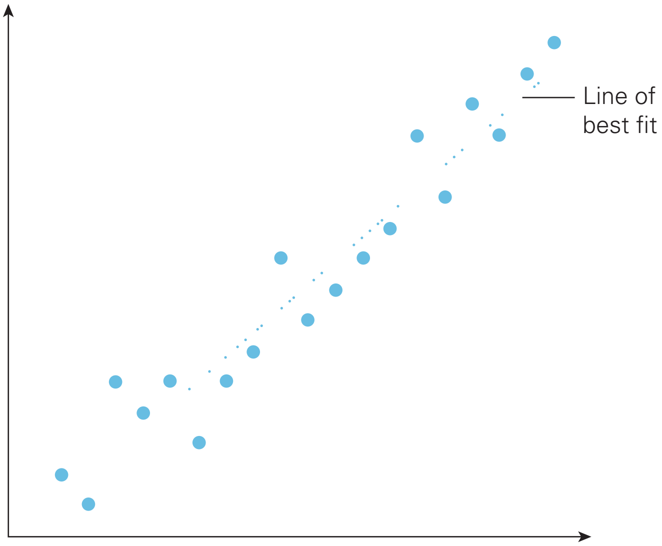

Figure 1.15 A scatter plot with a line of best fit. Even though the line is not touching any of the points, it is drawn as close to all the points as possible.

Correlation

Scientists need to understand if a relationship exists within their data. Data might be correlated positively or negatively, or it might have no correlation. You can usually determine this relationship by simply glancing at an x–y plot.

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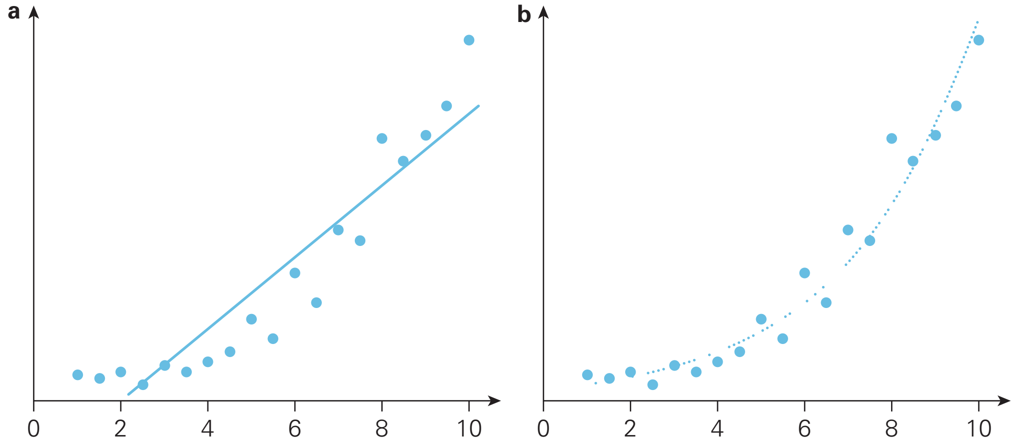


Figure 1.16 The data points here suggest that the relationship between the x and y variables is non-linear, meaning that the line that best fits the data is curved (graph **b**) rather than straight (graph **a**).

When interpreting a correlation between variables, it is important not to assume that one variable is having an effect on the other. A correlation may actually be caused by a confounding variable. That is why it is important to use the word ‘suggests’ rather than ‘proves’ or ‘causes’ when talking about possible relationships between variables.

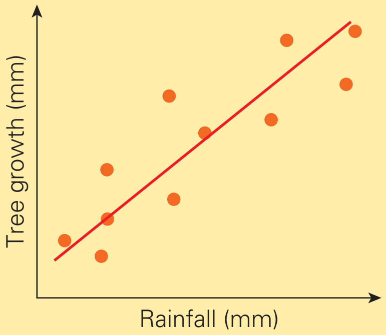
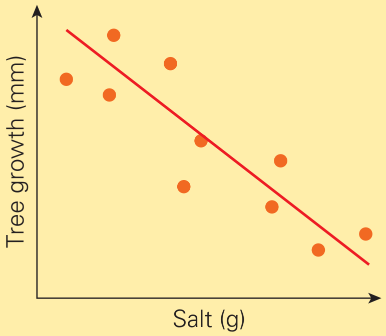
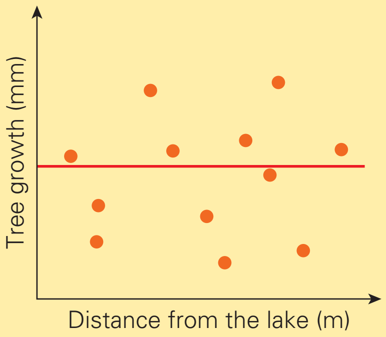
Correlation	Example graph	Interpretation
Positive (one variable increases as the other variable increases)		The results suggest that more rainfall may contribute to an increase in tree growth in a specific area.
Negative (one variable decreases as the other variable increases)		The results suggest that increased salt added to the soil in a specific area inhibits (hinders) tree growth.
No correlation (no pattern in the way the variables increase or decrease)		The results suggest that a tree’s growth is not affected by its distance from a lake.

Table 1.4 How x–y scatter plots can show correlation between two variables

Remember, if two variables show a correlation, it does not necessarily mean that one has an effect on the other. The correlation may be due to other factors, such as confounding variables.

Extrapolation

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

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 in Figure 1.17. In general, the more data points that are available, the more confident you can be in the accuracy of extrapolating beyond the observed data. Likewise, if the trend or pattern in the data is consistent, there is more confidence in extrapolating beyond the observed range.

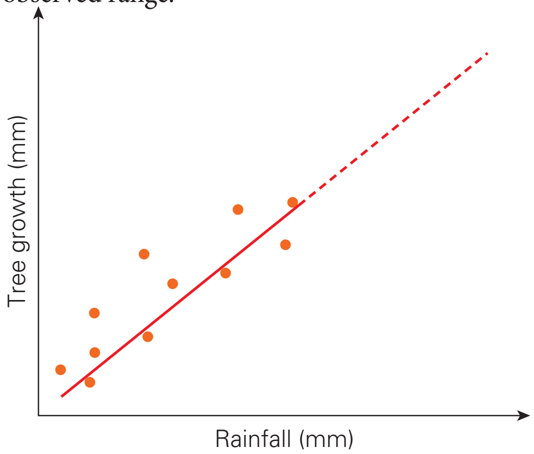


Figure 1.17 Extrapolation of how rainfall affects tree growth

However, it is important to note that extrapolation always involves a degree of uncertainty and risks introducing error into the data. This is particularly true when extrapolating over large ranges or making predictions far into the future.

Quick check 1.6

1 State whether you would expect positive, negative or no correlation for each of the following examples.
  - a The volume of a set of headphones on hearing damage
  - b A high temperature forecast on the expectation of bushfires
  - c Eating fatty foods on having healthy cholesterol levels
  - d Students' absences on grades

2 Refer back to Quick check 1.5.
  - a Predict whether the trend line for the graph you drew will be linear or non-linear.
  - b Identify whether there is positive, negative or no correlation.
  - c Describe what the data suggests would happen if you reduced the amount of food added.
  - d Extrapolate the data to 5 weeks.

Section 1.3 questions

QUIZ

Retrieval

1 **Name** four features of an *x*–*y* plot.

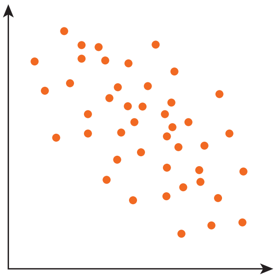
Applying

2 **Explain** how the mean is calculated.

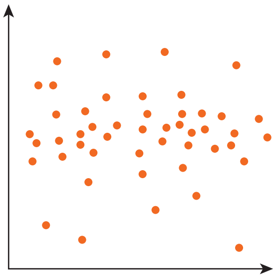
Analysis

3 **Classify** the correlations that can be seen in the following scatter plots.

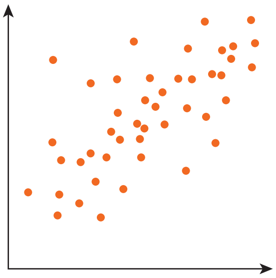
a



b



c



Knowledge utilisation

4 **Construct** an x–y scatter plot of the following data from an experiment measuring 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

5 **Construct** the appropriate graph for the following data of a heating curve for the temperature of water measured after every 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

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1.4 Evaluating and communicating

WORKSHEET
Evaluating and communicating

Learning goals

1. To be able to assess the validity and reproducibility of methods.
2. To be able to evaluate the validity of conclusions and claims.
3. To be able to communicate ideas, findings and arguments effectively.

Evaluating the validity of data is an important step in any research process, whether you are using primary data or using secondary data. Validity refers to how accurately the data represents the phenomenon it is intended to measure. By evaluating the validity of data, researchers can make informed decisions about the quality of the data and ensure that their conclusions and recommendations are based on accurate and reliable information.

It is also crucial to effectively communicate research ideas, findings and arguments to make them more accessible to a wider audience. This can help to increase the impact of the research.

Using primary data

primary data
data that researchers collect themselves for a specific purpose; obtained from observations, experiments, surveys or interviews

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

When using **primary data**, you should assess the validity and **reproducibility** of the methods used. Reproducibility refers to whether the research produces consistent results when repeated by other researchers. Any gaps or weaknesses in the conclusions drawn from the data may be due to problems with the validity or reproducibility of the methods used.

Assumptions made in research methods can also affect the validity of the conclusion. For example, if a researcher assumes that the study population is representative of the general population, but it is not, this could lead to biased or inaccurate conclusions. Similarly, if a researcher assumes that a particular method of data collection is the most accurate or appropriate, but it is not, this could also affect the validity of the conclusion.

Figure 1.18 In the late 1990s, British doctor Andrew Wakefield claimed that the MMR (measles, mumps and rubella) vaccine was linked to autism and bowel disease. Wakefield's study was later found to be fraudulent, but it led to a decline in MMR vaccination rates in the UK and other countries. This resulted in outbreaks of measles and other diseases, causing serious harm and even death in some cases. Wakefield was eventually found guilty of professional misconduct and the study was withdrawn.

It is also essential to identify any facts taken for granted in the research and evaluate their reasonableness. For example, if a study assumes that a particular medicine is safe and effective, but there is limited evidence to support this claim, this could lead to flawed conclusions.

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Figure 1.19 A 2010 article published in the journal *Behavioural and Brain Sciences* claims that individuals studied in a significant portion of psychology literature are WEIRD – Western, Educated, Industrialised, Rich and Democratic – but this group is 'among the least representative populations one could find for generalising about humans'.

It is important to evaluate whether assumptions are reasonable and consider areas of uncertainty when determining if there is enough evidence to support the conclusion or if there is a viable alternative conclusion.

Evaluating secondary data

Secondary data refers to data that has been collected by someone else for a different purpose, but which may be relevant to your investigation question or claim. This can include data from published studies, government reports and other sources.

A key consideration when examining secondary data is ensuring that it does not contain personal information that could potentially harm individuals. This is particularly important when dealing with sensitive data, such as medical records, criminal records and financial information. Before using any secondary data, review it carefully and ensure that any identifying information has been removed or anonymised.

plagiarism the process or practice of using another person's idea or work and pretending that it is your own

You should cite secondary data correctly. This involves identifying the original source of the data and providing a clear and accurate reference to it in any reports or publications. Failing to cite sources correctly can lead to accusations of **plagiarism** or academic misconduct and can damage the credibility of your research. Correct citing also allows readers to locate and verify the information that has been cited.

It is important to ensure that the secondary data is relevant to the investigation question or claim. This means carefully reviewing the data and assessing its quality, reliability and validity. Validity in secondary sources can be evaluated by considering several factors. Consider the:

- credibility of the data by examining if it is from a reputable source, and whether it provides references to support its claims
- currency of the information to ensure that it is recent and relevant

- objectivity of the source by examining if it has a particular bias that may influence the information presented
- methodology used to ensure that there were no potential sources of bias or error in the data collection process
- consistency of the information compared with other sources of information to identify any inconsistencies or contradictions.

Try this 1.1

Evaluating headlines

In 2018, a research paper was co-written by William McAuliffe, a psychology PhD student, in the esteemed journal *Nature Human Behaviour*. The paper suggested that people tend to become less generous over time when making decisions in an environment where they lack knowledge or interaction with others.

However, the university's press department may have sought to increase the study's appeal to news outlets by exaggerating its findings. The press release announcing the study's publication carried the headline 'Is big-city living eroding our nice instinct?'

Consequently, various media outlets picked up the story, with headlines such as 'City life makes humans less kind to strangers' and 'Big city living "switches off human instinct to be nice"'. However, these interpretations of the study were inaccurate, as it was conducted in a lab, not a city, and only measured investment behaviour rather than overall kindness.

When reading reports of scientific studies in the media, it is important to evaluate the methods used by scientists to conduct their research to ensure the validity of the headlines. Here are some steps you can take when evaluating these factors.

1. Read beyond the headline. The headline of an article is designed to grab your attention, but it may not provide a complete or an accurate summary of the study. Read the full article to get a better understanding of the research and the methods used.
2. Check the source. Look for reputable sources of information, such as **peer-reviewed** scientific journals.
3. Look for replication. Scientific findings should be replicated by other researchers before they are accepted as true.
4. Check the sample size. Studies with larger sample sizes are generally more reliable than studies with small sample sizes.
5. Check the methodology. Look for studies that use rigorous methods to control for confounding variables and minimise bias. **Randomised controlled trials** are generally considered the best.
6. Look for limitations. No study is perfect, and there may be limitations to the methods used or the findings reported. Look for studies that acknowledge their limitations.

Your teacher will provide you with headlines and the scientific report they are based on. Research the methods used by scientists in the provided studies and evaluate the validity of the headlines written in the media.

peer review
a process where work is examined and approved by experts before being published

randomised controlled trial
a study design that randomly assigns participants to either an experimental group or a control group; the only expected difference is the variable being studied

Quick check 1.7

1. What is validity?
2. How can validity in secondary sources be evaluated?

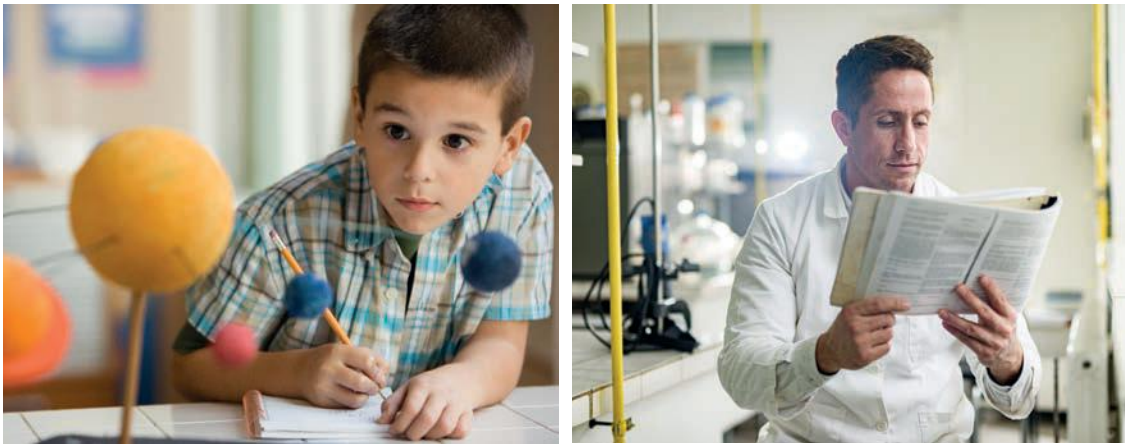

Figure 1.20 You should consider your audience when choosing how to present information.

Communicating results

Scientific texts can range from highly technical to more accessible, depending on their intended audience and purpose.

For example, a scientific paper published in a peer-reviewed journal will probably be written for a specialised audience of scientists, researchers and academics. Such papers will often use technical language and complex concepts that may be difficult for the public to understand.

In contrast, a popular science article or blog post will typically be written for a more general audience, with a focus on making complex concepts more understandable. These articles may include anecdotes or examples to illustrate key points and may be written in a more conversational tone. These articles try to engage and entertain the reader.

When comparing and contrasting these types of texts, it is important to analyse how the author's choice of language, tone and style affect the reader's understanding and engagement with the topic. For example, a highly technical paper may provide a more in-depth analysis of the data but may be less accessible to non-expert readers. A popular science magazine may be more engaging but will lack some of the detail.

Publishing a scientific paper

The process of publishing a paper in a scientific journal such as *Science* or *Nature* is rigorous and competitive. *Science* receives about 12 000 submissions every year, and the editors must evaluate each submission carefully to select the papers that are suitable for publication. Here are the steps involved in the process.

1. Submission: Authors submit their papers online through the journal's website.
2. Initial screening: Once submitted, the editors conduct an initial screening to check whether it meets the journal's requirements. They look at the scope of the paper and the quality of the writing.
3. Peer review: If the paper passes the initial screening, it is sent for peer review. The editors select a few experts who read the paper and provide feedback on its quality, originality and significance. This is usually a blind process, which means that the reviewers do not know the identity of the authors, and the authors do not know the identity of the reviewers.
4. Decision: Based on the feedback from the reviewers, the editors decide whether to accept, reject or request revisions to the paper. If the paper is accepted, it will be published in the journal.
5. Revision: If the editors request revisions, the authors will have to make the necessary changes and resubmit the paper. The editors will then review the revised version.
6. Publication: Once the paper is accepted, it is formatted before it is published online and in print.

Did you know? 1.1

Peptic ulcers

The work of Australian scientists Professor Barry Marshall and Dr Robin Warren on the cause of peptic ulcers was initially rejected for publication because their findings were contrary to the belief that ulcers are caused by stress, lifestyle and diet. Marshall and Warren discovered that ulcers are caused by a bacterium called *Helicobacter pylori*, but their research was met with scepticism and criticism from the medical community.

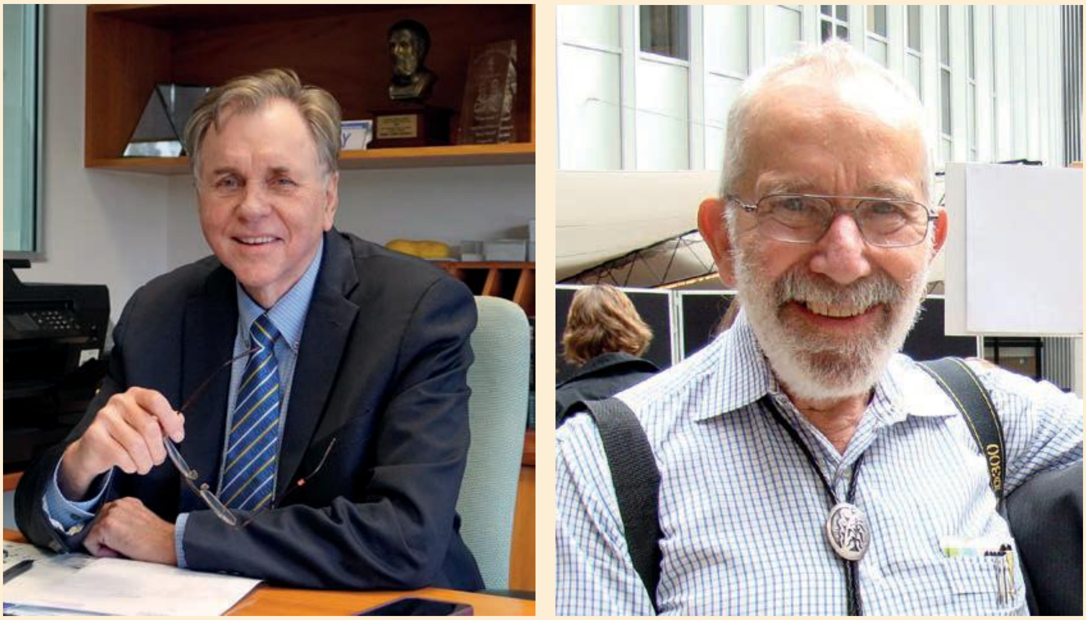

Figure 1.21 Professor Barry Marshall in 2021 (left) and Dr Robin Warren (right) in 2009

However, Marshall was so convinced of his findings that he ingested the bacteria to demonstrate that it caused gastritis, and later an ulcer. Despite the initial rejection and criticism, the researchers persisted and continued to gather evidence to support their findings.

Eventually, their work was validated through further research and clinical trials, which demonstrated the effectiveness of antibiotics in treating ulcers caused by *Helicobacter pylori*. Marshall and Warren were awarded the 2005 Nobel Prize in Physiology or Medicine for their discovery, which revolutionised the understanding and treatment of peptic ulcers.

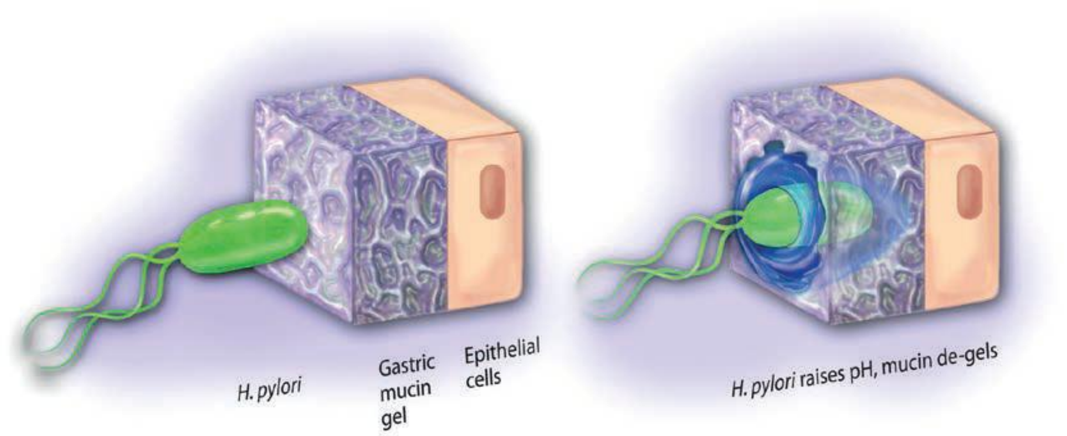

Figure 1.22 *Heliobacter pylori* produces urease, an enzyme that neutralises stomach acid. As a result, the protective mucin layer of the stomach lining is dissolved, allowing the bacteria to swim through it.

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Acknowledging and communicating First Nations Australians' knowledge

First Nations Australians' knowledges are grounded in a deep understanding of the natural world and have been developed over thousands of years through careful observation and experimentation. Contemporary science uses rigorous methods of observation, experimentation and analysis to develop an understanding of the natural world.

Acknowledging and identifying the relationship between First Nations Australians' knowledges and contemporary science promotes a more inclusive and collaborative approach to knowledge production. This is known as working 'both ways' or combining traditional knowledge with contemporary scientific methods. When working 'both ways', it is important to recognise the value and contributions of both approaches.

Did you know? 1.2

Spinifex gel

Spinifex grass, which covers almost one-third of Australia, has been traditionally harvested for its durable, fine nanofibres 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.

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.

Figure 1.23 Spinifex grass (left) contains resins that are used to manufacture a thick gel (right).

When communicating First Nations Australians' knowledge, it is important to be culturally responsive and respectful, maintain cultural protocols, and avoid any offensive narratives, language or images. Generally, it is wise to seek permission from the relevant First Nations people or communities, 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.

Explore! 1.1

Traditional knowledge

Figure 1.24 Some groups of First Nations Australians traditionally use eucalyptus oil to treat respiratory infections.

First Nations Australians have a rich history of medicinal knowledge and practices that have been developed and refined over thousands of years. Their understanding of the human body and physiology, and the environment continues to contribute significantly to the advancement of modern medicine.

For example, the traditional use of eucalyptus oil to treat respiratory infections is now supported by modern research, which has shown that eucalyptus oil has antiviral and antibacterial properties. The use of tea tree oil as a topical antiseptic has also been validated by scientific research.

Similarly, the Kakadu plum has the highest concentration of vitamin C of any fruit in the world. Its high vitamin C content has been used to treat the disease scurvy, and its antioxidant properties have been studied for their potential in cancer treatment.

Research other plants that different groups of First Nations Australians have traditionally used as medicine.

Section 1.4 questions

QUIZ

Retrieval

1 **Recall** how you can consider the objectivity of a source.

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

Comprehension

3 **Explain** why peer-reviewed articles are considered of higher quality than articles that are not peer reviewed.

Analysis

4 **Contrast** primary data and secondary data.

Knowledge utilisation

5 In May 2023, the Queensland Government announced the allocation of more than $4 million over the next three years to implement various crocodile safety measures. These include:
   - installing barriers in high-risk waterways
   - developing an updated CrocWise strategy that includes input from First Nations people and behaviour-change experts
   - creating a new device using sonar and artificial intelligence software to detect saltwater crocodiles underwater.

   Create different headlines for this story that are targeted at different audiences.

Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
1.1	I can develop investigable questions, reasoned predictions and hypotheses to test relationships and develop explanatory models.	12	
1.2	I can plan and conduct valid, reproducible investigations to answer questions and test hypotheses.	8	
1.2	I can select and use appropriate equipment.	7	
1.3	I can select and construct appropriate representations of data.	9	
1.3	I can analyse and connect a variety of data and information to identify and explain patterns, trends, relationships and anomalies.	11	
1.4	I can assess the validity and reproducibility of methods.	5	
1.4	I can evaluate the validity of conclusions and claims.	13	
1.4	I can communicate ideas, findings and arguments effectively.	1	

Review questions

SCORCHER

Retrieval

1 **Recall** why it is important to cite sources correctly.

2 **State** the purpose of extrapolation.

3 **Recall** how chemical hazards should be addressed in experimental investigations.

Comprehension

4 **Contrast** primary data and secondary data, giving an example for each.

Analysis

5 **Reflect** on why sample size is important in any scientific investigation.

6 **Judge** the validity of the data when extrapolating from a graph.

7 **Sequence** the instruments in Figure 1.25, from highest to lowest accuracy.

Figure 1.25 (Left to right) Conical flask, measuring cylinder, beaker, graduated pipette

Knowledge utilisation

8 **Propose** a hypothesis to test an identified relationship of your choosing.

9 **Decide** on the appropriate graph to use and construct one for the following data 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

10 **Deduce** when a scientist might use a column graph rather than a scatter plot.

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 then counted the number of 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 then draw in a line of best fit for each set of data.
- 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.

12 **Discuss** why a scientific hypothesis must be able to be supported or refuted through evidence.

13 **Discuss** how the validity of media headlines can be evaluated.

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Data questions

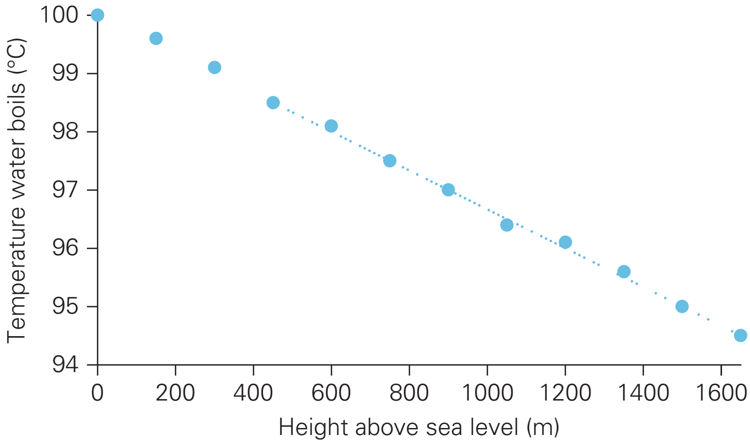


Figure 1.26 The different temperatures that water boils at different heights above sea level on Mount Bartle Frere

A Queensland 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 Bartle Frere in Queensland's Wooroonooran National Park. The mountain is 1611 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 1.26.

Apply

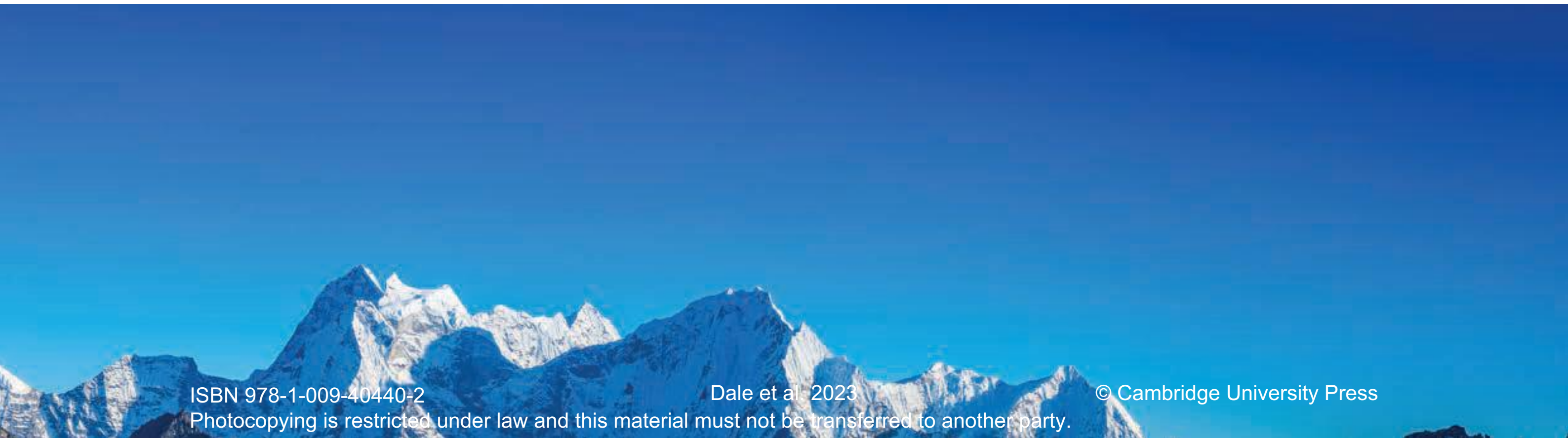
1 **Identify** two controlled variables in this experiment.
2 Use the graph to **determine** the independent variable in the experiment.
3 **Calculate** the range in the data presented.

Analyse

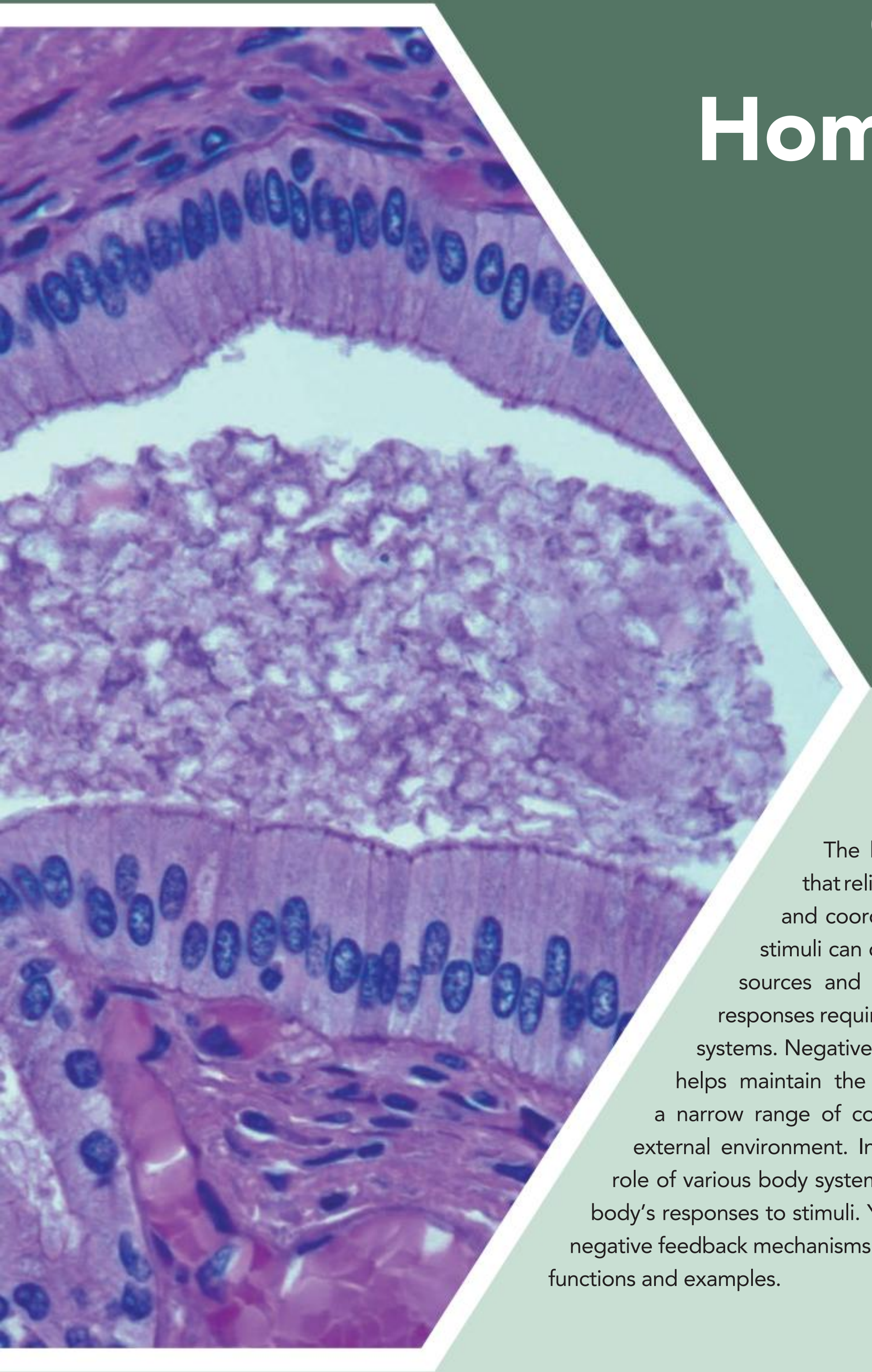
4 **Identify** the trend in water boiling temperature as height above sea level changes.
5 **Analyse** the data points and identify any outliers that should be removed from the trend line.
6 From the trend line, **infer** the temperature of boiling water at 700 m above sea level on Mount Bartle Frere.

Interpret

7 **Justify** that the linear trend line is a reliable fit for the data.
8 **Extrapolate** the data 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 of Mount Bartle Frere above sea level. **Predict** the temperature that water would boil at on a 3300 m peak in the Alps.



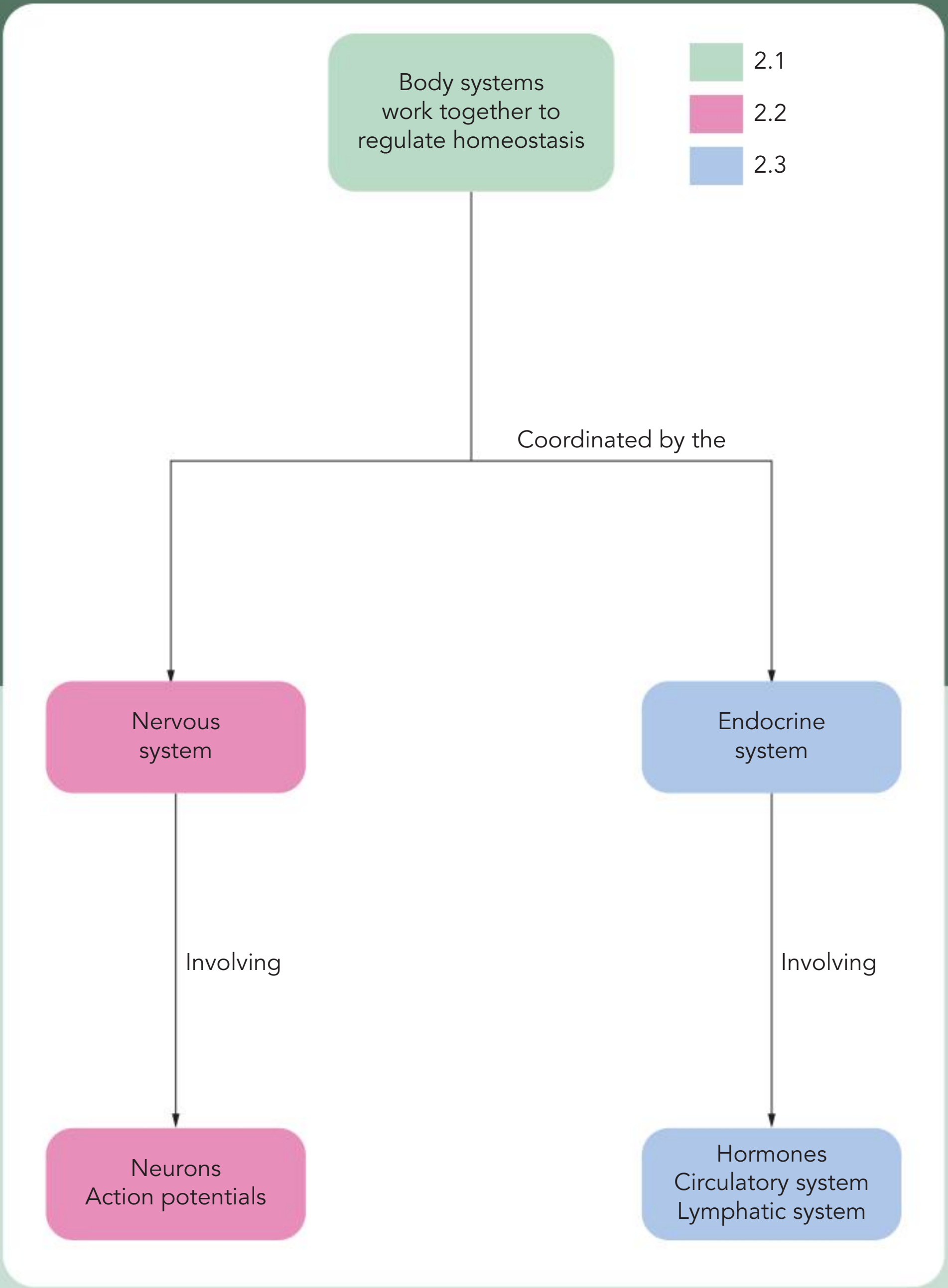
Chapter 2
Homeostasis



Chapter introduction

The human body is a complex organism that relies on various body systems to regulate and coordinate its responses to stimuli. These stimuli can come from both external and internal sources and the regulation and coordination of responses requires the collaboration of different body systems. Negative feedback is a critical mechanism that helps maintain the body's internal environment within a narrow range of conditions, despite fluctuations in the external environment. In this chapter, you will compare the role of various body systems in regulating and coordinating the body's responses to stimuli. You will also explore the operation of negative feedback mechanisms in detail, including their components, functions and examples.

Concept map



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Curriculum

Compare the role of body systems in regulating and coordinating the body's response to a stimulus, and describe the operation of a negative feedback mechanism (AC9S9U01)	
exploring the body's observable responses to external stimuli (such as changes in light or temperature, or presence of danger or pathogens) or internal stimuli (such as dehydration or hunger)	2.1
using models, flow diagrams and virtual simulations to explore and represent the relationships between body systems that are necessary to coordinate a response to stimuli	2.1
modelling how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector	2.1
describing how positive feedback mechanisms maintain the direction of a stimulus and accelerate its effect	2.1
comparing the role and function of electrical impulses and hormones in the body's responses to external stimuli	2.2, 2.3
examining how negative feedback mechanisms serve to maintain balance in internal systems, such as body temperature, blood sugar, iron levels or extracellular pH	2.1, 2.3
examining the effects of a disorder in a feedback system, such as diabetes-induced blindness or hypothermia	2.3
considering how understanding of feedback mechanisms has enabled the development of pharmaceuticals and other products to address issues or enhance performance, such as insulin or electrolytes in sports drinks	2.3

Adapted from © Australian Curriculum, Assessment and Reporting Authority (ACARA)

Glossary terms

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

2.1 Body systems working together

Learning goals

1. To be able to describe the body's observable responses to external or internal stimuli.
2. To be able to describe the relationships between body systems that are necessary to coordinate a response to stimuli.
3. To be able to explain how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector.
4. To be able to 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. The systems are:

- circulatory (sometimes called cardiovascular)
- endocrine
- skeletal
- reproductive
- 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**.

Negative feedback mechanisms play a crucial role in maintaining homeostasis. These mechanisms operate by sensing when a system deviates from a set point, and then activating responses to counteract the deviation and bring the system back to its set point. If there is a change in an animal's external environment, such as a rise in temperature, the body must adapt to maintain a stable internal environment. Physiological parameters that must be tightly regulated within the human body include blood glucose levels, blood pH and blood pressure.

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

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

Body systems working together

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.

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

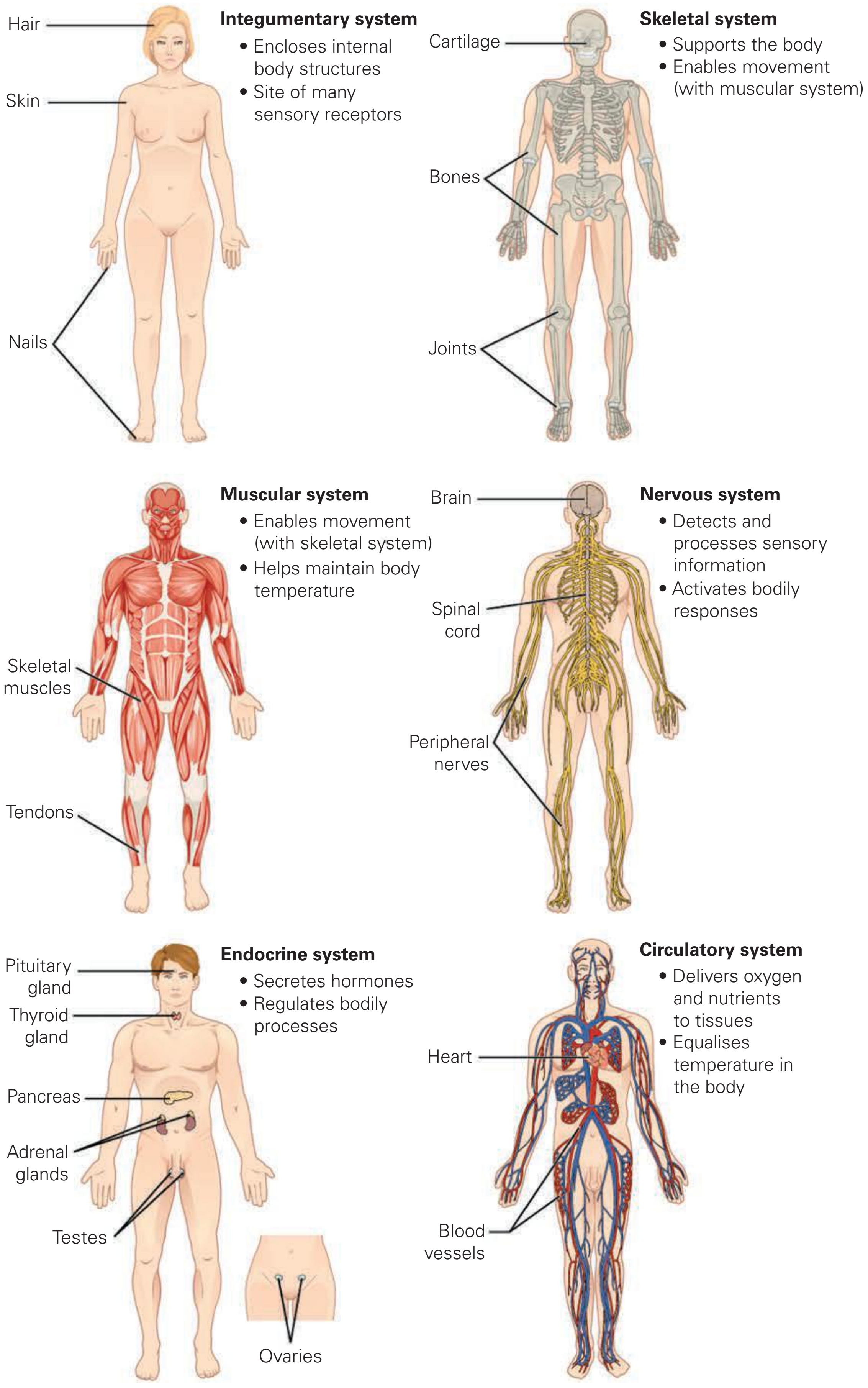
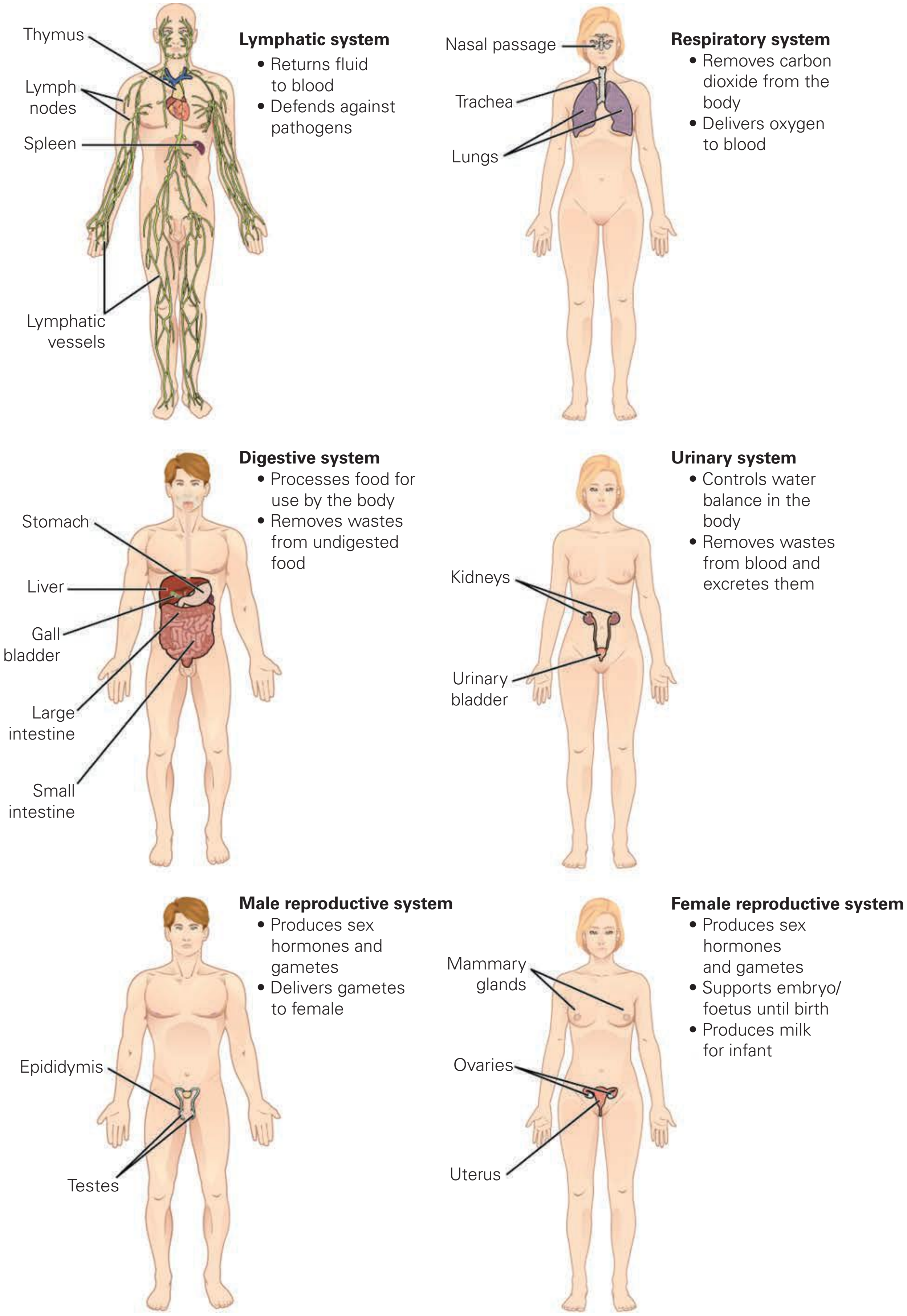


Figure 2.1 The different body systems work together to maintain homeostasis.



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 2.1 (*Continued*)

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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 and remove carbon dioxide. The respiratory system includes the lungs and airways. Oxygen is taken in through the lungs and transported to the body's tissues by the circulatory system. Carbon dioxide is removed from the body through the lungs and exhaled.

excression
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, a gland or an organ that carries out a response or action in response to a stimulus

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**.

Quick check 2.1

1. Define 'homeostasis'.
2. Explain why homeostasis is important for your survival.
3. What is negative feedback?

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 is 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.

Receptors are specialised structures throughout the human body that allow the body 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 (Figure 2.2). The different receptors are described in Table 2.1.

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 2.1 A summary of receptors in the body

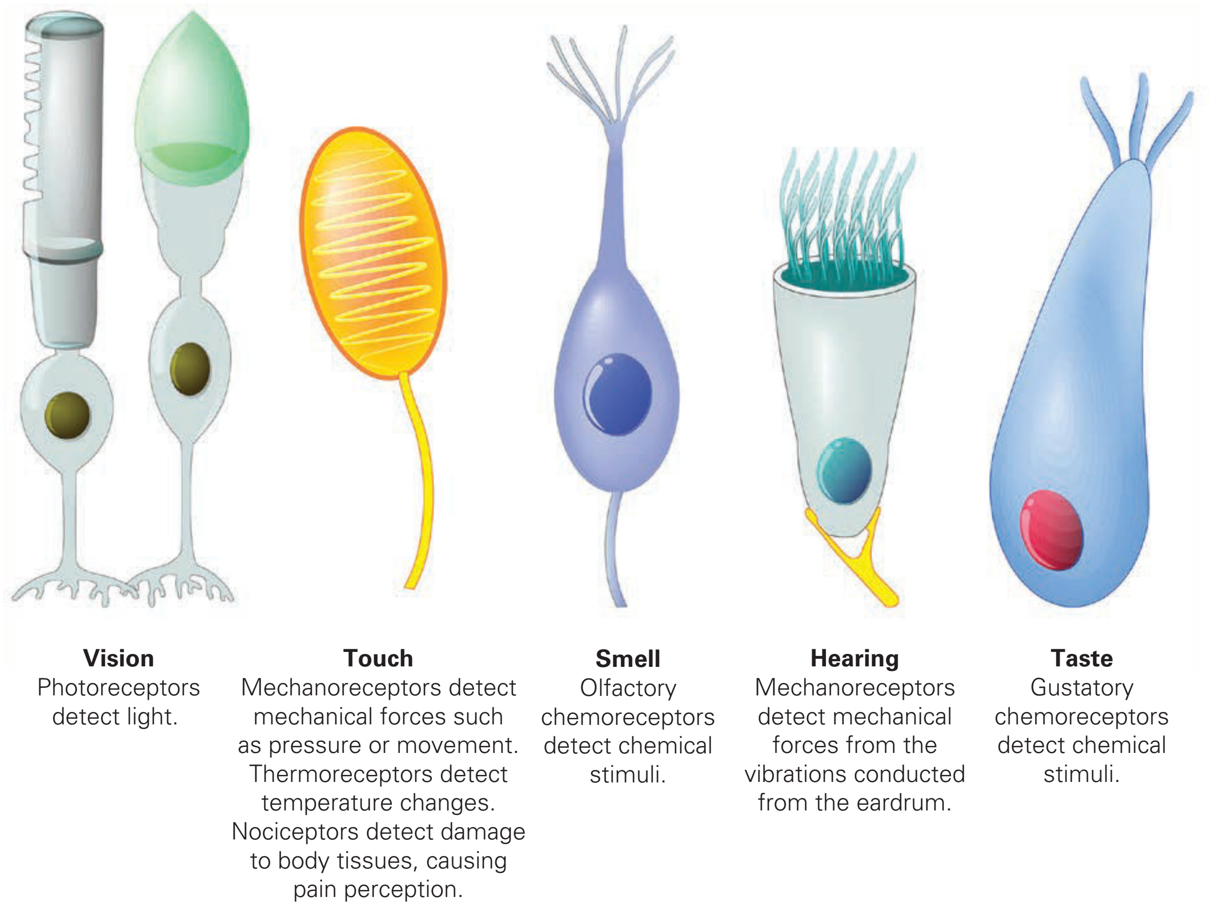

Figure 2.2 The different sensory receptors associated with your five senses. Their shape is closely associated with their specialised functions.

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 2.3.

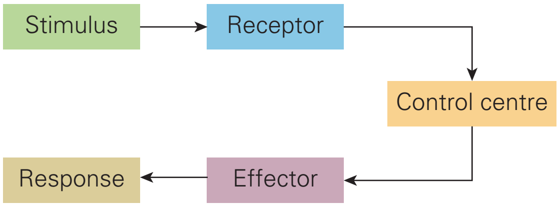

Figure 2.3 A flow chart outlining the stimulus–response model

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.

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

VIDEO
Negative feedback

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 its set point.

The body's observable responses to a drop in temperature are shown in Table 2.2.

Stage	Description	Example
Stimulus	A change in the internal or external environment that triggers a response	A sudden drop in external temperature
Receptor	Specialised cells that detect the change and transmit a signal to the control centre	Thermoreceptors in the skin and brain detect the drop in temperature and send a signal to the control centre.
Control centre	A structure in the brain (hypothalamus) that receives the signal and coordinates the response	The hypothalamus in the brain receives the signal and sends an electrochemical signal to the effector.
Effector	The muscles or organs that carry out the response	Muscles begin to contract and relax rapidly (shivering) to generate heat and increase the body's core temperature.
Response	The body returning to a state of balance so that the receptors are no longer active	The body's temperature returns to within a normal range, and shivering stops. As the body warms up, the thermoreceptors detect the increase in temperature and signal the hypothalamus to reduce the response.

Table 2.2 A summary of the stages of the stimulus–response model when temperature decreases

Figure 2.4 When the body's temperature increases, sweat glands are activated.

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Making thinking visible 2.1

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.

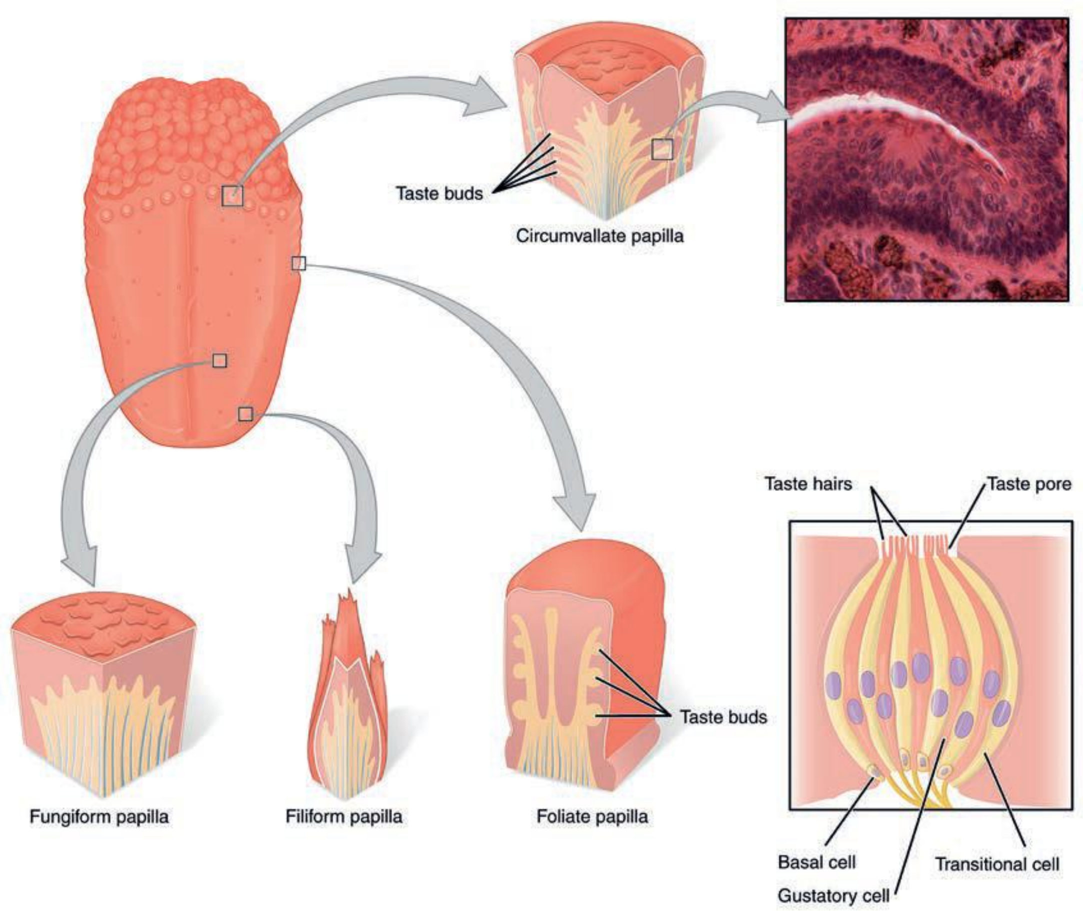

Figure 2.5 Animal tongues are covered with various types of papillae, and taste buds are hidden in the crevices between them.

continued…

…continued

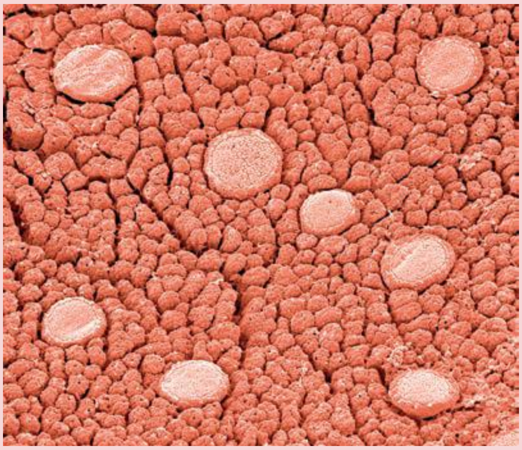

Figure 2.6 Papillae on a tongue

Figure 2.7 A cross-section of papillae. At 50× magnification, a taste bud is visible (circled) on the central papilla.

Look carefully at the images above 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.

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, therefore reducing the carbonic acid in the blood. The excretory system also plays a role in regulating extracellular pH by being able to excrete 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 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 (Figure 2.8).

Figure 2.8 A pupil constricts in bright light (left) and dilates In low light (right).

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, which acts as the body's master clock. The suprachiasmatic nucleus 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 (Figure 2.9).

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 2.10 Many organisms have a fight-or-flight response.

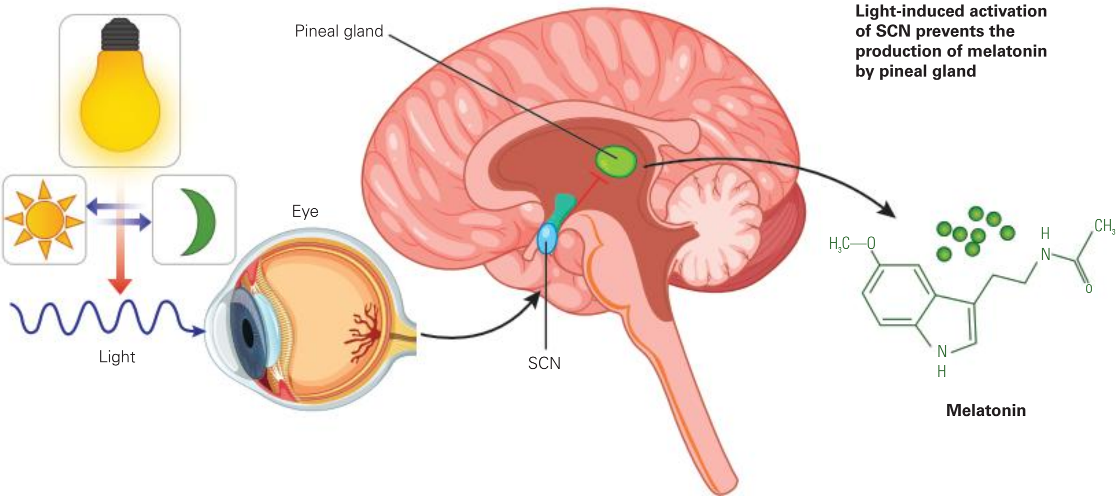

Figure 2.9 The suprachiasmatic nucleus (SCN) triggers the synthesis and release of the hormone melatonin by the pineal gland.

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, which 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, when 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.

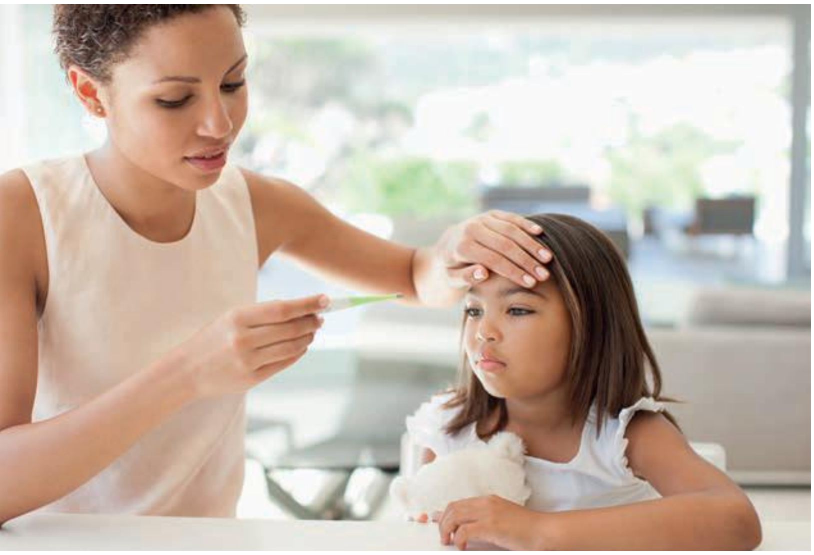

Figure 2.11 Fever is a physiological response to an infection caused by pathogens such as viruses, bacteria and fungi.

Quick check 2.2

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 2.3.
3. What body systems maintain the pH of the extracellular fluid?
4. 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.

An 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 (Figure 2.12). 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 (Figure 2.13) is rapid and therefore effective in stopping bleeding.

Figure 2.12 Activated platelets

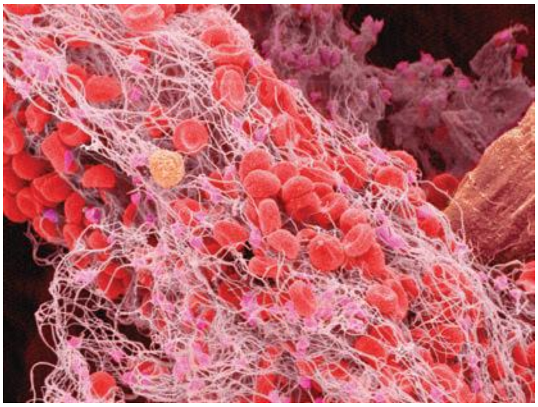

Figure 2.13 A blood clot Is the result of a positive feedback mechanism.

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Positive feedback is also important in childbirth (Figure 2.14). 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.

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.

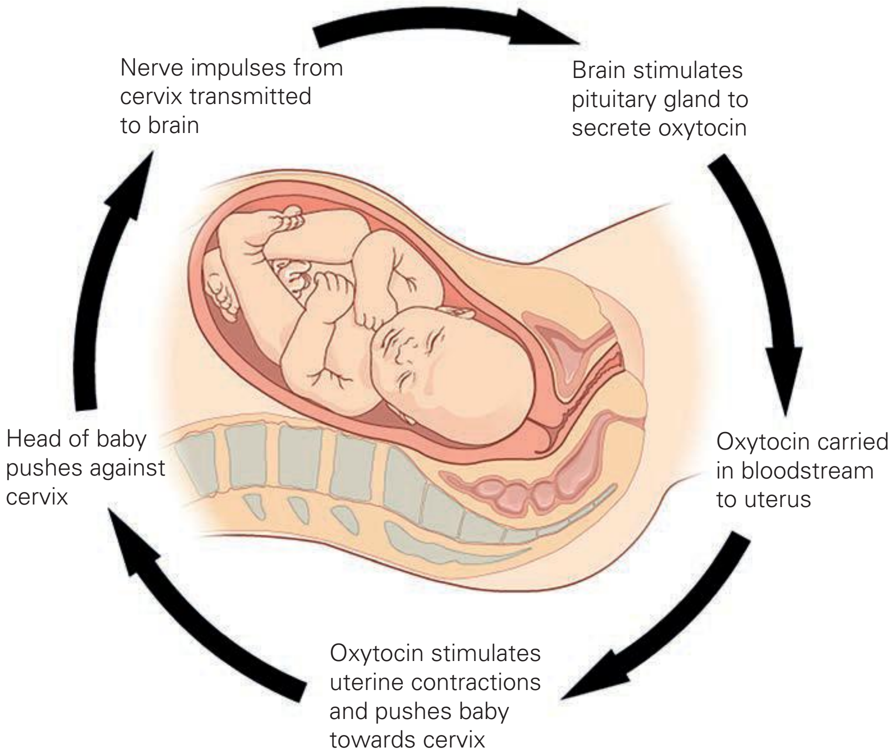

Figure 2.14 Positive feedback in childbirth involves the hormone oxytocin.

Section 2.1 questions

Retrieval

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.

QUIZ

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Comprehension

5 **Describe** the negative feedback mechanisms that occur when the body's temperature increases.

6 **Describe** how the respiratory system can control extracellular pH.

Analysis

7 **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 absorb glucose, which in turn reduces the amount of glucose in the bloodstream.

8 **Contrast** positive and negative feedback.

Knowledge utilisation

9 **Discuss** why the lungs and kidneys are both considered to be organs involved in excretion.

10 **Construct** a Venn diagram showing the digestive, circulatory and respiratory systems. In their overlapping zones, summarise in dot points the way the systems interact.

11 **Construct** a labelled diagram showing the stages of the stimulus–response model.

2.2 The nervous system

Learning goal
To be able to describe the role and function of electrical impulses in the body's responses to external stimuli.

WORKSHEET
Neurons

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

Nervous system

The fundamental units of the nervous system are **neurons** (also spelled 'neurones') (Figure 2.15). A neuron is a single nerve cell responsible for transmitting signals between the brain and 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.

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. Figure 2.16 shows the key components of the human nervous system.

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

VIDEO
The nervous system

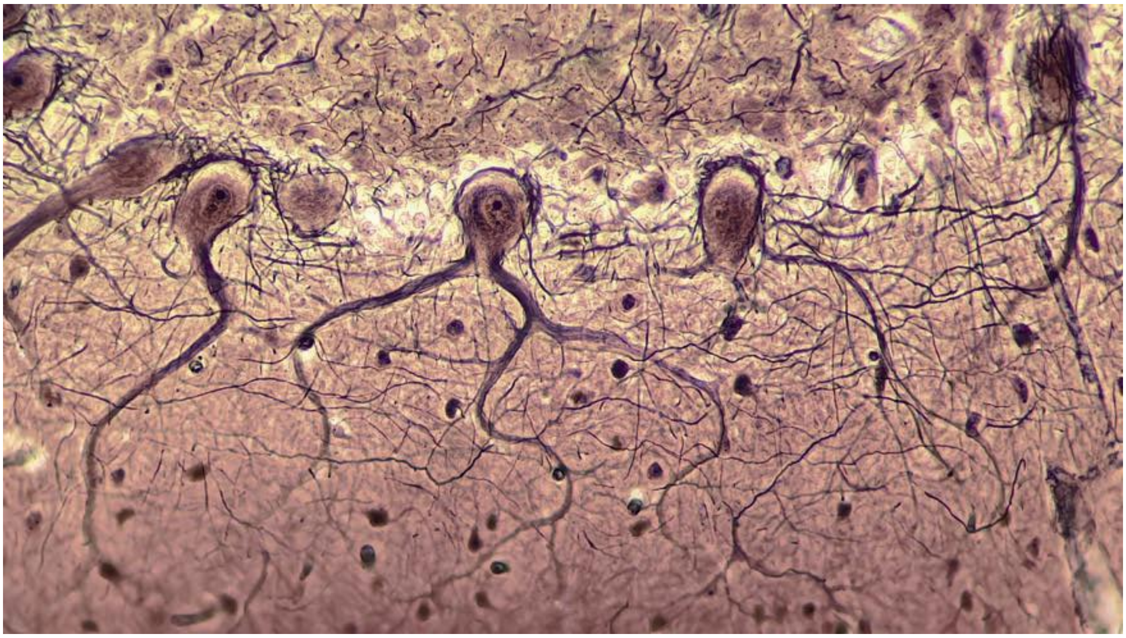

Figure 2.15 The neuron is the basic building block of the human nervous system.

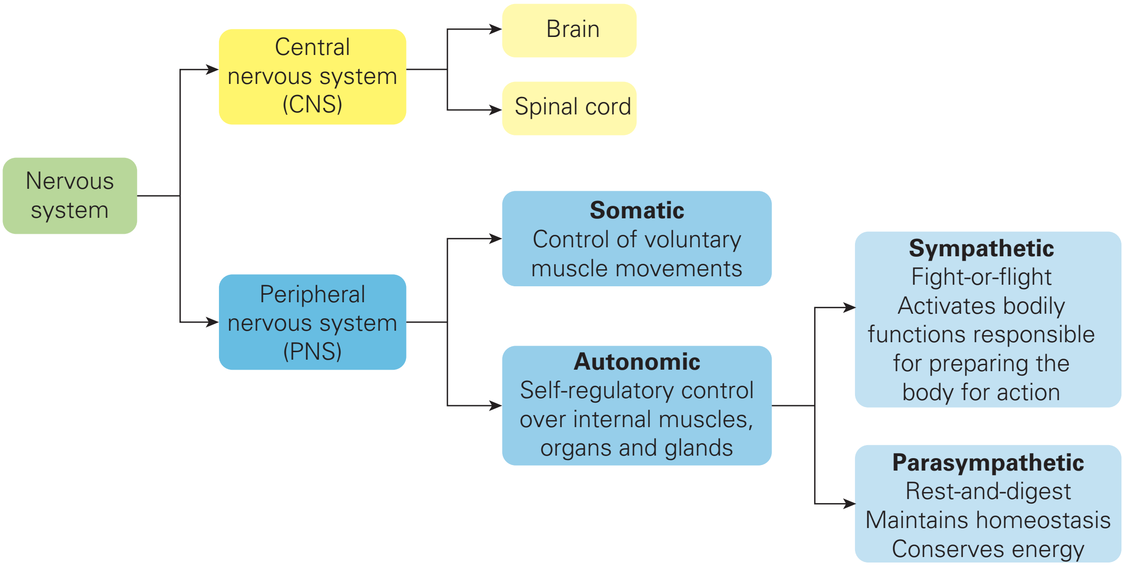

Figure 2.16 The components of the human nervous system

Quick check 2.3

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 (Figure 2.18).

- **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.

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

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

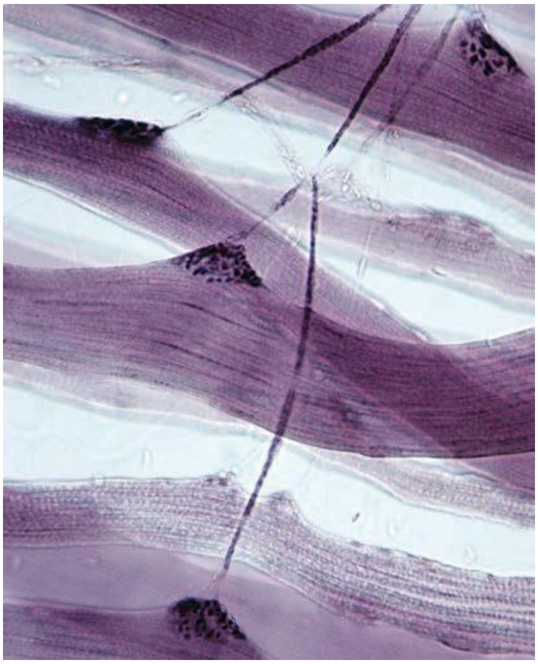

Figure 2.17 100× magnification of motor neurons attached to muscle cells

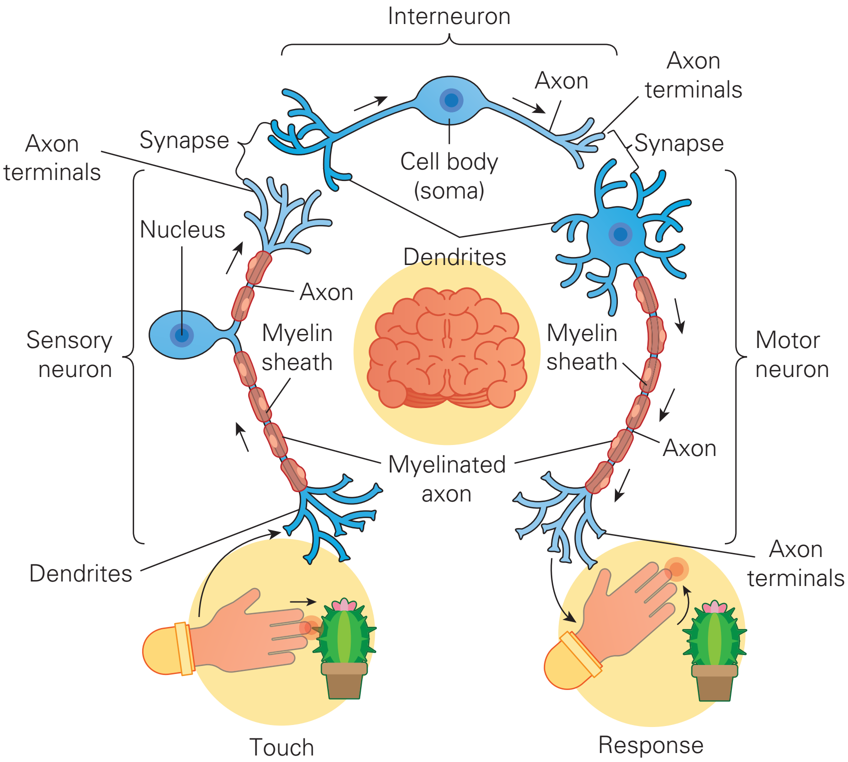

Figure 2.18 The three types of neuron (sensory, inter and motor) form an arc. Note how the sensory neuron has receptors to detect a stimulus and the motor neuron causes the response.

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 2.3 and Figure 2.19 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
Axon	Transfers electrical impulses from the cell body to the synapse. Axons are called 'nerves' when they are grouped together in a bundle.
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.
Cell body (soma)	Contains most of the cell's organelles, including the nucleus
Dendrite	Contains receptor sites that receive neurotransmitters from neighbouring neurons
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.
Nucleus	Control centre of the cell that contains its genetic material
Schwann cells	Specialised cells that form the myelin sheath
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 2.3 Neuron structures and their associated function

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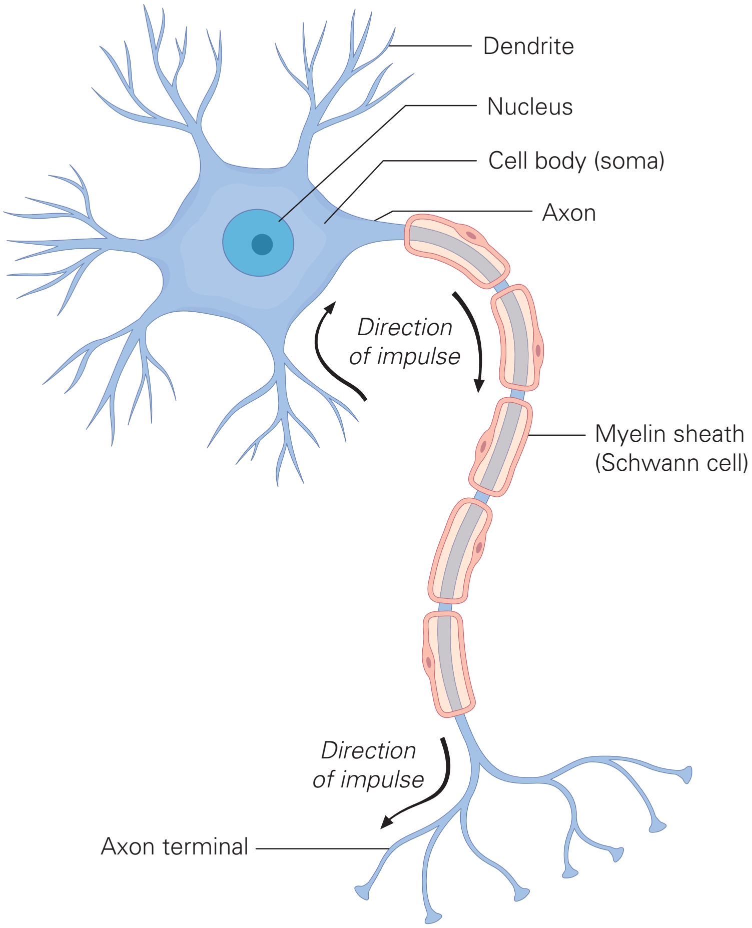

Figure 2.19 The key structures of a motor neuron. The neural impulse travels in one direction only along the neuron, from the dendrites to the axon terminals.

Quick check 2.4

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.

Try this 2.1

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, 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.

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.

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

The speed of an action potential moving along an axon varies for different neurons. The fastest travel more than 100 metres per second; the slowest travel at about 1 metre per second. The speed depends upon 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.

Explore! 2.1

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. 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.

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 FIND-seq useful in the treatment and monitoring of MS?
3. Why is the drug cladribine effective in MS treatment?

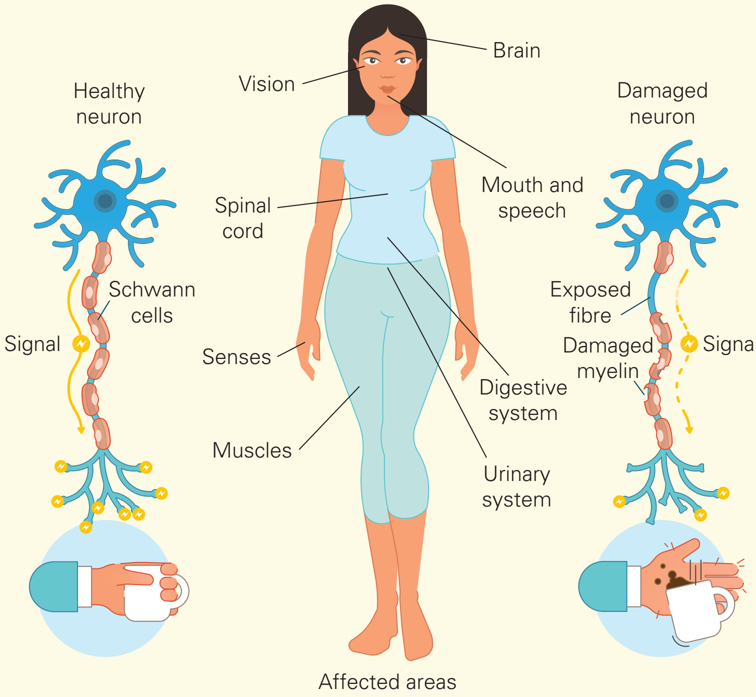

Figure 2.20 Multiple sclerosis affects many areas of the body.

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 this number. Some of the more common neurotransmitters are described in Table 2.4.

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 2.21 and 2.22.

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 2.4 Some common neurotransmitters and their roles

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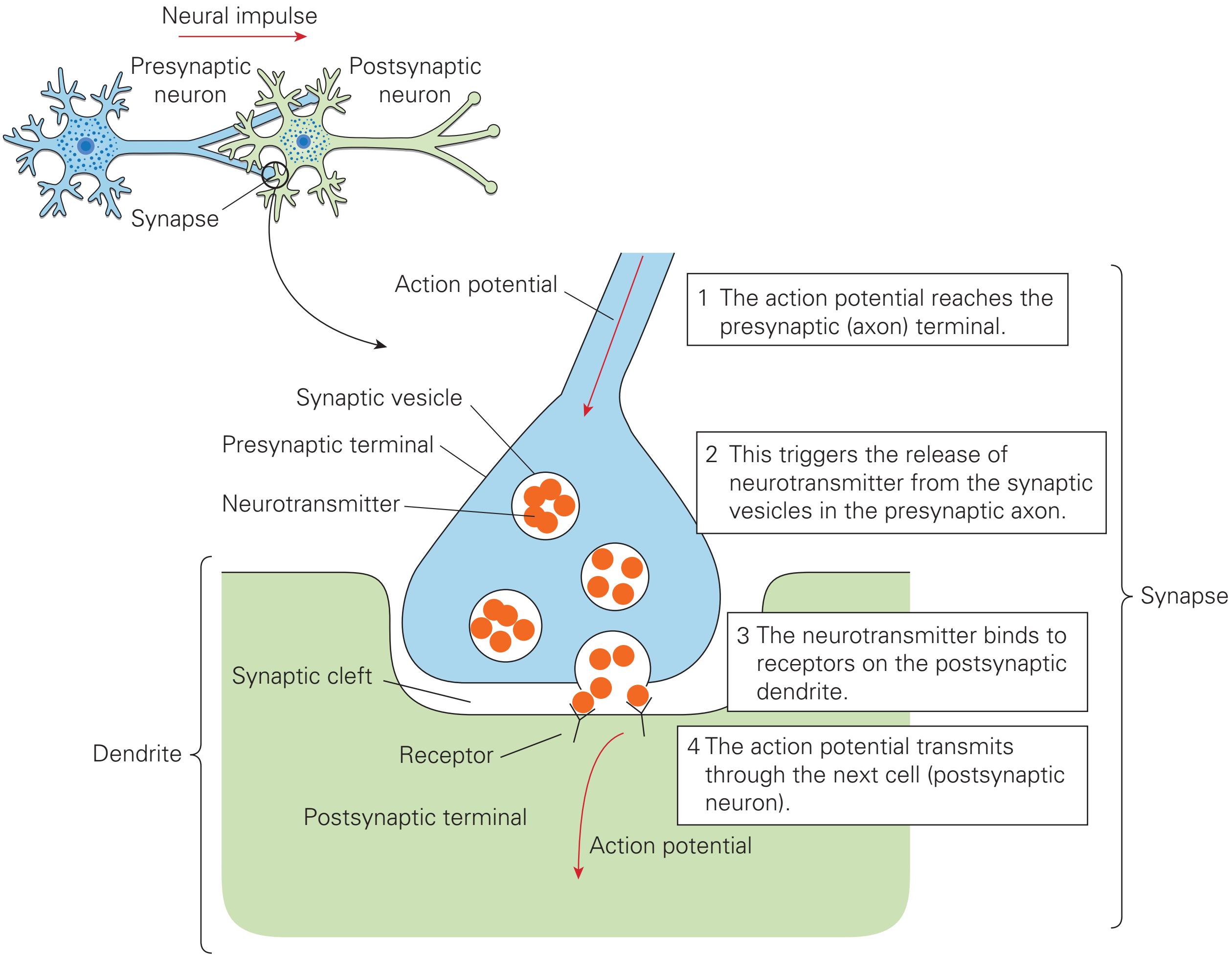

Figure 2.21 Communication between neurons. An action potential triggers the release of neurotransmitters from their synaptic vesicles in the presynaptic neuron. The neurotransmitters move across the gap and bind to receptors on the postsynaptic neuron.

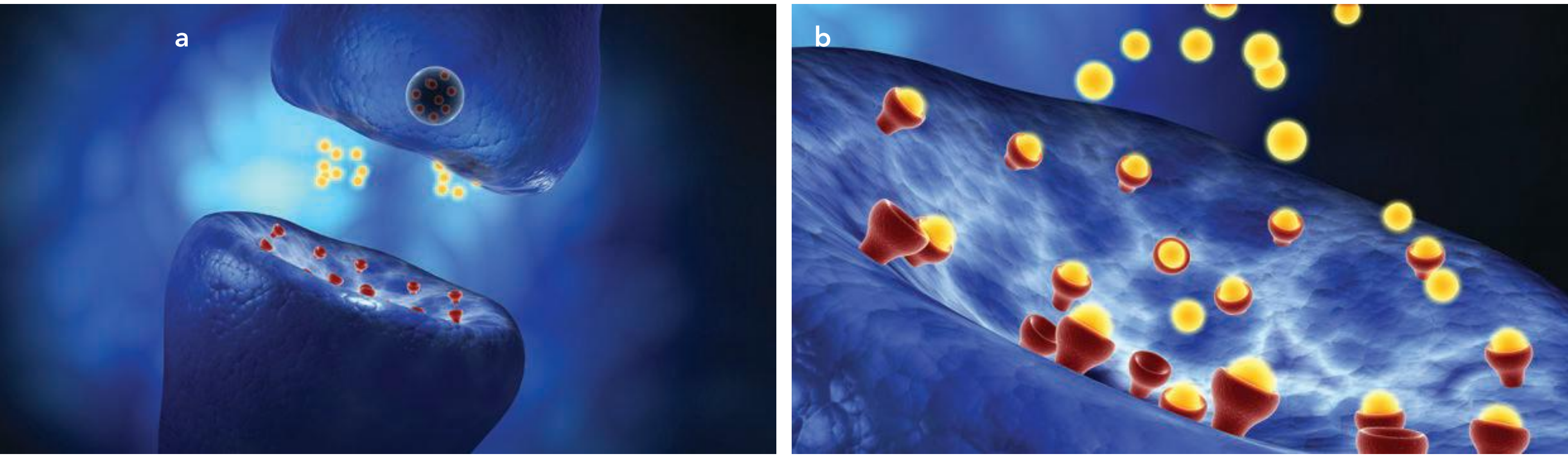

Figure 2.22 An illustration of a synapse. **a**) A synaptic vesicle in the axon terminal storing neurotransmitters, and the neurotransmitters (yellow) crossing the synapse to be received by the receptor sites (red) on the neighbouring neuron's dendrite. **b**) Neurotransmitters (yellow) being released 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? 2.1

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 1 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 cm, which is about as thick as your thumb!

Figure 2.23 The sciatic nerve contains the longest nerve In the human body.

Making thinking visible 2.2

Headlines: Mapping the human brain

The human brain consists of billions of neurons that 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.

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?

Figure 2.24 The first digital connectome of an organism – a fruit fly. A connectome is a map of neural connections in the brain.

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

Quick check 2.5

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 function.
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 initiated once threshold is reached	Neurotransmitters released into synaptic cleft	Action potential travels along axon of presynaptic neuron	Neurotransmitters bind to receptor sites on dendrites of postsynaptic neuron

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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 2.25 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.

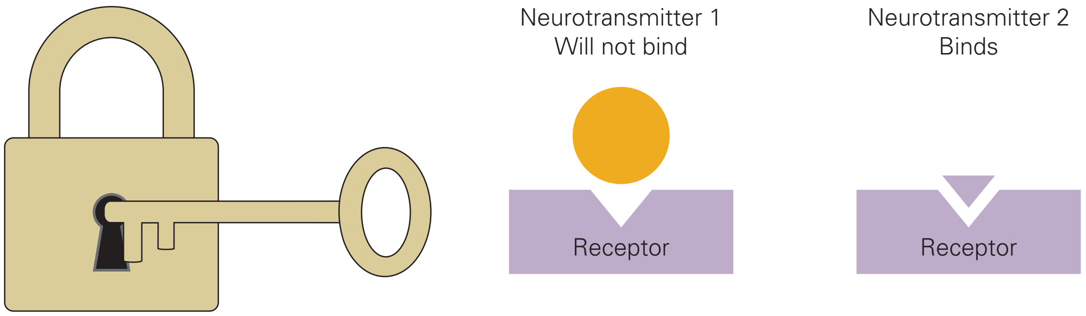

Figure 2.25 Similar to a key fitting into a lock, a specific neurotransmitter will bind only to its corresponding receptor, which ensures that it only causes the intended response.

Try this 2.2

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.

Did you know? 2.2

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. Alternatively, 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.

Explore! 2.2

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.

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.

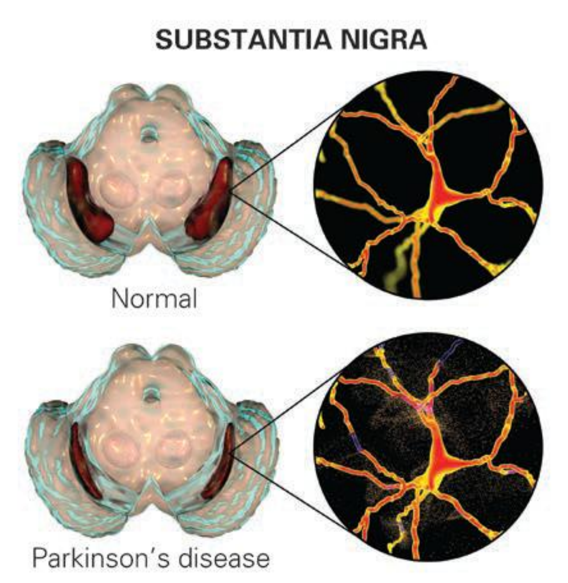

Figure 2.26 A computer-generated illustration of the human brain showing a healthy substantia nigra (top) and a degenerated substantia nigra (bottom)

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; 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.

Reflex actions

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

DOC
WORKSHEET
Response time data analysis

A **reflex action** is a fast, automatic response that protects the body from harm. At times, the body must react quickly without waiting for instructions from the brain. 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.

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 2.27 shows an example of a reflex arc.

When the brain is responsible for detecting and responding to a stimulus, the process is referred to as the stimulus–response model.

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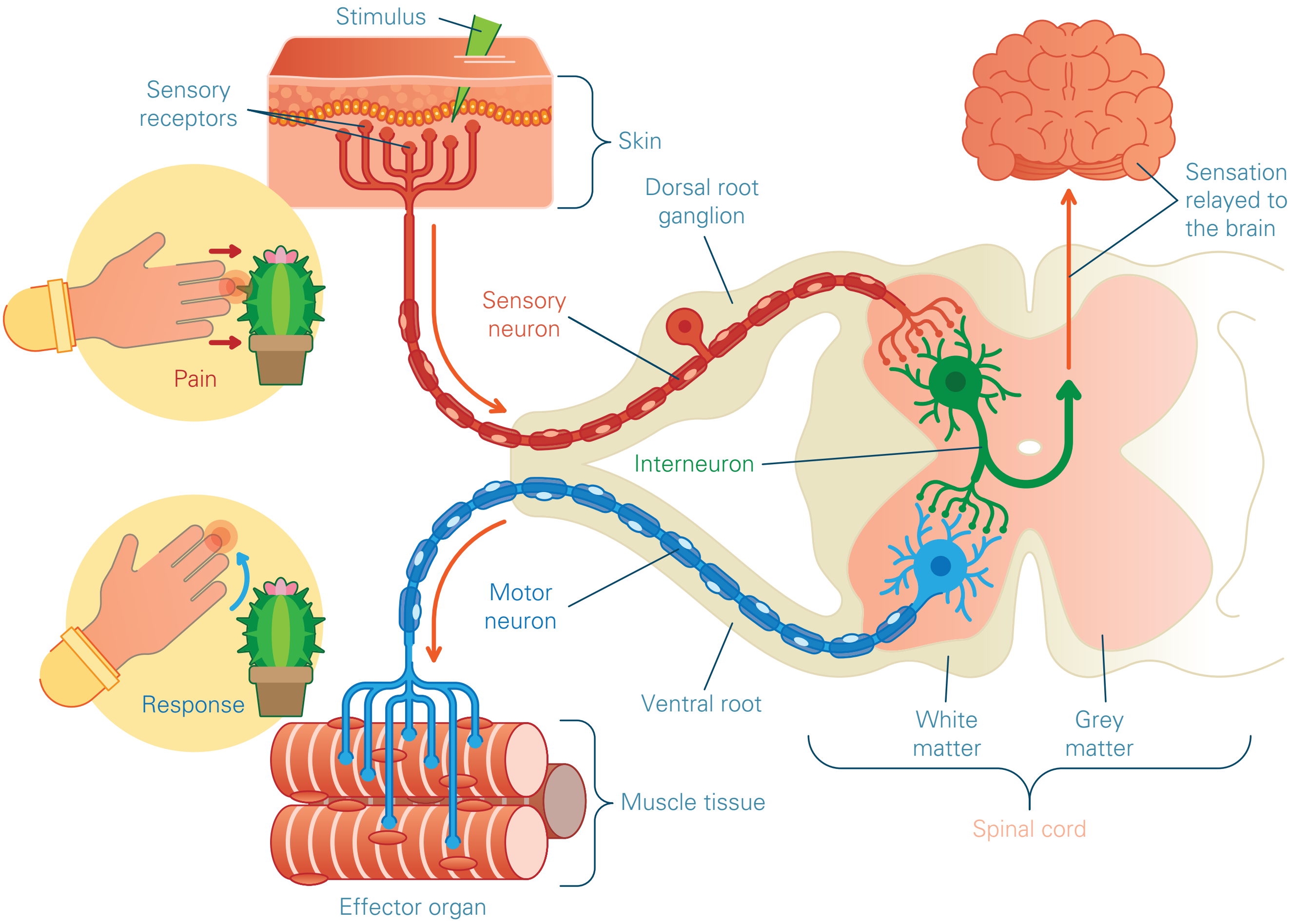

Figure 2.27 An example of a reflex arc. When you touch a prickly cactus with your finger, a receptor in a sensory neuron detects the pain and initiates an action potential. The impulse is carried to the spinal cord where the sensory neuron connects to an interneuron. The interneuron then connects to 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.

Try this 2.3

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 table below, 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 which 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

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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 (Figure 2.28). 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.

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.

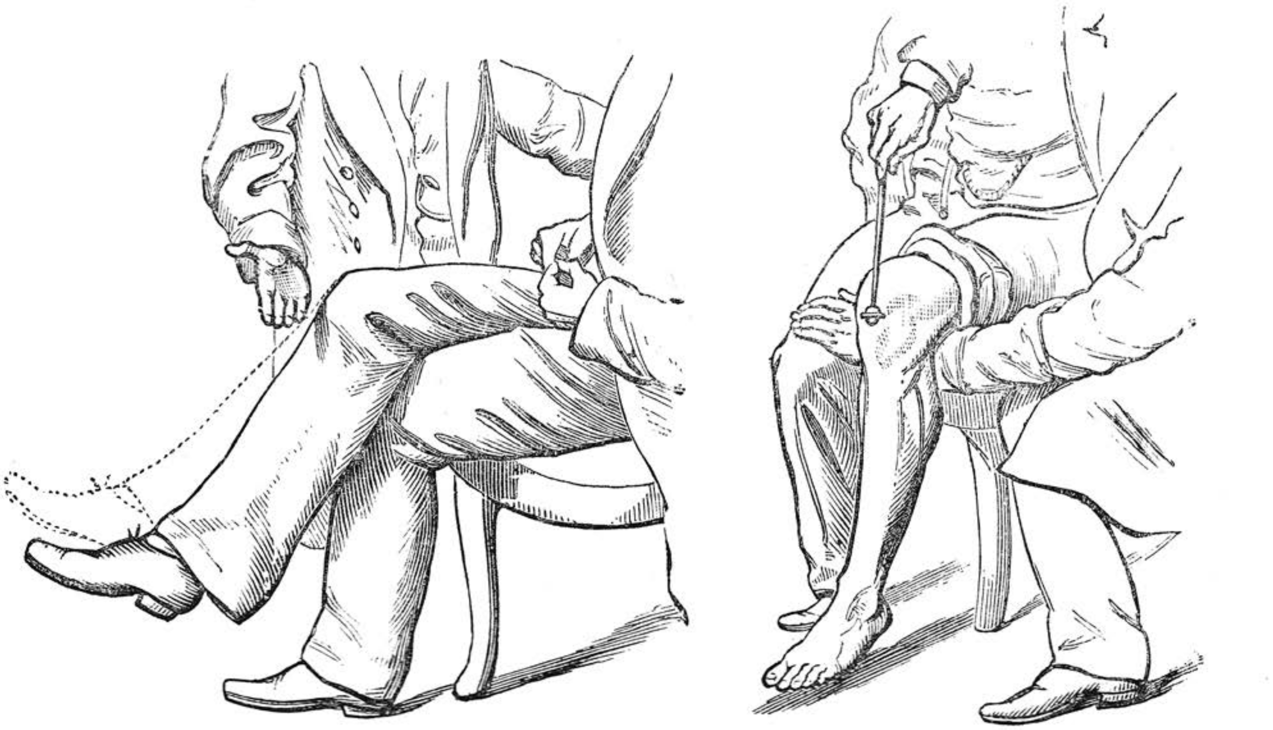

FIG. 1.—THE KNEE-JERK.
The dotted line indicates the movement which follows the blow on the patellar tendon.

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

Figure 2.28 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.

Investigation 2.1

Testing your reflexes and response times

Background information

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. You will design your own investigation to explore the effect of practice time on reaction time.

Aim

To plan and investigate the effect of practice time on automatic reflexes and response times

Planning

1. Write a rationale on reaction times and the factors that affect this.
2. Create a relevant and specific research question for this investigation.
3. Write a risk assessment for this investigation.

Materials

- stopwatch
- ruler
- well-lit room

Method

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.

1. Have your partner lean their forearm on a bench with their weakest 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.
2. Dangle the ruler above their hand so that the end marked 0 cm is hanging between their thumb and index finger.
3. Instruct them to catch the ruler with their thumb and index finger when they notice you have released it.
4. Release the ruler without warning.
5. 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 2.5) to determine the reaction time.
6. Each person should complete the drop test 15 times. Record the ruler reading and reaction time for each test.

Results

Create a results table for this experiment.

Data processing

Draw a graph of drop test number against reaction time.

continued…

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…continued

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 2.5 Conversion table for reaction times

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?

Evaluation

Limitations

1. Identify any potential sources of error in this experiment.

Improvements

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

Conclusion

Draw a conclusion from this experiment regarding practice time and reaction time. Justify your answer with data.

Did you know? 2.3

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
Tend to vary	Tend to occur in the same way each time
Can be learned	Do not require learning
Can be controlled	May not be controllable

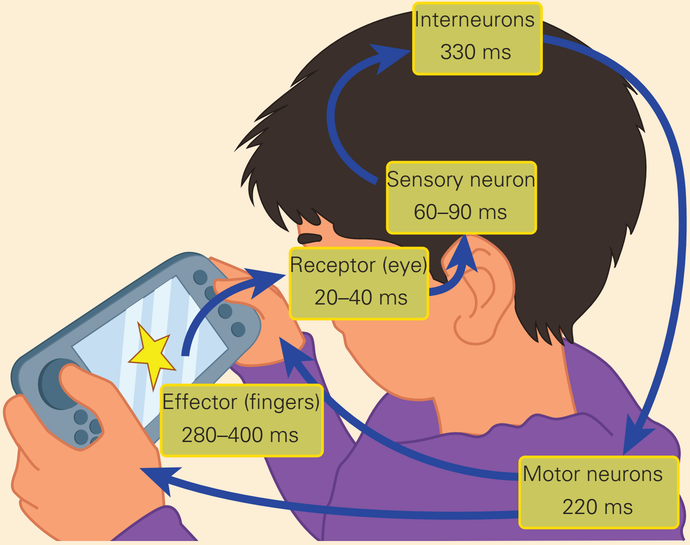

Figure 2.29 A child playing a game is an example of a conscious response. The approximate time in milliseconds (ms) is shown at each step of the process, from stimulus (light from the screen) to response (moving fingers to press buttons).

Quick check 2.6

1 'The brain is not immediately involved in a reflex arc.' Propose whether this statement is true or false.

2 Illustrate 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 2.2 questions

QUIZ

Retrieval

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.

Comprehension

5 A person picks up a very hot cup of coffee and immediately drops it, breaking the cup. **Illustrate** a flow chart of this action, beginning at stimulus and ending in response, and highlight the section of the flow chart that demonstrates whether this is a reflex or a response coordinated by the brain.

6 **Illustrate** a motor neuron, labelling all the key structures.

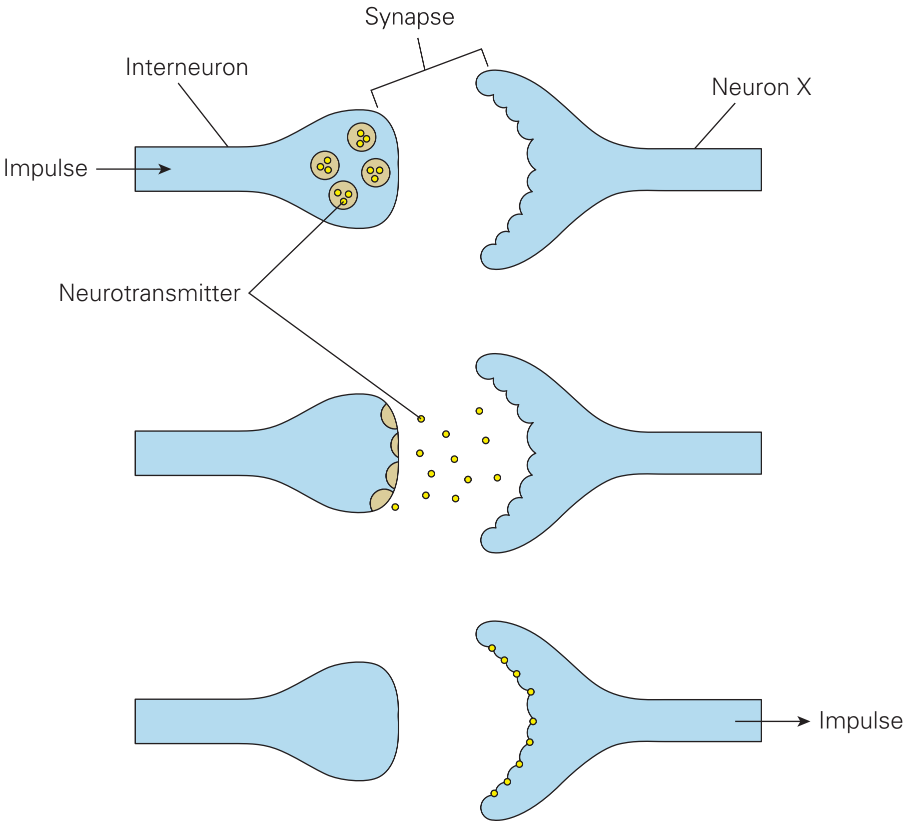
7 **Describe** how an action potential is triggered and transmitted from one neuron to the next.

8 **Describe** a synapse.

9 **Explain** how neurotransmitters cross a synapse.

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

11 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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Analysis

12 **Distinguish** between the stimulus and the response in the knee-jerk reflex.

13 **Contrast** conscious and unconscious responses.

14 **Contrast** the functions of the motor neuron and the sensory neuron.

Knowledge utilisation

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.

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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2.3 The endocrine system

DOC
WORKSHEET
Body communication systems

Learning goals

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

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

VIDEO
Parts of the endocrine system

The nervous system does not work in isolation, it works with the body's sense organs and 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 linked 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 (Figure 2.30).

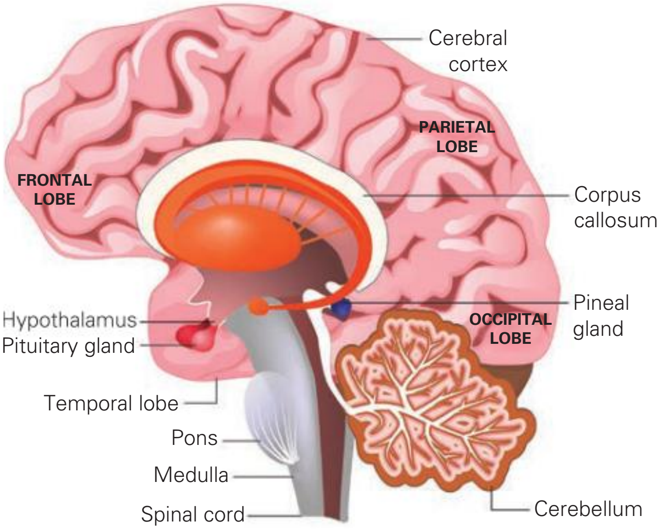

Figure 2.30 A cross-sectional view of the brain showing the location of the pineal gland, pituitary gland and hypothalamus

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 (Figure 2.31). These glands are involved in regulating metabolism, fight-or-flight responses and reproductive processes.

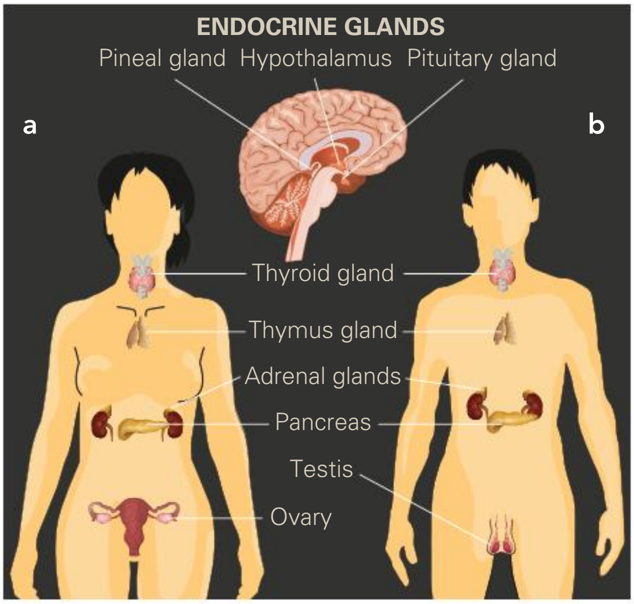

Figure 2.31 Endocrine glands in the (**a**) female and (**b**) male body

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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. The cells they affect are called **target cells**.

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 2.6 shows where some hormones are produced and what effect they have on the human body.

VIDEO
Hormones

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, it 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.
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 2.6 Endocrine glands and their hormones and actions

Explore! 2.3

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? 2.4

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.

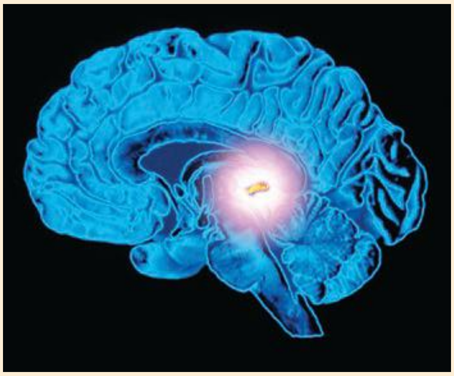

Figure 2.32 The pineal gland (highlighted) secretes the hormone melatonin, which controls the body's biological clock.

Try this 2.4

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 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.

Explore! 2.4

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.

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.

Figure 2.33 Lambs born in colder areas are increasingly being outfitted with plastic raincoats. These lamb macs are designed to shield the lambs from harsh weather conditions and reduce their susceptibility to hypothermia.

Quick check 2.7

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 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.

Negative feedback mechanisms play a crucial role in maintaining blood sugar levels and this is controlled by two 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 (Figures 2 34 and 2.35). Once blood sugar levels return 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).

insulin
a hormone secreted by the pancreas that triggers cells to take up glucose from the bloodstream and the liver to store glucose 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

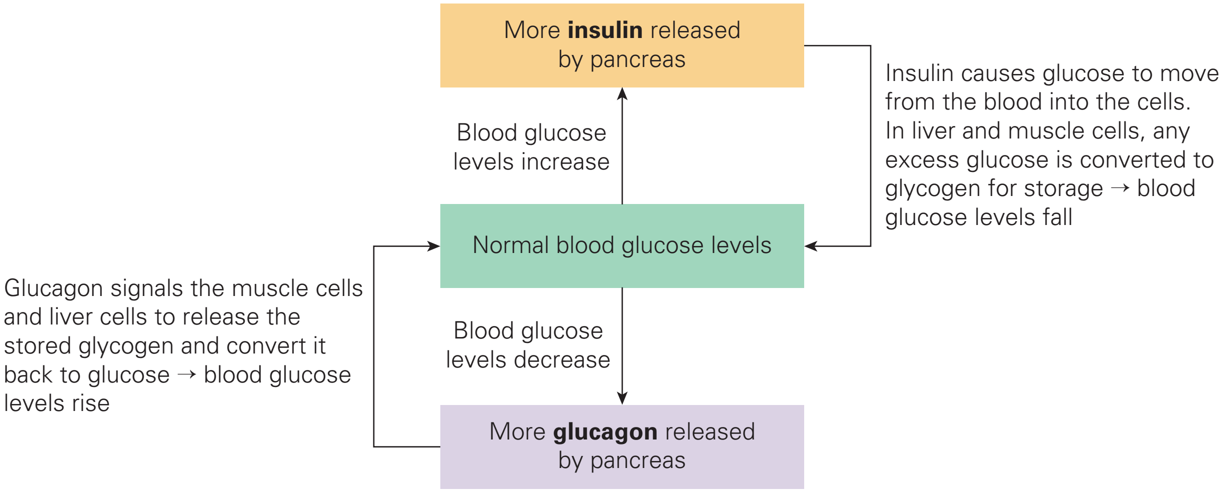

Figure 2.34 A flow chart showing insulin and glucagon maintain stable blood glucose levels

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.

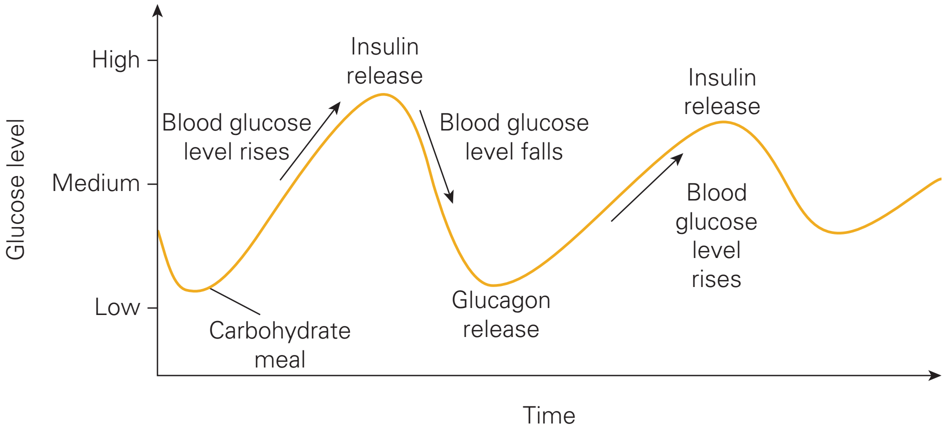

Figure 2.35 After a carbohydrate-rich meal, insulin levels in the bloodstream increase because the body needs to decrease the blood glucose levels.

Try this 2.5

Stimulus–response model and blood glucose levels

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for control 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 and response.

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

Explore! 2.5

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.

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.

Figure 2.36 Adhesive patches can be used to continuously monitor blood sugar levels.

Quick check 2.8

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. What is hypoglycaemia?
3. What role does glucagon play in the body?

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Explore! 2.6

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.

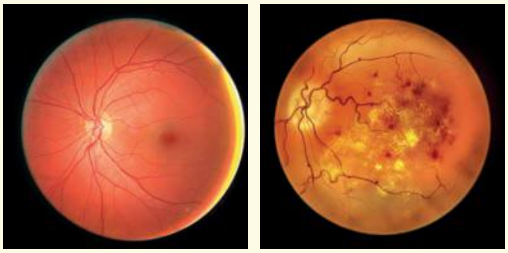

Figure 2.37 A normal retina (left) and a retina damaged from diabetes (right)

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). The flow chart in Figure 2.38 steps of osmoregulation.

osmoregulation the regulation of water levels in the blood/body

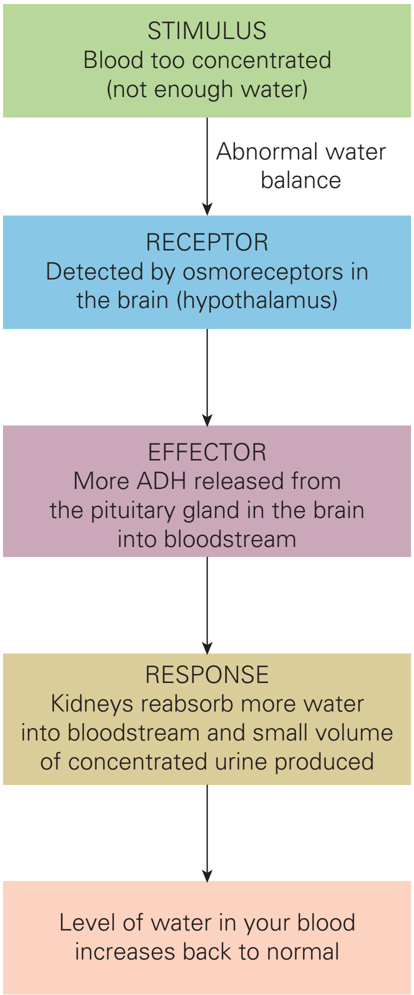

Figure 2.38 The stimulus–response flow chart for when water levels are low

Try this 2.6

Stimulus–response model and blood water levels

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

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.
2. The hypothalamus triggers the pituitary gland (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. Water levels in the blood increase to their normal level.

Figure 2.39 shows a dehydration colour chart. By matching the colour of urine to the chart, you can tell whether you are dehydrated.

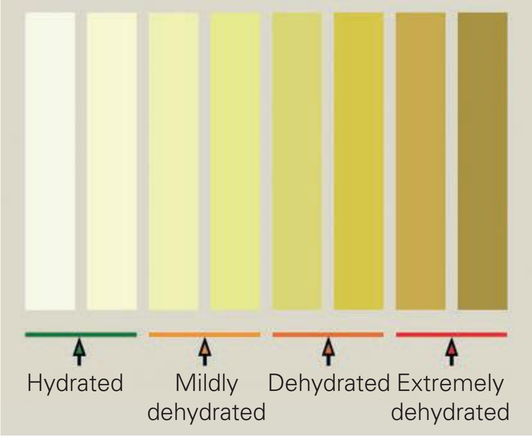

Figure 2.39 The dehydration colour chart. The colour of urine indicates how concentrated it is, and therefore how dehydrated a person is.

Quick check 2.9

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 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 and signals to the brain that the body has enough energy stores, suppressing appetite and promoting energy expenditure (Figure 2.40).

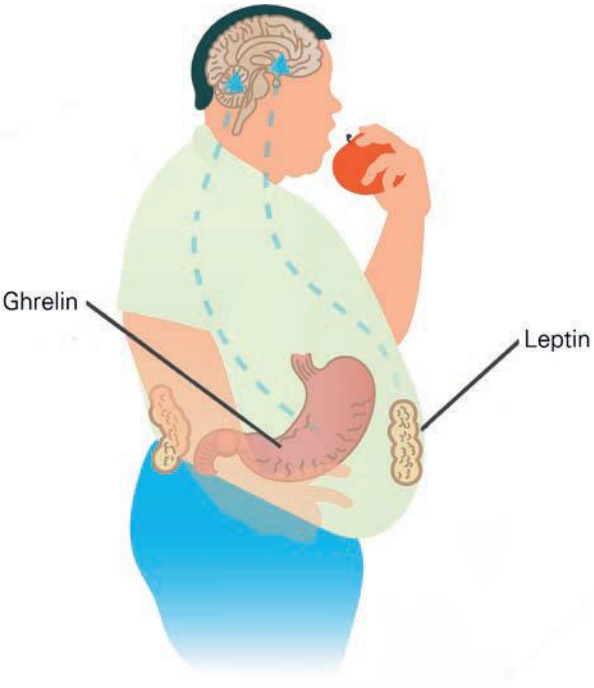

Figure 2.40 Ghrelin is produced by the stomach, and leptin is produced by fat cells.

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Explore! 2.7

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.

Figure 2.41 Insulin is injected into the body by a person with type 1 diabetes.

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 2.42 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 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 back 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? 2.5

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 2.43 A patient measuring their own blood pressure with an electronic blood pressure monitor

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Explore! 2.8

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 2.44 Extreme fatigue and weakness are common symptoms of iron deficiency.

Try this 2.7

Stimulus–response model and blood pressure

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for control 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 and response.

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

Quick check 2.10

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

Practical skills 2.1

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

Planning

Construct a specific and relevant research question for this activity.

Materials

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

Method

1 Copy the results table on the following page.

2 Measure your partner's resting heart rate by placing your index and middle fingers on the inside of their wrist (see Figure 2.45). Using the stopwatch, count the number of beats in a 15-second period. (Optional: wear a heart rate monitor.)

Figure 2.45 How to measure heart rate

3 Get your partner to count how many times they exhaled in this 15-second period.

4 Multiply both numbers by 4 to get heart rate (beats per minute) and breathing rate (breaths per minute). Record these in the table.

5 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.

continued…

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…continued

6 Multiply both values by 4 and record this in the table.
7 Measure the heart rate and breathing rate twice more: once 1 minute after they stopped walking and once 2 minutes after.
8 Instruct your partner to run around outside and use the stopwatch to time them 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.
9 Multiply both values by 4 and record this in the table.
10 Measure the heart rate and breathing rate twice more: once 1 minute after they stopped running and once 2 minutes after.

Results

Copy and complete the following table.

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.

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.

Evaluation

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

Conclusion

Draw a conclusion from this experiment regarding the level of exercise intensity and heart rate and breathing rate. Justify your answer with data.

Extension

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

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 2.7.

Feature	**Nervous system**	**Endocrine system**
Signals	Electrochemical messengers (via electrical impulses and neurotransmitters)	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 through a network of neurons, the information is relayed to your brain. Subsequently, additional messages are conveyed through your spinal cord, and using motor neurons, your skeletal muscles receive stimulation, causing them to contract. As a result, 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 in his system, it triggers sperm production, muscle development, hair growth and changes to his voice.

Table 2.7 A comparison of the nervous and endocrine systems

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Section 2.3 questions

QUIZ

Retrieval

1 **Name** two endocrine glands in the brain.

2 **Recall** how hormones reach their target cells.

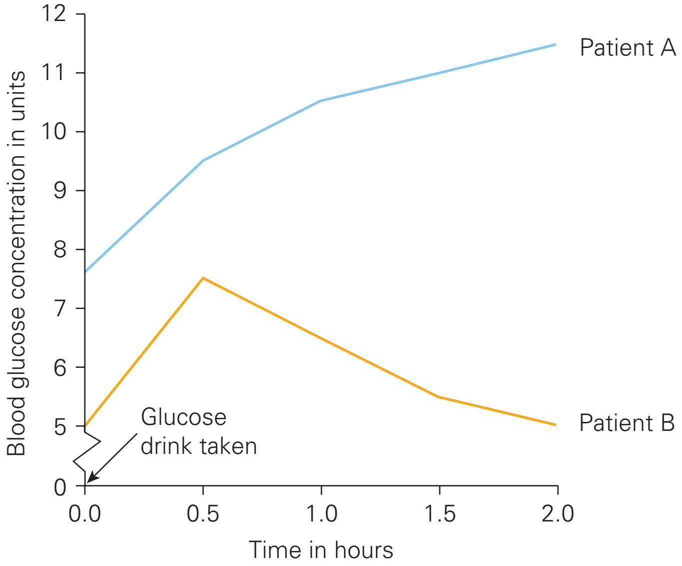
3 **Recall** the hormones secreted by the pancreas and what effect they have.

Comprehension

4 **Explain** the difference in the speed of transmission within the nervous and endocrine systems.

Analysis

5 The graph below 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.



6 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.

Knowledge utilisation

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

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.

Chapter review

Chapter checklist

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

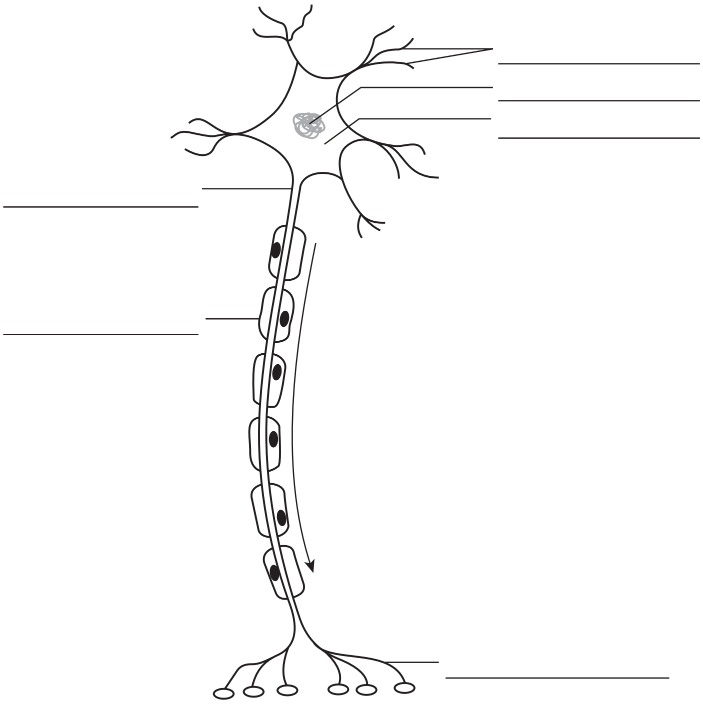
Success criteria		Linked questions	Check
2.1	I can describe how the body responds to external and internal stimuli.	2, 3, 10	
2.1	I can describe the relationships between body systems that are necessary to coordinate a response to stimuli.	11	
2.1	I can explain how the process of regulation is monitored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

Review questions

SCORCHER

Retrieval

1 **Name** the key structures of the following neuron.



2 **Define** 'homeostasis'.

3 A professional hockey player loses several litres of water during the game. **Recall** two homeostatic responses her body would use to retain water and maintain her blood pressure.

Comprehension

4 **Describe** a synapse.

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

6 **Describe** how a disorder in a feedback system can lead to hypothermia.

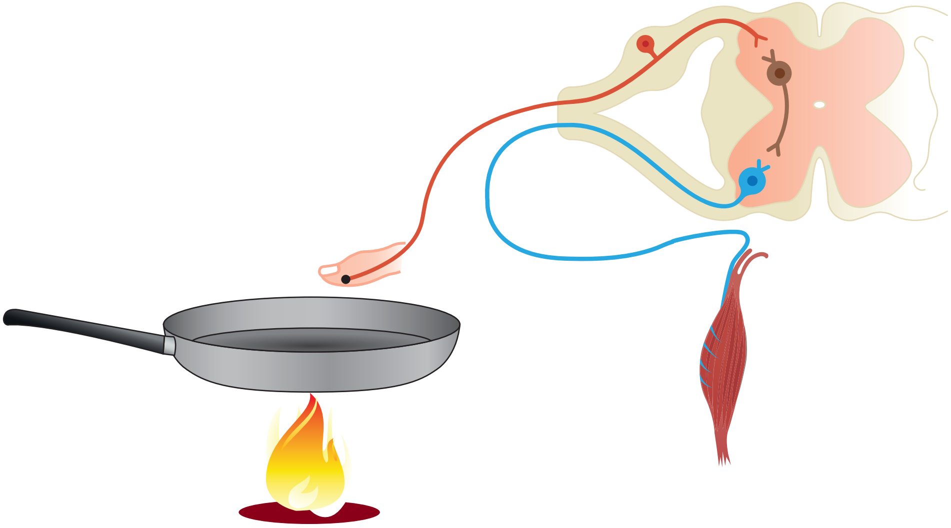
7 **Explain** how the process of regulation is monitored and adjusted by connections between the receptor, command centre and effector.

Analysis

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 intestine to move food along

10 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.

11 **Summarise** how the digestive, circulatory and respiratory systems interact with each other.

12 **Categorise** the following organs as receptors or effectors.
  a Hypothalamus
  b Mechanoreceptors
  c Liver
  d Kidney tubules
  e Pancreas
  f Skeletal muscles

13 **Compare** the role and function of electrical impulses and hormones in the body's responses to external stimuli.

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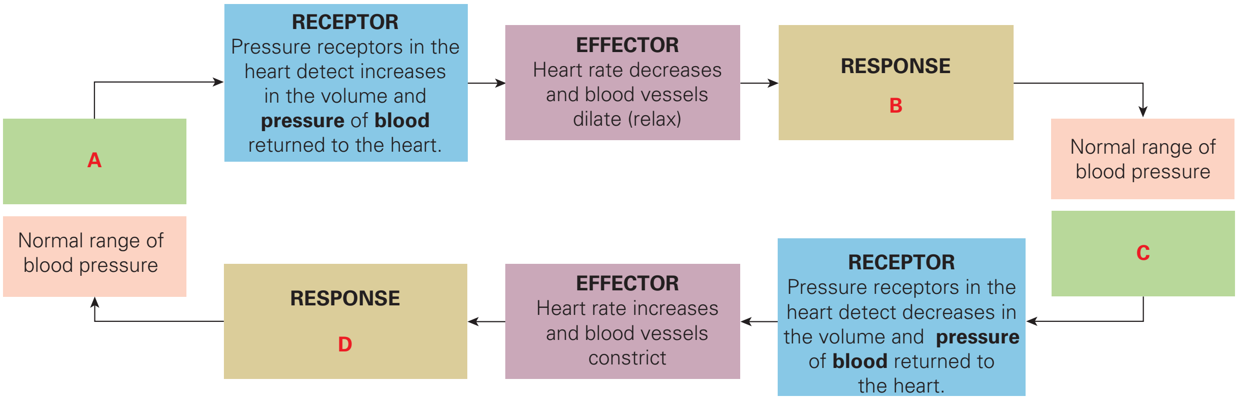
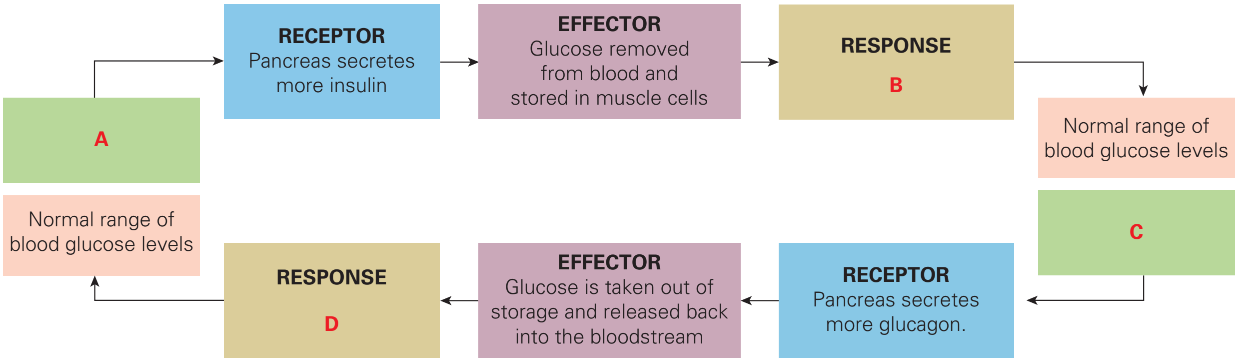
14 Copy and complete the flow charts to **compare** the ways in which the body responds to each of the following scenarios. You can do this by identifying what the letters represent.

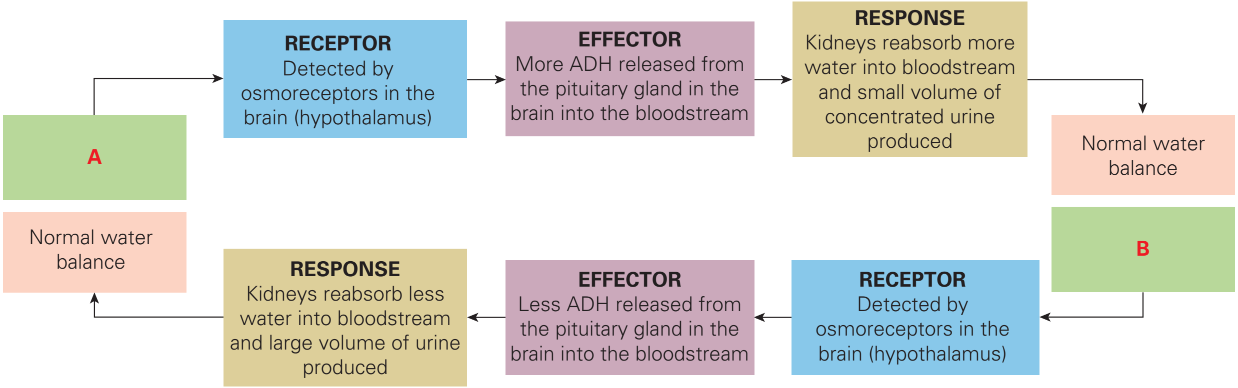
a High blood pressure versus low blood pressure



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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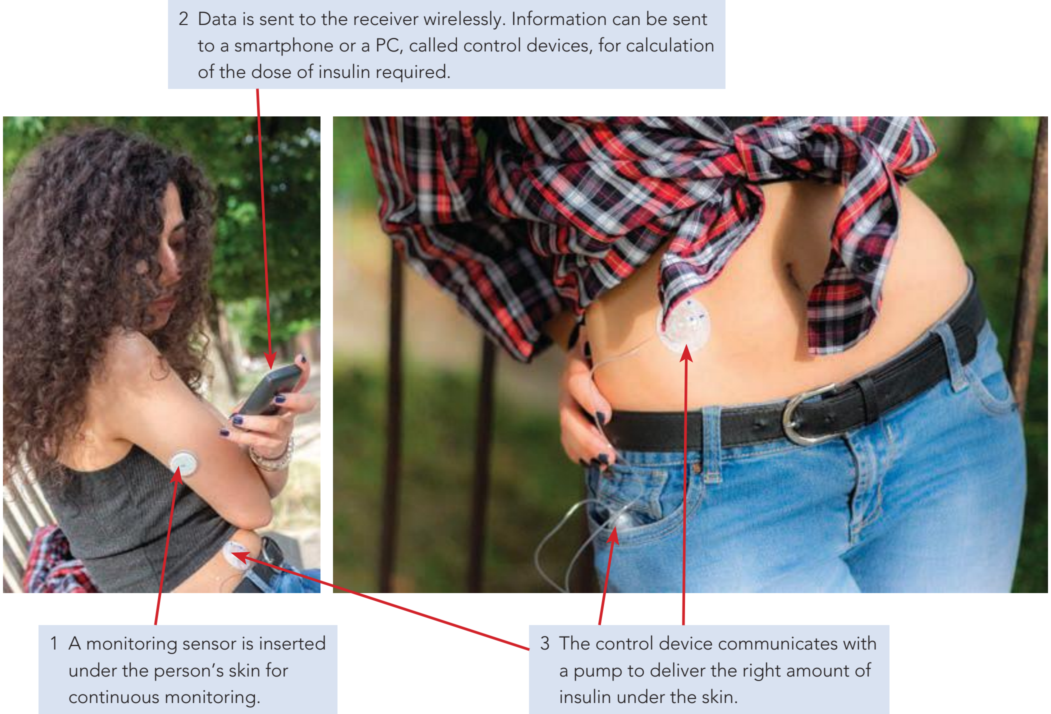
Knowledge utilisation

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.



2 Data is sent to the receiver wirelessly. Information can be sent to a smartphone or a PC, called control devices, for calculation of the dose of insulin required.

1 A monitoring sensor is inserted under the person's skin for continuous monitoring.

3 The control device communicates with a pump to deliver the right amount of insulin under the skin.

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 of what happens to return the blood glucose levels to normal.

b Assess some problems that might occur in 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 2.46. 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.

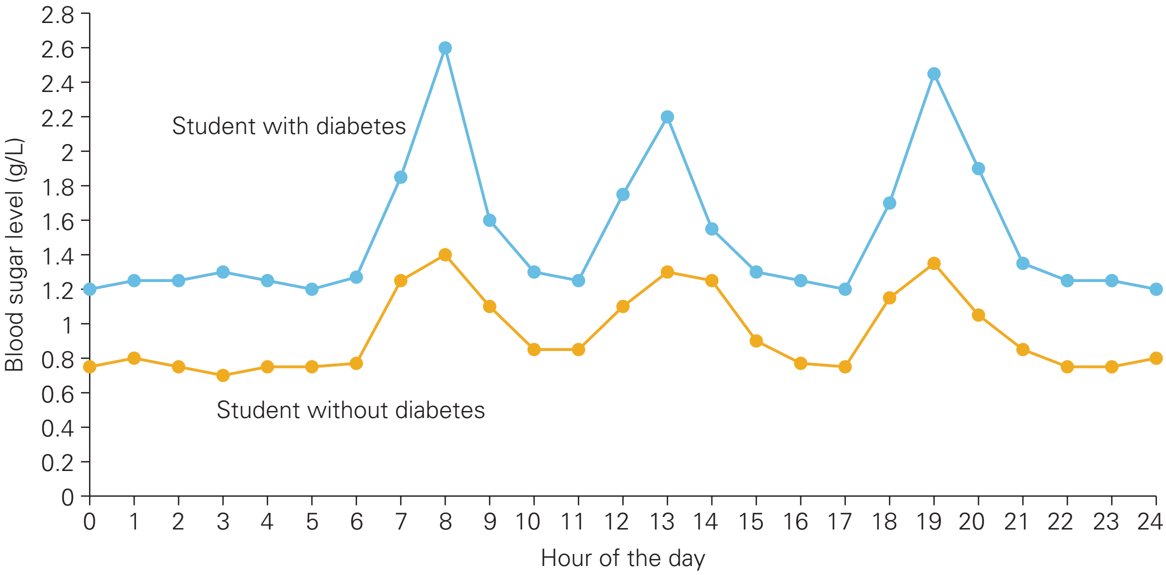

Figure 2.46 Relative blood sugar level over a 24-hour period

Apply

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.

Analyse

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.

Interpret

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?

Design brief: Investigate whether texting is a distraction to people performing tasks.

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.

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.

Figure 2.47 In Queensland, it is illegal to use a mobile phone while driving and can result in a fine of $1078 and four demerit points added to your traffic history. This applies even if you're stopped at traffic lights or in traffic.

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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.

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 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 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 times, 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 out there in the real world. How could you use ICT tools (e.g. apps, video, slow-motion camera) to enhance this experiment?

9 The results may change when a different type of ruler is used, such as metal, plastic or timber. 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. Do your responses slow with so many sensory signals?

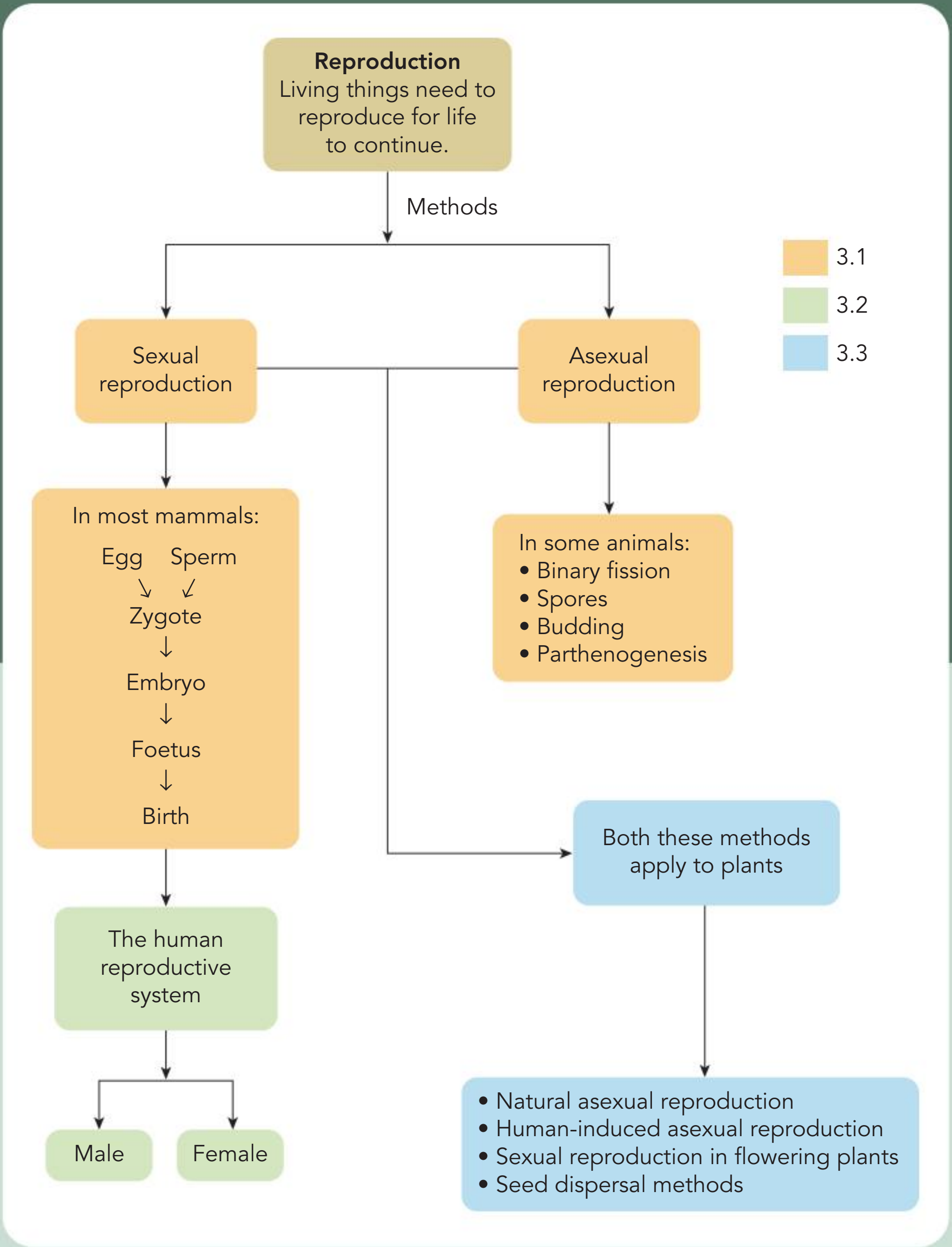
11 Create a graphical representation of your results and present your results to the class in the same way you would present to the Queensland Department of Transport and Main Roads.

Chapter 3
Reproduction

Chapter introduction

From bacteria to elephants, every living organism on Earth has its own way of reproducing. Reproduction is a fundamental process that enables organisms to produce offspring and pass on their genetic information to the next generation. In this chapter, you will examine structures of male and female reproductive organs and how they work together as a system to facilitate reproduction. You will also explore the different gametes produced by males and females and how they relate to their specific function. You will consider asexual and sexual reproduction and gain an understanding of how each organism's method of reproduction is linked to its complexity and its environment.

Concept map


Reproduction
Living things need to reproduce for life to continue.
Methods
Sexual reproduction
Asexual reproduction
🟧 3.1
🟩 3.2
🟦 3.3
In most mammals:
Egg Sperm
↘ ↙
Zygote
↓
Embryo
↓
Foetus
↓
Birth
In some animals:
• Binary fission
• Spores
• Budding
• Parthenogenesis
Both these methods apply to plants
The human reproductive system
Male
Female
• Natural asexual reproduction
• Human-induced asexual reproduction
• Sexual reproduction in flowering plants
• Seed dispersal methods

Curriculum

Describe the form and function of reproductive cells and organs in animals and plants, and analyse how the processes of sexual and asexual reproduction enable survival of the species (AC9S9U02)	
exploring how sexual reproduction creates a greater rate of variation among offspring compared with asexual reproduction	3.1
examining how the reproductive strategies of multicellular animals are related to their environment and the complexity of the organism	3.1
examining how the number of offspring produced by animals is related to the amount of parental care	3.1
examining how the male and female reproductive organ structures work collectively as a system	3.2
explaining how the forms of male and female gametes relate to their specific function	3.2
identifying and comparing sexual and asexual reproductive strategies in plants	3.3

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Glossary terms

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

3.1 Asexual and sexual reproduction in animals

Learning goals

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

DOC
WORKSHEET
Sexual reproduction

Reproduction is the biological process by which living things produce offspring. There are two main types of reproduction: asexual and sexual.

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 amoebas. Asexual reproduction is a highly efficient way of reproducing because it does not require the involvement of another organism.

In contrast, **sexual reproduction** involves two parent organisms, and results in offspring with genetic variation. Humans and most other animals reproduce through sexual reproduction, which allows for diversity in offspring.

Sexual reproduction

Sexual reproduction is a process that involves the fusion of **gametes** (sex cells), one from each parent, resulting in offspring that are genetically unique and not identical to their parents. 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 to form a **zygote** (Figure 3.1). The zygote contains the complete set of genetic material necessary to form a new organism of the same species. The zygote then undergoes cell division and develops into an **embryo** (Figure 3.2).

Figure 3.1 A zygote results from the fusion of an egg cell and a sperm cell.

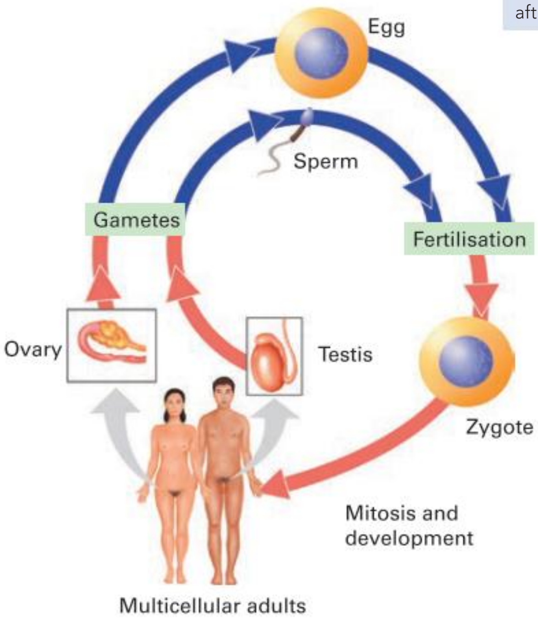

Figure 3.2 The human reproductive cycle

asexual reproduction	a method of reproduction in which a single parent produces offspring genetically identical to itself
sexual reproduction	a method of reproduction that involves two parent organisms and results in genetic variation in the offspring
gamete	a sex cell (egg or sperm), which 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
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

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VIDEO
Asexual and sexual reproduction

Figure 3.3 Sexual reproduction creates a greater rate of variation among offspring than asexual reproduction does because it involves the mixing of genetic material from two different parents.

Quick check 3.1

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

Did you know? 3.1

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

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

Fertilisation methods

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.

In most mammals, the development of the embryo is also internal, which provides protection to the developing embryo from any threats in the outside world. Although other land animals such as reptiles and birds also have internal fertilisation, the development of their young happens externally, in waterproof eggs.

Figure 3.5 Internal fertilisation in most reptiles is followed by external embryo development.

Figure 3.6 Internal fertilisation allows reproduction to take place on land without gametes drying out.

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, and then be united in water.

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

Figure 3.7 A school of fish and a cloud of gametes that have been released in external fertilisation

Because the eggs and sperm are released outside the body, it is harder for them to meet, and the fertilised eggs have little protection. Consequently, organisms that use this type of fertilisation have evolved to produce large quantities of eggs and sperm cells, which are released simultaneously and near each other.

However, this presents several potential problems.

- The eggs and sperm may not meet.
- The eggs may be eaten by predators.
- Environmental conditions may not be favourable (e.g. strong currents in the wrong direction).

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Quick check 3.2

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.

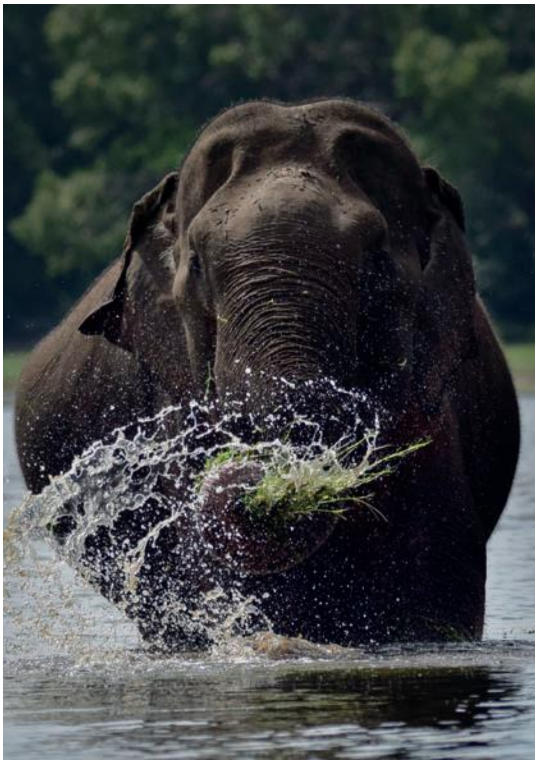

Figure 3.8 A heavily pregnant elephant. Elephants have a gestation period of nearly 2 years!

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 her body. This is commonly known as 'pregnancy'. Gestation typically lasts about 280 days (9 months) in humans, but varies among different mammalian species. More complex organisms tend to have longer gestation times.

Did you know? 3.2

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 to 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 5 million mice being produced in a year.

The quick gestation times play a significant role in creating mouse plagues. This phenomenon only occurs in China and Australia and occurs when mouse populations explode, leading to an overabundance of mice. These plagues can have devastating effects on agriculture, natural ecosystems, and public health.

Figure 3.9 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 40 weeks.

Egg to zygote

The unfertilised egg is released from the ovary and travels along the fallopian tube towards the uterus (see Figure 3.10). 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.

Zygote to embryo

After fertilisation, the zygote starts to divide and splits into two cells, which further divide repeatedly and form a ball of cells. This ball of cells takes about 5 days to travel through the fallopian tube where it finally implants into the lining of the uterus. The cells within the ball continue to divide and begin to specialise, forming what is now known as an embryo.

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, diseases 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.

differentiation the process by which cells become specialised

Figure 3.11 A nine-week-old human foetus

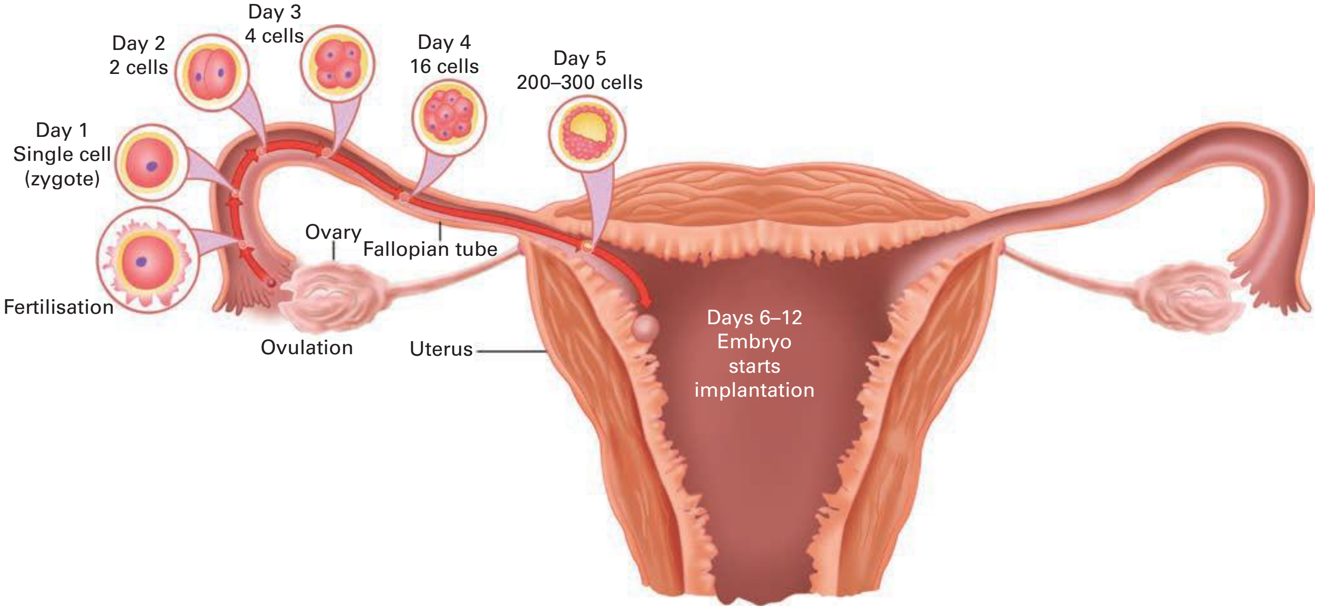

Figure 3.10 The stages of embryonic development in the female reproductive system

VIDEO Microscopic view of an IVF procedure

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

Explore! 3.1

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 life span
Human	280 days			
Dog				
Giraffe				
Choose your own animal				

Explore! 3.2

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 and 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.

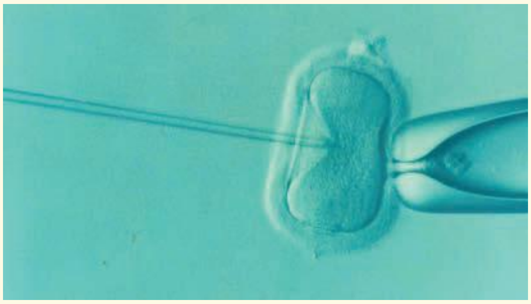

Figure 3.13 Intracytoplasmic sperm injection is a fertility treatment procedure where a single sperm is directly injected into an egg to help with fertilisation. It can be used when conventional IVF has failed.

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Quick check 3.3

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

At the onset of birth, the mother starts labour, which can range from a few hours to several days. During this process, the cervix dilates, and the uterus contracts to facilitate the delivery of the baby through the vagina, usually headfirst. However, complications such as breech birth can occur, where the baby's feet emerge first. This can pose a medical emergency, necessitating surgical intervention to remove the baby. This procedure is known as a caesarean section (C-section) and involves making an incision across the mother's abdomen.

Figure 3.14 A newborn baby in the operating room

Development

Most mammals undergo internal development within their mother's uterus and are born generally resembling adult organisms. During internal development, humans and other animals receive nourishment directly from their mother through the umbilical cord. However, marsupials, such as kangaroos, are exceptional in that their young are born in an extremely underdeveloped state and emerge from the vagina at the size of a jellybean. The newborn then makes its way up the mother's body and into the pouch, where it undergoes further development (Figure 3.15).

Figure 3.15 A baby kangaroo is called a joey. After being born, the joey wriggles its way into its mother's pouch to feed.

Offspring of birds, reptiles, amphibians and insects typically undergo external development outside the mother's body. They develop within an egg and hatch when they are developed enough to survive in their environment.

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.

The amount of parental care provided by animals is generally 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 generally provide minimal parental care, because the sheer number of offspring increases the chances that some offspring will survive.

Figure 3.16 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.

Figure 3.17 A kangaroo mother's pouch provides a safe environment for her offspring.

Explore! 3.3

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 20th 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 3.18 Dr Helen Mayo's research helped reduced infant mortality rates in Australia.

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Did you know? 3.3

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 seafloor. 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 3.19 An octopus guarding her egg mass

Asexual reproduction

Certain organisms can reproduce asexually without the assistance of a mate. This type of reproduction is advantageous for organisms that are geographically isolated or have limited mobility. Asexual reproduction is also beneficial as it is quick and does not waste time and energy searching for a mate. The offspring produced are clones – genetically identical to the parent. This is advantageous if the parent is well-adapted to the environment. However, if environmental conditions change or a disease that the organisms are vulnerable to is introduced, the entire species can be at risk of extinction.

Asexual reproduction involves the division of a single cell into two, and there are various mechanisms by which this can occur. Binary fission, fragmentation, spore formation, budding and parthenogenesis are all examples of asexual reproduction.

Binary fission

Binary fission is a type of asexual reproduction of 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 identical daughter cells, each containing a copy of the genetic material (Figure 3.20). Binary fission is a rapid process and enables the organism to produce large numbers of offspring quickly.

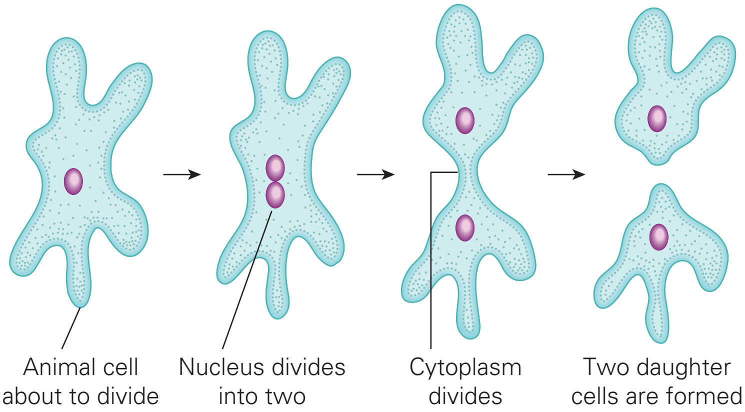

Figure 3.20 Binary fission in an amoeba (a unicellular organism)

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.

binary fission
a type of asexual reproduction in which genetic information is copied and the cell splits in half

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

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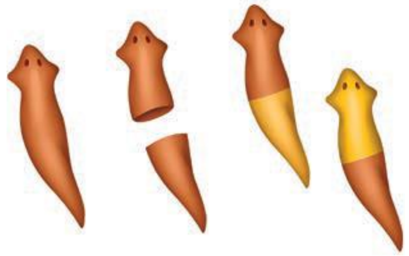

Figure 3.21 Fragmentation in a flatworm

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

budding
a type of asexual reproduction by organisms such as yeast and hydra, in which the daughter offspring grows off the side of the parent and drops off

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 3.22 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 formation

Fungi and some plants, such as ferns, produce single-celled **spores** that 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 3.23 Spores under a fern leaf

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 many types of 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 (Figure 3.24).

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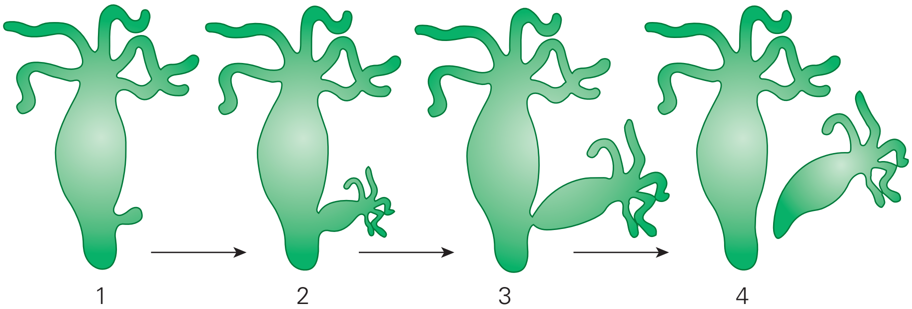

Figure 3.24 Budding in a hydra – a daughter offspring grows off the side of the parent and drops off.

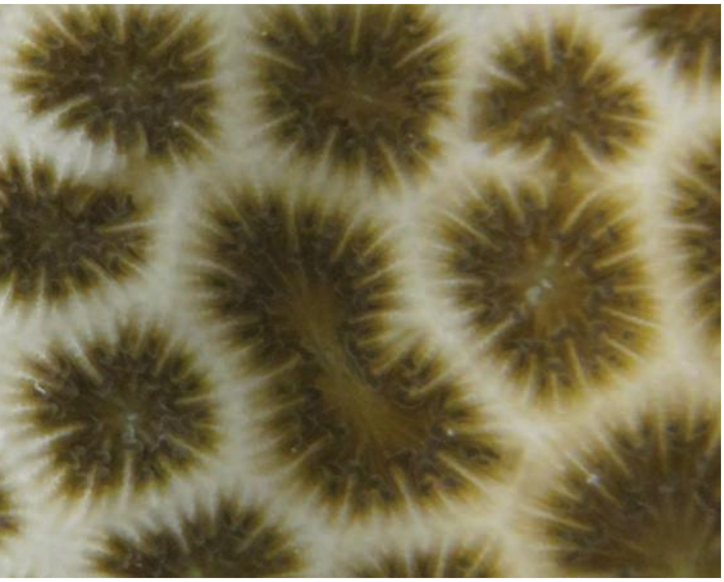

Figure 3.25 Corals reproduce asexually by fragmentation or budding. In the centre, a *Leptastrea purpurea* coral polyp has produced a large bud, which will split off.

Parthenogenesis

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 also 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 identical, to the mother.

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

Did you know? 3.4

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 that have the ZW sex-determination system, parthenogenesis can produce offspring with either two Z chromosomes (male) or one Z and one W chromosome (female).

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.

Figure 3.26 Parthenogenesis in Komodo dragons produces offspring that are exclusively male.

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Figure 3.27 The New Mexico whiptail (*Aspidoscelis neomexicanus*) is a female-only species of lizard.

Quick check 3.4

1 State two advantages of asexual reproduction.
2 State one disadvantage of producing genetically identical offspring.
3 Name four types of asexual reproduction and give an example of an organism that reproduces by each method.

Try this 3.1

Asexual versus sexual reproduction

Draw a Venn diagram comparing asexual and sexual reproduction. Remember, the overlapping section of the circles is for characteristics shared by both types of reproduction.

Section 3.1 questions

QUIZ

Retrieval

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.

Comprehension

5 **Explain** why an aquatic animal can use external fertilisation more easily than a land-dwelling animal can.
6 **Explain** why it could be advantageous for an organism to reproduce asexually.
7 **Summarise** the benefits of internal fertilisation.

Analysis

8 **Contrast** internal fertilisation and external fertilisation.
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.

Knowledge utilisation

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.
13 **Propose** why organisms produced by asexual reproduction are sometimes called clones.
14 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.

3.2 The human reproductive system

Learning goals

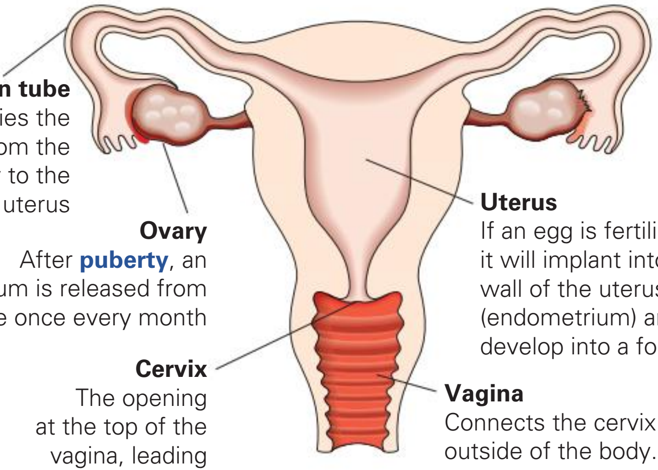
1. To examine how the male and female reproductive organ structures work collectively as a system.
2. To describe how the forms of male and female gametes relate to their specific function.

WORKSHEET
Human reproductive organs

Humans reproduce sexually by internal fertilisation and have highly specialised body systems to support this process. Females and males share some structural similarities; for example, both possess gonads, which are the site of gamete production. However, many of the other structures are different.

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 (Figure 3.28).



Fallopian tube
Carries the ovum from the ovary to the uterus

Ovary
After **puberty**, an ovum is released from here once every month

Cervix
The opening at the top of the vagina, leading to the uterus

Uterus
If an egg is fertilised, it will implant into the wall of the uterus (endometrium) and develop into a foetus

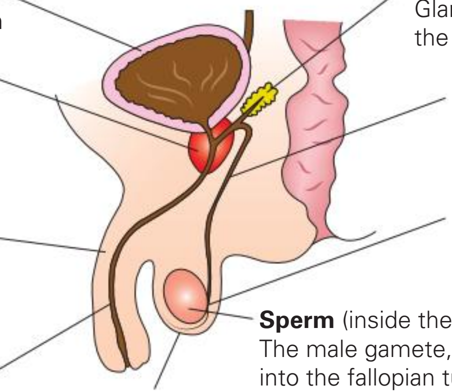
Vagina
Connects the cervix to the outside of the body. Sperm is deposited here

Figure 3.28 The female reproductive system

ovum	egg, or female gamete
puberty	the time of transition from juvenile form to adult form

Male reproductive system

The male reproductive system consists of several organs and structures that work together to produce, store and transport sperm (Figure 3.29).



Bladder
Holds urine for excretion

Prostate
Gland that releases an alkaline liquid, which helps to neutralise the acidic conditions of the vagina

Penis
Contains erectile tissue and urethra

Urethra
Tube through which semen and urine leave the body

Seminal vesicle
Gland that releases liquid, which mixes with the sperm to form semen

Sperm duct (vas deferens)
A tube that transports sperm from the testes to the penis

Testes
After puberty, produce sperm continuously for the remainder of the male's life

Sperm (inside the testes)
The male gamete, adapted to swim into the fallopian tube to fertilise an egg

Scrotum
A protective sac of skin that holds the testes and responds to changes in temperature

Figure 3.29 The male reproductive system

Female and male gametes

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

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, a female typically has from 1 million to 2 million eggs stored in her ovaries, enclosed in small sacs called follicles. However, many of these eggs will naturally deteriorate before she reaches puberty.

Once she reaches 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 of the body. This area remains approximately 2–3°C cooler than the core body temperature, a temperature that 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 (Figure 3.30). 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 vast quantities throughout a male's life.

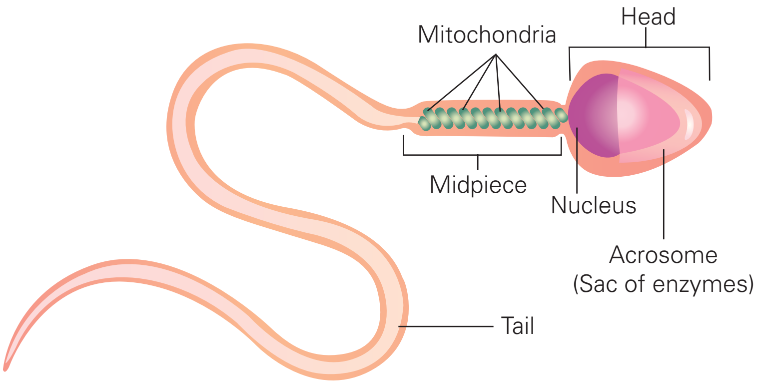


Figure 3.30 Sperm adaptations enable them to move quickly to the egg.

Quick check 3.5

1. From where are eggs released and into what structure?
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.

Try this 3.2

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.

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. However, the timing of puberty varies among individuals, and this variation is considered 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 that is responsible for the development of female **secondary sexual characteristics** such as breasts, wider hips, and pubic and underarm hair (Figure 3.31).

In males, LH and FSH are responsible for triggering the production of testosterone in the testes. Testosterone is the primary male sex hormone that is responsible for the development of male 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.

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 which distinguishes between the sexes but is not directly involved in reproduction

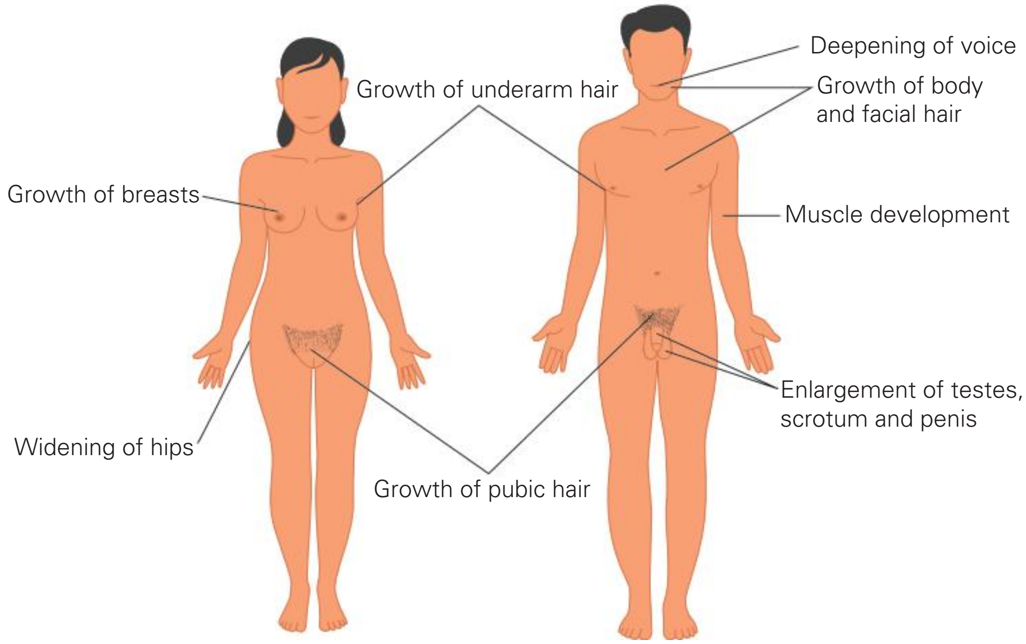


Figure 3.31 Secondary sexual characteristics in puberty

Did you know? 3.5

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 acne can result.

Figure 3.32 Some unpleasant side effects of puberty: body odour and acne

Menstrual cycle

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

Hormones also control a woman's **menstrual cycle**, which usually lasts about 28 days (Figure 3.33).

1 The pituitary gland in the brain releases FSH.
2 FSH causes one of the eggs in the ovary to mature. It also stimulates the ovaries to make oestrogen.
3 Oestrogen stimulates the pituitary gland to release LH.
4 LH triggers the release of an egg (ovulation).
5 Oestrogen also inhibits further production of FSH (stopping other eggs maturing). It also repairs the uterine lining (endometrium).

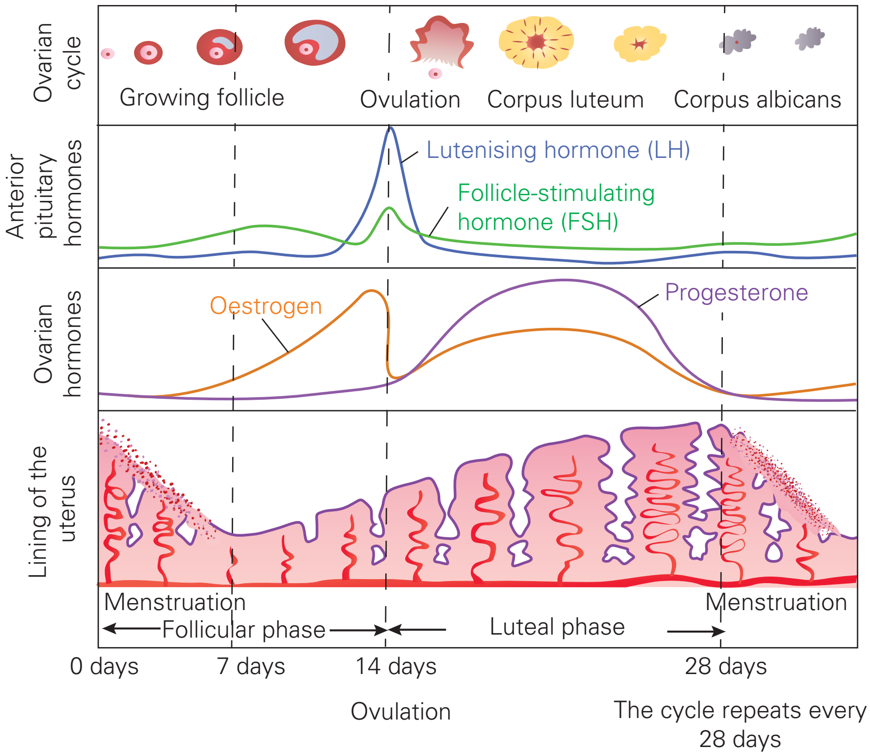


Figure 3.33 The link between the different hormones in the female reproductive system and the action of the follicles. After the follicle releases an egg, it is known as the corpus luteum.

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6 Once the egg has been released, progesterone is produced by the empty follicle (called the corpus luteum or a yellow body). This maintains the uterus lining and inhibits LH.
   a If a woman becomes pregnant, 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. As a result, the progesterone and oestrogen levels drop towards the end of the menstrual cycle, the uterine lining breaks down and menstruation occurs.

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

Did you know? 3.6

Cloaca: one hole does it all!

Humans have 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 one hole that does all 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.

Figure 3.34 A turtle laying an egg through its cloaca

Figure 3.35 A kākā with its cloaca visible

Quick check 3.6

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

Explore! 3.4

Early puberty

Research has confirmed that the age of puberty in girls has declined by around 3 months a decade since the 1970s, with boys showing a similar yet less pronounced trend. The cause of this trend 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 also play a role.

Figure 3.36 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.

Section 3.2 questions

QUIZ

Retrieval

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.

Comprehension

6 **Describe** the cloaca.

Analysis

7 Refer to the graph of the menstrual cycle in Figure 3.33. **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.
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.

Knowledge utilisation

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

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3.3 Plant reproduction

Learning goal
To be able to 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 sexual reproduction increases genetic diversity, asexual reproduction offers several advantages, including a relatively quick process that requires less energy and the ability to produce offspring in environments that are unfavourable for sexual reproduction. However, asexual reproduction produces offspring that lack genetic diversity.

Figure 3.37 Plants are a very diverse kingdom, including non-flowering plants such as **(a)** moss, **(b)** ferns, **(c)** conifers and **(d)** flowering plants.

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Asexual reproduction in plants

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

All asexual reproduction in conifers and flowering plants is classed as **vegetative propagation**. It involves part of a plant growing into a new plant and can occur naturally or through human manipulation.

Natural methods and human-induced methods of asexual reproduction are summarised in Tables 3.1 and 3.2.

Vegetative propagation method	Definition	Examples	
Bulb	• Underground stem for food storage • Food is stored in large leaves • Each bulb develops into a new plant	Onions, hyacinths, daffodils	 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	 Strawberry leaves and runner
Tuber	• Underground stem that contains stored food • The eyes of a potato can develop into new plants	Potatoes, sweet potatoes	 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	 A ginger rhizome with sprout

Table 3.1 Natural methods of asexual reproduction in plants

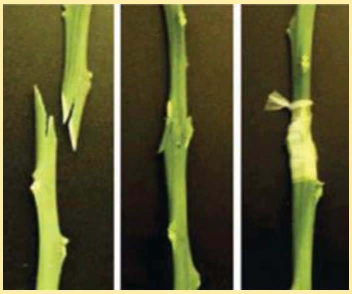
Vegetative propagation method	**Definition**	**Examples**	
Cutting	- Taking pieces of a root or stem - Each piece grows into a new plant	Bananas, roses, sugar cane	 Cuttings growing roots in water
Grafting	- Connecting part of a plant to another plant, combining the two plants	Citrus, grapes, apples, stone fruit, roses	 The two pieces of stem are tied in place and will eventually grow into one stem.

Table 3.2 Human-induced methods of asexual reproduction in plants

Figure 3.38 Some trees can have multiple fruits grafted onto the same tree. For example, plums, nectarines and peaches can be grafted together.

Figure 3.39 Growing new plants from cuttings is a way of making clones.

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Practical skills 3.1

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 three 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 *x*-axis.
- Place the dependent variable on the *y*-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.

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

Analysis

1. Describe a trend you see in your graph.
2. Explain why you calculated an average using other groups' data as well as your own.
3. Suggest another plant that could be used for a similar activity.
4. Propose an independent variable that you could add to this activity to turn it into a different experiment.

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Quick check 3.7

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.

Sexual reproduction in plants

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) and the female gamete known as the **embryo sac** is inside the **ovule**. The parts of a flower are shown in Figure 3.40.

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, in addition to the sweet **nectar** they produce, and pick up pollen while they are feeding (Figure 3.41). 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.

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
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

DOC

WORKSHEET
Sexual plant reproduction

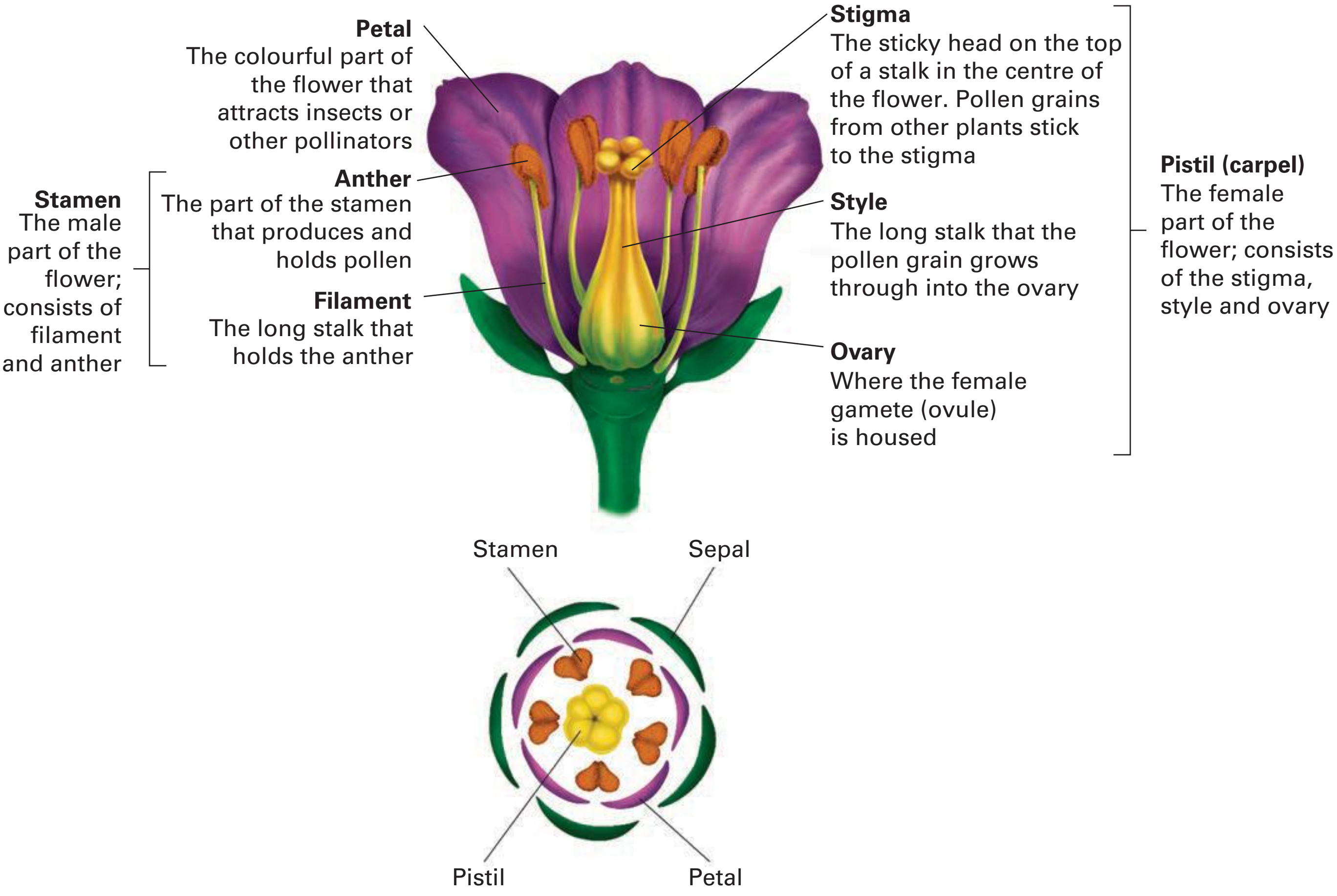

Figure 3.40 Top: a vertical section showing the reproductive parts of a flower. Bottom: a cross-section of the reproductive parts.

WIDGET
Sexual and asexual reproduction

VIDEO
Pollination methods

Figure 3.41 A bee with a large yellow pollen sac on its leg

Explore! 3.5

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 and allow pollination to occur – examples are wind, insects, birds and animals.

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 more likely to be able to survive changes in the environment.

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

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, size) of the flowers, 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 3.42 These flowers are pollinated by different methods. Can you identify what the methods are?

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Did you know? 3.7

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.

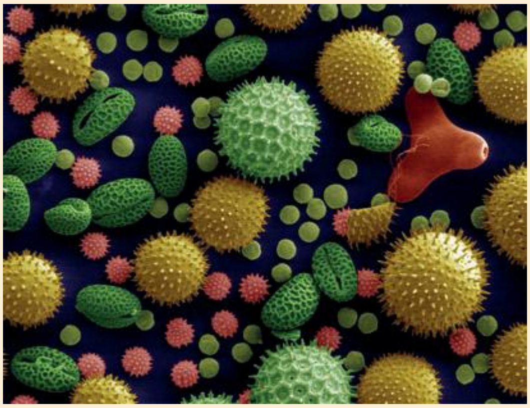

Figure 3.43 There are many types of pollen in the air.

Making thinking visible 3.1

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.

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 (Figure 3.44).

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 drones.

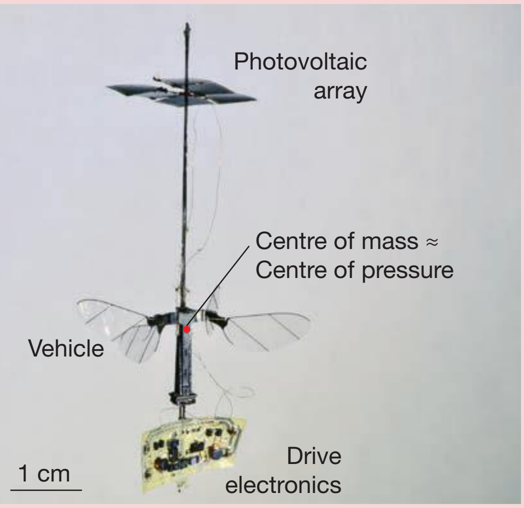

Figure 3.44 The 2019 untethered prototype of the RoboBee, with an additional set of wings

continued …

… continued

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 the pollen growth, possibly because of the soap's properties. The team is working on developing an environmentally friendly soap bubble solution that would biodegrade more quickly, potentially leading to even more effective and sustainable pollination methods. However, this approach is not suitable for use on windy days!

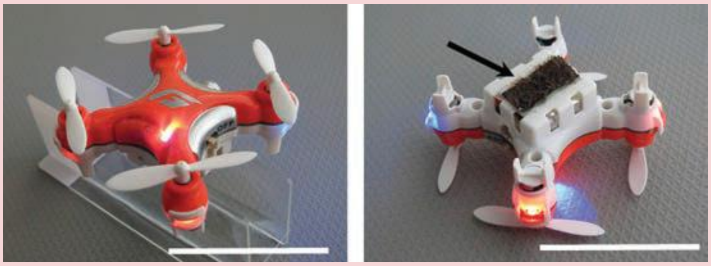

Figure 3.45 Dr Miyako's horsehair drone

Figure 3.46 Dr Miyako's bubble gun pollinating drone

Complete the Compass points activity about robot pollinators:

E = Excited

What excites you about RoboBee and robot pollinators? What are the potential benefits?

W = Worrisome

What worries you about this idea? What are the potential drawbacks?

N = Need for information

What other details or facts do you need to evaluate this idea?

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.

Humans are attracted to flowers because of their beautiful and varied colours and scents, but there is much more the flowers than the colourings that we can see. Unlike us, numerous 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 3.47. These patterns serve as a guide for insects, directing them precisely to the nectar source.

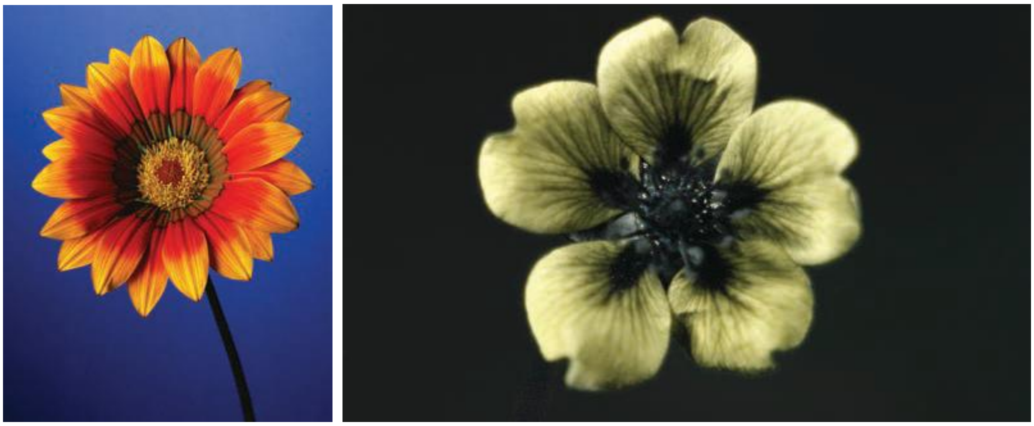

Figure 3.47 Flowers with (left) a bullseye pattern and (right) a landing strip pattern

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Quick check 3.8

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 3.48 Conifers such as pine trees have separate male (left) and female (right) 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 on the lower branches.

Practical skills 3.2

Flower dissection

Aim

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

Be careful

Be very careful when handling the razor blade.

Materials

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

Method

1 Refer to Figure 3.40 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 3.40.
3 Draw a diagram of the flower, and label all the parts of the flower you can recognise. Add 'M' next to the male parts of the flower and 'F' next to the female parts of the flower.

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… continued

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 of it. 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.

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.

Explore! 3.6

Citizen science

Bees pollinate most of our crops, but bee numbers are decreasing rapidly. Bees can fly between flowers at about 25 km/h and visit up to 5000 flowers in one 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.

Australian Pollinator Count:

Just 10 minutes.
Make a difference.
Make it count.

Figure 3.49 The Australian Pollinator Count takes place every year around November, and anyone can get involved!

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Did you know? 3.8

FlyGro

When managing an avocado and lychee farm in Mareeba, far north Queensland, James Wheildon began exploring the use of flies for pollination.

Flies are just as efficient pollinators 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 3.50 A fly pollinating a flower

VIDEO
Seed dispersal methods

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 3.51 A tomato flower and young fruit

Pine trees and other conifers produce cones, 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.

seed
a plant embryo enclosed in a protective coating

seed dispersal
the spread of seeds away from the parent plant

Plants produce many seeds, to increase the chances of survival. Many seeds will be eaten by animals, land on areas where they cannot grow, or be destroyed. Adult plants often take up a lot of space and resources, and so, for the offspring to thrive, the seeds need to spread to new places. This is known as **seed dispersal**, and plants have many clever ways of doing this.

Figure 3.52 A pine cone ready to drop its seeds

Seed explosions

The seed pods of a group of plants known as impatiens are ticking time bombs. When the fruit is ripe, the slightest touch can trigger the pod to explode suddenly, flinging the seeds it contains in many directions, although the seeds often do not travel far (Figure 3.53).

Figure 3.53 A Himalayan Balsam seed pod exploding

Figure 3.54 Burrs caught on a dog's fur. They are transported by the dog until the dog scratches them off and they are dispersed at a new location.

Hitching a ride on the outside

Certain plants, including grasses, have spiky pods (burrs) that latch onto fur or clothing to disperse (Figure 3.54). The spiky pod stays on the animal's fur until the animal gets itchy and scratches it off, and then the pod falls to the ground in a new location.

Hitching a ride on the inside

Some plants have extra sweet fruit, which encourages animals to eat the fruit containing the seeds (Figure 3.55). The seeds have a tough coat so that they won't be digested. When the seeds eventually pass intact through the animal, they are in a new location, where they may begin to grow.

Figure 3.55 Animals ingest seeds in fruit and then defecate the seeds in a new location.

Shooting the breeze

Dandelion seeds are so light that they are blown extremely long distances by just a gust of wind. A fluffy tuft called a pappus acts as a parachute to carry each seed away (Figure 3.56). A dandelion head is not just one flower but is made up of many florets that each produce an individual seed. One dandelion head can make about 500 seeds. This is why dandelions are such an effective weed.

Floating away

A coconut is one giant seed. It is hollow, so it can float (Figure 3.57). This is how coconuts can move between islands and possibly even across oceans.

Figure 3.56 Dandelion seeds leaving a dandelion clock after getting caught in the breeze

Figure 3.57 A floating coconut. Wild coconuts are typcially found in coastal areas because their floating seeds are well suited to dispersal over water.

Quick check 3.9

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

Investigation 3.1

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, heat).

Planning

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 the instruments and exact measurements you will use. Set it out in step-by-step form. Include the number of repeats you expect to conduct. Do not forget to mention how the data is 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.

continued …

… continued

Materials

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

Results

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

Analysis

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

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

Draw a conclusion from this experiment, using data to support your statement.

Explore! 3.7

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.

On 1 March 2023, the Millennium Seed Bank announced they 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.

Figure 3.58 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.

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

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Section 3.3 questions

QUIZ

Retrieval

1 **State** four ways in which plants can reproduce asexually in nature.
2 **State** the purpose of the petals of a flower.
3 **Define** 'pistil'.

Comprehension

4 **Explain** why some flowering plants' ovaries develop into fleshy fruit.
5 **Explain** how seed dispersal by wind is effective.
6 **Describe** some ways in which a plant can be pollinated.

Analysis

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

Knowledge utilisation

9 Hay fever is caused by pollen irritating the nasal passageways. Evan lived in England for 15 years and never experienced hay fever. Since moving to Australia, Evan 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, and justify your answer, based on its method of seed dispersal.

Figure 3.59 An isolated island, which was formed by a volcanic eruption

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
3.1	I can describe how sexual reproduction creates a greater rate of variation among offspring than asexual reproduction does.	7, 11, 17	
3.1	I can describe how the reproductive strategies of multicellular animals are related to their environment and the complexity of the organism.	5, 8, 12	
3.1	I can describe how the number of offspring produced by animals is related to the amount of parental care.	10	
3.2	I can describe how the male and female reproductive organ structures work collectively as a system.	2, 16	
3.2	I can explain how the forms of male and female gametes relate to their specific function.	9	
3.3	I can identify and compare sexual and asexual reproductive strategies in plants.	1, 6, 18	

Review questions

SCORCHER

Retrieval

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, and for each method give an example of one animal that uses it.

Comprehension

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.

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.

Analysis

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 male and female secondary sexual characteristics during puberty by using a Venn diagram.

Knowledge utilisation

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 her 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 names of the structure at each stage and approximate timeframes.

17 A biologist is investigating a species of frog that lives in an environment that is changing rapidly. **Propose** a reason why sexual reproduction would be better for this species of frog.

18 The flowers of certain orchids closely resemble the shape of a female wasp (Figure 3.60). **Justify** a reason for this adaptation.

Figure 3.60 *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.

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 3.61 shows her results.

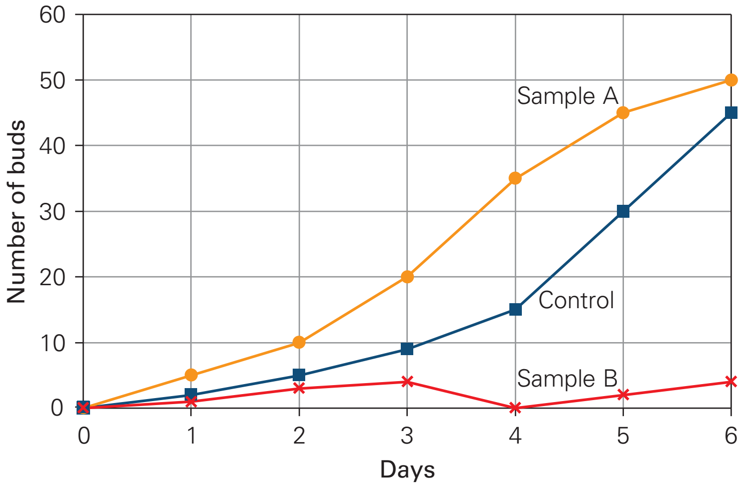

Figure 3.61 The number of hydra buds in the samples each day

Apply

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 one day with no buds.

3 **Determine** how many days it took for each sample to reach more than 10.

Analyse

4 **Contrast** the patterns of the three samples.

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

Interpret

6 **Deduce** which substance, A or B, is a growth activator (i.e. helps growth) and which is a growth inhibitor (i.e. prevents growth).

7 **Compare** the control sample with sample A after day 4. What evidence is there to suggest that the sample culture was getting crowded?

8 **Predict** how many buds there would be for each sample if Meera extended the experiment to the seventh day.

STEM activity: Artificial bees to save the planet

Background information

Australia has many native bee species (the estimated total being more than 1700 types). Queensland is host to *Tetragonula carbonaria*, a stingless bee.

Figure 3.62 *Tetragonula carbonaria*, also known as the sugarbag bee, is considered a 'safe' bee.

However, all bees play an important role in pollinating plants, and native bees might have just the right skills to help keep our local food chain safe.

A bee's skills in moving pollen are highly evolved. Different species have evolved differently to suit the surrounding plants. Some bees can buzz at certain frequencies, which for some plants is essential. Others have specialised bristles on their forelegs to rake the pollen out.

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 as creative and incorporate as many types of technology as possible.

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

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 to the group and discuss your key connections between how bees distribute pollen and your prototype. Discuss the best 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 of design and sustainability for the prototype.

9 Evaluate the issues arising from a human solution to an environmental problem.

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Chapter 4

Global systems

Chapter introduction

The carbon cycle is one of the most critical biogeochemical cycles that operates on Earth, regulating the flow of carbon between the planet's different spheres. This process is vital for maintaining Earth's climate and sustaining life. In this chapter, you will explore how the carbon cycle operates and the critical role that key processes, such as combustion, photosynthesis and respiration, play in maintaining the balance of carbon. You will also consider how human activities are affecting the carbon cycle and the potential consequences of these changes. Finally, you will explore strategies for mitigating the effects of global warming, such as carbon sequestration and new technologies to capture and store carbon.

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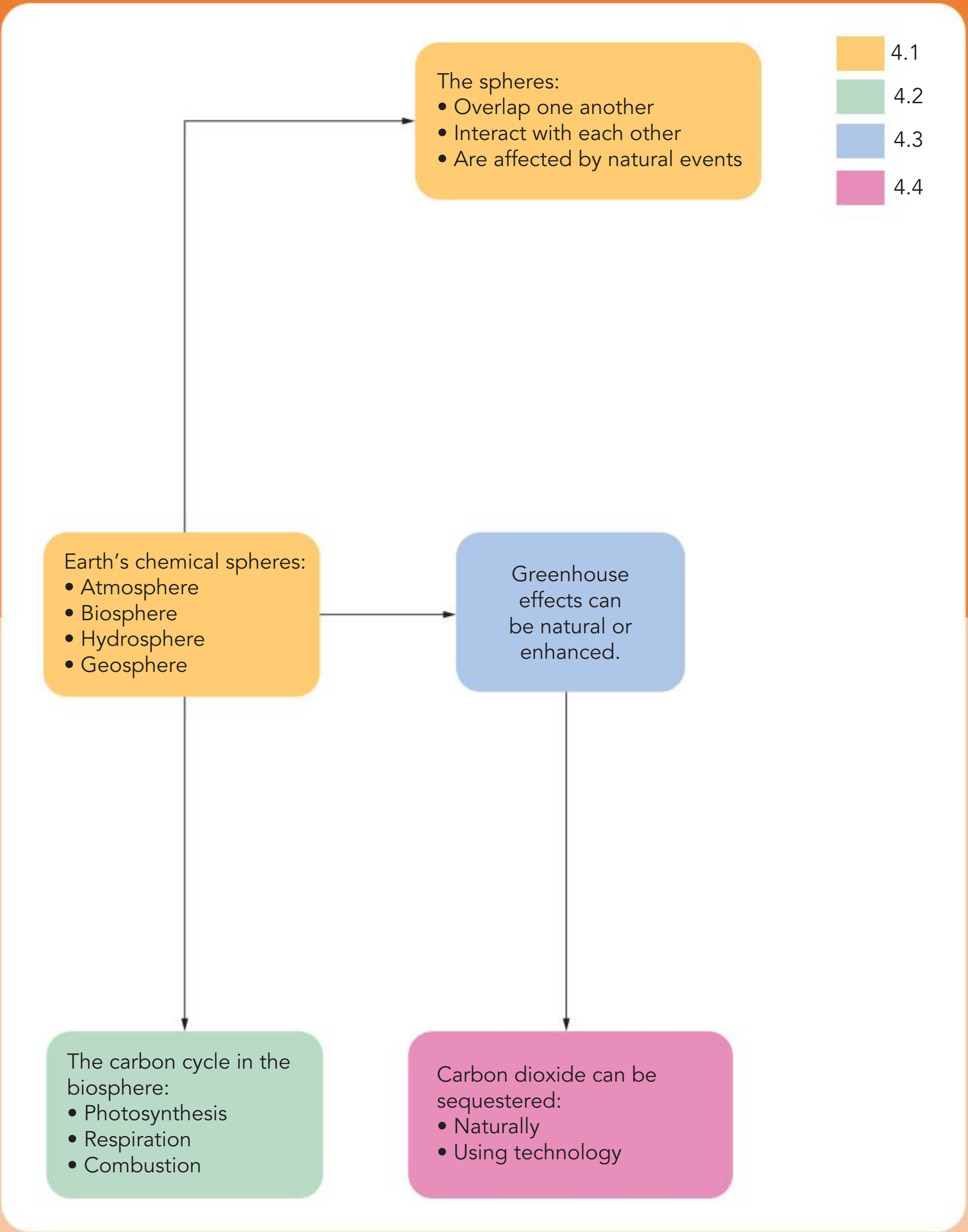
Concept map



🟧 4.1

🟩 4.2

🟦 4.3

🟪 4.4

Earth's chemical spheres:
- Atmosphere
- Biosphere
- Hydrosphere
- Geosphere

The spheres:
- Overlap one another
- Interact with each other
- Are affected by natural events

Greenhouse effects can be natural or enhanced.

The carbon cycle in the biosphere:
- Photosynthesis
- Respiration
- Combustion

Carbon dioxide can be sequestered:
- Naturally
- Using technology

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Curriculum

Represent the carbon cycle and examine how key processes including combustion, photosynthesis and respiration rely on interactions between Earth's spheres (the geosphere, biosphere, hydrosphere and atmosphere) (AC9S9U03)	
identifying Earth as a system, describing Earth's spheres and discussing examples of interactions between different spheres	4.1
examining the carbon cycle using diagrams, animations or simulations and explaining the role of photosynthesis and respiration in that cycle	4.2
investigating how First Nations Australians use fire-mediated chemical reactions to facilitate energy and nutrient transfer through the practice of firestick farming	4.2
identifying the impact of combustion reactions as a result of human activity on the carbon cycle	4.2
investigating the greenhouse effect and relating it to the role carbon dioxide plays in maintaining temperatures that support life on Earth	4.3
investigating how First Nations Australians are reducing Australia's greenhouse gas emissions through the reinstatement of traditional fire management regimes	4.3
calculating an individual's carbon footprint, examining the impact of human activities and suggesting strategies to reduce carbon dioxide emissions	4.3
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	4.4
identifying how carbon dioxide is captured and stored naturally or through the use of technologies	4.4

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Glossary terms

Atmosphere
Biosphere
Carbon sequestration
Carbon sink
Carbon source
Decomposer
Enhanced greenhouse effect
Geosphere
Global warming
Greenhouse effect
Greenhouse gas
Hydrosphere
Lithosphere
Stratosphere
Sustainable ecosystem
Troposphere

4.1 Earth's interacting spheres

Learning goals

1. To be able to identify Earth as a system.
2. To be able to describe Earth's spheres and discuss examples of interactions between different spheres.

WORKSHEET
Earth's spheres

Earth is a system consisting of various interacting spheres, each playing a crucial role in maintaining the balance of the planet. These spheres include the biosphere, the atmosphere, the hydrosphere, and the geosphere, all of which interact to create the unique environment we call home. Understanding how these spheres interact with each other allows scientists to identify and address the environmental challenges facing our planet today.

Atmosphere

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 (Table 4.1).

In total, the atmosphere is about 500 km thick and consists of five layers: the **troposphere**, **stratosphere**, mesosphere, thermosphere and exosphere (Figure 4.2).

Figure 4.1 The view of the crescent moon through the top of Earth's atmosphere

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 4.1 The proportion of gases in Earth's atmosphere

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.

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 containing the ozone layer

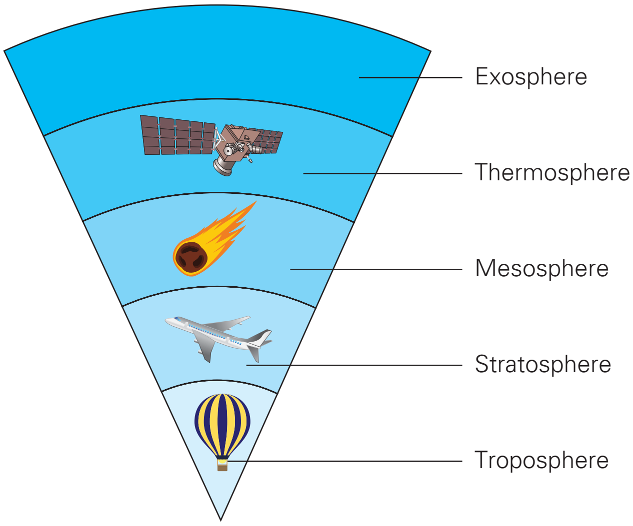

Figure 4.2 The five layers of Earth's atmosphere

Quick check 4.1

1 Name the gas that is found at 21% concentration in Earth's atmosphere.
2 What atmospheric layers are most important to humans?

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Troposphere

The troposphere is the layer closest to the surface of Earth and averages between 8 km and 15 km thick. It contains about 75% of the mass of the entire atmosphere. It is in the troposphere that most of the weather occurs because of hot air rising and cold air sinking within this layer. Greenhouse gases, carbon dioxide, methane and water vapour are found in the troposphere. You will read more on this later in the chapter.

Stratosphere

The stratosphere lies directly above the troposphere and is about 35 km deep. Within the stratosphere is the ozone layer, a thin layer of ozone molecules (O_3). The ozone layer protects Earth from high-energy UV radiation released from the Sun, and helps to regulate Earth's temperature. The high concentration of ozone in the stratosphere also helps to trap heat, creating a warming effect that contributes to the overall temperature balance of Earth.

Most jet aircraft fly in the lower part of the stratosphere because this layer plays a critical role in the movement of air and weather patterns around the globe. It contains powerful wind currents, known as jet streams.

Figure 4.3 Most of Earth's weather occurs in the troposphere (top). Jet aircraft often fly in the lower stratosphere to avoid turbulence (bottom).

Quick check 4.2

1 List some of the roles of the stratosphere.

2 In which atmospheric layer does weather occur?

Explore! 4.1

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.

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?

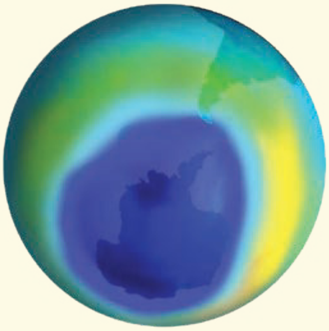

Figure 4.4 The hole in the ozone layer above Antarctica. The bluish-purple areas show the least amount of ozone.

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Biosphere

The **biosphere** consists of all areas of Earth and its atmosphere that contain life. It comprises all the living organisms on the planet, including plants, animals, fungi and microscopic organisms such as bacteria and protists.

Hydrosphere

The **hydrosphere** is made up of all the water on Earth. This includes the oceans, rivers, lakes, glaciers, rain, water vapour, underwater basins and even puddles.

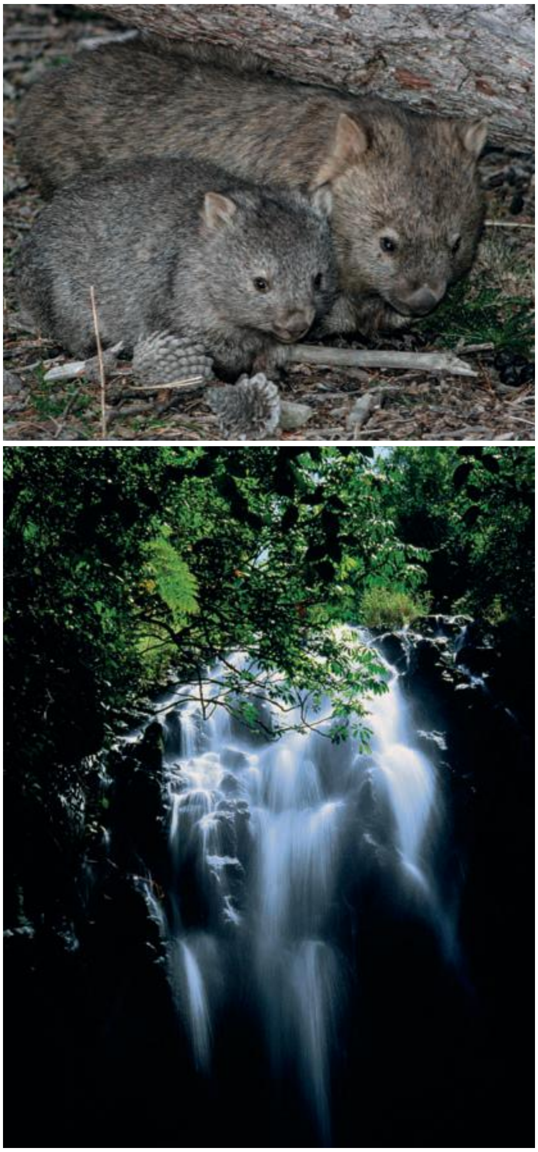

Figure 4.5 Wombats, as living organisms, are part of the biosphere (top). Ellinjaa Waterfall is part of the hydrosphere (bottom).

Quick check 4.3

1 What is the hydrosphere?

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 magma, lava, rocks and minerals, both on the surface and below it. This includes all the rocks and sand on dry land and the ocean floor, as well as minerals, lava and magma beneath Earth's crust.

biosphere
all the areas on Earth and in its atmosphere that contain life

hydrosphere
all of the water found on Earth (e.g. lakes and rivers)

geosphere
all Earth's geological materials, including magma, lava, rocks and minerals

The geosphere undergoes a continuous cycle: matter is constantly in motion through the various processes of the rock cycle. Volcanic eruptions expel magma that 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 4.6 The Sphinx in Girraween National Park is part of the geosphere.

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Figure 4.7 The geosphere is constantly in motion because of the many processes involved in the rock cycle.

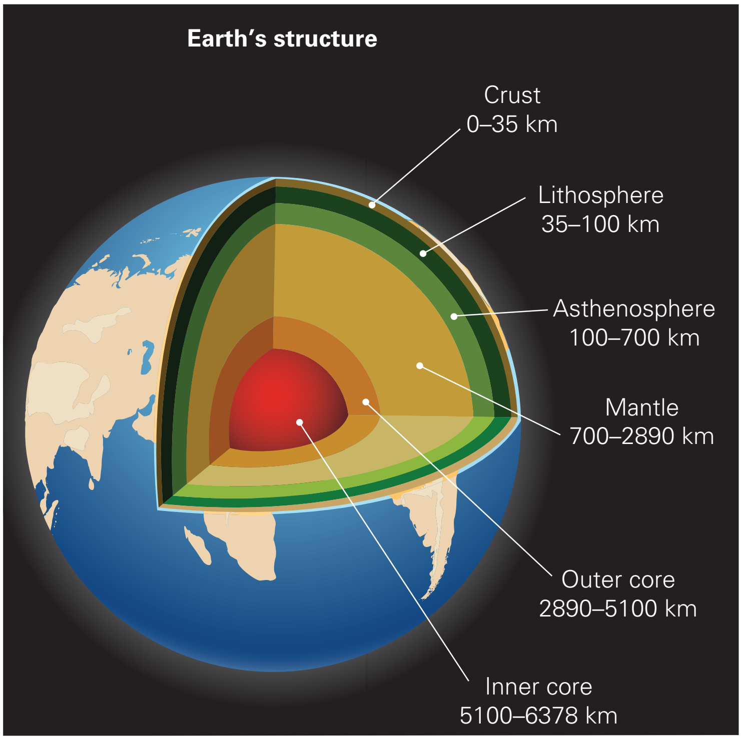

Figure 4.8 The structure of Earth's geosphere, measured from Earth's surface

Lithosphere

lithosphere the geological parts of Earth's crust and upper mantle only

The **lithosphere** refers specifically to Earth's crust and the upper mantle, whereas the geosphere consists of all of the planet's minerals and rocks from the crust to the inner core.

The lithosphere is subdivided into tectonic plates that rest on the mantle. Most earthquakes and volcanic eruptions take place at the boundaries between these plates.

Quick check 4.4

1. Where do most volcanoes and earthquakes occur?
2. What is the lithosphere?
3. Why is the geosphere in constant movement?

Overlapping and interacting spheres

Sometimes it is not easy to exclusively classify substances into one sphere – some matter belongs to two or more spheres at the same time. A productive soil contains plenty of water, air, minerals and bacteria, as well as other organic matter. If we were to assign soil to a sphere, you could argue that it belongs to them all: water from the hydrosphere, air from the atmosphere, minerals from the lithosphere and bacteria from the biosphere.

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.

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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.

Figure 4.9 There are many sphere interactions happening at Windin Falls.

Quick check 4.5

1. How does the water cycle illustrate the interaction between the hydrosphere and atmosphere?
2. Describe the sphere interactions occurring in Figure 4.9.

Making thinking visible 4.1

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.

VIDEO
Cyclones and Earth's spheres

Natural events affecting spheres

Natural events such as earthquakes, volcanoes and cyclones influence the interactions between the spheres. Table 4.2 summarises how natural events cause sphere interactions.

Effect on	**Natural event**		
	Earthquake	**Volcano**	**Cyclone**
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 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 4.2 How natural events influence the interaction between spheres

Section 4.1 questions

QUIZ

Retrieval

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.

Comprehension

4 **Explain** the effect of earthquakes on the lithosphere.

5 **Describe** why Earth's spheres can be described as overlapping.

Analysis

6 **Identify** the spheres present in Figure 4.10.

Figure 4.10

7 **Identify** the sphere interactions taking place in Figure 4.11.

Figure 4.11

Knowledge utilisation

8 **Discuss** how the biosphere interacts with all other spheres.

9 **Discuss** how the atmosphere protects life on Earth.

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4.2 The carbon cycle

WORKSHEET
Understanding the carbon cycle

VIDEO
The carbon cycle

Learning goals

1. To be able to describe the carbon cycle.
2. To be able to describe the role of firestick farming in facilitating energy and nutrient transfers.
3. To be able to identify the impact of combustion reactions as a result of human activity on the carbon cycle.

The cycling and recycling of nutrients such as nitrogen, carbon 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.

sustainable ecosystem
a biological environment that can support itself without outside assistance

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 4.3 summarises the forms of carbon in each of the spheres.

Sphere	Carbon content
Atmosphere	Carbon dioxide (CO_2), 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)
Lithosphere	Decomposed organic matter in soils Fossil fuels (coal, oil and gas) Limestone (calcium carbonate ($CaCO_3$))

Table 4.3 A summary of the carbon content in each sphere

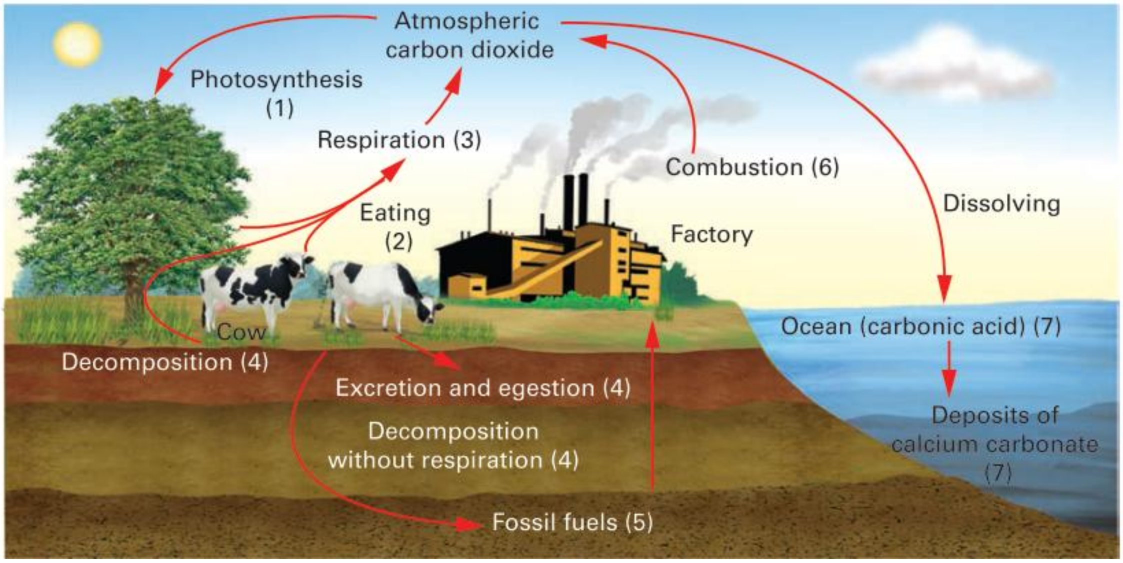

Figure 4.12 The main stages and processes in the carbon cycle

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The carbon cycle can be summarised in seven processes (Figure 4.12), 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.

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.

carbon dioxide + water → glucose + oxygen

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O \quad \text{(full)}$$

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \quad \text{(net)}$$

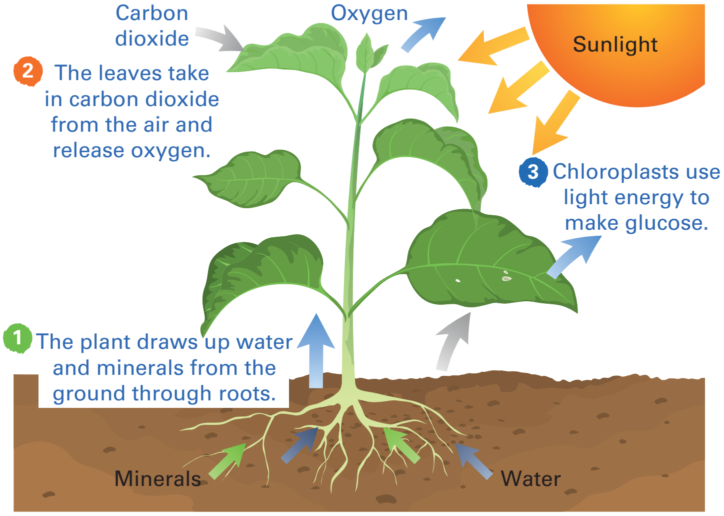

Figure 4.13 Plants remove carbon dioxide from the atmosphere during photosynthesis.

Quick check 4.6

1 What is a sustainable ecosystem?
2 Why is the recycling of carbon important?
3 Give the name of the form of carbon in the hydrosphere.
4 Carbon dioxide is converted into what form of carbon in photosynthesis?

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 4.14 The carbon content of the toad is being transferred to the kookaburra.

Respiration

Plants and animals break down glucose, using oxygen to form carbon dioxide and water. This process is called respiration. The carbon dioxide is added to the atmosphere when organisms breathe out.

Figure 4.15 During respiration, organisms release carbon dioxide gas into the atmosphere.

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The following equation summarises respiration.

glucose + oxygen → carbon dioxide + water + ATP (energy)

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

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).

Figure 4.16 Egestion of faeces, such as these cube-shaped wombat faeces, increases the carbon content of the soil.

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.

decomposer
a living organism, such as bacteria and fungi, that breaks down dead organic matter

Try this 4.1

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.

Quick check 4.7

1 How do animals obtain their carbon in the carbon cycle?
2 Apart from carbon dioxide, what other product is released during the breakdown of glucose in respiration?
3 Name ways that animals can increase the carbon content of soil.

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 4.17 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.

Combustion

Combustion reactions that involve the burning of fuels (such as the bushfire shown in Figure 4.18) 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.

Figure 4.18 Bushfires release carbon dioxide into the atmosphere.

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Often, these are fossil fuels such as coal, oil and natural gas. The following equation shows the combustion of octane, a component of oil.

octane + oxygen → carbon dioxide + water

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

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.

Making thinking visible 4.2

See, wonder, connect: Firestick farming

Figure 4.19 A 1817 watercolour by Joseph Lycett

Firestick farming is a land management technique that is traditionally used by many groups of First Nations Australians for a variety of purposes. The technique involves the controlled use of fire to create a mosaic of different vegetation types and habitats across the landscape.

Firestick farming relies on the use of fire-mediated chemical reactions to facilitate energy and nutrient transfer. The practice can be used to achieve both immediate and long-term results. In the short term, it can force prey animals to move towards the hunters, increasing the chances of capture. In the long term, the ash left behind by the burned vegetation provides a source of nutrients for the soil, which in turn supports the growth of new plants that are more nutritious and accessible to grazing animals.

Look closely at the watercolour painting by Joseph Lycett shown in Figure 4.19.

1 What do you notice? List your observations.
2 What questions do you have? What do you wonder about firestick farming?

The *See, wonder, connect x2* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Explore! 4.2

Traditional fire management

Figure 4.20 A koala rescued from a bushfire

New research carried out at the University of the Sunshine Coast has found that traditional fire burning practices of First Nations Australians can help protect koalas. The research was conducted over two years in collaboration with the Quandamooka people on North Stradbroke Island.

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 burns. The study found no negative impacts on koala population densities or their stress levels.

In small groups, investigate how First Nations Australians' fire management practices are informing and being adopted in contemporary fire management. 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.

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 4.21 Fossils of an extinct group of calcareous (containing calcium carbonate) sponges in limestone

Table 4.4 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 4.4 A summary of the gains and losses of atmospheric carbon within the carbon cycle

Quick check 4.8

1. Give an example of a fossil fuel.
2. Name the process in which fossil fuels are burned, releasing carbon dioxide back into the atmosphere.
3. What is the scientific name and formula for limestone?

Practical skills 4.1

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. Draw the table shown in the Results section.
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.

continued …

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… continued

Results

Copy and complete the following table.

	Colour	pH
Before blowing		
After blowing		

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.

Conclusion

Explain how your observations support your claim.

Practical skills 4.2

Limestone and carbon dioxide

Be careful

Wear appropriate personal protective equipment. Wear safety glasses.

Aim

To determine whether limestone is a store of carbon dioxide

Materials

- calcium carbonate chips
- hydrochloric acid (1 M)
- limewater
- 2 × 10 mL measuring cylinders
- 2 test tubes
- 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 acid, and at the same time 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 journal.

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.
3. Identify the part of the carbon cycle represented by this investigation.

Section 4.2 questions

QUIZ

Retrieval

1 **State** the name and formula of a compound in which carbon is found in the atmosphere.

2 **Recall** why animals and plants require carbon.

3 **Select** 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; that is, it does not require any outside assistance

C A system that is a mixture of biotic and abiotic factors

Comprehension

4 **Explain**, with the use of a word equation, why respiration is part of the carbon cycle.

5 **Describe** the process of photosynthesis to show how carbon dioxide from the atmosphere is transferred to plants and animals.

6 **Summarise** the role of decomposers in the carbon cycle.

7 **Explain** where the carbon in coal, oil and gas originally came from.

8 **Describe** how carbon moves between the atmosphere and the biosphere.

Analysis

9 **Infer** what would happen to the carbon cycle if all human activities that emit carbon were suddenly stopped.

10 **Categorise** the following as atmospheric carbon gains or atmospheric carbon losses.

- Formation of fossil fuels
- Respiration
- Excretion
- Photosynthesis
- Limestone formation
- Combustion

Knowledge utilisation

11 Evan says that humans are affecting the carbon cycle in a negative way. Trent disagrees with this statement and thinks that humans have no effect at all. **Decide** who you think is correct.

12 **Discuss** the role of limestone in the carbon cycle.

13 **Discuss** how burning fossil fuels and deforestation affect the carbon cycle.

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4.3 The greenhouse effect

Learning goals

1. To be able to describe the greenhouse effect and relate it to the role carbon dioxide plays in maintaining temperatures that support life on Earth.
2. To be able to describe how First Nations Australians are reducing Australia's greenhouse gas emissions through the reinstatement of traditional fire management regimes.
3. To be able to calculate an individual's carbon footprint.
4. To be able to describe strategies that can reduce carbon dioxide emissions.

WORKSHEET The enhanced greenhouse effect

In extremely cold regions, it is not possible to grow some fruits and vegetables. In these places, growers may use greenhouses to cultivate weather-sensitive or temperature-sensitive plants or plants that are out of season. Greenhouses provide a protective shield against harsh weather conditions, ensuring optimal growth conditions for the plants. The advantage of using a greenhouse is that it offers more control over the growth conditions, allowing growers to tailor the environment to the specific needs of the plants.

Greenhouses are typically constructed from glass or plastic materials. When the Sun's radiation passes through the greenhouse's walls and roof, it heats the ground and air inside the greenhouse. The heated ground emits infrared radiation, which is reflected back into the greenhouse by the glass or plastic. The hot air rises but cannot leave the greenhouse because of the design of the roof and walls (Figure 4.22). As a result, the temperature inside rises. This helps to keep the plants at an optimum temperature, promoting healthy growth.

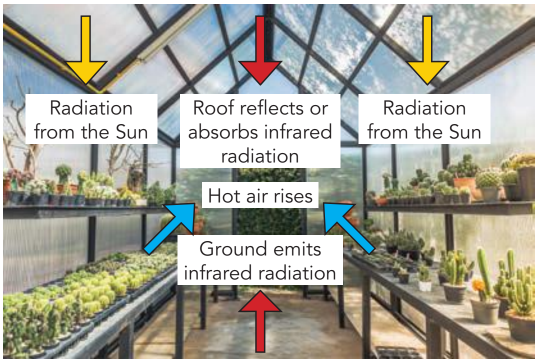

Figure 4.22 Greenhouses protect plants from cold and adverse weather conditions by keeping in the thermal energy.

Quick check 4.9

1. Name a type of radiation emitted from the ground.
2. Explain why greenhouses are made of glass or plastic.

Natural greenhouse effect

Earth naturally retains heat through a process similar to a greenhouse, 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 the 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.

greenhouse gas a gas that contributes to the greenhouse effect

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Table 4.5 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.

Figure 4.23 The Sun emits radiation, which passes through the atmosphere.

Feature	**Carbon dioxide (CO_2)**	**Methane (CH_4)**	**Nitrous oxide (N_2O)**
Proportion of total greenhouse gases (%)	84	9	5
Persistence in the atmosphere	100 years	10 years	100 years
Effectiveness of trapping heat compared to carbon dioxide		30 times more effective	300 times more effective

Table 4.5 A summary of the three most common greenhouse gases, excluding water vapour

greenhouse effect
the trapping of the Sun's warmth by a layer of gases in the lower atmosphere

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 the Earth warm. Without this conversion of solar radiation to infrared radiation, we would lose all the thermal energy back into space, making Earth less habitable. The greenhouse effect maintains a consistent average temperature that is crucial for the survival of organisms on Earth.

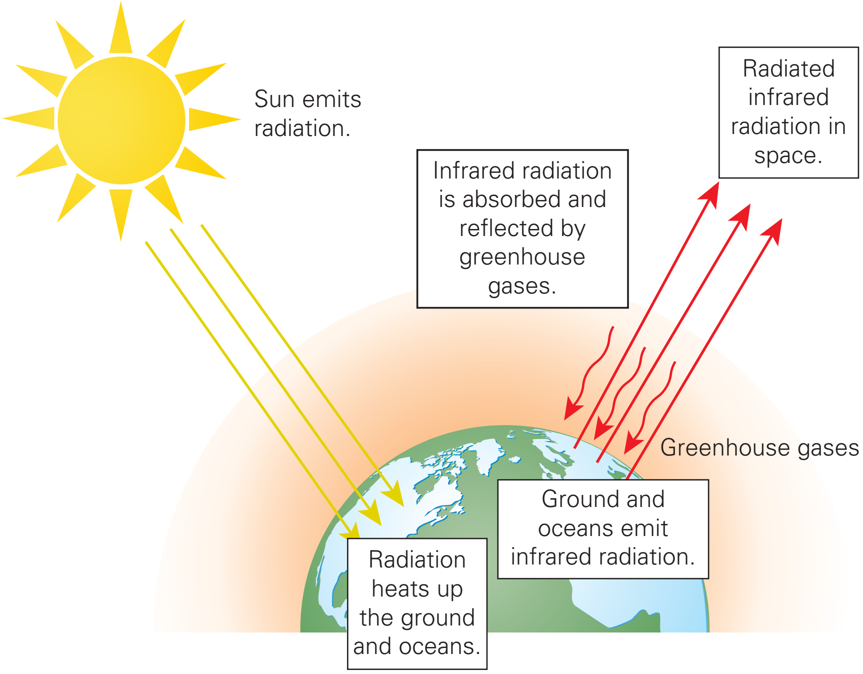

Figure 4.24 A summary of the greenhouse effect

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Quick check 4.10

1 Give the name and formula of one common greenhouse gas.
2 Most of the radiation emitted from the Sun heats the ground and the oceans. What happens to the rest of this radiation?

Did you know? 4.1

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 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 it consumes more energy from using the computer.

Figure 4.25 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.

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. 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.

Explore! 4.3

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?

Table 4.6 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 4.6 Features of solar and infrared radiation

Quick check 4.11

1 Name a source of short-wave radiation.
2 Name the radiation that is absorbed by greenhouse gases in the atmosphere.

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 the hotter Earth becomes.

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

Enhanced greenhouse effect

The **enhanced greenhouse effect** 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**.

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 4.7 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 fossils fuels such as coal, oil and gas. Currently, 70% 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, which increases the amount of nitrogen in the nitrogen cycle, therefore increasing 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 4.7 How humans have increased the concentration of greenhouse gases in the atmosphere

Try this 4.2

Reinstatement of traditional fire management practices

Conduct some research on how technological advances in monitoring greenhouse gas emissions and other environmental factors have contributed to the reinstatement of traditional fire management practices as a strategy to reduce atmospheric pollution.

Quick check 4.12

1 State one way in which we have increased the concentration of carbon dioxide in the atmosphere.
2 Give one way we have increased the concentration of nitrous oxide in the atmosphere.
3 What has the enhanced greenhouse effect led to?

Investigation 4.1

Comparing the natural and enhanced greenhouse effects

Be careful

Take care when handling the lamp because it can become hot with prolonged use. Wear heat-resistant gloves.

Aim

To compare the impacts of the natural and enhanced greenhouse effects

Materials

- baking soda
- water
- vinegar
- 2 × 500 mL beakers
- 100 mL measuring cylinder
- cling wrap
- 2 elastic bands
- 2 weighing boats
- balance
- marker pen
- sticky tape
- stopwatch
- 2 thermometers
- high-intensity lamp
- heat-resistant gloves

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: Prepare the equipment

1 With the marker pen, label one of the 500 mL beakers 'Control'.
2 Using the sticky tape, tape one of the thermometers to the inside of this beaker. It must be about 5 cm above the bottom of the beaker.
3 With the marker pen, label the second beaker 'CO_2'.
4 Tape the thermometer to the inside of this beaker, again making sure it is 5 cm from the bottom.
5 Prepare the cling wrap and elastic bands for sealing; you will cover each beaker immediately after you have poured in the liquid.

Part 3: Collect the data

1 Using the balance, weigh 35 g of baking soda into each weighing boat and pour it into each beaker.
2 Using the 100 mL measuring cylinder, measure 65 mL of water and pour it into the control beaker. Immediately cover it with the cling wrap and elastic band.

continued …

… continued

3. Using the same 100 mL measuring cylinder, measure 65 mL of vinegar and pour into the CO_2 beaker. Immediately cover it with the cling wrap and elastic band.
4. Swirl the contents of each beaker to make sure that the baking soda has fully dissolved.
5. Place both beakers underneath the lamp.
6. Record the starting temperature of each atmosphere before the lamp is turned on.
7. Turn on the lamp and start the stopwatch.
8. Measure the temperature in each beaker every 2 minutes for 8 minutes. Record the temperatures in your results table.
9. At 8 minutes, measure the temperature and then turn off the light.
10. Record the final temperature 2 minutes later.

Data processing

1. Calculate the increase in temperature in each container by the difference between the temperature at 8 minutes and the starting temperature.
2. Calculate the thermal energy retention by the difference in the temperature at 8 minutes to the temperature at 10 minutes.

Analysis

1. State the container that showed the greatest increase in temperature. Did this match your prediction?
2. State the container that retained the most thermal energy in the final 2 minutes.
3. Explain these results by using your own knowledge and scientific research.

Conclusion

1. State a conclusion about the enhanced greenhouse effect based on this experiment.
2. Support the statement by using your data.

Explore! 4.4

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.

- 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 can reduce your carbon emissions. For example, you can consider walking or riding a bicycle instead of travelling to school in the car, reducing energy consumption at home, or reducing waste.

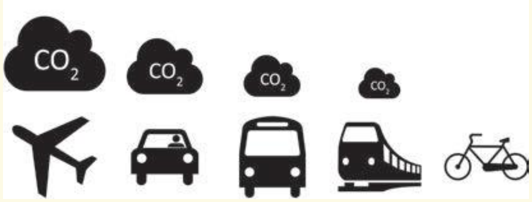

Figure 4.26 Some methods of transport have a bigger environmental impact than others.

Try this 4.3

Reducing carbon footprints

Plan a social media campaign to encourage young people to reduce their carbon footprint.

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Out of balance

Carbon dioxide emissions from human activity are our 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).

Figure 4.27 Trees and the ocean are examples of carbon sinks.

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.

Scientific consensus about global warming

VIDEO
The greenhouse effect

There is overwhelming evidence that Earth's climate is changing, and that human activities are the primary cause of this 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 continue to increase, Earth's temperature will continue to rise.

carbon source
a process or an area that releases carbon

carbon sink
an area where carbon is stored (e.g. ocean, forests or fossil fuels)

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).

Technological advances

The need to minimise greenhouse gas production has led to significant scientific and technological advances. To reduce greenhouse gas emissions, scientists and engineers have developed innovative technologies such as renewable energy sources like wind, solar and geothermal power. These technologies are becoming increasingly cost-effective and widely adopted.

Advances in energy efficiency have also helped to reduce greenhouse gas emissions. Buildings, vehicles and appliances are being designed to use less energy, resulting in reduced emissions.

Figure 4.28 Advances in building design have resulted in eco houses that produce less greenhouse gas emissions.

Quick check 4.13

1. Define 'carbon source' and give an example.
2. Define 'carbon sink' and give an example.

Section 4.3 questions

QUIZ

Retrieval

1. **Name** three gases in the atmosphere that are responsible for the greenhouse effect.
2. **Define** 'enhanced greenhouse effect'.
3. **State** the name of the radiations emitted from the:
   - a Sun
   - b ground and oceans.
4. **Recall** the sources of methane in the atmosphere.

Comprehension

5. **Explain** the differences between the natural and enhanced greenhouse effects.
6. **Explain** why the following statement is incorrect: 'The greenhouse effect is caused by humans'.
7. **Explain** how a greenhouse mimics the greenhouse effect.
8. **Illustrate** a diagram to show how the greenhouse effect keeps Earth warm.

Analysis

9. **Compare** short-wave radiation and long-wave radiation.
10. **Distinguish** between greenhouse gases and other gases in the atmosphere, such as nitrogen and oxygen.
11. **Contrast** carbon sinks and carbon sources by giving examples.

Knowledge utilisation

12. **Predict** what the conditions on Earth would be like without greenhouse gases and the greenhouse effect.
13. **Decide** why our focus related to the enhanced greenhouse effect is on carbon dioxide and not on other greenhouse gases.
14. We have known about the damaging effects of carbon emissions for a long time. **Propose** why Australia still produces 70% of its electricity from coal.
15. **Discuss** the reasons why the carbon cycle is altered by the release of carbon emissions from burning fossil fuels.

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4.4 Carbon sequestration

Learning goals

1. To evaluate carbon sequestration in an ecosystem.
2. To be able to identify how carbon dioxide is captured and stored naturally or through the use of technologies.

WORKSHEET
Carbon
sequestration

carbon sequestration the process of storing carbon in a carbon sink

Carbon sequestration refers to the process of capturing carbon dioxide from the atmosphere and storing it in long-term carbon sinks. These carbon sinks help to reduce the amount of carbon dioxide in the atmosphere.

Capturing and storing carbon naturally

Forests

Forests are one of the most significant carbon sinks on Earth, playing a crucial role in carbon sequestration. As trees grow, they absorb carbon dioxide from the atmosphere through photosynthesis, using it to build biomass. Trees store carbon in their trunks, branches, leaves and roots, where it remains for many years. A mature forest can store vast amounts of carbon, depending on its age, species composition and location.

Tropical rainforests are known for their high carbon-storage capacity due to their dense vegetation and high rates of photosynthesis. In contrast, temperate and boreal (cold temperature) forests tend to store more carbon in the soil, especially in the form of organic matter.

Figure 4.29 Deforestation and forest degradation are major sources of carbon emissions, because they release stored carbon into the atmosphere.

Explore! 4.5

Producing more effective fire-reduction strategies

The publication of data and findings related to the reintroduction of First Nations Australians' traditional fire regimes has informed more effective fire-reduction strategies and policies in several ways. The Queensland Parks and Wildlife Service works in partnership with First Nations people to enhance their fire management strategies.

Conduct some research on the following partnerships and how they have produced more effective fire management practices:

- the development of Township Fire Management Strategies for vulnerable communities on Minjerribah (North Stradbroke Island) in collaboration with the Quandamooka people
- the development of joint management arrangements on Cape York Peninsula, under an Indigenous Management Agreement.

Figure 4.30 Prescribed burns can help reduce the risk of catastrophic wildfires while also promoting forest growth and carbon sequestration.

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Practical skills 4.3

Carbon sequestration in an ecosystem

Trees can sequester carbon. Scientists estimate that the average tree can sequester 25 kg of CO_2 per year, with an average of 250 kg over its lifetime. However, the rate of carbon sequestration depends on factors such as the tree 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 the following table.

		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.

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Quick check 4.14

1 Why can tropical forests sequester more carbon than cold climate trees?
2 State one way in which carbon storage can be measured in an ecosystem.
3 How do plants remove carbon from the atmosphere?

Oceans

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 marine organisms' shells. When marine organisms die, their bodies sink to the ocean floor, taking the stored carbon with them.

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. As more carbon dioxide is taken up by the ocean, the water becomes more acidic, which is harmful to the marine organisms that rely on calcium carbonate to build their shells.

VIDEO
Blue carbon

Figure 4.31 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.

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Soil

Carbon sequestration in soil occurs through the process of photosynthesis, where plants take in carbon dioxide from the atmosphere and convert it into organic matter. When plants die, this organic matter is deposited in the soil where it can be stored.

Peatlands are particularly important ecosystems for carbon sequestration (Figure 4.32). Peatlands are wetlands that accumulate organic matter in the form of partially decomposed plant material called peat. This occurs in waterlogged conditions where oxygen is limited, so decomposition is slowed down. As a result, peatlands can store large amounts of carbon in their soils.

When peatlands are drained or disturbed, such as through agriculture, forestry or peat extraction, the organic matter in the peat is exposed to oxygen and begins to decompose, releasing carbon dioxide into the atmosphere.

Quick check 4.15

1 Which is more effective at storing carbon dioxide – cold water or warm water?
2 What does carbon form in oceans?

Figure 4.32 Peatlands are estimated to store twice as much carbon as all the world's forests.

Explore! 4.6

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 4.33 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, including their preferred habitats and the types of dung they prefer, as well as examining the economic benefits of dung beetle introduction, including increased farm productivity and reduced fertiliser costs.

Try this 4.4

Carbon storage in your area

In your class, collaborate to prepare a written report for your local government on estimated carbon storage across different local ecosystems. Propose ways to increase carbon storage across your local area.

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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 4.34, have the potential to significantly reduce carbon emissions and help slow the pace of climate change, but there are still significant challenges that must be overcome to make large-scale carbon capture readily available.

Figure 4.34 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.

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 4.8 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.

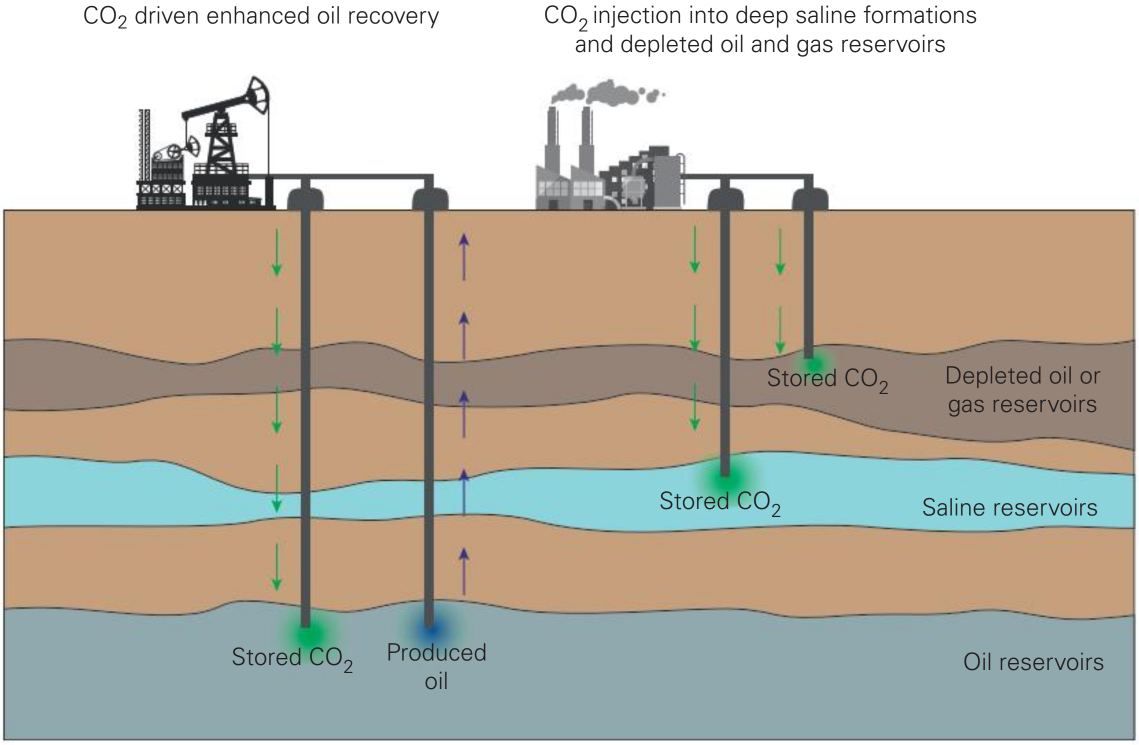

Figure 4.35 Injecting CO_2 underground can help increase oil recovery (left) or allow it to be stored underground in depleted oil and gas reservoirs (right).

Quick check 4.16

1. How is carbon dioxide used in the food industry?
2. What are some of the ways in which carbon dioxide can be stored once it has been captured?
3. Which carbon capture technology recovers more carbon dioxide by burning fuels in pure oxygen?

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Section 4.4 questions

QUIZ

Retrieval

1 **Recall** why tropical rainforests have higher carbon-storage capacity than temperate and boreal forests.
2 **Define** 'carbon sequestration'.
3 **State** the main component of marine organism shells.
4 **Recall** the role of Landcare in Australia.

Comprehension

5 **Describe** how enhanced oil recovery works.
6 **Explain** why when peatlands are drained or disturbed, carbon dioxide is released back into the atmosphere.
7 **Describe** the consequences of ocean warming on ocean carbon sequestration.

Analysis

8 **Contrast** pre-combustion and post-combustion carbon capture.

Knowledge utilisation

9 **Discuss** how forests could be managed to maximise carbon sequestration.
10 **Predict** how global carbon sequestration will be affected if global warming continues.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
4.1	I can identify Earth as a system.	17	
4.1	I can describe Earth's spheres and discuss examples of interactions between different spheres.	1, 22	
4.2	I can describe the carbon cycle.	11, 14	
4.2	I can describe the role of firestick farming in facilitating energy and nutrient transfers.	16	
4.2	I can identify the impact of combustion reactions as a result of human activity on the carbon cycle.	21	
4.3	I can describe the greenhouse effect and relate it to the role carbon dioxide plays in maintaining temperatures that support life on Earth.	15	
4.3	I can describe how First Nations Australians are reducing Australia's greenhouse gas emissions through the reinstatement of traditional fire management regimes.	23	
4.3	I can describe strategies that can reduce carbon dioxide emissions.	13	
4.4	I can evaluate carbon sequestration in an ecosystem.	6	
4.4	I can identify how carbon dioxide is captured and stored naturally or through the use of technologies.	24	

Review questions

SCORCHER

Retrieval

1 **Recall** the four spheres that make up Earth's system.
2 **Recall** the two main gases that make up Earth's atmosphere.
3 **Name** the materials that are typically used to construct greenhouses.
4 **Name** the forms of carbon found in the atmosphere and lithosphere.
5 **Identify** the most abundant greenhouse gas.
6 **Recall** the average amount of CO_2 that a tree can sequester per year.

Comprehension

7 **Explain** how decomposition contributes to the carbon cycle.
8 **Explain** why the recycling of nutrients is important for ecosystems.
9 **Describe** the natural greenhouse effect.
10 **Describe** what happens to long-wave radiation emitted from the ground and oceans.

11 **Construct** a word equation to show how the process of photosynthesis leads to a decrease in atmospheric carbon dioxide.
12 **Describe** the impact of deforestation on carbon emissions.
13 **Describe** some strategies that can reduce carbon dioxide emissions.
14 **Illustrate** a diagram of the carbon cycle.
15 **Describe** the role carbon dioxide plays in maintaining temperatures that support life on Earth.
16 **Describe** the role of firestick farming in facilitating energy and nutrient transfers.
17 **Explain** why Earth is described as a system.

Analysis

18 **Compare** the effectiveness of methane and carbon dioxide at trapping heat.
19 **Analyse** the sphere interactions that are taking place in Figure 4.36.

Figure 4.36 Possible sphere interactions

20 **Critique** how the reintroduction of traditional fire regimes can be helpful in carbon sequestration.
21 **Analyse** the impact of combustion reactions on the carbon cycle.

Knowledge utilisation

22 **Discuss** what scientists can learn from understanding how the spheres of Earth interact with each other.
23 **Discuss** how First Nations Australians are reducing Australia’s greenhouse gas emissions through the reinstatement of traditional fire management regimes.
24 **Evaluate** the role of forests in carbon sequestration.

Data questions

The graph in Figure 4.37 shows the distribution of organic carbon on land by ecosystem type in soil and above and below ground plant biomass.

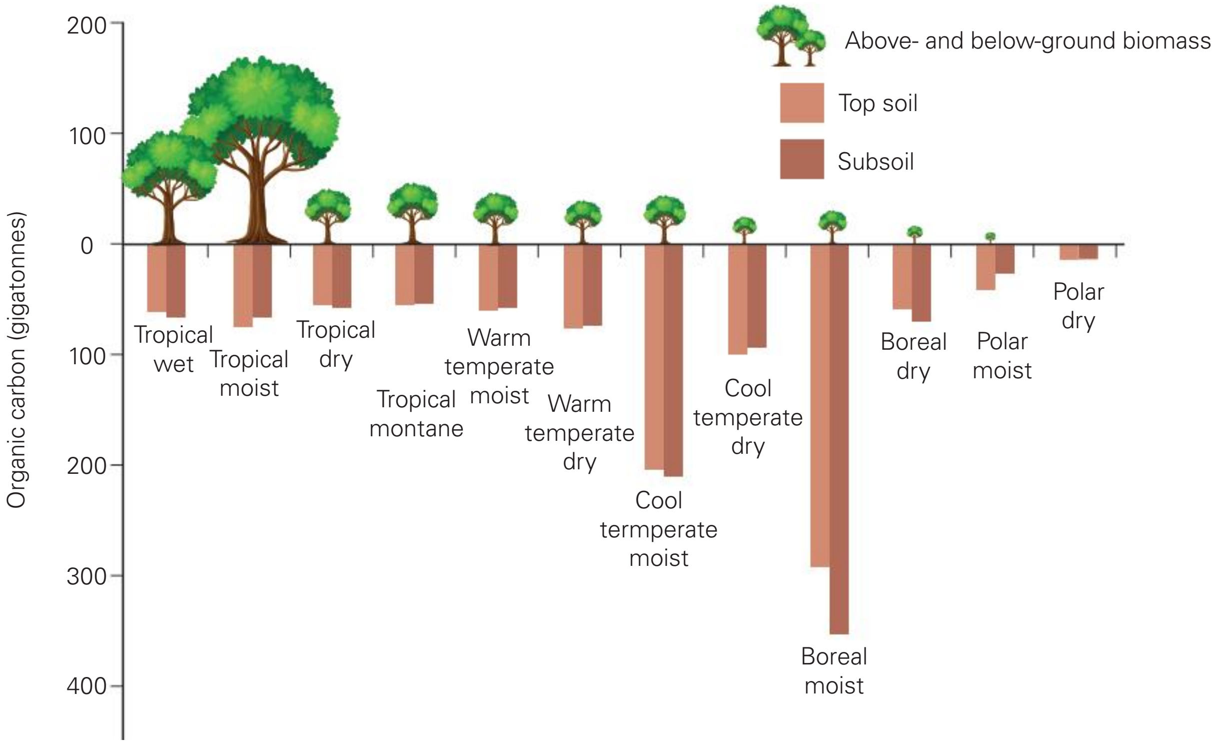

Figure 4.37 The total mass of organic carbon stored in different types of ecosystems, distributed between plant biomass, topsoil and subsoil.

Apply

1 **Identify** the forest that stores the most carbon in its soil.

2 **Determine** the ecosystem that has approximately half the organic carbon in the soil compared to the soil in the cool temperate moist ecosystem.

3 **Determine** the approximate organic carbon found in the plant biomass of a tropical moist ecosystem.

Analyse

4 **Identify** any general relationship in the data.

5 **Sequence** the following ecosystems in order of total carbon mass, from most to least: boreal moist, polar dry, tropical dry, warm temperature moist, cool temperate dry.

Interpret

6 Can the data in Figure 4.37 be used to **justify** the following statement? ‘Tropical ecosystems sequester more carbon.’

STEM activity: Designing a carbon-neutral house

Background information

As people become more aware of the impact of climate change, there is increasing interest in reducing our carbon footprint in every aspect of our lives. A carbon-neutral home is designed and built to minimise its carbon footprint and environmental impact. This means that the house produces zero net greenhouse gas emissions. Carbon-neutral homes are becoming increasingly popular as people look for ways to reduce their impact on the environment while still enjoying the benefits of modern living. In this activity, you will explore the concept of carbon-neutral homes and design your own carbon-neutral house.

Design brief: Design a carbon-neutral house that meets the needs of a modern family while minimising its carbon footprint.

Figure 4.38 Solar panels on external shades on a building in Singapore

Activity instructions

As an architect, you are part of a team of house-building professionals that includes engineers, policymakers and environmental researchers. Your team has been given the task of designing a carbon-neutral home that meets the needs of a modern family while minimising its environmental impact. This requires an understanding of environmental design principles, sustainable building materials, and renewable energy sources.

To design a carbon-neutral home, you must first consider the energy required to heat and cool the home and power appliances and electronics. You must also consider the energy required to produce the building materials used in the construction of the home.

One of the key components of a carbon-neutral home is incorporating renewable energy. This can include solar panels, wind turbines and geothermal systems. By using renewable energy technology, the home can produce its own energy, reducing the need for energy from traditional power sources that produce greenhouse gas emissions.

Another important consideration is the use of water. Water-efficient fixtures and appliances can help reduce water usage, which can help minimise the environmental impact of the home. Additionally, rainwater harvesting systems can help reduce the amount of water required from traditional sources.

You should also consider the materials used to construct the home. Sustainable building materials, such as bamboo, straw bales and recycled materials, can help reduce the carbon footprint of the home. The use of locally sourced materials can help reduce the energy required to transport building materials to the site.

To ensure the home is carbon neutral, it is also important to consider the landscaping surrounding the home. The use of native plants, which require less water and maintenance, can help reduce the environmental impact of the landscaping. Additionally, permeable paving and other sustainable landscaping techniques can help reduce water usage and run-off.

Suggested materials

- graph paper or digital design software
- rulers, pencils, erasers and other drafting tools
- access to internet for research

Research and feasibility

1. Conduct some research and compare the carbon footprints of different types of homes, such as single-family homes, apartments and tiny homes.
2. In small groups, brainstorm ideas for what features a carbon-neutral house might have. Some examples are shown in Figures 4.39–4.41. Some suggestions are:
   - solar panels or other renewable energy technologies
   - insulation and energy-efficient appliances
   - water-efficient fixtures and appliances
   - low-impact building materials
   - sustainable landscaping.

Figure 4.39 The BedZED housing development in London. BedZED (Beddington Zero Energy Development) was the UK's first carbon-neutral eco-community. The buildings are constructed of materials that store heat when conditions are warm and release it when it cools down. Where possible, natural, recycled or reclaimed materials were used.

3. Once your group has developed a list of potential features, conduct some research on each idea to determine its feasibility and effectiveness. You should also research the costs associated with each idea.

Design

4. Using graph paper or digital design software, design a floor plan and elevation for your carbon-neutral house. You should incorporate the ideas that you have researched and consider how each feature will work to minimise the house's carbon footprint.

Create

5. Work with other groups in your class to design a community of carbon-neutral houses, considering factors such as shared resources and transportation options.

Evaluate and reflect

6. Reflect on what you have learned and how you might apply these concepts to your own lives.
7. As a class, discuss the challenges and benefits of designing a carbon-neutral house.

Figure 4.40 Tecla Houses are a revolutionary type of housing that combines advanced 3D printing technology with sustainable and locally sourced materials. They are printed by a 3D printing technique called Crane WASP, in which a large robotic arm deposits layers of natural materials, such as clay and rice husks, to create the house. The process is highly efficient and can finish a house in a matter of days.

Figure 4.41 The Waste House in Brighton, UK, is a sustainable building made entirely out of waste materials, including old toothbrushes, bicycle inner tubes, and DVD cases. It was designed and built by the University of Brighton's Faculty of Arts and Architecture, and demonstrates the potential of 'closed loop' architecture, where waste is repurposed and reused in construction. The house has solar panels, rainwater harvesting systems, and other energy-saving features.

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Chapter 5
Transfer of energy

Chapter introduction

Energy sources, renewable and non-renewable, are used to transfer and transform energy into useful forms in everyday life. The transfer of energy obeys the law of conservation of energy where energy cannot be created or destroyed, but that doesn't mean that energy transfer is 100% efficient. Energy is often lost to the surroundings as waste in the form of heat, light or sound. Heat energy can be transferred through materials in a variety of ways, including conduction, convection and radiation. This chapter will explore the efficiency of energy transfer, from its source to its intended use.

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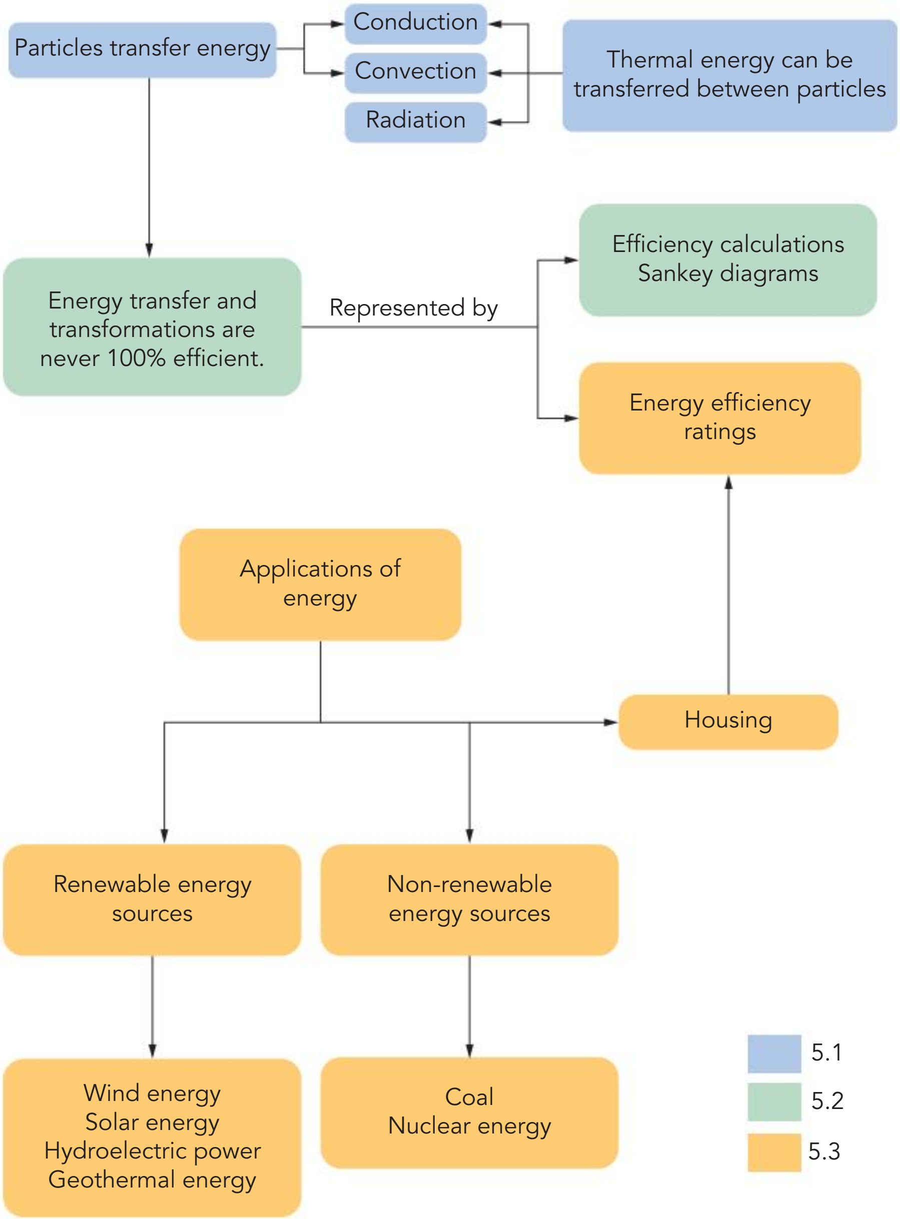
Concept map



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Curriculum

Use wave and particle models to describe energy transfer through different mediums and examine the usefulness of each model for explaining phenomena (AC9S9U04)	
describing the processes underlying convection and conduction of heat in terms of the particle model	5.1
investigating aspects of heat transfer and conservation in the design of First Nations Australians' bedding and clothing in the various climatic regions of Australia	5.1
Apply the law of conservation of energy to analyse system efficiency in terms of energy inputs, outputs, transfers and transformations (AC9S9U05)	
explaining that the law of conservation of energy explains that total energy is maintained in energy transfer and transformation in a system	5.2
explaining efficiency and recognising that in energy transfer and transformation a variety of processes can occur, so that the amount of usable energy is reduced and the system is not 100% efficient	5.2
using and critiquing representations such as Sankey diagrams to show energy inputs, changes and outputs in a system	5.2
investigating the efficiency of ground ovens used by First Nations Australians	5.2
comparing the efficiency of electricity generation from coal and other sources such as nuclear, hydroelectricity, gas, solar and wind	5.3
examining the meaning of energy star ratings given to appliances such as refrigerators and washing machines and criteria used to determine these ratings	5.3
examining how improving efficiency in energy transfer and transformations in sporting activities such as pole vaulting or archery improves athletic performance	5.3

Glossary terms

Conduction
Conductor (heat)
Convection
Efficiency
Enrichment
Fossil fuel
Free electron
Geothermal energy
Heat
Hydroelectric power
Insulator (heat)
Kinetic energy
Law of conservation of energy
Non-renewable
Radiation
Renewable
Sankey diagram
Solar energy
Sustainable
Temperature
Thermal energy
Useful energy

5.1 Particles transfer energy

Learning goals

1. To be able to describe the difference between thermal energy and temperature.
2. To be able to explain heat transfer by conduction, convection and radiation.

WORKSHEET
Thermal energy transfer

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.

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.

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 (Figure 5.1).

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.

Therefore, the thermal energy of an object can be explained by the particle model as the total energy all of its particles have 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.

kinetic energy	the energy of moving matter
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

Quick check 5.1

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.

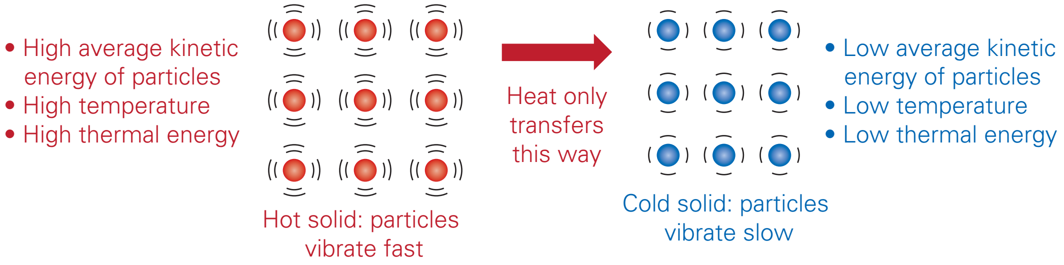

Figure 5.1 The particles in hot and cold solid objects of the same mass. The relationship between average kinetic energy of particles, thermal energy, heat and temperature is shown. This diagram also applies to liquids and gases, but those particles aren't vibrating; instead they are moving around.

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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.

Figure 5.2 A bath of warm water contains more thermal energy than a cup of hot chocolate, even if the bath is at a lower temperature.

Try this 5.1

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 of the warm and cold containers of water and 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?

Investigation 5.1

Investigating thermal energy

Be careful

Ensure general fire safety is followed. Use appropriate personal protective equipment when handling hot equipment.

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.

change in thermal energy = mass × specific heat capacity × change in temperature

$$\Delta Q = mc\Delta T$$

where:

ΔQ = change in thermal energy (J)

m = mass (kg)

c = specific heat capacity (J/kg/°C)

ΔT = change in temperature (°C)

Note: Δ means 'change in'.

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
- 4 × 600 mL glass beakers
- thermometer
- stopwatch

Method

1 Draw the results table below.
2 Put 200 mL of water in a beaker and measure the temperature. Record this in your results table.
3 Remove the thermometer and heat the water over the Bunsen burner for 2 minutes.
4 Stir the water and measure the final temperature after it has been heated. Record this in your results table.
5 Repeat steps **2–4** with 300 mL, 400 mL and 500 mL of water, and using a new beaker each time. Make sure the initial temperature of the water is the same.

Results

Copy and complete the following table.

Volume (mL)	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)	Change in thermal energy (J)
200				
300				
400				
500				

Data processing

1 Calculate the change in thermal energy (ΔQ) by using the equation given above. Remember, 1 litre 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.

continued…

…continued

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

Draw a conclusion about volume and thermal energy from this experiment, supporting your statement with data.

Quick check 5.2

1. Define 'thermal energy' of an object.
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.

VIDEO
Conduction

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.

In Figure 5.3, 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 burn the marshmallows – **convection**. Finally, as you sit around the camp fire, you feel an intense warmth on your skin – **radiation**.

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

Figure 5.3 Keeping warm around a camp fire is an example of a transfer of heat energy.

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 (Figure 5.4). This causes the slower vibrating particle to vibrate faster, increasing its kinetic energy and, therefore, its temperature.

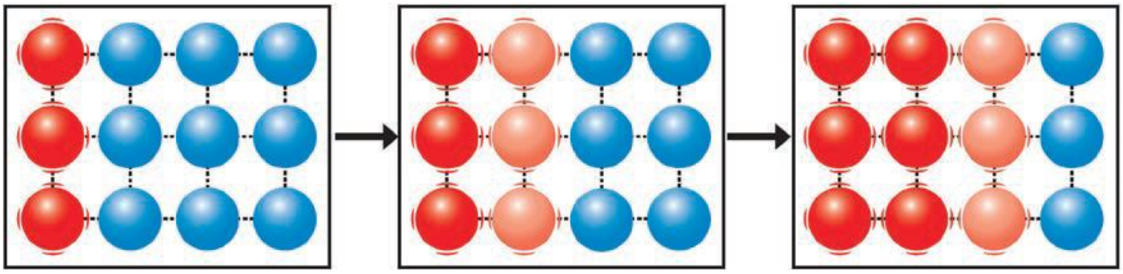

Figure 5.4 A time sequence showing heat flowing through the particles of a solid by conduction. The heat source (not shown) is on the left of the particles. At first, only the particles next to the heat source become hot and vibrate. They bump into particles next to them, which warm up, and so on.

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.

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 and result in vibrations (and the associated kinetic energy) passing more quickly between particles in a metal. So thermal energy in metals spreads quickly from hot to cold (see Figure 5.6).

Figure 5.5 Warming up your hands with a hot drink on a cold day is an example of heat transfer by conduction.

Other materials, such as polystyrene, do not conduct heat well and are called **insulators**.

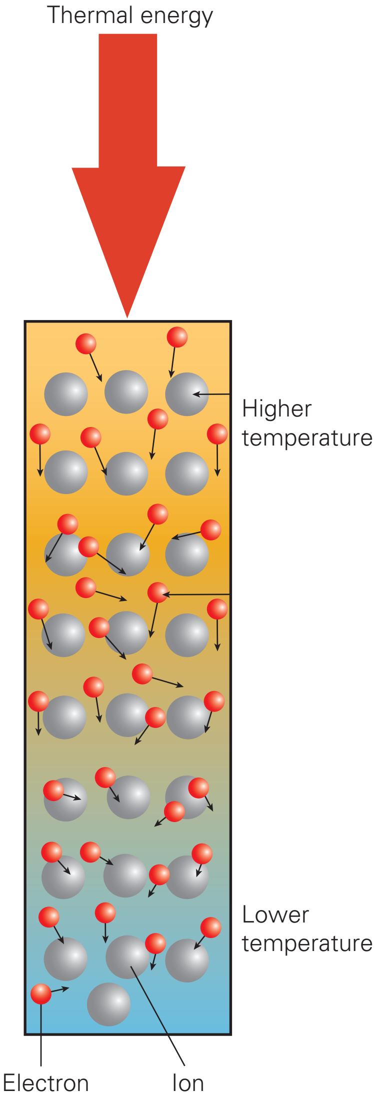

Figure 5.6 Free electrons can travel through metals and help thermal energy spread quickly from hot to cold areas.

conductor (heat)
a substance 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 easily

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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 begin to rise. Figure 5.7 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.

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. Within Earth, convection currents move layers of magma. In the oceans, convection creates currents.

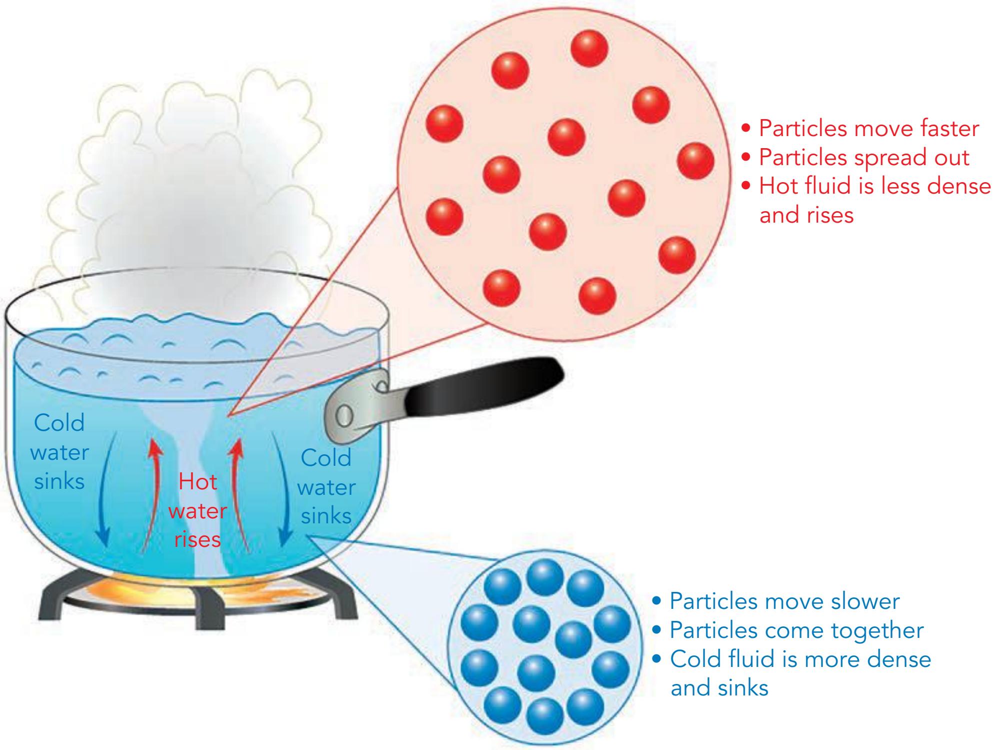

Figure 5.7 When water is heated, the hotter, less dense water at the bottom rises and the colder, more dense water sinks to take its place.

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Explore! 5.1

El Niño versus La Niña

El Niño and La Niña are opposite phases of the El Niño–Southern Oscillation (ENSO) cycle, which describes sea temperature and atmospheric air pressure changes between the eastern and western parts of the tropical Pacific Ocean. El Niño occurs when ocean temperatures are significantly higher than average in the eastern tropical Pacific and La Niña occurs when there is a cooling of the same part of the ocean.

Use the Australian Bureau of Meteorology website to answer the following questions.

Figure 5.8 The El Niño–Southern Oscillation (ENSO) cycle is often responsible for high amounts of rainfall in Queensland.

1 Explain how the movement of thermal energy by convection currents produces the weather patterns observed during periods of El Niño and La Niña.
2 Explain how El Niño affects temperatures and rainfall in Queensland.
3 Explain how La Niña affects temperatures and rainfall in Queensland.

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 (explored further in Chapter 6). This differs from convection and conduction, as it does not rely on particles and can travel through a vacuum.

Figure 5.9 A pizza is baked using radiant heat in an oven.

VIDEO
Radiation

Explore! 5.2

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 5.10 A cold-blooded eastern water dragon (*Intellagama lesueurii lesueurii*) sunbathing

Quick check 5.3

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.

Practical skills 5.1: Self-design

Modelling heat transfer

Aim

To design your own experiment that models the three types of heat transfer with the hypothesis that if objects of different temperatures are placed in contact, heat energy will transfer from an object of higher temperature to an object of lower temperature until both objects reach the same temperature

Be careful

Ensure general fire safety is followed. Use appropriate personal protective equipment when handling hot equipment.

Materials

- metal, wooden and plastic spoons
- water
- Bunsen burner
- tea bags and tea leaves
- ice blocks
- radiant heater

Method

Design an experiment that demonstrates the three types of heat transfer. 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.

Analysis

Explain how your self-designed experiments demonstrated how thermal energy is transferred through conduction, convection and radiation.

Did you know? 5.1

Clothing technology

Australia has a large variety of climatic regions, and various First Nations Australian communities have developed different technologies that enable them to live and thrive successfully 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.

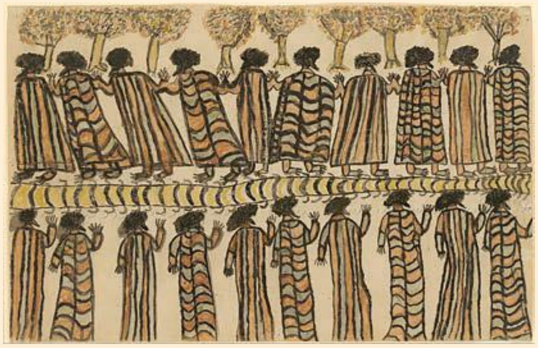

Figure 5.11 Artwork by William Barak, an influential First Nations Australian spokesperson, depicts the use of possum skin cloaks.

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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 away. Therefore, radiation is explained by the wave model.

VIDEO
Summary of heat transfer

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 next to the heat vibrate or move more, so their kinetic energy increases. They 'bump' neighbouring atoms, passing on this kinetic energy and allowing heat energy to move through the object or substance.	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.
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 without the presence of particles	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 but gets toasted because of the transfer of thermal energy through space by radiation.

Table 5.1 The three different processes of heat transfer

Section 5.1 questions

QUIZ

Retrieval

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.

Comprehension

4 **Explain** how an object that has a higher temperature can have less thermal energy than an object that has a lower temperature.

5 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.

6 **Explain** why energy is received from the Sun by radiation and not by convection or conduction.

7 Convection occurs in liquids and gases. **Explain** why convection does not (as a general rule) occur in solids.

Analysis

8 **Classify** the following as heat transfer by either conduction, convection or radiation.
  a Heat escaping from the bottom of a cup of a hot coffee
  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.

Knowledge utilisation

11 **Decide** at what point thermal energy transferring between two substances in contact will stop being transferred.

12 1 L of gas in a cylinder is rapidly compressed by a piston until it occupies 0.1 L. As a result, the molecules of gas have less space to move, 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 particles differs.

5.2 Energy transfers and transformations

Learning goals

1. To be able to calculate the efficiency of energy output.
2. To be able to describe energy transfers and transformations.
3. To be able to interpret Sankey diagrams, illustrating energy transfers.

WORKSHEET
Energy transfers and transformations

Energy is constantly changing from one form to another. For example, the characteristic lights and sounds produced by fireworks are the result of a range of energy transformations. When a firework explodes, thermal energy, in the form of a lit fuse, in addition to chemical potential energy, is transformed into heat, light and sound energy, as well as kinetic and gravitational potential energy.

Not all energy transformations are this complex. For example, a toaster transforms electrical energy to thermal energy, which toasts the bread by radiation. Regardless of how simple or complex the transformations are, energy is conserved in all energy conversions. In other words, all conversions abide by the **law of conservation of energy** in that energy can be neither created nor destroyed; it can only be converted from one form of energy to another.

Figure 5.12 Fireworks are the result of many energy transformations.

Energy efficiency

law of conservation of energy a scientific law that states that energy can be neither created nor destroyed, only converted from one form of energy to another

The optimisation of many machines involves ensuring that as much of the input energy is transferred or transformed to the output energy that is required. Consider the incandescent light bulb in Figure 5.13. Only about 10% of the total electrical energy input is transformed into visible light energy. The remaining 90% is transformed into thermal energy.

Figure 5.13 Incandescent light bulbs can be quite inefficient.

As producing thermal energy is not the main use of a light globe (producing light is!), the thermal energy produced is said to be wasted energy. This loss of useful energy does not mean that energy has disappeared, because the waste (thermal) energy is still accounted for according to the law of conservation of energy. However, the high proportion of wasted energy (90%) shows that the energy transfer is inefficient.

Achieving a 100% efficient energy conversion is extremely unlikely, especially for machines that do work, because energy in some form is almost always lost to the system. Consider the soccer ball being dropped from a height onto a concrete surface in Figure 5.14. At its maximum height, the ball has a large amount of gravitational potential energy. When the ball is dropped, this gravitational potential energy is converted to kinetic energy, which reaches a maximum just before the ball hits the ground. As the ball hits the ground, the kinetic energy is converted into elastic potential energy. This is converted back into kinetic energy as the ball bounces up again. If this system was 100% efficient, the ball would bounce back up to its starting height and have the same amount of gravitational potential energy as before being dropped. We know that this is not the case because with each bounce, the ball reaches a lower maximum height until eventually the ball comes to a stop.

Let's look at how energy is lost from this system. First, as the ball is falling towards the ground, it is encountering air particles. Contact with these particles results in friction and heat – thus, energy is lost as heat to the surrounding air particles. When the ball bounces, it creates a sound and there is also friction between the ball and the ground. Therefore, each successive bounce of the ball has less energy than the preceding bounce. As a result, the ball slows down, before coming to a stop when all the energy initially possessed by the ball is lost to the system.

Figure 5.14 The bounce of a soccer ball on a surface is not 100% efficient because energy is lost from the system.

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Explore! 5.3

Energy transfer in sport

There are many sports in which performance depends on the interaction of a human and an object; for example, a cricketer's technique when bowling or batting, or the technique used when throwing or kicking a rugby ball. In individual sport, it might be the interaction of a pole vaulter and the pole or of an archer and the bow. Performance in these sports requires peak energy efficiency in the energy transfer processes.

Draw an energy flow diagram and explain how energy is optimally transferred between:

a a pole and a pole vaulter
b an archer and an arrow.

Figure 5.15 Athletic performance can be improved with efficient energy transfer.

Did you know? 5.2

Earth ovens

Some communities of First Nations Australians use earth ovens as a method of transferring heat energy to cook food by conduction, convection and radiation. A hole is made in the ground and lined with hot rocks heated from a fire. The food is then placed on the hot rocks and often covered with leaves and more rocks to insulate the heat, creating an oven environment.

Like all ovens, the earth oven is not 100% efficient; energy is lost from the cooking process as heat and light to the surroundings as well as contributing to other chemical reactions. However, earth is an excellent insulator due to pockets of air in the soil. This makes earth ovens an energy-efficient method of cooking food.

Calculating energy efficiency

The **efficiency** of a machine is a measure of how good the machine is at converting the input energy to **useful energy**. The percentage of input energy that is converted to useful energy is used to give the machine an efficiency rating.

efficiency
the percentage of input energy that is converted to useful energy by a machine

useful energy
the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it produces

The formula used to calculate the efficiency rating of a machine is:

$$\text{efficiency (\%)} = \frac{\text{useful output energy}}{\text{input energy}} \times 100$$

Figure 5.16 Running up hill converts chemical energy into kinetic energy. Once the woman reaches the top of the hill, energy has been converted to gravitational potential energy.

Worked example 5.1

Energy efficiency of a kettle

A kettle uses 261 500 J of electrical energy to heat 500 mL of water. If the thermal energy of the water is 209 200 J, calculate the efficiency of the kettle. For simplicity, assume that the water starts with no thermal energy.

Working	Explanation
Useful output energy = 209 200 J Input energy = 261 500 J	List the relevant data that has been provided.
$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{input energy}} \times 100$	Recall the definition of energy efficiency and the equation.
$\text{Efficiency (\%)} = \frac{209\,200}{261\,500} \times 100$	Substitute the relevant data into the equation.
Efficiency = 80%	Solve the problem, giving an answer with appropriate units.

Worked example 5.2

Energy efficiency of muscles

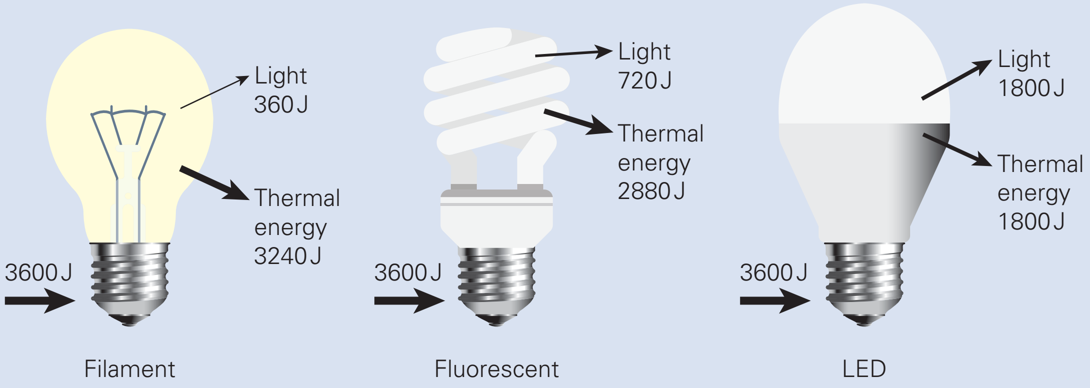
A girl runs upstairs and uses up 4000 J of energy from food she has eaten. If this energy is used to output 1000 J of gravitational potential energy, calculate the efficiency of her muscles.

Working	Explanation
Useful output energy = 1000 J Input energy = 4000 J	List the relevant data that has been provided.
$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{input energy}} \times 100$	Recall the definition of energy efficiency and the equation.
$\text{Efficiency (\%)} = \frac{1000}{4000} \times 100$	Substitute the relevant data into the equation.
Efficiency = 25% The other 75% would be waste energy, lost mainly as thermal energy as she climbs the stairs.	Solve the problem, giving an answer with appropriate units.

Try this 5.2

Calculating energy efficiency

Calculate the energy efficiency of each of the globes shown. State which globe is no longer recommended for household use and justify your choice.



Making thinking visible 5.1

See, think, wonder: Smartphones

Scientists and engineers continually strive to make smart devices such as smartphones more energy efficient. That is, when you charge your smart device, not only does the battery last longer, but the chemical energy is being used to efficiently perform the tasks required of the device.

See: What do you see that scientists and engineers have done to make smart devices more energy efficient?

Think: What thoughts come to mind as you consider these strategies?

Wonder: Given the progress towards energy-efficient smart devices, what do you wonder about the future of energy-efficient smart devices?

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

Quick check 5.4

1 Define ‘energy efficiency’.

2 Copy and complete the following table by giving an example of the useful energy and waste energy produced by each device.

Device	Useful energy output	Waste energy output
Light bulb		
Car		
Lawnmower		

3 A light bulb uses 3000 J of electrical energy. Of this, 600 J is transformed into light energy and 2400 J is transformed into thermal energy. Calculate the energy efficiency of this globe.

Try this 5.3

Energy efficiency of bouncy balls

Aim

To investigate which type of bouncy ball is most energy efficient

Materials

- a range of bouncy balls
- metre rulers

Method

Design an experiment that will test the rebound height of a range of bouncy balls. In a group, discuss how you will carry out this experiment, and write a step-by-step method.

Results

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

Analysis

By using the energy efficiency equation, calculate the efficiency of each type of ball. Use the drop height and the rebound height in your calculations.

Evaluation

1. Identify sources of uncertainty in your experiment.
2. Suggest how your experiment may be improved.
3. Describe the effect of the surface on the efficiency of the bouncing ball.

Sankey diagrams

Sankey diagram a flow chart that represents the flow of energy through a system

A **Sankey diagram** is a flow chart that represents the flow of energy through a system. A Sankey diagram has a wide arrow at its base, which represents the energy input into a system. The flow diagram then branches off into two or more arrows, the size and thickness of which is directly proportional to the amount of output energy in that form.

For example, Figure 5.17 shows a Sankey diagram for an incandescent light globe where only 10% of output energy is in a useful form of light. The Sankey diagram shows that most of the electrical energy is transformed into thermal energy (thicker arrow) rather than light, which is a useful form of energy output. The thermal energy produced is said to be lost or wasted energy.

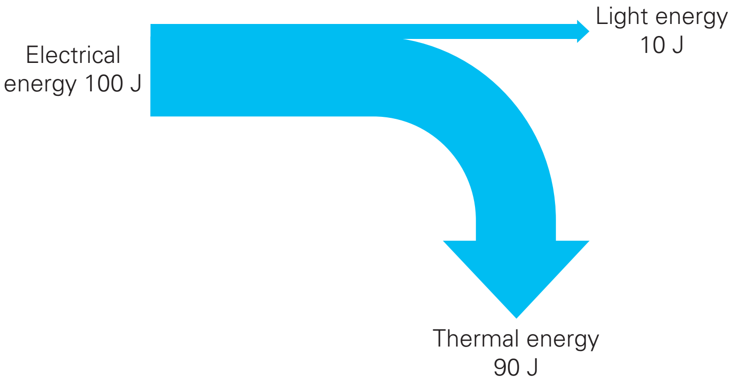


Figure 5.17 A Sankey diagram for an incandescent light globe showing the amount of input energy (100 J) as well as the amount of output energy in its various forms.

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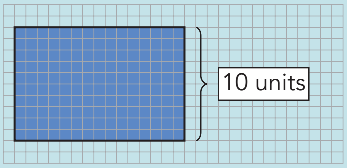
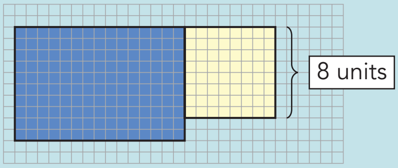
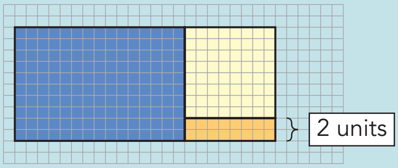
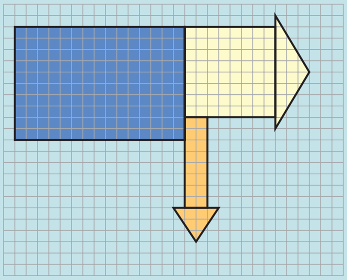
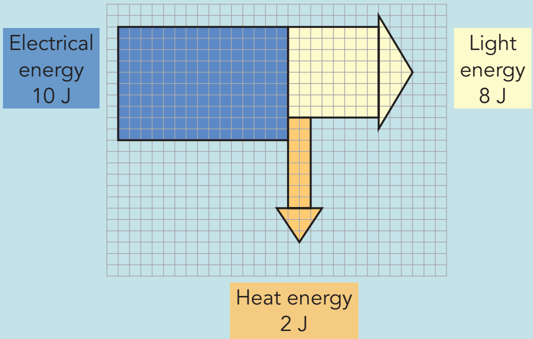
Worked example 5.3

Drawing a Sankey diagram

Draw the Sankey diagram of an energy-efficient light bulb with an input energy of 10 J, an output energy of 8 J in the form of light and wasted output of 2 J in the form of heat.

Working	Explanation
	The height of the box represents the amount of energy that is put in. In this case it is 10 J, so it should be 10 units high. Note that the length of the box does not matter.
	The height of the next box represents the amount of useful energy. In this case, it is 8 units high.
	The height of the final box represents the amount of wasted energy. In this case, it is 2 units high.
	Rotate the wasted energy box 90° clockwise so it points down. This shows that it is wasted energy. Add arrows to the output boxes.
	Finally, add the labels.

Quick check 5.5

1. Outline the energy changes that take place when you jump on a trampoline. Explain why you do not bounce back up to the same height after successive bounces.
2. Calculate the efficiency of an electric stove that has an input of 1500 J of energy and produces 200 J of light energy and 1300 J of thermal energy.
3. Draw a Sankey diagram for the electric stove in Question **2**.

Section 5.2 questions

QUIZ

Retrieval

1 **Define** 'useful energy'.

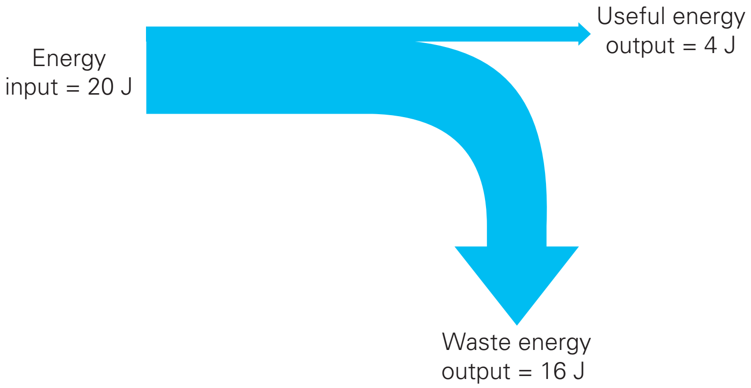
2 **Recall** the energy transformations that occur when fireworks explode.

3 **State** what usually happens to wasted energy.

4 An organism uses 500 J of chemical potential energy stored in its body to produce 125 J of kinetic energy so that it can climb a tree. **Calculate** the energy efficiency of this process.

5 A kettle has an energy efficiency of 89%. **Calculate** how much electrical energy is required to produce 1068 J of thermal energy.

6 The following Sankey diagram is for a light globe.



  a **Identify** the useful energy output that the light globe is designed to produce.
  b **Recall** the effect that the wasted energy has on the surrounding air.
  c **Calculate** the efficiency of this light globe.

Comprehension

7 A car has an energy efficiency of 35%. **Explain** what this means in terms of energy.

8 **Explain** what the term 'efficiency' means.

9 **Explain** how the law of conservation of energy still applies to a system despite energy being 'lost' during a transformation.

10 On cold days, some of the heat transferred from a hot car engine is used to warm the air inside the car. **Describe** the effect that this has on the overall efficiency of the car engine.

Analysis

11 **Organise** the following processes from the highest amount of energy to the lowest:
Falling raindrop: 85×10^{-6} J
Cosmic ray: 1.6×10^{-9} J
Car travelling on the Bruce Highway: 4.00×10^{5} J
Strong earthquake: 1.0×10^{16} J
Falling snowflake: 6.50×10^{-7} J

Knowledge utilisation

12 Incandescent light globes convert 10% of their input energy into light energy, whereas LEDs (light-emitting diodes) convert 60% of their input energy into light energy. **Determine** which type of light globe is more energy efficient.

13 As Kryon slides down a playground slide, the amount of kinetic energy that he gains is less than the amount of gravitational energy that he loses.
  a **Predict** where the missing energy goes.
  b **Propose** what Kryon can do to minimise the amount of wasted energy.

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5.3 Applications of energy

Learning goals

1. To be able to describe the significance of energy ratings of household appliances.
2. To be able to provide examples of renewable and non-renewable sources of energy.

WORKSHEET
Sources of energy

Energy in housing

In our homes, there are machines or appliances that we use in our daily lives. Some appliances use little energy, others use a lot, some are very efficient, and some are inefficient. The energy source for most appliances in the typical home is electricity, although gas, **solar energy** and the chemical energy from batteries are also widely used.

One of the big expenses in maintaining a home is the cost of energy. Electricity and gas are both expensive; however, solar energy is free after solar panels have been installed. Solar panels can transform the light energy from sunlight into other useable types of energy such as electricity or thermal energy.

Energy ratings

Most appliances in Australia have an energy rating label as part of the Australian Government's Equipment Energy Efficiency Program. The energy rating label may be one of the three forms depicted in Figure 5.19 – a rating out of 6 stars, a rating out of 10 stars for super-efficient appliances, or a 10-star pool pump rating.

The more stars an appliance has, the more energy efficient it is – that is, the more input energy that is transformed to useful output energy. The number of stars is determined by the energy consumption value in kilowatt hours (kWh) per year, which is also provided on the label. The lower the energy consumption value, the higher the energy rating.

solar energy a renewable source of energy that converts the light energy from sunlight directly into another useable type of energy

Figure 5.18 This house has solar panels on the roof to generate electricity. It also has two panels for generating hot water.

Figure 5.19 Three types of energy rating labels found on appliances in Australia

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Try this 5.4

Home electricity audit

Use the Australian Government's 'Energy rating calculator' website to audit the energy efficiency of appliances around your house, such as your TV, washing machine, dishwasher and fridge. Compare how much it costs to run each appliance for a year.

Which appliance costs the most to use? Compare one appliance and its yearly running costs with that of a classmate. Who has the more cost-saving model?

Quick check 5.6

1. Name one type of renewable energy that can be easily used in households.
2. Explain how you can easily compare the energy efficiency of two models of a washing machine.
3. Explain why it is beneficial to buy energy-efficient appliances, even though they can be more expensive than other models.

Sources of energy

renewable can be replenished within a human lifetime

non-renewable cannot be replenished in a human lifetime

fossil fuel a non-renewable energy source, such as oil, coal or natural gas, that has formed underground from plant and animal remains millions of years ago

Sources of energy used on Earth can be classified according to whether they can be replaced within a human lifetime or not. Sources that are replaceable are called **renewable** sources of energy, and include wind, solar, hydroelectric and geothermal. Sources of energy that cannot be replaced in a human lifetime are called **non-renewable** and a typical example is **fossil fuels**, which include coal, oil and natural gas.

Transferring the energy provided by renewable and non-renewable sources to useable forms of energy requires various methods of energy transformation. Methods of energy production that are non-polluting or have little effect on the environment are called **sustainable**. Methods that are not sustainable include mining substances or burning substances that release greenhouse gases into the atmosphere. These methods have a large impact on the local environment, as well as the potential to accelerate climate change globally.

sustainable causing little or no damage to the environment, and therefore able to continue for a long time

Figure 5.20 The production of greenhouse gases from burning fossil fuels is leading to habitat loss for many animals, including polar bears in the Arctic.

Figure 5.21 A wind-energy turbine (foreground) uses renewable energy, whereas a coal-fired power station (background) burns a non-renewable energy source.

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Science as a human endeavour 5.1

Queensland Electric Super Highway

The Queensland Government has made a Zero Emission Vehicle Strategy in which it aims for 50% of new passenger vehicles to be zero emission by 2030. As part of this plan, the Queensland Electric Super Highway has been constructed, providing frequent electric vehicle charging stations along the coast from Port Douglas in the north to Coolangatta in the south. A planned further phase of this development will extend the electric super highway to rural inland communities such as Mt Isa.

This development consolidates Queensland's progress towards the use of innovative energy transfer in the transition to an electric vehicle future.

Figure 5.22 A charging station for an electric vehicle on the Queensland Electric Super Highway

Non-renewable sources of energy

Coal

Fossil fuels are a non-renewable source of energy. Most deposits of coal formed 300 million years ago during the Carboniferous period. This was 100 million years before the dinosaurs, when Earth was warm, wet and covered with giant forests. Eventually the forests died and layers of sand, which later turned into rock, covered the dead trees. Deep underground and under high temperatures and pressure, the remains of the forest trees changed into coal.

Figure 5.23 Queensland is home to many coal mines.

Figure 5.24 The Gladstone Power Station in Queensland converts the chemical potential energy in coal to electrical energy.

Coal is mined and then transported to a power station where it is burned to generate thermal energy and then electrical energy. The burning of coal produces carbon dioxide gas, a greenhouse gas, which will take millions of years to produce new fossil fuels deep in Earth.

The energy flow diagram for a coal-fired power station is shown in Figure 5.25.

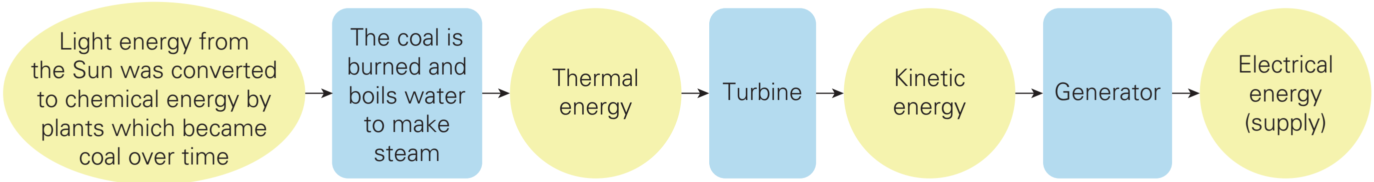

Figure 5.25 An energy flow diagram for a coal-fired power station

Nuclear energy

Nuclear energy is an option for countries that have the technology to build nuclear power stations. The fuel for a nuclear reactor comes from radioactive substances, mainly uranium, which can be mined from Earth's crust. The mass of fuel required is a tiny fraction of that required to run a coal-burning power station. Although the materials used in nuclear power generation are not renewable, it is unlikely that the world will ever run out of nuclear fuel as the energy released from a nuclear reaction with a very small amount of fuel is immense.

The energy flow diagram for a nuclear power station is shown in Figure 5.26.

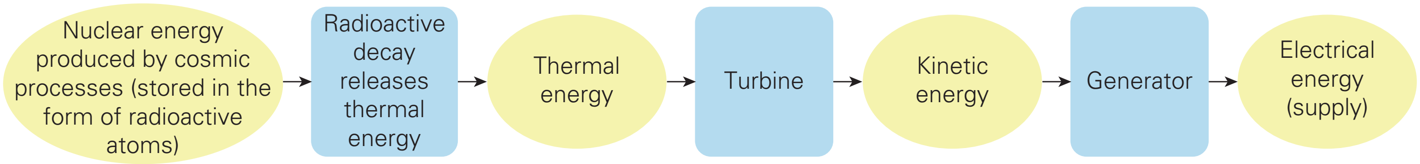

Figure 5.26 An energy flow diagram for a nuclear power station

Figure 5.27 The Maanshan Nuclear Power Plant in Taiwan converts nuclear potential energy into electrical energy and is one of the closest nuclear power stations to Queensland.

A nuclear power station does not produce polluting greenhouse gases in its reactor. The energy released heats water, which produces steam to turn turbines and generate electricity. However, some steam (water vapour) is released from the top of nuclear stacks (towers), and water vapour itself is a greenhouse gas!

Although nuclear energy has the potential to supply the world's energy needs when fossil fuels start to run out, there are some problems with nuclear energy that need to be considered. You might remember the problems associated with nuclear energy from your investigations in Year 7.

Did you know? 5.3

The radioactive nucleus

enrichment
the process of increasing the purity of a particular isotope in a substance

Knowledge of the structure of the atom and the energy contained within the nucleus of the atom has changed over thousands of years. Today, scientists not only know about the energy holding together subatomic particles in the nuclei of atoms of different elements, but they also know how to make a nucleus more unstable so that it releases some of that energy by breaking nuclei into smaller fragments. The process of purifying a radioactive substance is called **enrichment**, and a common enriched nuclear fuel is the nuclear isotope, uranium-235.

The Australian Nuclear Science and Technology Organisation (ANSTO) is Australia's only nuclear facility, and it operates to produce nuclear medicines and enable scientific research, rather than to produce electricity from nuclear energy. It uses low enriched uranium, which has just under 20% enriched uranium-235, to achieve its goals.

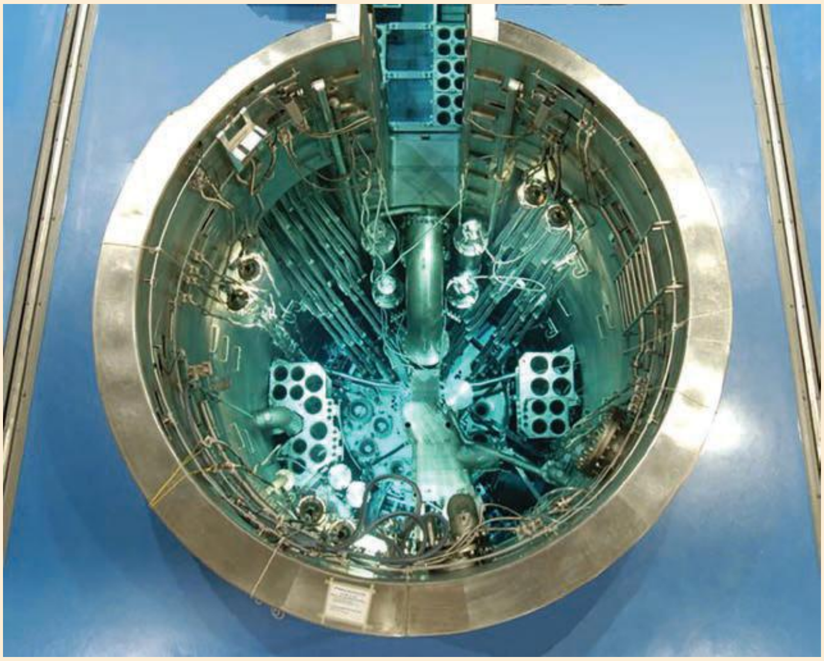

Figure 5.28 Inside the Open Pool Australian Lightwater (OPAL) nuclear reactor at ANSTO

Quick check 5.7

1 Define 'non-renewable'.
2 Recall the types of non-renewable energy sources used in Australia.
3 Define 'sustainable'.

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VIDEO
Australian
renewables

Renewable energy sources

Wind energy

Wind energy is a renewable energy source. Electrical energy is generated by large wind turbines, usually built in groups called wind farms. The advantage of wind energy is that, once the wind turbine has been built, wind energy is free, non-polluting and available at night. The main disadvantage is that it depends on the availability of the wind. For this reason, the energy that wind turbines produce is intermittent and must be combined with a storage capability, such as a battery, to provide a continuous energy supply.

The energy flow diagram for a wind turbine is shown in Figure 5.30.

Figure 5.29 Wind turbines at the Windy Hill Wind Farm near Ravenshoe, Queensland

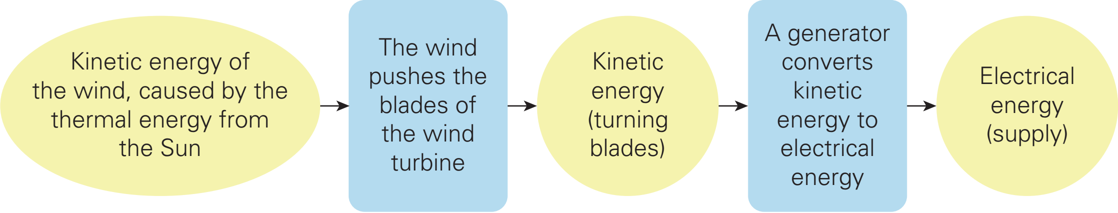

Figure 5.30 An energy flow diagram for a wind turbine

Solar energy

Solar energy is a renewable energy source. Solar panels convert the light energy from sunlight directly into electrical energy and can also supply energy to heat water. The advantages of solar panels are that the energy they produce is free once the initial cost is met, and they are non-polluting to use. When solar panels are combined with storage batteries, they can provide a constant supply of energy, as the batteries store energy during the day and release it at night.

The energy flow diagram for a solar panel is shown in Figure 5.32.

Figure 5.31 Solar panels convert light energy from sunlight into electrical energy.

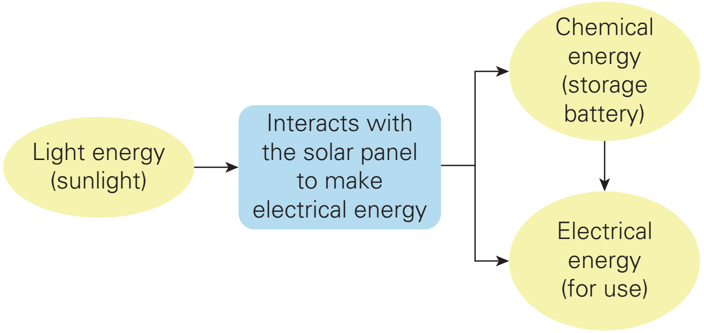

Figure 5.32 An energy flow diagram for a photovoltaic solar panel with a storage battery

WIDGET
Energy conversion flow diagrams

Hydroelectric power

Hydroelectric power is generated by using the gravitational potential energy of water held in dams to drive turbines that generate electricity (see Figure 5.33). The dams are designed so that the water surface is as high above the turbines and generators as possible. The water's gravitational potential energy is converted to kinetic energy by turbines at the base of the dam. These turbines turn generators that convert this kinetic energy into electrical energy.

Some countries, such as Norway, China and Brazil, are mountainous and are well suited to hydroelectric energy generation. For example, Norway generates about 95% of its energy in this way. In Queensland, hydroelectric energy accounts for only 1.2% of total energy production. Tasmania has extensive hydroelectric power generation and Snowy Hydro 2.0 in New South Wales is a large hydroelectric project designed to help provide renewable energy into the future.

hydroelectric power
a renewable source of energy that harnesses the gravitational potential energy of water to generate electrical energy

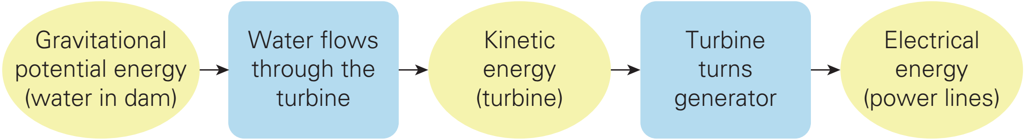

Figure 5.33 An energy flow diagram for hydroelectricity generation

Figure 5.34 The Burdekin Falls Dam in north Queensland holds water higher than a lower surface below. The water is carried by gravity through the pipes, from the dam down to turbines and generators in the power station (bottom right), converting gravitational potential energy into electrical energy.

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Explore! 5.4

Efficiency of electricity generation

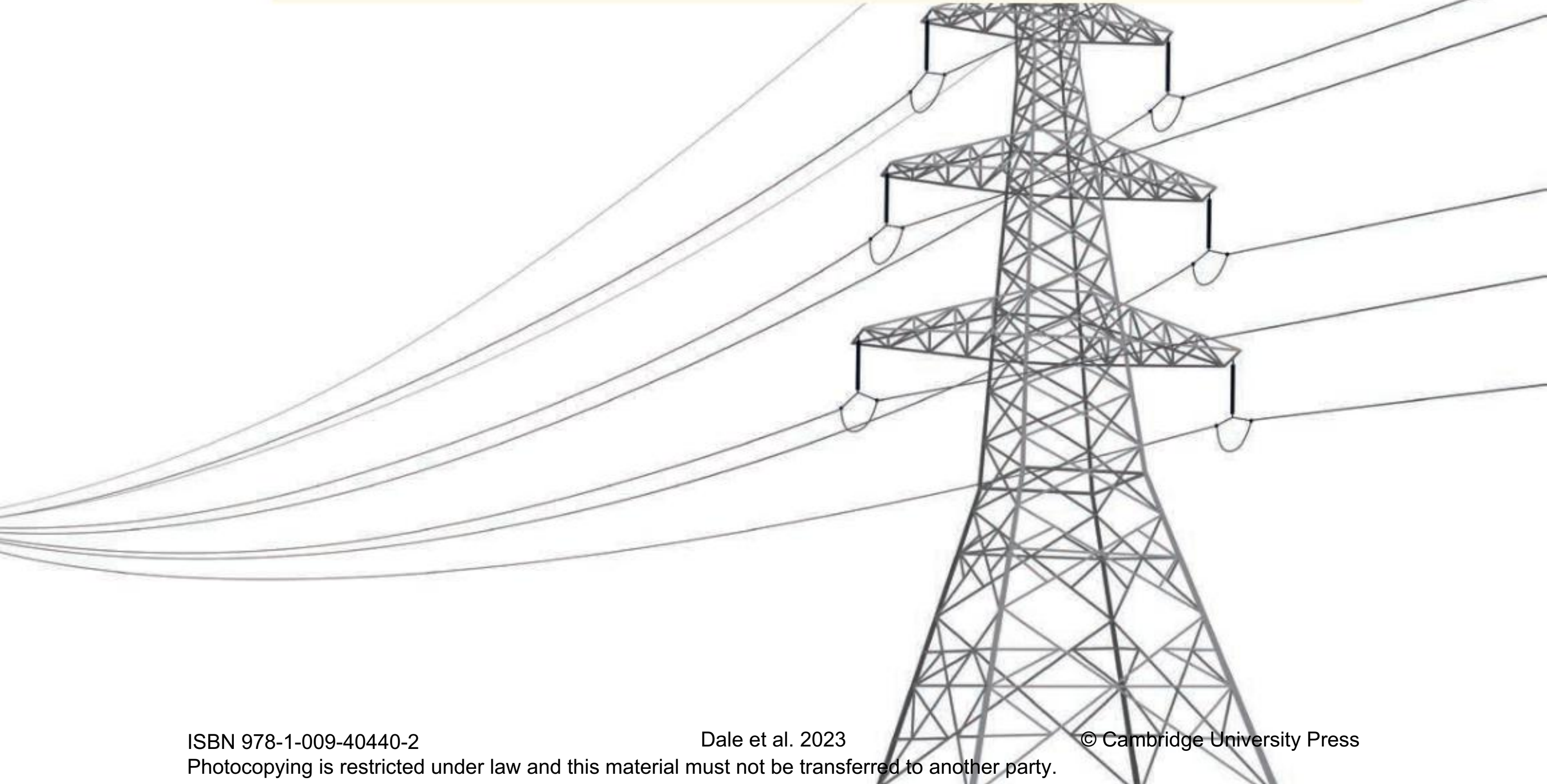
Renewable and non-renewable sources of energy provide the capacity to transform various energy types into useable energy, but the different sources have different energy efficiencies.

Conduct some research to find the average energy efficiency of the following electricity sources.

- Coal
- Nuclear
- Hydroelectricity
- Gas
- Solar
- Wind

Which are the most efficient and least efficient processes? Is this what you expected?

Figure 5.35 This house concept has battery packs to store energy captured by renewable technologies.



Geothermal energy

Geothermal energy is both sustainable and renewable. It is thermal energy left over from Earth's formation, as well as being produced by radioactive decay. Where Earth's crust may be fractured or thin, it is possible to drill down to find rocks hot enough to boil water. Cold water is pumped down to this hot rock. The water boils, producing steam, which is brought to the surface and used to turn a turbine and generate electrical energy.

geothermal energy thermal energy that originates from inside Earth

A flow diagram for a geothermal energy power station is shown in Figure 5.37.

Figure 5.36 The Matsukawa Power Station in Japan uses geothermal energy to produce electricity.

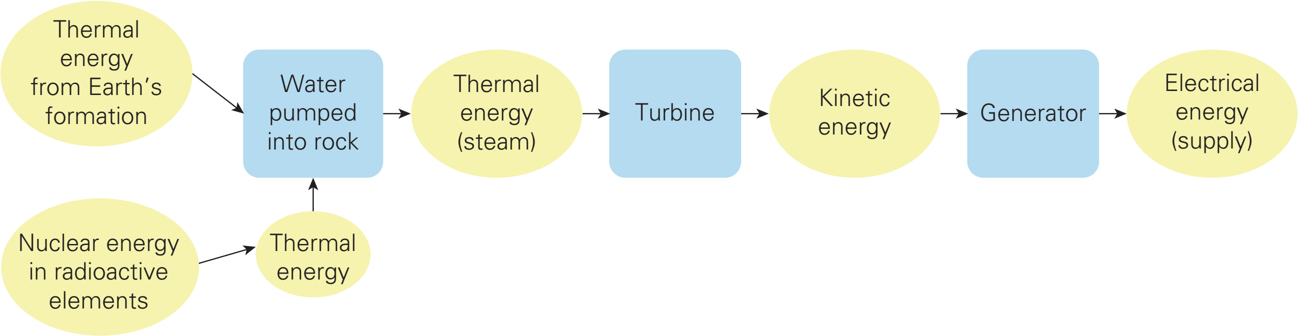


Figure 5.37 An energy flow diagram for a geothermal power station

Quick check 5.8

1. Define 'renewable energy source'.
2. Recall some different types of renewable energy.
3. Draw a flow diagram to show the energy transformations that occur while producing electricity from wind turbines.

Science as a human endeavour 5.2

Queensland's renewable energy target

At the start of 2023, Queensland's renewable energy consumption contributed to almost 23% of energy usage. The Queensland Government have set the Queensland renewable energy target at 50% renewable energy by the year 2030. This is an ambitious target, but one in which many factors have been considered for the benefit of Queensland's population. The advancements in renewable technologies, the potential cost savings and energy security are all important considerations for Queensland's energy future. Furthermore, the advancements in battery and energy storage technology have made the use of solar, wind and hydroelectric technologies even more feasible. While the target has been set for the state, individuals, businesses and communities will also benefit, which means that attaining the goal is even more important to the whole population!

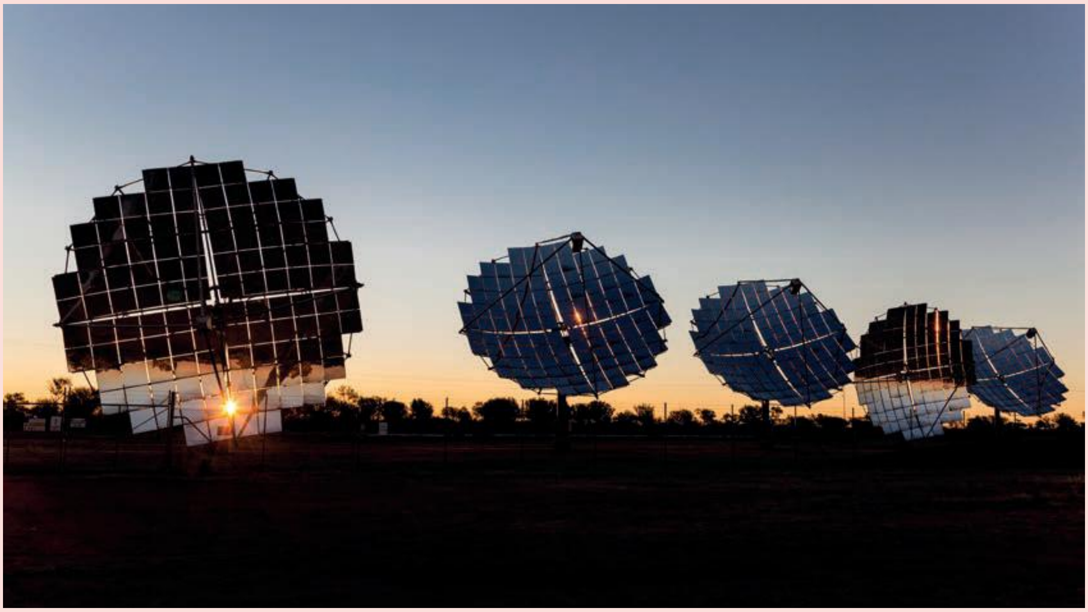


Figure 5.38 The Windorah Solar Farm is contributing to the Queensland renewable energy target.

Section 5.3 questions

QUIZ

Retrieval

1 **State** the fossil fuels used to provide energy in Australia.

2 **Recall** approximately how many years ago coal deposits were formed.

3 **State** a source of energy that harnesses the gravitational potential energy of water.

4 A cyclist used 1000 kJ of energy riding to work. Of this, 250 kJ was transformed into kinetic energy to move his muscles. The other 750 kJ was transformed into thermal energy. **Calculate** the energy efficiency of the cyclist.

Comprehension

5 **Describe** the main reason behind switching to renewable energy sources.

6 **Explain** how energy is produced using thermal energy from Earth.

7 **Draw** an energy flow diagram for a hydroelectric power station.

8 **Explain** the difference between 'renewable' and 'sustainable'.

9 **Explain** why nuclear energy is not considered renewable.
10 **Explain** how non-renewable energy sources such as natural gas are not sustainable for the future. Discuss their impact on the environment.
11 **Explain** why each renewable source of energy is considered ‘renewable’.
12 **Draw** an energy flow diagram for a petrol engine car travelling at a constant speed on a flat road.
13 **Summarise** ways in which you can make your house more energy efficient. For each suggestion, explain how it works.

Analysis

14 The following information applies to two different models of fridge. Note that the cost of electricity in Queensland is about $0.24 per kilowatt hour (kWh).

	Energy star rating	Energy consumption per year (kWh)	Price ($)
Model 1	4	185	550
Model 2	3	240	499

Compare the fridges and decide which one you would buy. Give reasons for your choice.

15 **Consider** what the tradesperson is doing in Figure 5.39. Explain why the homeowners have hired him to do this job.

Figure 5.39 What is this tradesperson doing?

Knowledge utilisation

16 **Propose** one drawback of using solar energy as an energy source.
17 **Propose** two reasons why coal may not be suitable as a long-term energy source.
18 **Discuss** why inner-city trains and trams are powered by electrical energy.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
5.1	I can distinguish between temperature and thermal energy.	1	
5.1	I can compare the transfer of energy by conduction, convection and radiation.	9, 10c	
5.2	I can describe energy transfers and transformations.	4	
5.2	I can calculate the energy efficiency of a system.	5, 10a	
5.2	I can illustrate the efficiency of a system using a Sankey diagram.	10b	
5.3	I can describe the significance of energy rating labels on household appliances.	3	
5.3	I can describe examples of renewable and non-renewable sources of energy.	2, 7, 8	

SCORCHER

Review questions

Retrieval

1 **State** the difference between temperature and thermal energy.
2 **List** four types of renewable sources of energy.
3 **Describe** how energy rating labels on appliances provide useful information to consumers.
4 **Define** ‘energy transfer’ and ‘energy transformation’.

Comprehension

5 A light bulb has an input of 1400 J and an output of 1250 J of light energy and the remainder is lost as thermal energy. **Calculate** the energy efficiency of the light bulb.
6 **Explain** what types of waste energy might be present in a First Nations Australian ground oven.

Analysis

7 **Compare** the energy efficiency of coal and wind as sources of energy.
8 **Compare** coal and solar as renewable or non-renewable sources of energy.
9 **Contrast** convection and radiation in terms of thermal energy transfer.

Knowledge utilisation

10 A ceiling fan has an input of 2400 J of electrical energy. Of this, 300 J of energy output is lost as thermal energy due to friction between metallic parts and 40 J is lost as sound energy.
  a **Calculate** the energy efficiency of the fan.
  b **Sketch** a Sankey diagram for the ceiling fan.
  c **Describe** how thermal energy is transferred between the metallic parts.

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Data questions

Solar panels are used across Australia to convert the energy provided by sunlight into electricity. The electricity produced by a typical commercial solar panel in Queensland throughout a sunny day is shown in Figure 5.40. The efficiency and price of six different solar panel models is also shown in Table 5.2.

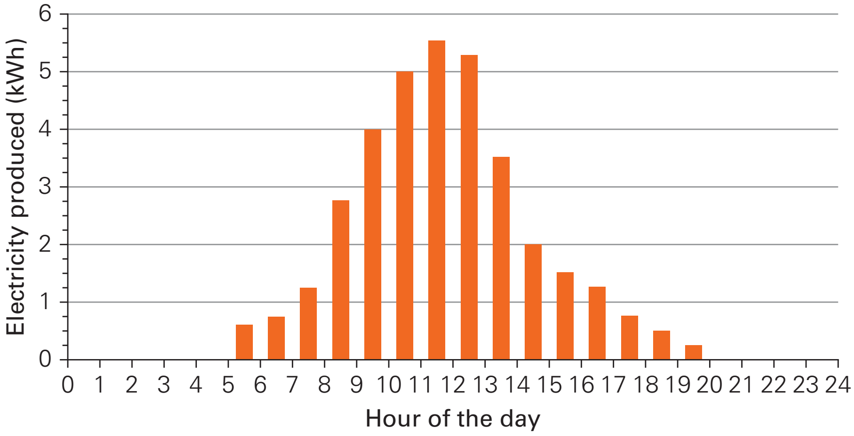


Figure 5.40 The electricity produced, in kilowatt hours, by a typical commercial solar panel throughout a sunny day

Solar panel model	Efficiency (%)	Estimated price ($/m²)
A	46	>2 000 000
B	44	>1 000 000
C	37	>100 000
D	22	120
E	17	80
F	15	70

Table 5.2 Efficiency and cost of different solar panel models

Apply

1 **Identify** the time of the day the solar panel presented in Figure 5.40 produces the most electricity.

2 **Calculate** how many hours per day the solar panel can produce electricity.

Analyse

3 **Identify** the pattern of electricity production throughout a sunny day.

4 Refer to Table 5.2 and **identify** the trend between the efficiency of a solar panel and the price per square metre.

Interpret

5 **Infer** whether the cost of a solar panel is directly proportional to the efficiency.

6 **Deduce** why electricity is not produced between midnight and 4 a.m. and again between 8 p.m. and midnight.

7 **Predict** the effect on the data in Figure 5.40 if the weather was an overcast and rainy day.

8 A domestic household owner in Queensland would like to install solar panels on the roof of their home. The owner would like a solar panel with an efficiency above 20% to cover 3 m^2. **Deduce** the type of solar panel and the lowest price that the homeowner could pay for these requirements.

9 Based on the general shape of the data presented in Figure 5.40, **justify** why the angle at which the solar panel is oriented on a roof is important for a higher electricity production.

STEM activity: Can you see the renewables?

Background information

Have you ever thought about the amount of carbon emissions produced when you perform an internet search on your smartphone or tablet? Experts have estimated that a simple search consumes enough energy to release 0.2 grams (g) of carbon dioxide into the atmosphere. The number might seem small but imagine the emission from more than 15 billion connected devices today!

Governments worldwide invest in renewable and sustainable energy sources because fossil fuel sources are finite. As the world's population grows, greenhouse gases are being released into the atmosphere at an alarming rate. Now, more than ever, it is important that we all do our best to change our current practices into more sustainable ones.

There are many ways to demonstrate this message to the world; one of the most powerful involves storytelling. Good stories have the power to bring us together and encourage us to understand and empathise with many causes. Recently, digital storytelling has been used by many professionals (including famous social media influencers) to tell (or sell) their ideas, opinions or products.

Design brief: Design and create a 60-second infomercial to be shared in your local area that promotes the use of renewable energy.

Activity instructions

In teams (maximum of four people), use the digital storytelling process (described on the following page) to create a 60-second video to answer a specific scenario. It is recommended that you and your colleagues think about assigning roles and tasks for this project (e.g. videographer, researcher, movie editor) so everyone has the chance to develop and use different skills.

Scenario

Your local council has just informed its residents that they wish to invest in securing the energy needs for its residents for the next 20 years. One local company, Coal Co., has lobbied heavily for funds to expand an old open-cut coal mine in the region. Another company, a new start-up business, Argus Renewables, has hired your team to create a 60-second video to gain support from residents for the development of a large solar farm in the region.

Figure 5.41 Even tablets and smartphones contribute to carbon dioxide levels in the atmosphere.

Suggested materials

- mobile device, camera to record footage
- laptop or tablet with a video editor
- paper to create a storyboard
- your imagination!

Research and feasibility

1. Discuss within your group who your target audience is going to be. Include discussion about your local area.
2. Conduct some research on advantages and disadvantages of renewable energy compared with non-renewable energy that should be communicated to your audience through the infomercial and make a table to rank them in order of importance for your project. You can use the table below as a guide.
3. Conduct some research on the population of your local area. Discuss and then list important information about your target audience. Considering this information about your target audience, add comments to your advantages and disadvantages research.

Design and sustainability

4. As a group, decide the key issues you are going to present in your infomercial. Then write the script for the video, assign roles to individual members and reflect on what is required to achieve the goal.
5. Design a storyboard to put the script together with a visual representation.

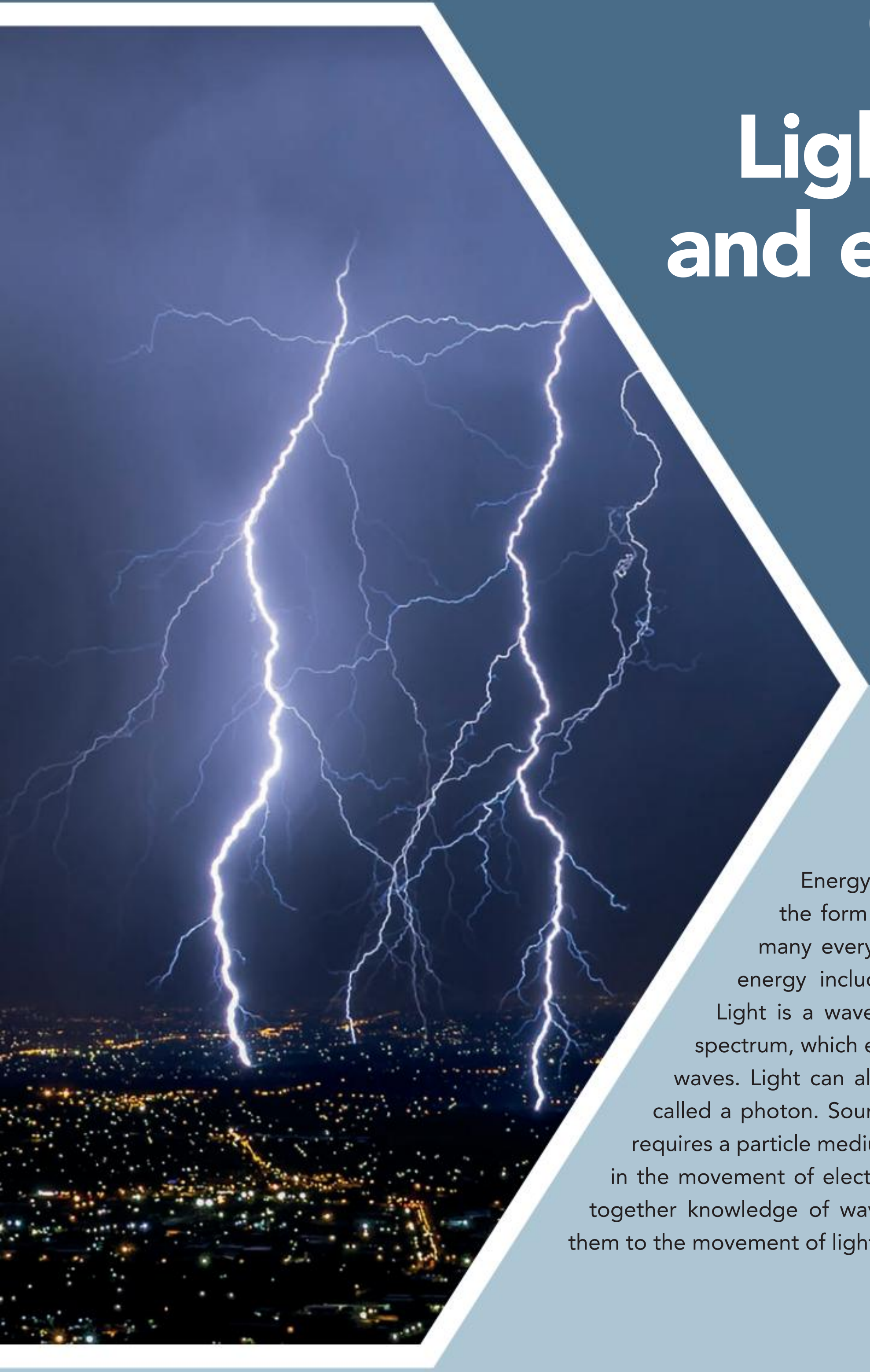
Create

6. Create the video by recording the storyboard sections. As a group, gather short clips and images, and/or record your own video using a mobile device.
7. Put it all together using video-editing tools such as iMovie, Movie Maker or Adobe Spark (recommended) to put your ideas into video format.

Evaluate and modify

8. In your group, discuss the challenges you encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.
9. Evaluate the effectiveness of your infomercial by sharing it with your target audience.
10. Create a range of evaluative questions to use to gauge the success of your infomercial. Show your infomercial to a target audience and use the questions to test its effectiveness.

	Rank of importance	**Comments when considering target audience**
Advantages of renewable energy compared with non-renewable energy		
Disadvantages of renewable energy compared with non-renewable energy		



Chapter 6

Light, sound and electricity

Chapter introduction

Energy can be transferred in useful ways in the form of light, sound 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 as 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 and electrical energy.

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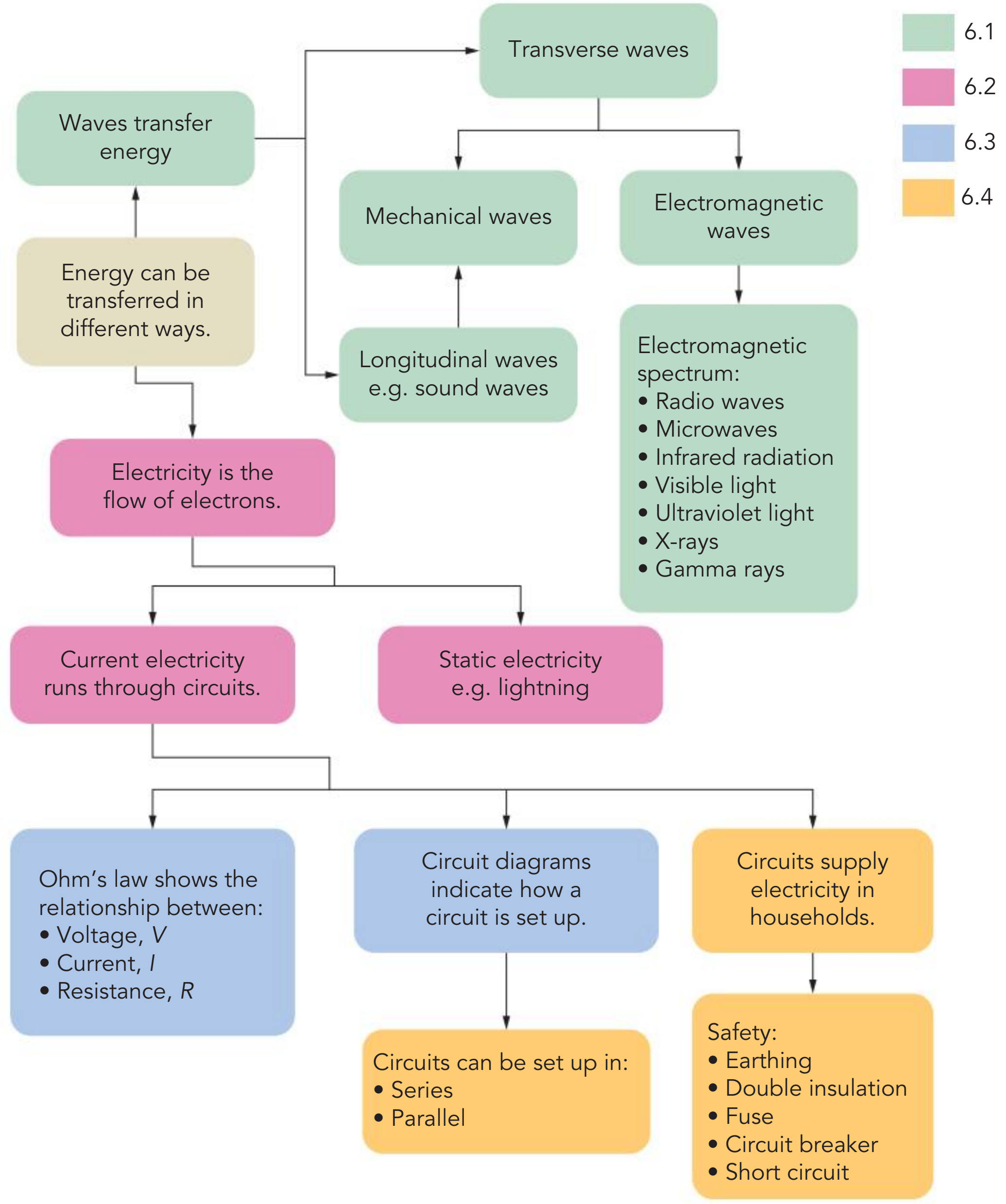
Concept map


Transverse waves
Waves transfer energy
Mechanical waves
Electromagnetic waves
Energy can be transferred in different ways.
Longitudinal waves e.g. sound waves
Electromagnetic spectrum:
• Radio waves
• Microwaves
• Infrared radiation
• Visible light
• Ultraviolet light
• X-rays
• Gamma rays
Electricity is the flow of electrons.
Current electricity runs through circuits.
Static electricity e.g. lightning
Ohm's law shows the relationship between:
• Voltage, V
• Current, I
• Resistance, R
Circuit diagrams indicate how a circuit is set up.
Circuits supply electricity in households.
Circuits can be set up in:
• Series
• Parallel
Safety:
• Earthing
• Double insulation
• Fuse
• Circuit breaker
• Short circuit
6.1
6.2
6.3
6.4

Curriculum

Use wave and particle models to describe energy transfer through different mediums and examine the usefulness of each model for explaining phenomena (AC9S9U04)	
modelling the transfer of sound energy as waves using slinky springs and relating to the medium through which the sound is transferred	6.1
examining how the particle model of electricity explains static electricity and electrical current and relating this to voltage, conductors and insulators	6.2, 6.3, 6.4
discussing the wave and particle models of energy transfer, including the concept of photons, and how they are useful for understanding aspects of light and other forms of electromagnetic radiation	6.1
investigating the impact of material selection on the transfer of sound energy in First Nations Australians' traditional musical, hunting and communication instruments	6.1
examining the forms of electromagnetic radiation that are used in different modern communication technologies and identifying any limitations	6.1

Glossary terms

Alternating current
Ammeter
Ampere
Amplitude
Battery
Cell
Circuit
Circuit breaker
Cochlea
Component
Compression
Conductor (electricity)
Coulomb
Crest
Current
Cycle
Direct current
Displacement
Double insulated
Dry cell
Earthed
Electricity
Electrocution
Electromagnetic radiation
Electromagnetic wave
Electrostatic charge
Frequency
Fuse
Gamma ray
Hertz
Infrared radiation
Insulator (electricity)
Ionising radiation
Load
Longitudinal wave
Mains electricity
Mechanical wave
Medium
Microwave
Ohm
Ohm's law
Oscillating
Parallel circuit
Periodic motion
Photon
Pitch
Potential difference
Radio wave
Rarefaction
Resistance
Seismic wave
Self-propagating
Series circuit
Short circuit
Static discharge
Static electricity
Transverse wave
Trough
Ultraviolet light
Vacuum
Visible light
Voltage
Voltage drop
Voltmeter
Wave
Wavelength
X-ray

6.1 Light and sound waves

Learning goals

1. To be able to distinguish mechanical and electromagnetic waves.
2. To be able to label the amplitude and wavelength of a transverse and longitudinal wave.
3. To list the different types of electromagnetic radiation.
4. To be able to 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 6.1 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. They create a disturbance in the medium that transfers the energy without the matter moving as a whole.

Another kind of wave, called **electromagnetic waves**, 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 a wave (a force that starts the disturbance in the medium). The medium can be in any state – solid, liquid or gas – as long as there are particles present. In mechanical waves, a disturbance in a medium results in the transfer of energy by the vibration or **periodic motion** of particles. Therefore, mechanical waves require particles in order for the energy to travel through matter. 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 (Figure 6.2).

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

Figure 6.2 As a ripple passes through the medium (water), the fishing float is temporarily displaced as it bobs up and down, before returning to its original position.

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DOC
WORKSHEET
Wavelength, frequency and amplitude

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.

Quick check 6.1

1. Define 'mechanical wave'.
2. What is the medium of a mechanical wave?
3. List three types of mechanical 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 position of a particle when it has moved away from its rest position on the centre line of the wave
cycle	one complete vibration or periodic movement of a particle through the crest and trough 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 centre line of the wave

Transverse waves

A **transverse wave** is a wave in which the disturbance of the medium is at right angles to the direction of energy transfer (Figure 6.3).

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.

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 the waves is called the **wavelength**. The **amplitude** of a wave is how far the wave displaces from its middle position (centre line) (Figure 6.4).

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.

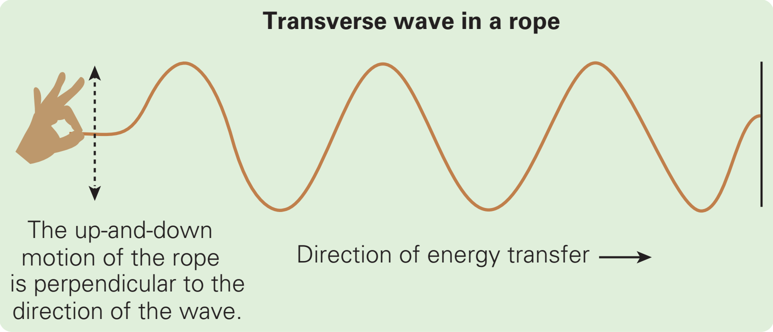

Figure 6.3 In a transverse wave the particles move perpendicular (at right angles) to the direction of the energy transfer.

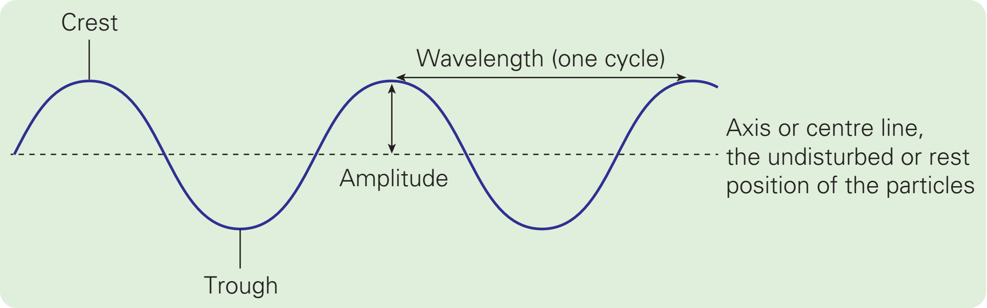

Figure 6.4 Describing a transverse wave

Try this 6.1

Looking at wavelength and amplitude

Copy the diagram in Figure 6.5, using a ruler to make the sides of the grid squares exactly 1 cm long. On your copy, label the wavelength and amplitude of the waves. Use a ruler to measure these features.

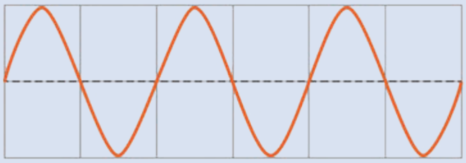

Figure 6.5 A depiction of a transverse wave

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Quick check 6.2

1 Explain what the word '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 6.6 When the strings of a guitar are plucked, they vibrate up and down while waves travel along the string to its ends.

Electromagnetic waves

Electromagnetic waves are another example of transverse waves. They consist of **oscillating** electric and magnetic fields, rather than disturbances in matter as a medium. **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 that carries a specific amount of energy related to its frequency or wavelength is called a **photon** of light.

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.

seismic wave
a wave that travels through Earth and over its surface and is caused by earthquakes

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

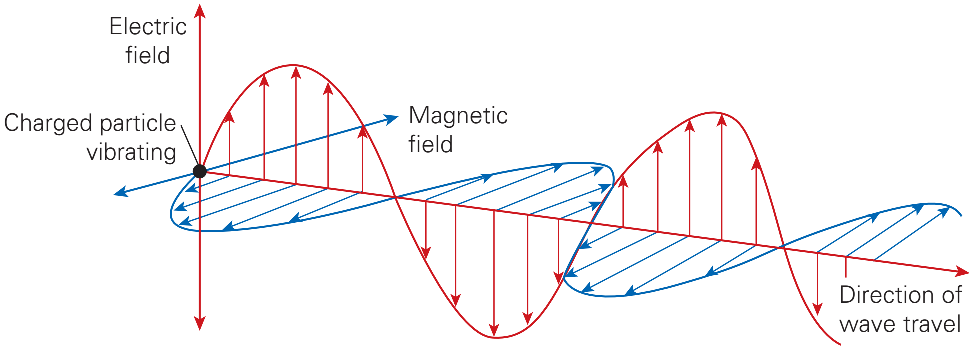

Figure 6.7 A vibrating charged particle generates vibrating electric and magnetic fields. These fields are perpendicular to each other and to the direction of the wave.

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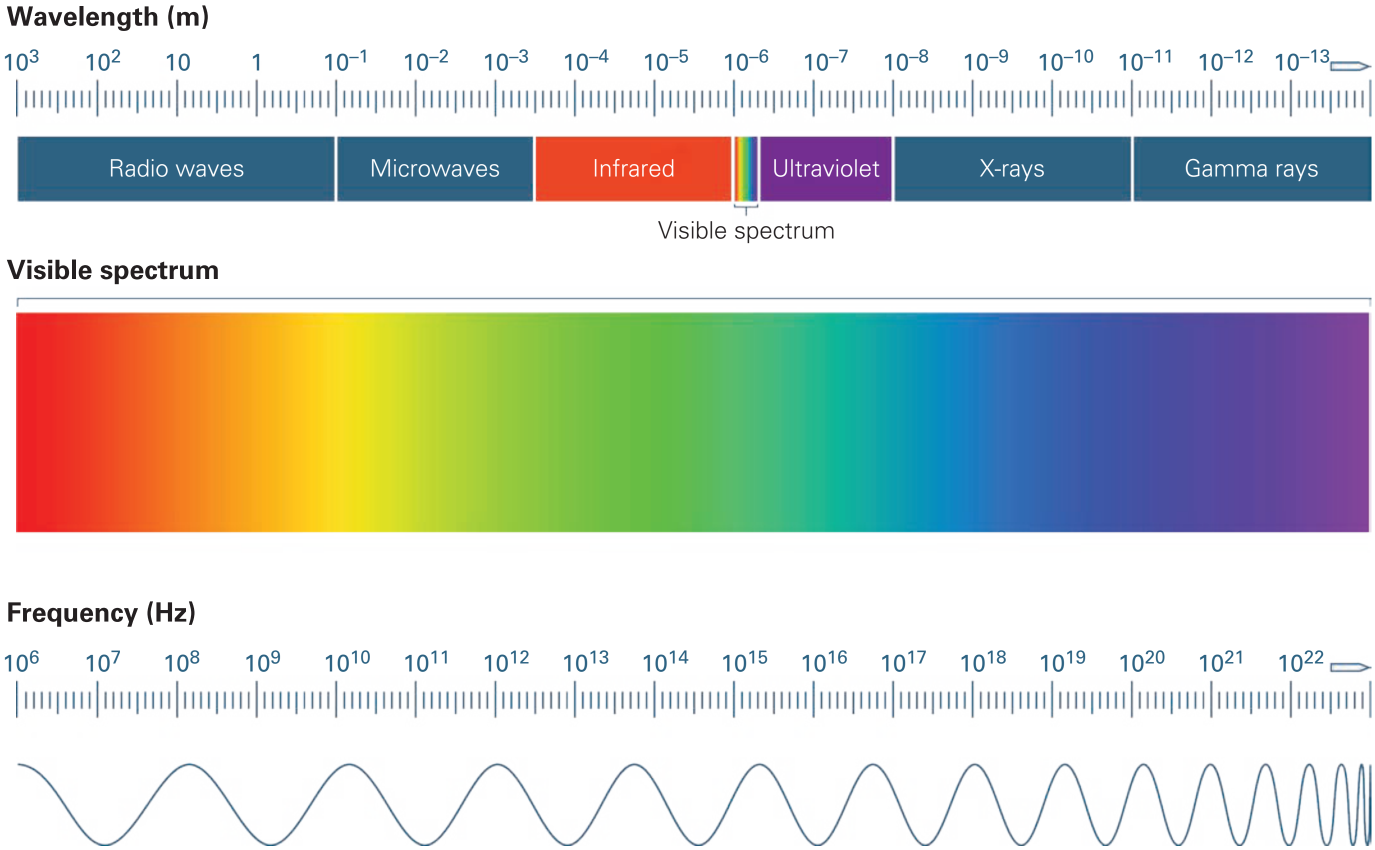

Figure 6.8 The electromagnetic spectrum extends beyond the visible spectrum (visible light).

Unlike mechanical waves, electromagnetic waves all travel at the same speed through a vacuum – the speed of light, $c = 3 \times 10^8$ 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:

$$\lambda\ (\text{m}) = \frac{c\ (\text{m/s})}{f\ (\text{Hz})}$$

radio wave
a type of electromagnetic radiation that has the longest wavelength

microwave
a type of electromagnetic radiation used for cooking, communications and Wi-Fi; lies between radio waves and infrared radiation

The different types of electromagnetic waves, from lowest to highest energy, and their uses are listed below and illustrated in Figure 6.8.

- **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.

Figure 6.9 Communication towers send and receive microwaves to mobile phones (left). TV remote controls use infrared radiation to transmit signals to a TV (right). The remote must be pointed at the TV to work, because obstructions will block the infrared radiation from reaching the TV.

- **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 home 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 that are used to create images of bones. Bone absorbs most of the radiation whereas X-rays pass through soft tissue such as fat and muscle. 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, and although they can cause cancer, they can also be used in its treatment.

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.

infrared radiation
a 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
a type of electromagnetic radiation that lies between visible light and X-rays; 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 that has short wavelengths and that can pass through flesh to give images of bones; hazardous and can cause cancer

gamma ray
a type of electromagnetic radiation that has high energy and a very short wavelength; produced when radioactive atoms decay

ionising radiation
higher-frequency ultraviolet rays, X-rays and gamma rays, which can turn atoms and molecules into ions, which can potentially damage living cells

Explore! 6.1

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 6.10 X-rays are used as a diagnostic tool in medicine.

Making thinking visible 6.1

See, think, wonder: The night sky

See: Observe the night sky as seen from a town in Queensland in Figure 6.11.

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 inform scientists about the age of the universe? What questions do you have after thinking about the lights in the night sky?

Figure 6.11 The night sky in Bollon, Queensland

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

Explore! 6.2

Wi-Fi

Did you know that an Australian invented Wi-Fi? This physicist and engineer was actually studying radio waves being 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 6.1

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, the optic nerves are not working 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 optical 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 6.12 Eyes detect light and send nerve impulses to the brain (left). The Monash Vision Group’s bionic eye (right).

Did you know? 6.1

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 Queensland, 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. For example, this could affect warnings for early evacuation of areas in the path of a storm.

Figure 6.13 Meteorologists have raised concerns that the 5G network could interfere with the frequencies used by weather satellites to collect data used to predict and monitor dangerous storms, such as those that occur in Queensland.

Transverse wave summary

Table 6.1 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 6.1 The two types of transverse waves

Quick check 6.3

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 (that is, vibrate) parallel to (in the same direction as) the energy transfer. The particles vibrate back and forth. As can be seen in Figure 6.14, longitudinal waves have areas where the particles (coils of a spring in this case) are close together and areas where they are spread apart. Places where the particles in a medium are closer together are called **compressions**, and 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 farther from each other.

longitudinal wave a wave with vibrations 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 apart

VIDEO
Light and sound waves

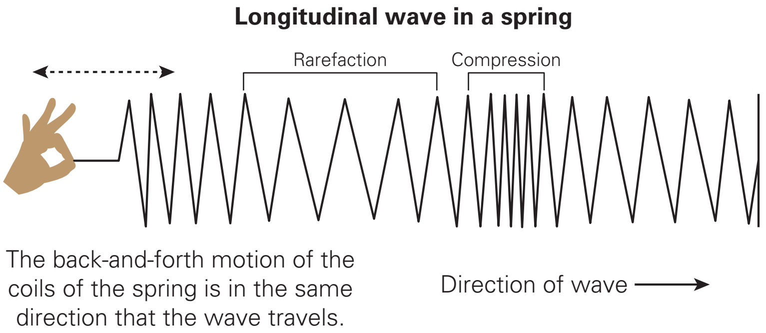

Figure 6.14 In a longitudinal wave, the particles move parallel to the direction of the wave.

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 (Figure 6.15). When a sound wave passes through air, the movement of the molecules 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 in air. It cannot travel at all through a vacuum (where there are no particles).

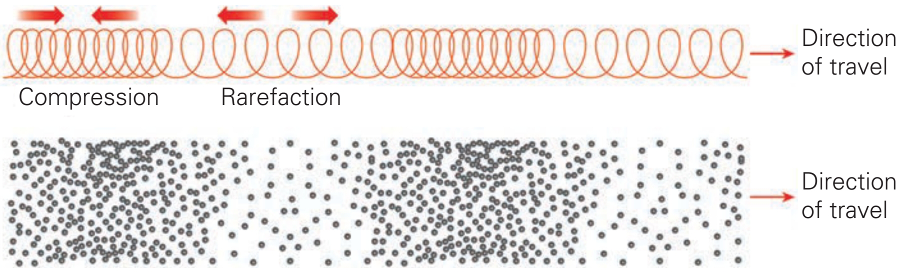

Figure 6.15 Longitudinal waves in a slinky can model longitudinal sound waves.

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Try this 6.2

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 back and forth along the length of the slinky.

Explore! 6.3

Sound waves and the didjeridu

First Nations Australians 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 example of a musical instrument is the didjeridu.

Conduct some research on the didjeridu to answer the following questions.

1 Where is the didjeridu believed to have got its name from?
2 How old is the didjeridu thought to be?
3 Describe the materials used for the construction of a didjeridu.
4 How does the length and flare end of a didjeridu affect the sound it makes?
5 Outline how a didjeridu produces its unique sound, including all components that play a role.

Figure 6.16 The didjeridu is made of bamboo or tree trunks that have been hollowed out by termites or other insects.

Quick check 6.4

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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Practical skills 6.1

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 turning 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.

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?

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 recap 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 air 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.

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

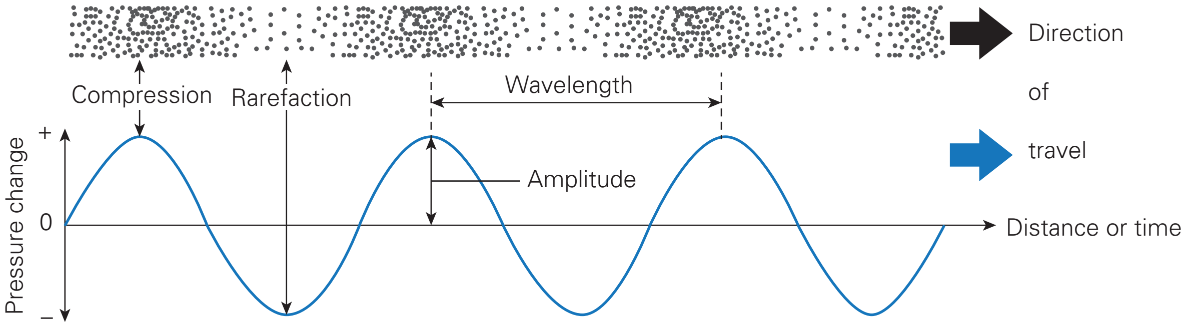

Figure 6.17 A sound wave represented as a graph of change in air pressure over distance or time. The air pressure change with no sound is 0, and + and – represent an increase or a decrease in pressure. The diagram above the graph shows the space between the air molecules and the regions of compression 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, or whether time or distance is the horizontal axis.

Figure 6.18 A whistle produces a high-pitched sound.

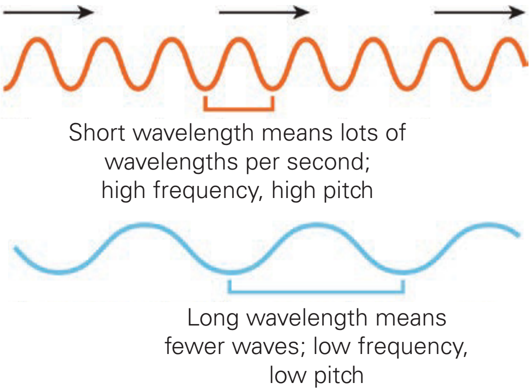

Figure 6.19 Which of the two waves do you think would be a whistle and which would be a bass guitar?

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. Meanwhile, anything at around 85 dB can start to damage your hearing. Sounds louder than 120 dB can quickly cause irreversible damage.

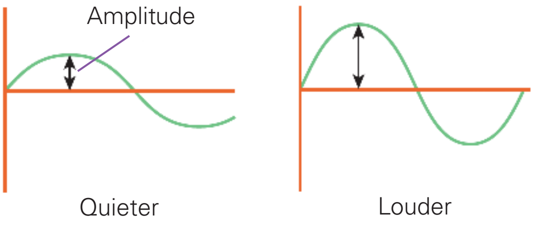

Figure 6.20 The amplitude of a sound wave indicates the loudness of the sound.

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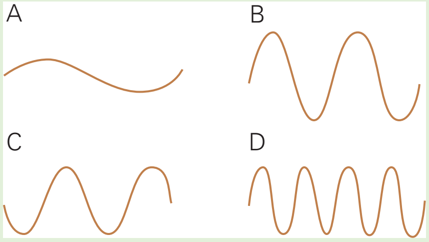
Quick check 6.5

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.



Identify which wave:
  - a has the highest frequency
  - b has the longest wavelength
  - c do you expect to have the highest pitch
  - d is the loudest.

Explore! 6.4

WIDGET Lightning speeds

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 6.21 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 m or 1 km.

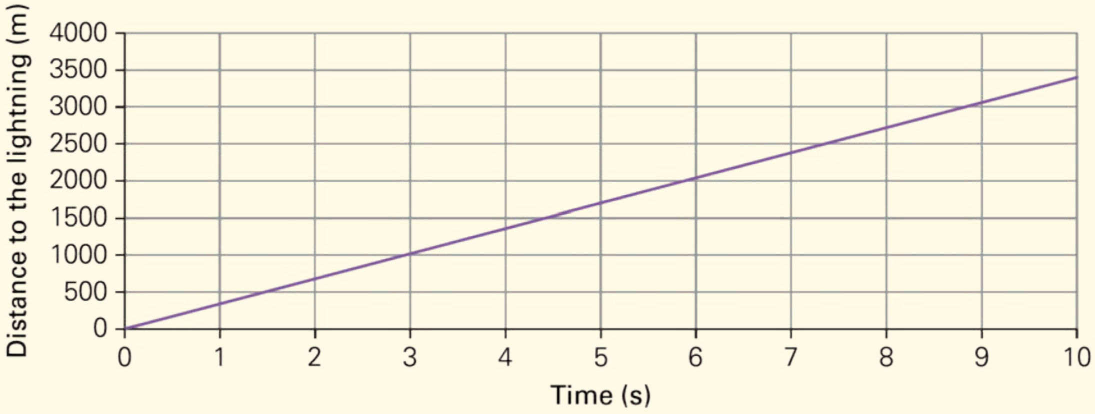


Figure 6.21 A graph of the time between seeing lightning and hearing thunder versus distance to the lightning

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Explore! 6.5

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 6.22 New earphone technologies actively cancel background noise.

Science as a human endeavour 6.2

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

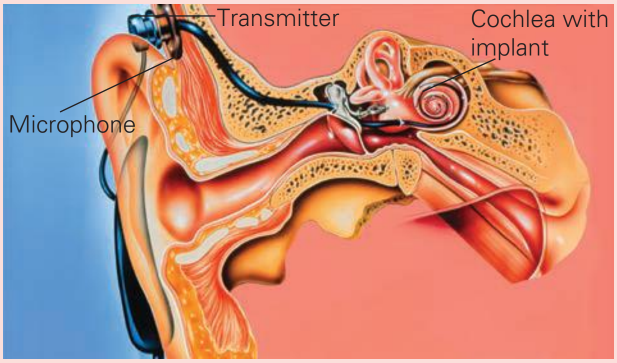

Figure 6.23 A cochlear implant. A microphone outside the ear can be seen. The transmitter behind the ear sends electrical signals through to the implant in the cochlea.

Figure 6.24 A toddler wearing the cochlear implant

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Did you know? 6.2

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 6.25 People who work with aircraft can be exposed to sounds above 140 dB, so they wear ear defenders.

Try this 6.3

Sound insulation

Some students at a Queensland 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 published data.

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Surface waves

Surface waves travel along the interface between two different surfaces. For example, water waves travel along the interface between water and air. Surface waves are neither transverse nor longitudinal. In a surface wave, the individual particles move in a circle before returning to their original positions.

Making thinking visible 6.2

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.

Comparing the wave and particle models

In Chapter 5 (section 5.1), you learned how energy can be transferred according to the particle model through conduction and convection. In this chapter, you have seen how energy can also be transferred in transverse or longitudinal waves. Table 6.2 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 6.2 A comparison of energy transfer in waves and particles

Section 6.1 questions

QUIZ

Retrieval

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.
4 **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.
5 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. Divide each distance by the speed of light.
  a Adelaide (726 km)
  b Brisbane (1781 km)
  c Canberra (662 km)
  d Perth (3406 km)
6 You see a flash of lightning and 20 seconds later hear the thunder. **Calculate** how far away the storm is.

Comprehension

7 **Explain** how microwaves heat up food.
8 **Explain** what is meant by the term ‘longitudinal wave’.
9 **Explain** why sound cannot travel through the vacuum of space.
10 **Explain** why you see the flash of lightning before you hear the thunder.

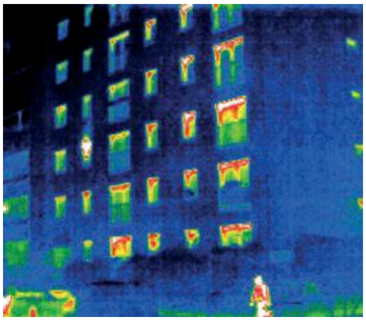
Analysis

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.

Knowledge utilisation

13 Use the image on the right to **determine** why the loudness of a sound decreases as you move away from the source of the sound.

14 The thermal image on the right is of an apartment building at night that has been produced by an infrared camera. **Decide** what the different colours mean.



15 **Decide** why it is important to find a balance between getting too much and too little ultraviolet radiation exposure.

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6.2 Electricity

WORKSHEET
What is electricity?

VIDEO
Electricity

Learning goal

To be able to define 'electricity', 'static electricity' and 'current electricity.'

Electrical energy does not travel in the form of waves like photons of light or longitudinal mechanical waves of sound. **Electricity** is a form of energy that results from either the accumulation of charge or the flow of charge.

electricity
a form of energy that results from the accumulation or the flow of charge

static electricity
an imbalance of charge on objects

electrostatic charge
a charge that stays on an object

static discharge
a sudden transfer of electrostatic charge

Charge can be positive (+) or negative (–). Atoms contain positive charge in the form of protons and negative charge in the form of electrons (Figure 6.26). Electricity is the movement of the negatively charged electrons carrying energy from atom to atom in a conductor.

VIDEO
Static electricity

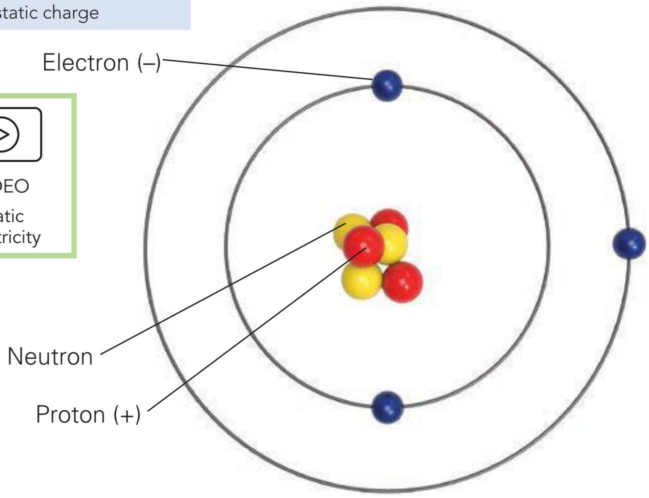

Figure 6.26 The modern Bohr model of a lithium atom with three neutrons, three positively charged protons and three negatively charged electrons. The net charge is 0, but when the atom loses an electron, the atom becomes a positively charged ion.

Static electricity and charge

Static electricity is produced when there is an imbalance of charge on objects; that is, there is a build-up of positive or negative charge. Usually, objects are neither positively nor negatively charged, but have an overall charge of zero. An imbalance can occur when electrons are transferred from one object to another. When negatively charged electrons are removed from an object, it becomes positively charged, whereas adding electrons to an object causes it to become negatively charged. The charge build-up is called **electrostatic charge** because it stays on the object ('static' means stationary or still).

You may have experienced the effects of static electricity when you have combed your hair, or you may have received a small shock when you got out of the car and touched the metal door. This is caused by the sudden flow of electrons from a charged object to you and is called **static discharge**. One of the most dramatic demonstrations of the energy of static electricity is seen during a thunderstorm. A bolt of lightning releases an enormous amount of energy in an electrical discharge.

Figure 6.27 This lightning strike in Brisbane, Queensland, is an example of a powerful static discharge.

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Explore! 6.6

Lightning's static electricity

Lightning occurs because of the same principle involved when you receive a small shock from a car or a doorknob, or see sparks when you take your jumper off. When particles of ice bump into each other in storm clouds, a huge amount of charge builds up. The top of the cloud becomes positively charged, while the bottom of the cloud becomes negatively charged. Eventually, the attraction between the charges becomes too great and a discharge of electrical energy occurs between them, producing lightning in the cloud. Sometimes the lightning moves from the cloud to the ground.

Conduct some research to answer the following questions.

1 a Statistically, does lightning strike more men than women?
  b Propose several reasons why this might be the case.
2 Explain what the lightning 30-30 rule is.

Figure 6.28 When the difference in electrical charge becomes too great, lightning discharges between clouds.

The presence of electrostatic charge can be dangerous. Aeroplanes being refuelled must be 'grounded' (that is, connected by wires to the earth) so that static electricity does not cause a spark and an explosion (see Figure 6.29).

Figure 6.29 The aeroplane is connected to earthing wires during refuelling to avoid sparks and a possible explosion.

Try this 6.4

Hair and static electricity

Blow up a balloon and tie it up. Rub it against your hair or ask a friend who has fine hair to rub the balloon against their hair. What do you observe? Can you explain what happened in terms of movement of charge?

Figure 6.30 When a balloon is rubbed against hair, electrons from the hair transfer to the surface of the balloon, giving the balloon an overall negative charge, while the hair now has a positive charge. Recall that like charges repel and opposite charges attract, so the hair (+) is now attracted to the balloon (–).

Did you know? 6.3

History of static electricity

The Ancient Greek philosopher Thales of Miletus, in about 600 BCE, was the first to describe a form of static electricity. When he rubbed a piece of amber (fossilised tree resin) on fur, Thales noticed that he could attract light objects such as hair, straw and small pieces of wood shavings. He could even produce small electrical sparks by more vigorous rubbing of the amber. In Ancient Greek, the word for amber is *elektron*, which gave its name to the electron and electricity.

Figure 6.31 Amber rubbed on fur produced static electricity.

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Quick check 6.6

1 Outline the structure of an atom.
2 Define:
  a electricity
  b charge
  c static electricity.
3 How can rubbing two different materials together create static electricity?
4 How is static electricity created by combing your hair?

Current electricity

Static electricity is when charge gathers in one place, but in **current** electricity, charges move and may continue moving in a steady manner for a period of time. These charges are electrons. When the charge passes through an electrical **component**, such as a light bulb, it transfers energy to that component. The component then converts that energy into other forms of energy such as movement, light and heat.

current
the flow of electric charge, which may continue in a steady manner for a period of time

component
a part of a circuit

Try this 6.5

Uses of electrical energy
What are some electrical appliances you see used in the classroom or at home? In each case, what is electrical energy being converted into? What does a remote control convert electrical energy into?

Figure 6.32 Electricity is used to run many household items.

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Circuits

circuit
a structure through which charges can move

load
something that uses energy in a circuit

cell
a single electrical energy source that produces a current

battery
a portable source of power; made up of two or more cells

For electrical energy to be transferred, **circuits** must be configured to allow a flow of charge. Electric circuits can be simple (for example, a torch) or complex (for example, a computer's central processing unit), but they all consist of the same basic components and follow the same principles in their operation.

It is current electricity that moves in a circuit. If there is a break in the loop, then the electricity stops flowing. Electrons need a path out of and back to the power source to continue moving around the circuit. An electric circuit always has these three components:

- a power source (provides energy to electrons, such as a battery or power pack)
- a **load** (uses the energy, such as a light bulb)
- connecting wires (carry the moving electrons).

Power source

Figure 6.33 shows the symbol for a cell, the power source in a circuit. It consists of two vertical lines. The longer line represents the positive terminal, and the shorter line represents the negative terminal. Because there is an imbalance of charge, when the two terminals are connected in a circuit, electrons flow from the negative to the positive terminal. The **cell** supplies the energy to the electrons, which are then pushed around the circuit. An everyday **battery**, like you might have in a torch, is an electrochemical cell. Technically, a battery is made up of two or more cells. An example is a car battery – it is bigger and lasts longer than a single cell. A power pack is a bank of multi-cell batteries. In this text, we use battery in a general sense to mean a portable source of power (so, including cells).

Figure 6.33 The symbol for the power source in a circuit has two lines. The shorter line represents the negative terminal, while the longer line represents the positive terminal of the power source.

Did you know? 6.4

What happens to used batteries?

Australians use about 350 million batteries every year. About 80% of these (amounting to 6000 tonnes) are alkaline batteries, which are the most used **dry cell**. Most people do not use the recycling options available, and only about 4% of batteries are recycled. Batteries can contain cadmium, lead, mercury, nickel and lithium, which are all toxic and corrosive chemicals. When buried in landfills, these toxic metals corrode the battery casing and are released into the water supply.

Let's all do our part and recycle disposable batteries!

Figure 6.34 The dry cell is typically in the form of non-rechargeable AA and AAA batteries.

dry cell
a battery in which the electrolyte is absorbed in a solid to form a paste

Load

Electrons moving through a circuit carry energy from the power source to components that can transform that energy into other forms of energy as the electrons pass. These energy transformations occur because of the presence of 'loads' in the circuit, which are components that use the energy carried by the electrons. For example, in light globes, the energy being carried by the electrons is transformed into light and thermal energy.

Figure 6.35 An older style light globe transforms electrical energy into light and thermal energy. These are typically only 3–4% efficient in transforming electrical energy into light.

Figure 6.36 shows the most common circuit symbol for an incandescent light globe. Only a small amount of the energy is transformed into light energy – about 96% is wasted as thermal energy. Light bulbs that are not very energy efficient can get quite hot!

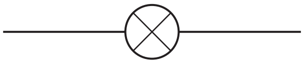

Figure 6.36 One of the circuit symbols for an incandescent light globe is a circle with a cross in the middle.

LEDs

Light-emitting diodes (LEDs) are tiny light bulbs that fit into electric circuits, as shown in Figure 6.37. They transform electrical energy into light energy much more efficiently than light bulbs, with only 20% of the energy being lost as thermal energy. The lifespan of LEDs is also much longer than that of incandescent light globes. LEDs are often used in appliances such as watches, microwaves, calculators, traffic lights and TV screens. The symbol for an LED is shown in Figure 6.38.

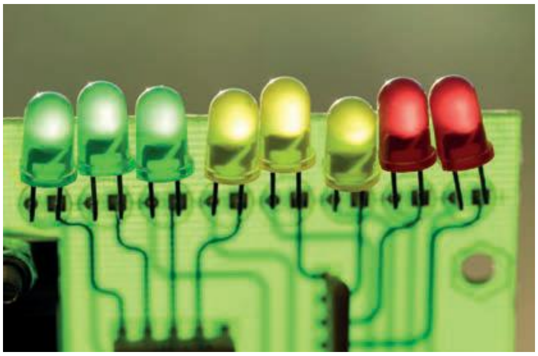

Figure 6.37 LEDs (light-emitting diodes) are tiny light bulbs that fit into electric circuits.

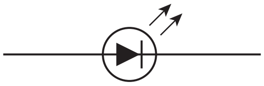

Figure 6.38 The two arrows on the circuit symbol for an LED indicate that light is being emitted.

Connecting wires

Current is the name given to the electrons (charge) flowing through the connecting wires in a circuit. While we know that it is the negatively charged electrons that move, in circuit diagrams the current is shown going in the opposite direction; that is, in the imagined direction of a positively charged particle moving from the positive to the negative terminal of the power source (see Figure 6.39). This is called conventional current, and follows the direction defined in the 1700s when electricity was first being experimented with. At that time, and electrons were unknown, so scientists assumed it was the positive charges moving, not negative ones (electrons).

An **alternating current** (AC) electricity source (like an AC power pack) reverses the direction of the current about 50 times every second. This is the power supply most used with appliances. By contrast, a battery produces a **direct current** (DC), which flows in one direction only. In this chapter, you will mainly be using DC sources.

alternating current
a form of electricity in which the current reverses direction in regular cycles

direct current
a form of electricity in which the current flows in one direction

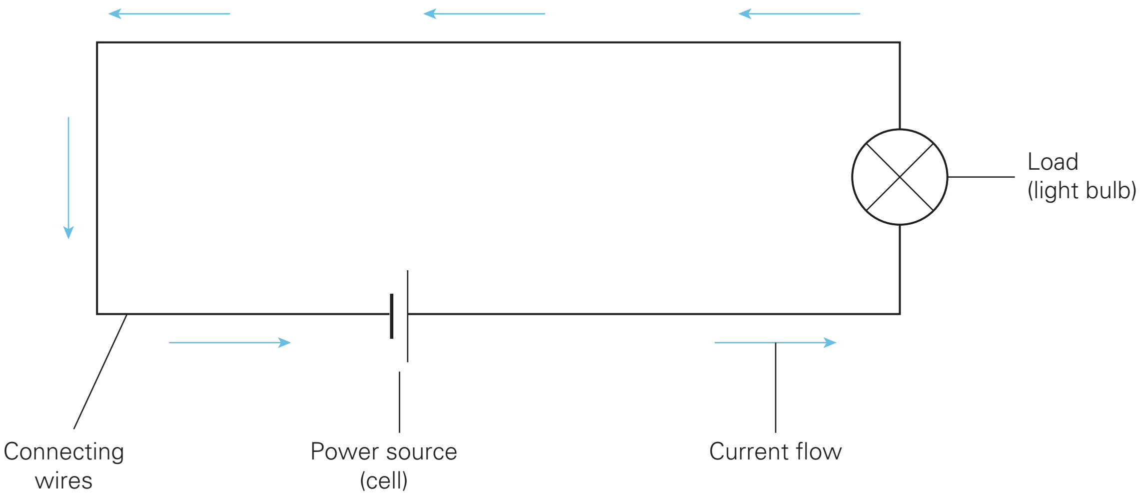

Figure 6.39 In this simple circuit, conventional current is indicated as flowing from the positive terminal to the negative terminal of a cell. The connecting wires are drawn as straight lines.

Quick check 6.7

1 Contrast current electricity and static electricity.
2 Contrast direct current and alternating current.
3 Identify what flows in the connecting wires of an electric circuit.
4 Why must a circuit be ‘closed’ or complete for it to work?

Section 6.2 questions

QUIZ

Retrieval

1 **Recall** the electric charge on a neutron, an electron, a proton and an atom.
2 **Name** the charged particles that carry an electric current through a circuit.
3 **Define**:
  a direct current
  b conventional current.
4 **State** the role of the connecting wires in an electric circuit.

Comprehension

5 **Explain** how rubbing amber produces electric sparks.
6 **Draw** a simple circuit diagram that shows how to light an LED.

Analysis

7 **Contrast** static electricity and current electricity and give examples of each.

Knowledge utilisation

8 It is often difficult to completely empty the plastic bag that contains breakfast muesli because small oat flakes seem to get stuck to the inside of the bag. **Propose** a possible explanation for this effect.
9 Lightning bolts contain large amounts of electrical energy. **Propose** reasons why the electricity from lightning bolts is not captured for our electrical needs.

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6.3 Simple circuits

Learning goals

1. To be able to construct a circuit diagram, using correct symbols for components.
2. To define 'voltage', 'current' and 'resistance' and their units.
3. To use Ohm's law to calculate voltage, current and resistance in a circuit.

WORKSHEET Simple circuits

Circuit diagrams

The circuit in Figure 6.40 shows a battery pack connected to a light globe with connecting wires and a switch. When the switch is pressed down, it completes the circuit, so electrons can flow from the negative terminal of the battery through the circuit and back to the positive terminal.

To understand a circuit and analyse how it works, you need to identify its component parts and see how they work together to make the circuit operate. We can represent a circuit as a diagram in which each symbol represents a different electrical component.

Figure 6.40 shows the circuit on the left in the form of a circuit diagram and symbols on the right.

As you investigate current electricity in closed circuits, you will use more of these simplified diagrams to represent circuits. You will begin by looking at the different symbols for the different components of circuits.

Circuit symbols

You have already seen some common electrical components and their circuit symbols in Section 6.2 (battery, load and connecting wires). Table 6.3 shows several other useful electrical components and their circuit symbols.

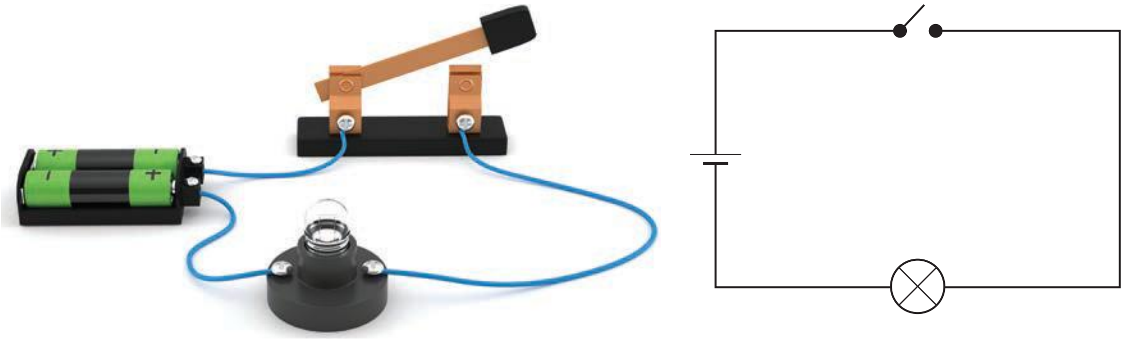

Figure 6.40 Left: a simple circuit can be made with a power source, light globe and switch. Right: the same circuit represented by a circuit diagram. Straight lines represent wires connecting the three parts together.

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ammeter a device for measuring electric current

voltmeter a device for measuring voltage between two points on an electric circuit

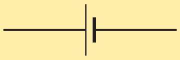
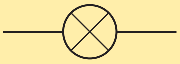
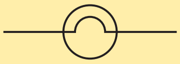
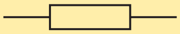
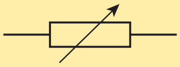
Component	Image	Symbol
Connecting wire		
Open switch		
Closed switch		
Cell		
Power supply or battery pack		
Load (e.g. light bulb)		 or 
Ammeter		
Voltmeter		
Resistor		 or 
Variable resistor		 or 

Table 6.3 Some common electrical components and their circuit symbols

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Making thinking visible 6.3

Parts, purposes, complexities: Electric circuits

1 List the minimum parts required for a circuit in which current flows.
2 What is the function of each part?
3 What components can be added to an electic circuit to make it more complex? What is the function of these components?

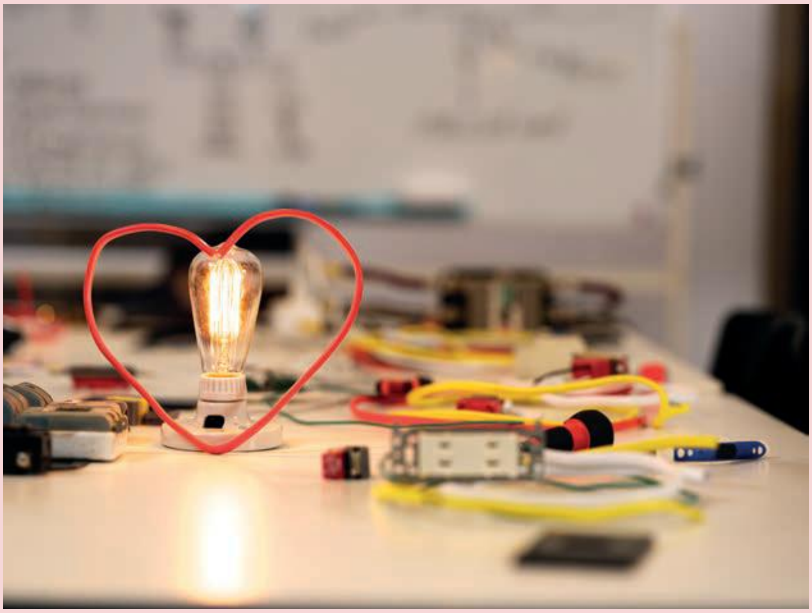

Figure 6.41 Electric circuits can be complex.

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

Drawing circuit diagrams

A circuit diagram is a diagrammatical representation of an electric circuit using basic symbols. It is a simple and fast way to see how all the circuit components are connected. Circuit diagrams should always be drawn with a ruler and pencil. All lines should be straight and joined at right angles.

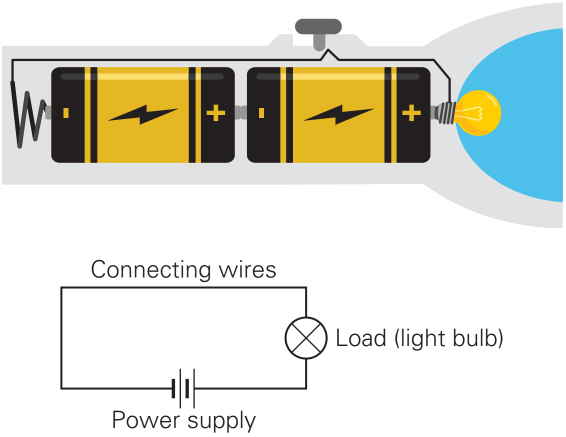

Figure 6.42 The top drawing shows the inside of a torch, but you use a simplified diagram like the bottom one to represent the circuit. The batteries are the energy source and the light bulb is the load. Can you think of one component that needs to be added to the diagram?

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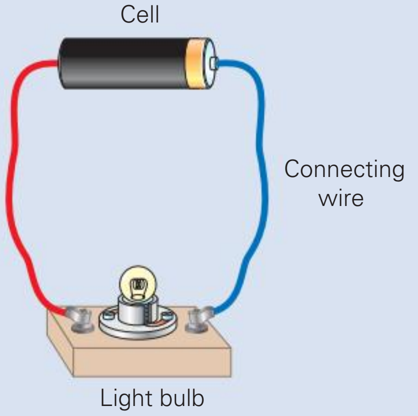
Try this 6.6

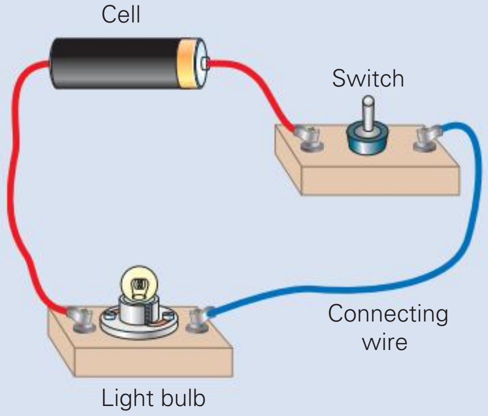
Circuit diagrams

Draw circuit diagrams for the following circuits.

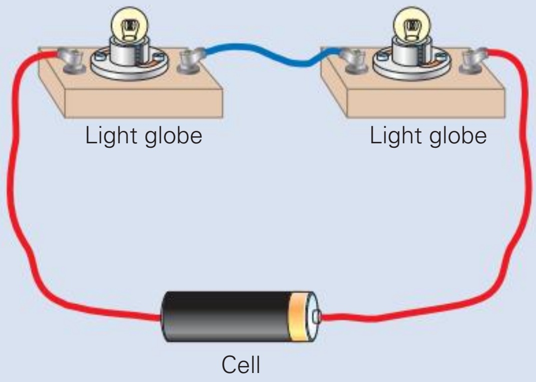
a



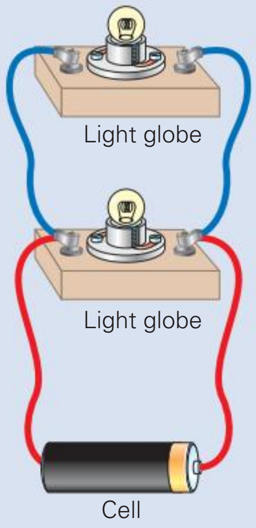
b



c



d



Quick check 6.8

1. List five components that could be included in a circuit.
2. Draw the circuit symbol for each component listed in Question **1**.
3. Explain why circuit diagrams are used.
4. List the rules that apply to drawing a circuit diagram.

voltage
the potential difference between two points in an electric circuit; measured in volts (V)

potential difference
the difference in electrical potential energy between the negative and positive terminals in an electric circuit

Voltage

When electrons flow from the negative terminal of a circuit, they flow towards a positively charged terminal. **Voltage** is the **potential difference** between two points in an electric circuit.

The potential difference describes the difference in electrical potential energy between the negative and positive terminals.

You can liken potential difference to the water pressure in a backyard hose. As the water tap is opened more, the water pressure at the start of the hose increases and so the water moves faster to the other end of the hose to escape. Similarly, a high voltage is when there is a large difference between negative charge at one end of the circuit and positive charge at the other end, causing charged particles to rush through the circuit, creating current.

Voltage is measured in volts (V), using a voltmeter. A voltmeter can measure the voltage of components of the circuit. In a circuit, a voltmeter must be connected to the start and the end of the component as the voltage will be measured across the component. This is called connecting in parallel to the circuit. The circuit symbol for a voltmeter is shown in Figure 6.43.

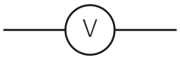


Figure 6.43 The circuit symbol for a voltmeter is a circle with a capital V in the middle.

Voltage drop is a phenomenon that occurs in electric circuits when the voltage level decreases across a component or a section of the circuit. This drop in voltage is caused by the resistance of the conductive material that the current is flowing through. Voltage drops can reduce the efficiency and performance of electrical systems.

Current

Current is the movement of charge or electrons around a circuit. It is possible to measure the rate at which charge passes any point in a circuit. Imagine being able to see the electrons moving along a conductor carrying an electric current. You could count the number that pass any particular point in a second and use that number as a measure of the current (in electrons per second). The unit of current is defined this way: 1 **coulomb** of charge per second is 1 **ampere** (A), or amp for short.

A coulomb can be described as the amount of charge transferred in 1 second with a current of 1 amp. You can increase the electric current flowing through a circuit by increasing the voltage as charge will flow more quickly with a greater magnitude of potential difference.

voltage drop
the reduction in voltage that occurs across a component or section of an electric circuit because of the resistance of the conductive material

coulomb
the amount of charge transferred in 1 s with a current of 1 amp

ampere
the unit of electrical current, usually shortened to amp (A); 1 amp = 1 coulomb per second

To measure the current in specific locations of a circuit, an ammeter is used. An ammeter is connected in line to measure the current through a circuit. This is called connecting in series with the circuit. The circuit symbol for an ammeter is shown in Figure 6.44.

An ammeter can measure current in amperes (A) or in milliamperes (mA):

$$1\ \text{A} = 1000\ \text{mA} \quad 1\ \text{mA} = \frac{1}{1000}\ \text{A}$$

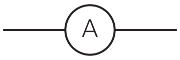


Figure 6.44 The circuit symbol for an ammeter is a circle with a capital A in the middle.

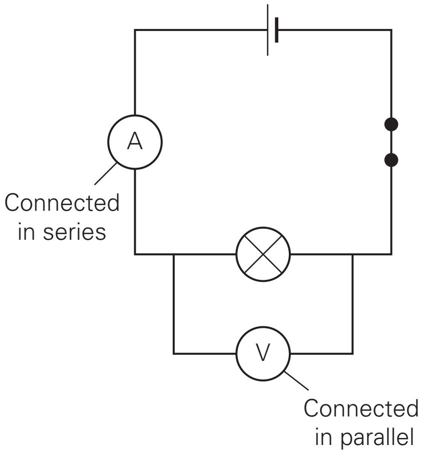


Figure 6.45 When building a circuit, you need to place the ammeter in series and the voltmeter in parallel.

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Quick check 6.9

1 Define:
  - a voltage
  - b voltage drop
  - c voltmeter
  - d current
  - e ampere
  - f ammeter.

2 How does current differ in a circuit when the switch is open and when the switch is closed? Explain your answer.

Resistance

resistance
the degree to which a substance resists the flow of current; measured in ohms (Ω)

ohm
the unit of electrical resistance (Ω)

The **resistance** in an electric circuit is a measure of a material's ability to resist the flow of current. Resistance is measured using the unit **ohm**. The symbol for ohms is the last letter in the Greek alphabet – omega (Ω).

Conductors

conductor (electricity)
a material that allows electric current to flow through it easily

If current can flow easily through a material, the material has a low resistance. Low-resistance materials are generally called **conductors**. Metals are a good example of conductors.

Figure 6.46 High-voltage (typically 550 000 V) power lines distributing electricity most often use aluminium wires as their main conductor.

Some metals are much better at conducting electricity than others. Copper is an excellent conductor of electricity. It is used in electric wiring, electric motors, telecommunications and electric cars. Gold is also an excellent conductor of electricity. However, it is much more expensive than copper. Because it does not easily oxidise and therefore deteriorate, gold is used in small amounts in critical electronic components such as computer chips and spacecraft electronics. Aluminium is another very good, low-resistance conductor. It's not as good a conductor as copper, but it is much lighter. This makes it suitable for conducting electricity in the high-voltage transmission lines that criss-cross the country.

A digital multimeter, as shown in Figure 6.47, is a tool used to measure current, voltage and resistance.

Figure 6.47 Digital multimeters can measure current, voltage and resistance.

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Did you know? 6.5

Saving lives

A defibrillator is a device that treats life-threatening heart problems by delivering a measured dose of electric current to the heart. When the heart is not beating properly, blood is not circulated around the body. To get the heart pumping, an electric shock is delivered to the heart. An automatic external defibrillator comes with instructions, which allows it to be used by untrained people and significantly improve survival rates for people having a heart attack.

Figure 6.48 An automatic external defibrillator can increase the chance of survival during a heart attack.

Insulators

High resistance means that it is difficult for electrons to pass through the material. Some materials have such high resistance that they block electric current almost completely. Such materials are called **insulators**. Examples of good electrical insulators are various plastics, glass, ceramics, wood and rubber.

Quick check 6.10

1. Define 'resistance'.
2. Explain what a conductor and an insulator are and give an example of each.

Ohm's law

Georg Simon Ohm was a German physicist. In 1827, Ohm began his research with the battery invented by the Italian scientist Alessandro Volta. Constructing his own equipment, Ohm found that electric current was directly proportional to the voltage applied across some conductors; that is, if you double the voltage, you double the current. There was also inverse proportionality between resistance and current; that is, if you double the resistance, you halve the current. This relationship is known as **Ohm's law**, where R is the resistance in ohms (Ω), V is the voltage in volts (V) and I is the current in amperes (A).

insulator (electricity)
a material that does not allow current to flow through easily

Ohm's law
a scientific law that states that the current that flows through most conductors is directly proportional to the voltage applied

$$V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$

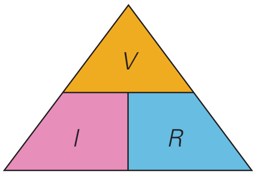

Figure 6.49 The formula triangle for Ohm's law. To use the formula triangle, cover the variable you want to calculate. If the other variables are on the same row, multiply them together. If they are on different rows, divide the top variable by the bottom variable.

For example, if a circuit has a 2.5 V power source and a 1 Ω resistor, the current would be:

$$I = \frac{2.5\text{ V}}{1\,\Omega} = 2.5\text{ A}$$

If the resistance is changed to 2 Ω while keeping the voltage at 2.5 V, then the current decreases to:

$$I = \frac{2.5\text{ V}}{2\,\Omega} = 1.25\text{ A}$$

Recall that resistance is how difficult it is for electrons to travel around a circuit. So, if you increase resistance, the current must decrease.

Quick check 6.11

1 Explain the relationship between current and voltage as stated in Ohm's law.

2 Using the formula $V = IR$, calculate the:
   - a resistance of a circuit where the voltage supplied is 6 V and the current is 2 A
   - b current in a circuit where the resistance is 50 Ω and the voltage is 25 V
   - c voltage in a circuit where the resistance is 100 Ω and the current in the circuit is 0.5 A.

Investigation 6.1

Investigating resistance

Be careful

Electric shocks may occur. Ensure the voltage output is not exceeded. Turn off the power supply when changing the circuit. Do not let the two alligator clips touch.

Aim

To investigate how the length of a wire affects its resistance

Materials

- DC power supply (6 V)
- 6 connecting leads
- resistance wire such as constantan or nichrome
- alligator clips
- ammeter
- voltmeter
- metre ruler

Planning

1 Write a rationale about the factors that affect resistance.

2 Create a relevant and specific research question for this investigation.

3 Identify the independent, dependent and controlled variables for this investigation.

Method

1 Connect the circuit shown in the diagram by following these instructions.
   - a Start on the positive side of the power supply.
   - b Connect a lead from the positive socket to the positive side of the ammeter.
   - c Connect a lead from the negative side of the ammeter to the alligator clip attached to the resistance wire at the zero end of the ruler.
   - d Connect another lead from the other alligator clip to the negative side of the battery. This lead will be used to connect to the other side of the resistance wire and disconnect the power supply between taking readings.

continued…

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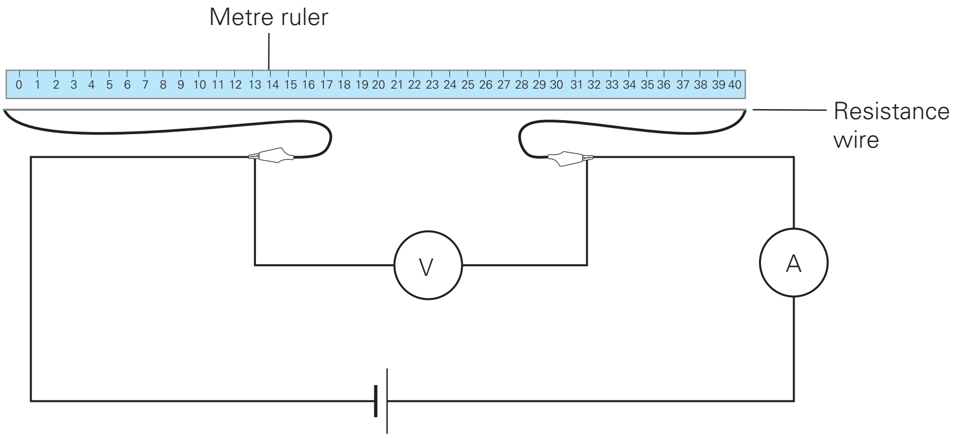
…continued

- **e** Connect a lead from the positive side of the voltmeter to the alligator clip that you connected to the ammeter.
- **f** Connect a lead from the negative side of the voltmeter to the other alligator clip attached to the switch lead.



2. Draw a suitable results table. (Hint: You should have four columns.)
3. Record the length of the wire between the alligator clips, and the readings on the ammeter and voltmeter in your results table.
4. Move the alligator clip attached to the disconnection lead to different points on the resistance wire, recording the ammeter and voltmeter readings at each length of wire. The voltmeter readings may not change.

Results

Record your results in your results table.

Data processing

1. Calculate and record the resistance for each length of wire, using the Ohm's law equation.
2. Plot a graph of length of wire (metres) against resistance (Ω), including a straight line of best fit.

Analysis

1. Identify any trends, patterns or relationships in your results.
2. Explain your results using your own scientific knowledge.

Evaluation

Your line of best fit may not go through the origin. Explain where the extra resistance came from.

Conclusion

Draw a conclusion from this experiment about length of wire and resistance, using data to support your statement.

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Variable resistors

Resistors can be tailored for various circuits to control the amount of current that flows through the other components. There are also variable resistors, which can have their resistance adjusted to change the amount of current flowing through a circuit. These can be used to control the sound volumes on stereos and televisions, or the brightness of the lights in dimmer switches. Some fixed resistors are shown in Figure 6.50. These are 1000 Ω resistors; the coloured bands can be used to work out the value of the resistance. The symbols for fixed and variable resistors are shown in Figure 6.51.

A light-dependent resistor (LDR) is a special type of variable resistor because its resistance depends on the amount of light falling on it. As light intensity increases, resistance decreases. LDRs are used in light-sensitive electronic circuits and act as light-sensitive switches; for example, they are used for lights that turn on automatically when it gets dark.

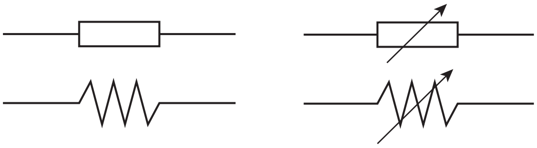

Figure 6.51 The symbol for a fixed resister (left) is either a rectangle or a zigzag line. The symbol for a variable resistor (right) is the same, but with an arrow through it.

Thermistors are another special type of variable resistor. Their resistance changes as the temperature increases or decreases. Thermistors regulate the temperature in air conditioners and refrigerators according to the relationship between voltage and resistance.

Quick check 6.12

Explain how a variable resistor works and give an example of how it may be used in your home.

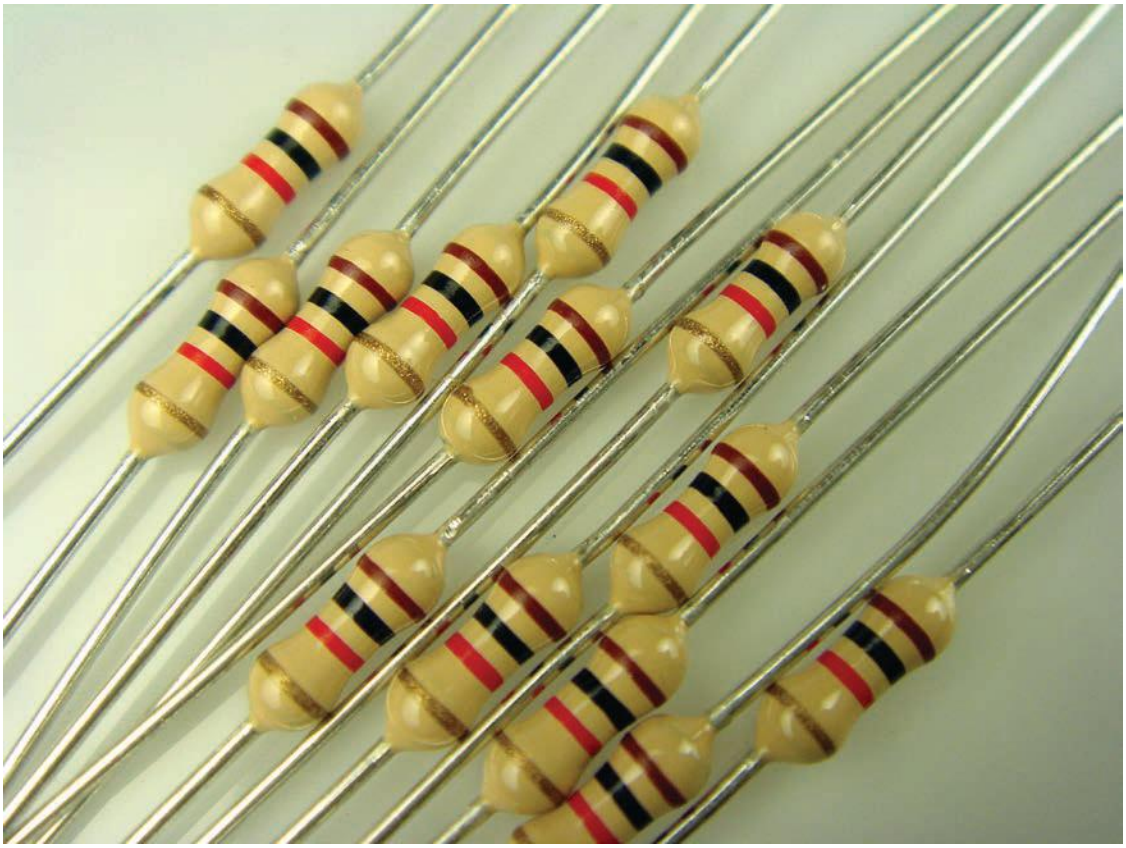

Figure 6.50 Fixed resistors have coloured bands that indicate their value.

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Explore! 6.7

Robotic sensors

Humans have five main senses: sight, smell, touch, hearing and taste. Engineers take a lot of inspiration from these senses and incorporate them into other pieces of technology, such as robots. For example, there are now robotic vacuum cleaners with sensors that tell the robot what part of the room it is in and where it has already vacuumed.

Figure 6.52 The robotic vacuum cleaner has sensors that tell it where it has already cleaned.

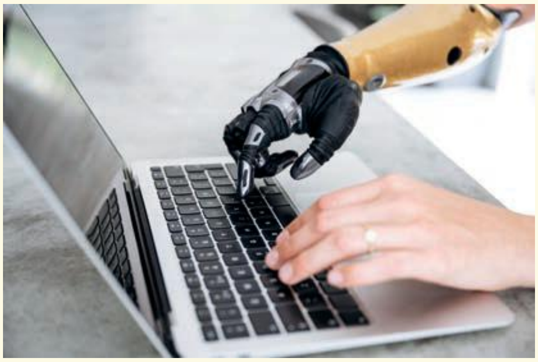


Figure 6.53 Bionic hands need to be able to replicate the senses in a working human hand to operate effectively.

Conduct some research to answer the following questions.

1 How are sensors being used in robots?
2 How can the study of human senses help people in the medical field?

Section 6.3 questions

QUIZ

Retrieval

1 **Define** the following terms and give an example of each.
  a Conductor
  b Insulator
  c Resistor
  d Variable resistor
2 **Recall** the device that measures current.
3 **Recall** the device that measures voltage.
4 **State** Ohm's law.

Comprehension

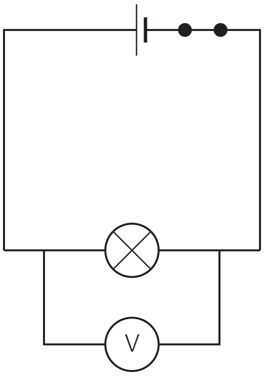
5 **Draw** the symbols for the following electrical components.
  a Single cell
  b Three cells in a row
  c Open switch
  d Resistor
  e Globe
6 a **Explain** why an ammeter must be connected in line with the other components of a circuit ('in series').
  b **Explain** why a voltmeter must be connected across the component whose voltage you are measuring in a circuit ('in parallel').
7 **Summarise** how a variable resistor works.

Analysis

8 Both aluminium and copper conduct electricity. **Identify** which of these two conducting metals you would be most likely to find in the following. Give reasons why.
  a Household wiring
  b High-voltage transmission lines

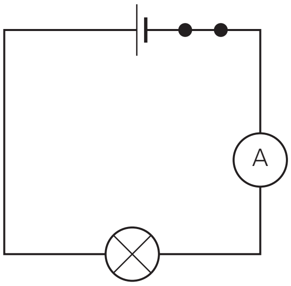
9 **Contrast** voltage and voltage drop.

10 The circuit shown was constructed from a 6 V battery, a switch, a 6 V globe and a voltmeter.
  a **Identify** each of the electrical components on the diagram.
  b **Identify** which side of the battery is positive on the diagram.
  c Copy and complete the table and **deduce** the voltage across each component when the switch is open (off) and closed (on).



Component	Voltage (V)	
	Switch open	Switch closed
Battery		
Switch		
Globe		

11 The circuit shown has been constructed from a 6 V battery, a switch, a 6 V light globe with a resistance of 5 Ω and an ammeter.



Copy and complete the table and **deduce** the current flowing through the circuit when the switch is open and closed for different positions of the ammeter.

Position of ammeter	Current (A)	
	Switch open	Switch closed
Between power source and switch		
Between switch and globe		
Between globe and power		

Knowledge utilisation

12 Use your knowledge of light-dependent resistors to **propose** a household appliance that uses them.

13 Conduct some research and **discuss** measures that could stop the wastage of resources associated with the excessive use of dry cell non-rechargeable batteries in Australia.

14 **Propose** three arguments for and three arguments against the widespread adoption and use of electric cars in Australia.

6.4 More circuits and their applications

Learning goals

1. To be able to draw series and parallel circuits.
2. To explore the safety aspects of household electricity.

WORKSHEET
More circuits and their applications

series circuit
a circuit in which the batteries and other components are all connected one after the other

Series circuits

A torch circuit in which the batteries, the switch and the globe are connected one after the other is an example of a **series circuit** (see Figure 6.54).

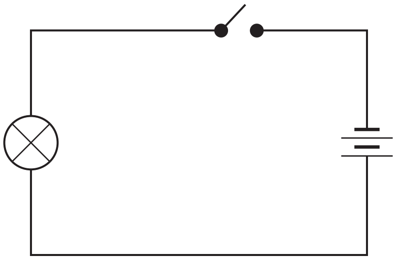


Figure 6.54 A series circuit diagram of a torch contains the symbols for a power source, light globe and switch.

Series circuits are easy to construct. However, if any part of the circuit fails, the circuit will not work because there is a break in the path through which current must flow. In the torch circuit, a flat battery, a faulty switch or a faulty globe would cause the circuit to stop working. Troubleshooting a faulty torch circuit would require systematically looking at each of these three components in turn.

Could you use a series circuit for car headlights? If one headlight globe burned out, both headlights would stop working. This would be extremely dangerous if you were travelling at night.

In a series circuit, the voltage, or energy, is shared among the load. For example, in the circuit in Figure 6.55, if the light globes are identical, the voltage across each is half that of the power source. The current is the same throughout the circuit.

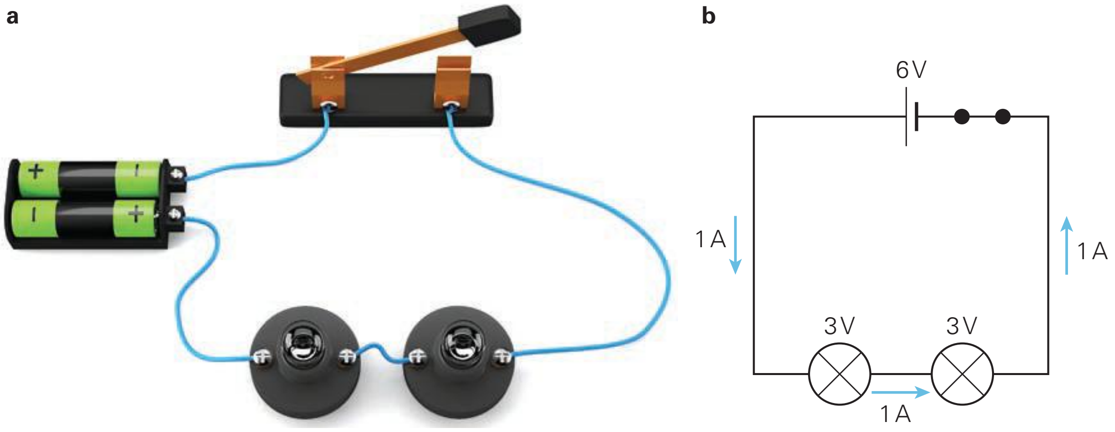


Figure 6.55 **a)** A car headlight circuit modelled as a series circuit. **b)** The matching circuit diagram with a 6 V power source and identical globes.

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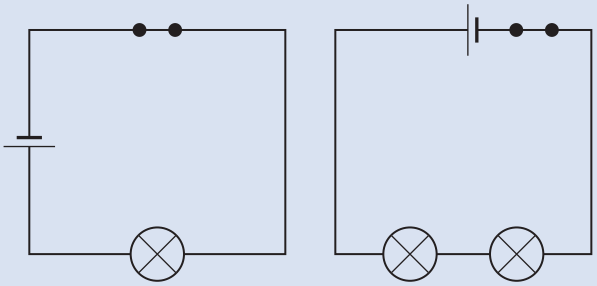
Try this 6.7

Series circuits

Two circuits have been set up for you by your teacher. They are shown here. Note the brightness of the globe in circuit 1.

Now look at circuit 2 where the two globes are connected in series.



Circuit 1 – Single globe **Circuit 2** – Two globes in series

1. Do the globes in circuit 2 glow as brightly as the globe in circuit 1? Explain your answer.
2. Predict what would happen if you disconnected the lead between the two globes in the circuit.
3. Disconnect the lead and note what happens. Explain what you observe.
4. What happens if you add another globe in series? Explain what you observe.

Parallel circuits

An alternative car headlight circuit could be constructed using the same components as you used previously, but in a way that will prevent both lights from turning off if one doesn't work. In this instance, you will model the headlight circuit using a **parallel circuit**, as shown in Figure 6.56.

parallel circuit
a circuit in which each component is connected in a separate conducting path

In a parallel circuit, the current is split at each branching. For example, if the light globes in Figure 6.56 are identical, the current in each branch is half that of the power source. The voltage is the same across all the components.

Now if one headlight fails, the other one will still work because there is a clear connecting path between the battery and the other headlight when the switch is on. You may have seen a car travelling with just one headlight at night. This indicates that car headlights have been wired in parallel.

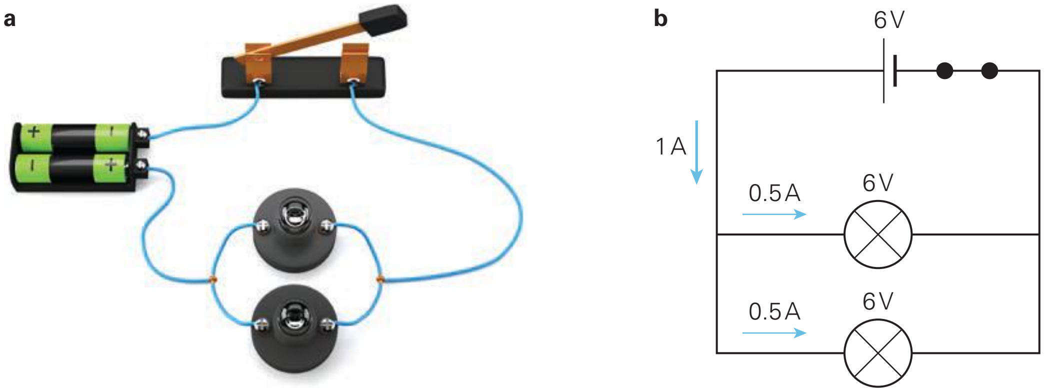


Figure 6.56 **a)** A car headlight circuit modelled as a parallel circuit. **b)** The matching circuit diagram; the blue arrows indicate current split.

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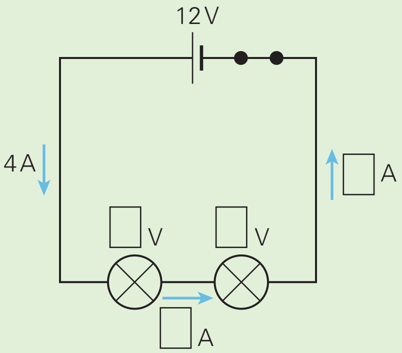
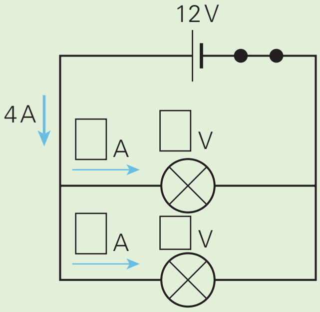
In a parallel circuit, each component is connected in a separate conducting path. This means that if one load component of the circuit is faulty, the other load components will still work. Most modern string lights are connected in parallel. If one of the 200 light globes fails, then the other 199 globes will still glow. In older-style string lights, all the globes were connected in series. This meant that if one globe failed, then none of the globes would glow. The globes had to be replaced one by one until the whole circuit lit up again when the faulty one was found!

Figure 6.57 Modern string lights are wired in a parallel circuit.

Quick check 6.13

1 Describe the differences between a series and a parallel circuit.
2 Explain why you would not wire your house in series configuration.
3 How does the brightness of globes compare in series and parallel circuits?
4 Copy and complete the values in the following diagrams. Assume that the light globes are identical.





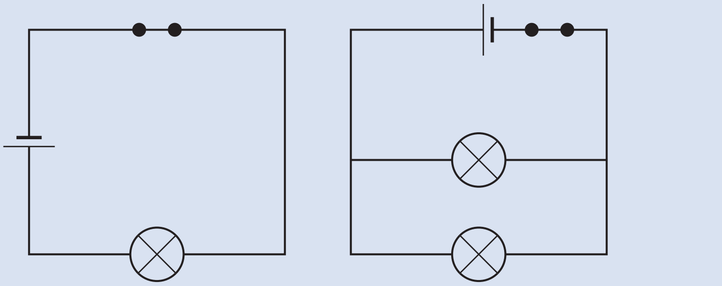
WIDGET
Simple circuits

Try this 6.8

Parallel circuits

Two circuits have been set up for you by your teacher. They are shown here. Note the brightness of the globe in circuit 1.

Now look at circuit 2 where the two globes are connected in parallel.



Circuit 1 – Single globe **Circuit 2** – Two globes in parallel

continued…

…continued

1 Do the globes in circuit 2 glow as brightly as the globes in circuit 1? Explain what you observe.
  a Predict what would happen if you disconnected the bottom globe in circuit 2.
  b Disconnect the lead. What happens to the brightness of the other globe? Explain what you observe.
  c What happens if you add another globe in parallel? Explain what you observe.
  d What happens if you add another globe in series with the bottom globe? Explain what you observe.

Practical skills 6.2

Series and parallel circuits

Be careful

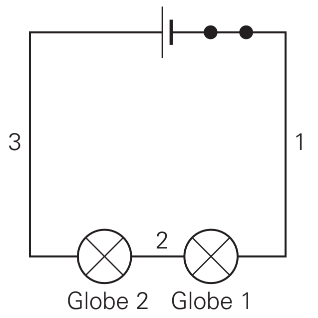
Electric shocks may occur. Ensure the voltage output is not exceeded. Turn off the power supply when changing the circuit.

Aim

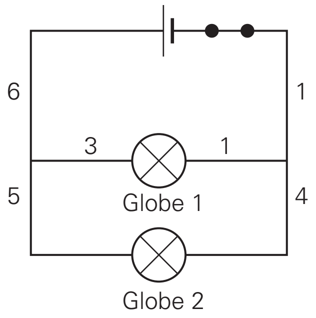
To observe and compare the values of current and voltage in series and parallel circuits

Materials

- DC power supply (6 V)
- 2 × 6 V light globes and 2 × 6 V globe holders
- connecting leads (alligator clips)
- ammeter
- voltmeter



Circuit 1 – Two globes in series



Circuit 2 – Two globes in parallel

Method

Draw the results tables in the Results section.

Series

1 Set up circuit 1 so that the two globes are connected in series.
2 Measure the current at positions 1–3. Then measure the voltage across the power supply, globe 1 and globe 2. Record the readings in your results tables.

Parallel

1 Set up circuit 2 so that the two globes are connected in parallel.
2 Measure and record the current at positions 1–6. Then measure the voltage across the power supply and each globe. Record the readings in your results tables.

continued…

…continued

Results

Copy and complete the following tables.

Current

	Position	Current (A)
Series circuit	1	
	2	
	3	
Parallel circuit	1	
	2	
	3	
	4	
	5	
	6	

Voltage

	Component	Voltage (V)
Series circuit	Power supply	
	Globe 1	
	Globe 2	
Parallel circuit	Power supply	
	Globe 1	
	Globe 2	

Analysis

1 Explain your observations about the current values in the series circuit.
2 Explain your observations about the current values in the parallel circuit.
3 Explain your observations about the voltage values in the series circuit.
4 Explain your observations about the voltage values in the parallel circuit.

Household electricity

In your house, all your electrical appliances and lights transform the electrical energy into other forms of energy as the electrons flow through the different components. Power stations supply AC to homes. In Australia, electricity is supplied to homes at a voltage of 230 V and is referred to as the **mains electricity**.

Power points (sockets) in the home have three slots: active, neutral and earth (Figure 6.58). When you plug in an electrical device and switch the power on, current flows between slots at the top through the appliance (between the active and the neutral via the appliance). The third slot is the earth slot. It is normally connected to a metal pipe in the ground; that is, directly connected locally to earth.

mains electricity the electricity that is supplied to homes

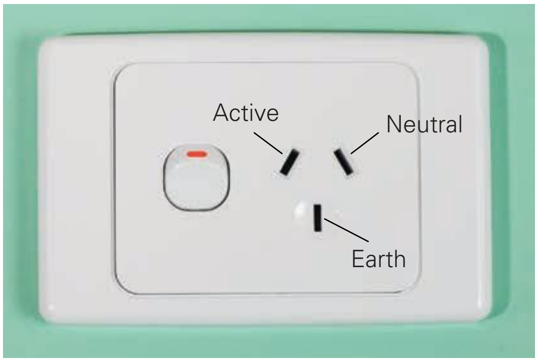


Figure 6.58 An Australian power point has three slots: active, neutral and earth.

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Figure 6.59 Power cords in Australia have either a 2-pin plug (left) or a 3-pin plug (right).

double insulated
having two levels of insulating materials between the electrical parts of an appliance and any parts on the outside that you touch

earthed
having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

Electrical plugs are designed to fit into these sockets. They may be 2-pin plugs or 3-pin plugs (Figure 6.59). This is because some electrical appliances are **double insulated** and only require a connection between the active and neutral pins. These appliances use a 2-pin plug. You might have a laptop computer with a 2-pin plug. Other electrical appliances, such as toasters, must be **earthed** to protect the user from stray current. These appliances use a 3-pin plug.

Safety

Earthing

You saw earlier that, in Australia, toasters and some other appliances have a plug with three pins, but why and how does earthing protect you? If your toaster has a metal casing, and there is a fault in the appliance, the metal casing might accidently become 'live'. Then, because the bottom earth pin fits into the earth socket, the electric current will flow via the earth pin to the ground (Figure 6.60). This prevents the current going through the body of a person who might be touching the metal case of the toaster.

Double insulation

Many newer small electrical appliances have two pins without the earth pin. Typical examples you may have at home are computers, printers, hair dryers and drills. These appliances are double insulated. They have two levels of insulating materials between the electrical parts of the appliance and any parts on the outside that you touch. The symbol placed on all double-insulated appliances is shown in Figure 6.61.

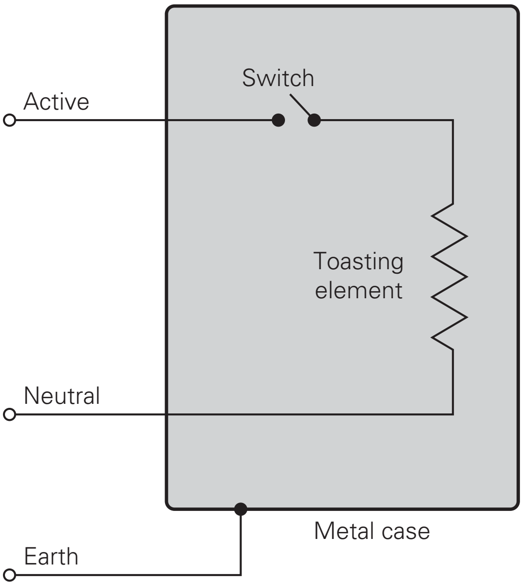

Figure 6.60 In an earthed appliance, like this toaster, any metal parts that can come into contact with the active part of the circuit and become 'live' automatically cause a large current to run to earth and blow a fuse or trip a circuit breaker. This is much better than having the current run through the user of the appliance!

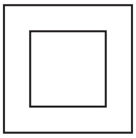

Figure 6.61 An appliance with this symbol on it is double insulated.

So, the primary difference between an electric drill with a 3-pin plug and another drill with a 2-pin plug electric is the case material. If the drill case is made of conductive material (for example, metal), then it must have an earth pin (3-pin plug). Industrial appliances generally have three pins because they may experience rougher treatment in an industrial environment. In contrast, a domestic appliance is more likely to have double insulation and two pins.

Did you know? 6.6

Electrical wiring

In Australia, the following colour code is currently used for electrical wiring. Some older electrical appliances may still have the old colour code (described in brackets):

- brown – the active wire, which is at mains voltage, 230 V (it used to be red – a colour normally associated with danger)
- blue – the neutral wire, which is nominally at 0 V (it used to be black)
- green and yellow stripes – the earth wire, which is connected to the earth (it used to be plain green).

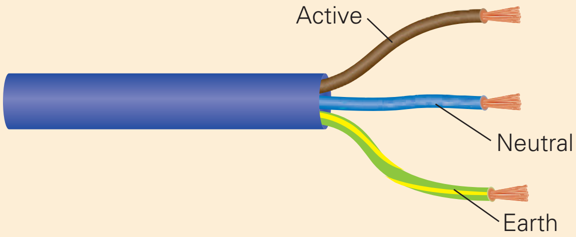

Figure 6.62 The modern colour code for electrical wires: brown for the active wire, blue for the neutral, and green and yellow for the earth.

Try this 6.9

Household electrical devices and appliances

Work in a group of three or four students.

1 Create a table with the same headings as in the following table but with four blank rows underneath.

Electrical device/ appliance	Connects to a 230 V power point	Has 2-pin connector	Has 3-pin connector	Has rechargeable battery	Has a non-rechargeable battery	Typical daily use (h)
LED/LCD TV	Yes	Yes	No	No	No	5.0
Laptop computer	Yes	Yes	No	Yes	No	7.5
Fridge	Yes	No	Yes	No	No	24
Old-style smoke alarm*	No	N/A	N/A	No	Yes	24

*Note: new smoke alarms are connected to the mains electricity (230 V) and have a 9.0 V back-up battery for blackouts. N/A – not applicable.

2 The characteristics of four electrical devices are shown in the table above.
Brainstorm in your group four other electrical devices commonly used in and around the home. Place them in your table and determine their characteristics.

continued…

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…continued

3 Explain why some plug-in devices have three pins while others only have two.
4 Explain why some devices have rechargeable batteries and others have non-rechargeable batteries.
5 If there was a power outage in your area from 6 p.m. to midnight, which of the electrical devices in your table would it be inconvenient to do without?
6 In the event of a sustained power outage (say, 24 hours), which of the electrical devices in your table would it be critical to do without?

VIDEO
Residual current device (RCD)

Electrical hazards

The mains electricity supply in Australia presents a potential hazard to life. Even a relatively small current passing through the human body can be deadly. Anyone using electricity should be aware of the associated dangers. All electrical work should be carried out by qualified electricians. People are injured or die every year because of carelessness, negligence and do-it-yourself electrical work. One of the main causes of **electrocution** in the home is the use of damaged cords and plugs. Frayed cords and plugs can expose the plastic-covered active, neutral and earth wires inside. If the plastic coatings are cracked, you could come in direct contact with a bare active wire. As Table 6.4 shows, the human body is very sensitive to relatively small currents. You can feel one-thousandth of an amp (1 mA), and a current of only 20 mA causes your muscles to involuntarily contract – meaning you cannot let go of the wire! If someone makes contact with you to save you, their muscles will most likely be paralysed as well, placing two people at risk of electrocution.

electrocution
when electric current passes through the body

Most modern homes have quick-acting special safety switches that can cut the current off in less than one-thirtieth of a heartbeat.

With appropriate care and caution, many of these unfortunate electrical incidents can easily be avoided.

Figure 6.63 Electrical hazard symbols are placed where there is a risk of deadly electric shock.

Current (mA)	Effect on the human body
1	Can be felt
10	Causes pain
20	Paralysed muscles – very difficult to let go
50	Severe shock
90	Breathing is affected
150	Breathing is very difficult
200	Death is likely
500	Serious burning, breathing stops, death inevitable

Table 6.4 The size of the current and its effect on the human body

Fuses and circuit breakers

A **fuse** is a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit. Many fuses used in cars are designed this way. Look at Figure 6.64 – notice the fuse on the right no longer provides an electrical connection.

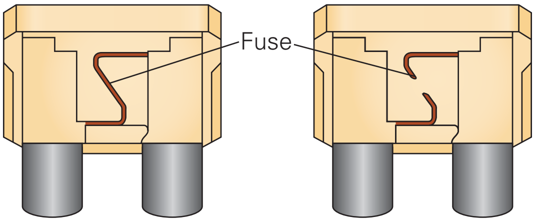


Figure 6.64 The wire inside a fuse will break if the current passing through it gets too high.

In most modern houses, fuses have been replaced with circuit breakers. A **circuit breaker** (see Figure 6.65) carries out the same function as a fuse by breaking the circuit when the current exceeds some safety limit, such as 20 A.

Safety switches (also known as residual current devices, RCDs) are different from circuit breakers. RCDs detect when current 'leaks' from circuits, possibly into a person. When 30 mA leaks from a circuit, these devices trip the power, preventing an electric shock.

Figure 6.65 Circuit breakers protect electrical systems in houses and safety switches protect people against electric shock.

Short circuit

A **short circuit** occurs when frayed electrical cords or faulty electrical appliances allow the current to flow from one conductor to another (for example, from active to neutral or from active to earth) with little or no resistance. The current increases rapidly, causing the wires to get hot and possibly cause a fire.

Figure 6.66 A short circuit can cause a fire.

fuse
a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

circuit breaker
a device that carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

short circuit
when current is allowed to flow from one conductor to another with little or no resistance

Did you know? 6.7

Tasers

Law enforcement officers around the world are using alternative weapons, such as pepper sprays and rubber bullets, instead of traditional firearms (for example, guns and rifles) to minimise serious injuries and deaths. One new weapon is the taser, which uses peak voltages of 50 000 V to immobilise a suspect.

But what does a 50 000 V shock do to a person's brain? Research has found that this electric shock can impair a person's ability to process and remember information. Cognitive function greatly declines immediately after being tasered, which can pose problems for those who are being questioned by law enforcement shortly after being tasered. This newfound knowledge may change the protocols surrounding taser use, which is now heavily regulated.

Figure 6.67 Tasers are used by law enforcement officers.

Quick check 6.14

1 Recall the voltage of mains electricity in Australia.
2 State the purpose of the third socket of a power plug.
3 Explain why some appliances do not have an earth socket.

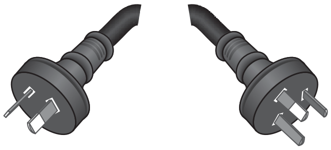
Section 6.4 questions

QUIZ

Retrieval

1 Using the labels *switch*, *earth*, *active* and *neutral*, redraw and then correctly **identify** the parts of the electrical power point shown.

2 Using the labels *2-pin*, *3-pin*, *earth*, *active* and *neutral*, redraw and then correctly **identify** the parts of the electrical plugs shown.



Comprehension

3 **Describe** the differences between series and parallel circuits.
4 a **Describe** the main disadvantage of a series circuit.
  b **Describe** two advantages of a parallel circuit.
5 **Explain** why some electrical appliances are earthed.
6 **Explain** why some electrical appliances are not earthed.
7 **Draw** a diagram to show how four 1.5 V batteries can be connected in parallel. What is the total voltage provided by this battery circuit? Label the positive and negative terminals of each battery.
8 a **Explain** what happens to your muscles when you experience a current of 20 mA from a live wire from the mains electricity. Draw a simple diagram modelling this scenario and label the components.
  b **Explain** why you should not grab a person who is being electrocuted by a current of 20 mA or more.
9 **Explain** the function of a safety switch in an electrical circuit.
10 A circuit breaker in your home fuse box continually trips off when you are using your toaster. **Explain** what this means and what you should do next.

11 **Explain** what would happen if an electrician who had red–green colour blindness and was using the old colour code for electrical wiring had connected the metal case of the toaster to the active wire (A – old colour red), the toaster element to the neutral wire (N – old colour black) and the earth wire (E – old colour green), as shown in Figure 6.68.

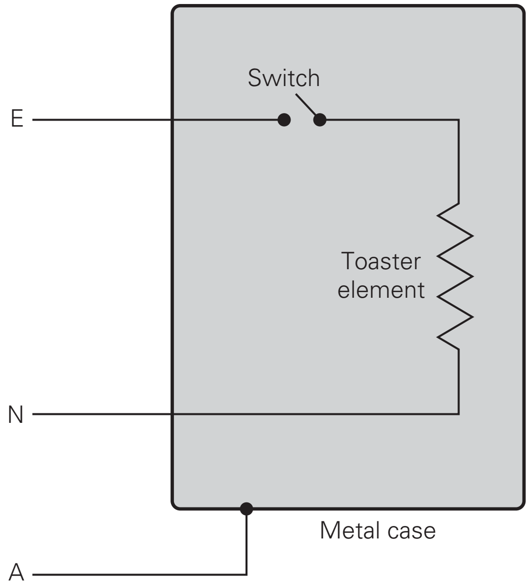
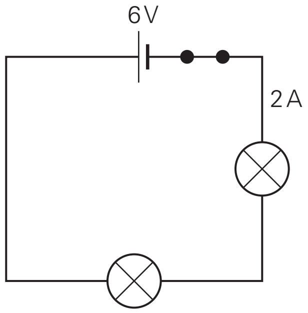


Figure 6.68 A circuit diagram of an incorrectly wired toaster

Analysis

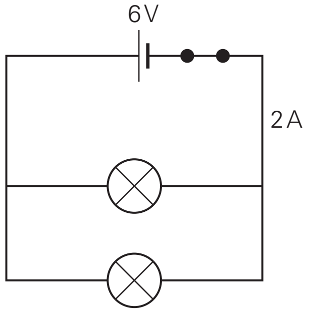
12 A student constructs circuit 1 as shown. The circuit contains a 6 V battery and two identical globes. The current through the circuit as 2.0 A.



Circuit 1

- a **Identify** whether this a series or parallel circuit. Explain your answer.
- b **Determine** the voltage drop across each globe.
- c **Calculate** the resistance of one globe.

13 A student constructs circuit 2 as shown. The circuit contains a 6 V battery and two identical globes of higher resistance than in Question **12**.



Circuit 2

- a **Identify** if this is a series or a parallel circuit. Explain your answer.
- b **Determine** the voltage drop across each globe.
- c **Calculate** the resistance of one globe.

Knowledge utilisation

14 **Decide** whether the use of tasers in Australia is justified. Write down three arguments supporting and three arguments against the adoption and use of tasers by the police in Australia.

15 **Discuss** why household circuits supplying your lights, television, computers, washing machines and similar appliances are wired in parallel, while the fuses (and circuit breakers) to these circuits are wired in series with the circuits.

Chapter review

Chapter checklist

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

Success criteria		**Linked questions**	**Check**
6.1	I can distinguish between mechanical and electromagnetic waves.	2	
6.1	I can identify different parts of a wave, including the wavelength, amplitude, trough and crest.	5	
6.1	I can recall the different parts of the electromagnetic spectrum.	16	
6.1	I can describe compression and rarefaction in longitudinal waves.	9	
6.2	I can define 'electricity', 'static electricity' and 'current electricity'.	3	
6.3	I can construct circuit diagrams using correct symbols.	8	
6.3	I can define 'voltage', 'current' and 'resistance'.	4	
6.3	I can calculate the voltage, current and resistance of a circuit using Ohm's law.	10	
6.4	I can distinguish between series and parallel circuits.	14, 15	
6.4	I can describe the safety aspects of household electricity.	17	

SCORCHER

Review questions

Retrieval

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 **Distinguish** static electricity and current electricity.

4 For a certain electrical circuit, 20 coulomb of charge flows past a point in 5 seconds. **Define** 'current' and **calculate** the current in amperes.

5 **Define**:
- a wavelength
- b frequency
- c amplitude
- d pitch.

Comprehension

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.

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8 **Draw** these electrical components: open switch, closed switch, ammeter, voltmeter, battery, incandescent light globe, LED, resistor.

9 **Describe** the difference between compression and rarefaction.

10 A 12 V car battery has an internal resistance of 0.02 Ω. **Calculate** the current passing through this circuit.

11 **Explain** what a good electrical insulator is and give an example of where it may be used.

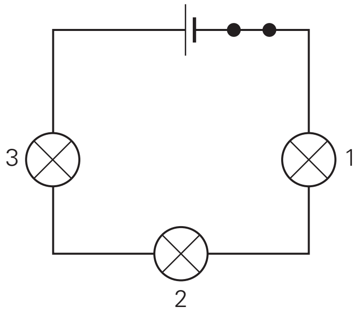
12 **Explain** why electrical wires made from gold or silver are not used for sending power from the power stations into households.

Analysis

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 a If one or more of the globes were broken in circuit 1, identify how it would affect the other globes. Copy and complete the following table to identify whether the globes would be on or off.

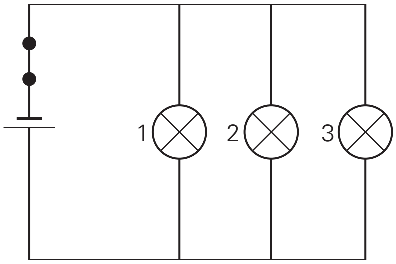
Globe broken	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
Globe 1			
Globe 2			
Globes 2 and 3			



Circuit 1

b If one or more of the globes were broken in circuit 2, **identify** how it would affect the other globes. Copy and complete the following table to identify whether the globes would be on or off.

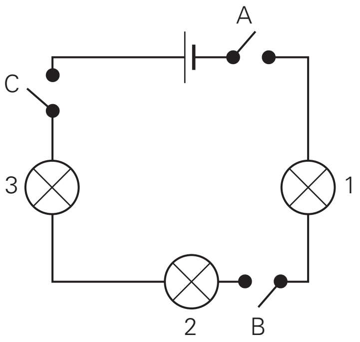
Globe broken	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
Globe 1			
Globe 2			
Globe 3			
Globes 2 and 3			



Circuit 2

15 a If one or more of the switches were turned on (closed) in circuit 3, **identify** how it would affect the globes. Copy and complete the following table to identify whether the globes would be on or off.

Switches turned on	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
A			
B, C			
A, B, C			



Circuit 3

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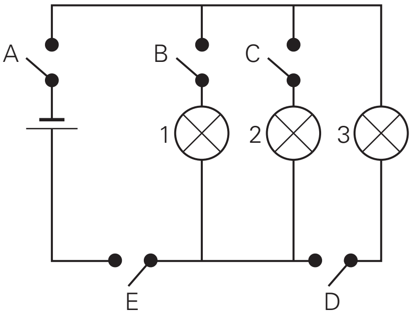
b If one or more of the switches were turned on (closed) in circuit 4, **identify** how it would affect the globes. Copy and complete the following table to identify whether the globes would be on or off.



Circuit 4

Switches turned on	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
A, B, C, D			
A, B, E			
A, C, D, E			
A, B, D, E			

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 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)	

Knowledge utilisation

17 **Propose** reasons for:

a household electrical wires being coated in plastic

b many household appliances being double insulated.

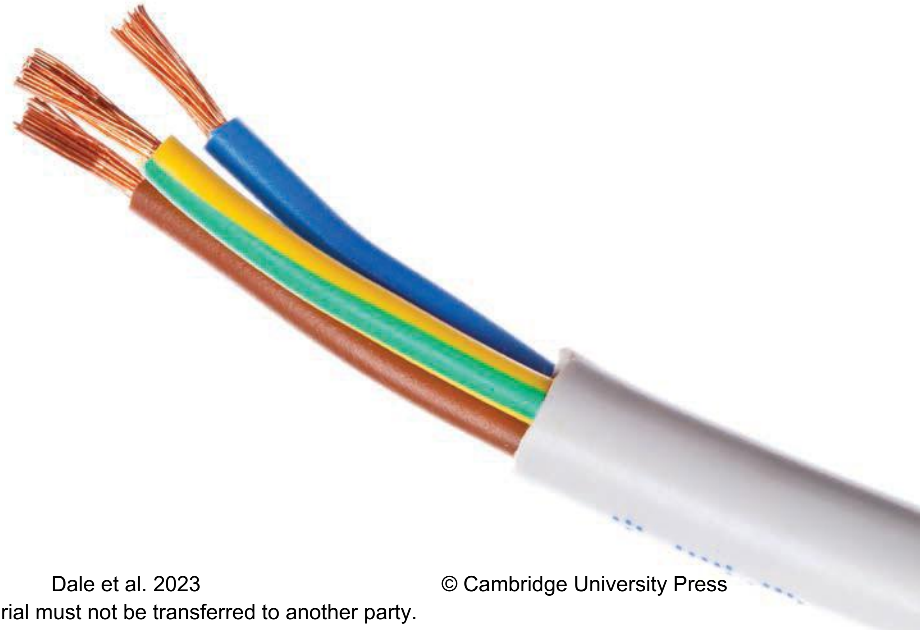
18 A person standing 1 km away shoots a gun. You see the flash of light to indicate that the gun has been fired but you do not hear anything immediately.

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 6.69. 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.

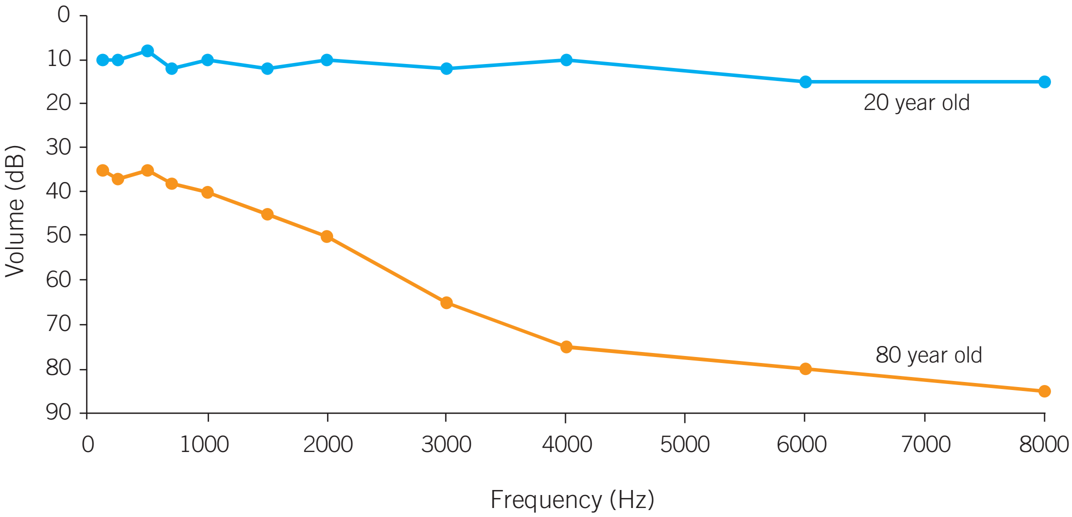

Figure 6.69 An audiogram for a 20 year old and an 80 year old

Apply

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.

Analyse

4 **Identify** a trend in volume and frequency for both the 20 year old and 80 year old.

5 **Analyse** the plot for the 80 year old and find any frequencies where the person suffers from severe hearing loss.

6 **Contrast** the two data sets between the frequencies of 1000 Hz and 2000 Hz.

Interpret

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 suffers from '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

Design brief: Design and build an accessible musical instrument from recycled materials.

Background information

Music is part of most 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 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 (for example, 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 (for example, the space inside a violin or a flute)
- an opening for the sound to effuse (flow out) from (for example, 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 even 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.

Traditionally, people with a disability 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 with disabilities engage with music.

Figure 6.70 In musical instruments, vibration produces sound, and this sound is often amplified in the body of the instrument.

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Activity instructions

In small groups your task is to design and build a musical instrument that is accessible to people with a disability or elderly people. The first step will be to decide what type of condition you would like to cater for. You may need to do some research into the condition to help understand the potential problems that elderly people or people with a 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.

Chapter 7
Atoms

Chapter introduction

This chapter is all about atoms. The idea of the structure of the atom was developed by philosophers and scientists over thousands of years. Combinations of atoms can be classified by terms such as elements, molecules and compounds. Atoms of the same element can have different atomic masses, and some unstable atomic masses decay to emit radiation. Different types of radiation can be used for new technologies, including medicine and materials.

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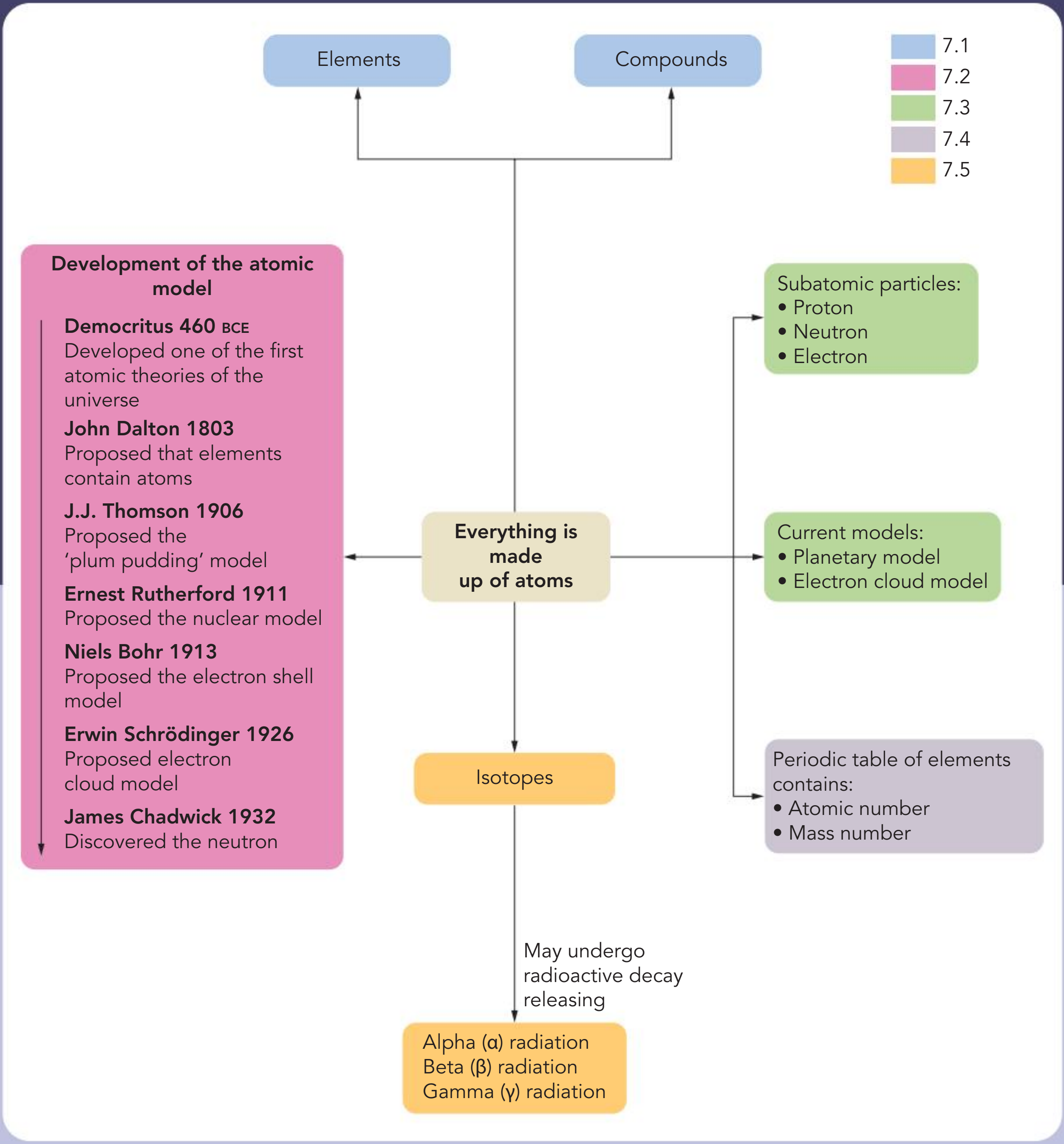
Concept map



Elements

Compounds

🟦 7.1
🟪 7.2
🟩 7.3
⬜ 7.4
🟧 7.5

Development of the atomic model

Democritus 460 BCE
Developed one of the first atomic theories of the universe

John Dalton 1803
Proposed that elements contain atoms

J.J. Thomson 1906
Proposed the 'plum pudding' model

Ernest Rutherford 1911
Proposed the nuclear model

Niels Bohr 1913
Proposed the electron shell model

Erwin Schrödinger 1926
Proposed electron cloud model

James Chadwick 1932
Discovered the neutron

Everything is made up of atoms

Subatomic particles:
- Proton
- Neutron
- Electron

Current models:
- Planetary model
- Electron cloud model

Periodic table of elements contains:
- Atomic number
- Mass number

Isotopes

May undergo radioactive decay releasing

Alpha (α) radiation
Beta (β) radiation
Gamma (γ) radiation

Curriculum

Explain how the model of the atom changed following the discovery of electrons, protons and neutrons and describe how natural radioactive decay results in stable atoms (AC9S9U06)	
comparing the mass and charge of protons, neutrons and electrons	7.3, 7.4
examining how the discovery of electrons, protons and neutrons resulted from experimental evidence and answered questions related to properties and behaviours of atoms	7.2
describing in simple terms how different unstable isotopes decay such as radon-222 releasing an alpha particle, iodine-131 releasing a beta particle and cobalt-60 releasing gamma radiation to form stable atoms	7.5
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	7.5
investigating how radiocarbon and other dating methods have been used to establish that First Peoples of Australia have been present on the Australian continent for more than 60 000 years	7.5
identifying where applications of radioactivity are used in medicine and industry such as diagnosing and treating cancer and checking for faults in materials used in aircraft and spacecraft	7.5
discussing how mass and energy are connected at all scales and energy conversion processes within atomic nuclei	7.5

Glossary terms

Alpha particle
Atom
Atomic number
Beta particle
Bioplastic
Compound
Electron
Gamma ray
Half-life
Ion
Ionic compound
Isotopes
Mass number
Molecule
Neutron
Nucleus
Nuclide notation
Proton
Radioactive decay
Relative atomic mass
Subatomic particle

7.1 Atoms, elements and compounds

Learning goal
To be able to define 'atoms', 'elements', 'compounds' and 'molecules'.

WORKSHEET
Atoms, elements and compounds

Atoms

The word 'atom' comes from the Greek word *atomos*, which means 'indivisible' or 'un-cuttable'. If you cut a platinum ring in half and then in half again, and continued to do this, you would eventually be left with an atom of platinum (Pt). Scientists have now provided evidence that there are particles even smaller than an atom, and that is something you will explore in this chapter.

An **atom** is the smallest possible form of an element, and there is a unique atom for every element. If a platinum atom was cut in half, it would not be platinum anymore, but would instead be two new elements.

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 7.1 Rings made of platinum atoms

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 been unseen.

atom
the building block of matter

Science as a human endeavour 7.1

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 has come in the study of atomic and molecular systems.

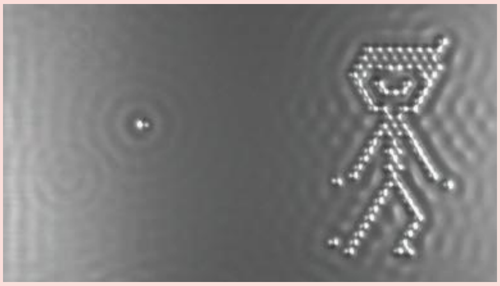


Figure 7.2 *A Boy and His Atom* constructed using carbon monoxide atoms.

Quick check 7.1

1 Define 'atom'.
2 Recall the name of the microscope that allowed scientists to view atoms.

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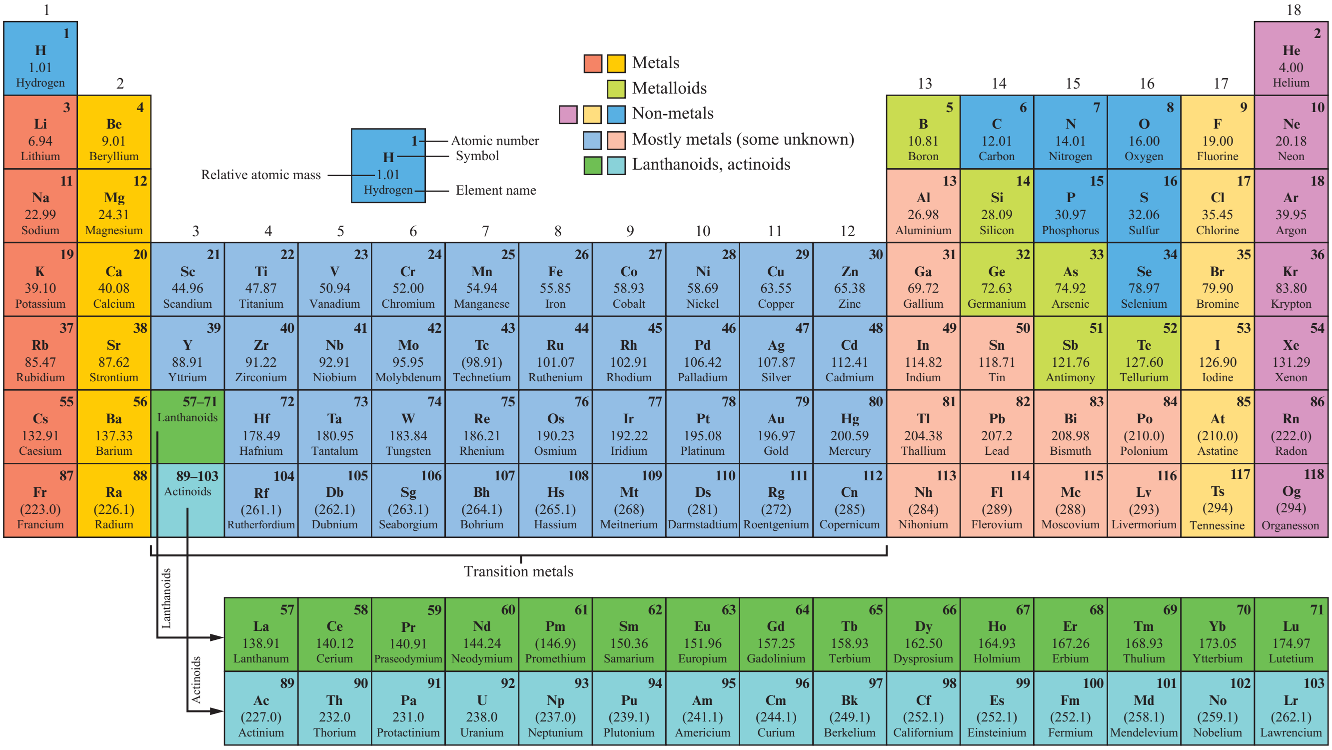
VIDEO
Uses of
elements

Elements and compounds

Elements

All elements contain atoms, but they contain only one unique type and these atoms are identical to one another. They cannot be changed chemically into a different type of atom. All the known elements are arranged on the periodic table according to their atomic and chemical properties. They are represented by a symbol using one or two letters.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.01 Hydrogen																	2 He 4.00 Helium
3 Li 6.94 Lithium	4 Be 9.01 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.06 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.63 Germanium	33 As 74.92 Arsenic	34 Se 78.97 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.95 Molybdenum	43 Tc (98.91) Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.29 Xenon
55 Cs 132.91 Caesium	56 Ba 137.33 Barium	57–71 Lanthanoids	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Tl 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po (210.0) Polonium	85 At (210.0) Astatine	86 Rn (222.0) Radon
87 Fr (223.0) Francium	88 Ra (226.1) Radium	89–103 Actinoids	104 Rf (261.1) Rutherfordium	105 Db (262.1) Dubnium	106 Sg (263.1) Seaborgium	107 Bh (264.1) Bohrium	108 Hs (265.1) Hassium	109 Mt (268) Meitnerium	110 Ds (281) Darmstadtium	111 Rg (272) Roentgenium	112 Cn (285) Copernicum	113 Nh (284) Nihonium	114 Fl (289) Flerovium	115 Mc (288) Moscovium	116 Lv (293) Livermorium	117 Ts (294) Tennessine	118 Og (294) Organesson

Lanthanoids	57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (146.9) Promethium	62 Sm 150.36 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.93 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thulium	70 Yb 173.05 Ytterbium	71 Lu 174.97 Lutetium
Actinoids	89 Ac (227.0) Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np (237.0) Neptunium	94 Pu (239.1) Plutonium	95 Am (241.1) Americium	96 Cm (244.1) Curium	97 Bk (249.1) Berkelium	98 Cf (252.1) Californium	99 Es (252.1) Einsteinium	100 Fm (252.1) Fermium	101 Md (258.1) Mendelevium	102 No (259.1) Nobelium	103 Lr (262.1) Lawrencium

Figure 7.3 The periodic table of the elements

Making thinking visible 7.1

Connect, extend, challenge: Element symbols

1 How do element symbols generally relate to their names in English?

2 Eleven element symbols do not match their English names. Can you identify all eleven elements?

3 Why is it important to know the origin of element symbols? How might this knowledge be important to a chemist?

Figure 7.4 Lead has the symbol, Pb, from its Latin name *plumbum*. It was used in Roman plumbing pipes, hence its name.

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

Compounds

Compounds are formed when two or more different elements combine in a fixed ratio by chemically bonding. The properties of 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.

Molecules

The term **molecule** is often used to describe a chemical species generally made up of

compound
a substance formed by the chemical combination of two or more different elements in a fixed proportion

molecule
a chemical species generally made up of two or more non-metal atoms; can be elemental or a compound

two or more non-metal 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 has different elements.

Aluminium oxide is not classed as a molecule because it contains a metal element and therefore its chemical structure will be different. Compounds consisting of metal and non-metals are often classified as **ionic compounds**.

ionic compound
a compound generally made up of both metal and non-metal atoms

Practical skills 7.1

Splitting molecules 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.

Aim

To split molecules into atoms

Materials

- baking soda
- distilled water
- 250 mL beaker
- 250 mL measuring cylinder
- stirring rod
- spatula
- 2 power leads
- 2 alligator clips
- power pack
- safety glasses

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 DC terminals of the power pack, setting the voltage to 9 volts (V).
4. To the other end of each lead, attach an alligator clip, making sure the wires do not touch each other.
5. Put the ends of the leads with the alligator clips into the beaker of baking soda solution, again making sure the leads do not touch each other at any point.
6. Leave this set up for 10 minutes. During this time you should see bubbles forming at each alligator clip.

Figure 7.5 In this molecular model of water, there are two hydrogen atoms (white) and one oxygen atom (red).

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.

Analysis

1. In this experiment, you split water molecules into their atoms. Identify 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 a reason why the use of distilled water was specified and suggest what, if any, effect this may have had on the outcome.

Quick check 7.2

1. Determine the elements that form each of the following compounds.
   a. Water (H_2O)
   b. Carbon dioxide (CO_2)
   c. Sodium chloride (NaCl)
2. Evaluate whether it is possible to predict if a substance is an element or a compound by its chemical formula or by its chemical name.

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Practical skills 7.2

Forming a compound using magnesium and oxygen

Aim

To show that compounds formed from elements have different physical and chemical properties

Materials

- small piece of magnesium ribbon
- tongs
- crucible
- matches
- Bunsen burner
- heatproof mat
- safety glasses

Be careful

Do not look directly at combusting magnesium. Ensure general fire safety is followed.

Method

1. Draw the results table below.
2. Set up a Bunsen burner on a heatproof mat.
3. Hold the piece of magnesium ribbon with the tongs and put it into the hottest part of the flame until it catches alight.
4. Collect the compound formed in a crucible and observe the contents.

Results

Copy and complete the following table. List the physical properties (appearance) of the substances in the reaction.

Substance	Physical properties (appearance)
Magnesium metal	
Oxygen gas	
Compound formed	

Analysis

1. Predict the name of the compound that was formed in the demonstration.
2. Propose a word equation for the reaction demonstrated.
3. List some observations in the reaction other than the new substances formed.

Section 7.1 questions

QUIZ

Retrieval

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.

Comprehension

3. **Explain** why some elements on the periodic table have symbols that do not match their English names.
4. **Explain** why carbon dioxide (CO_2) is not found on the periodic table.

Analysis

5. **Compare** an atom, an element and a compound.

Knowledge utilisation

6. **Decide** which of the following substances contain compounds: oxygen, potassium, water, sugar, candle wax, hydrogen, petrol. Justify your choice.

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7.2 Development of the atomic model

Learning goal

To be able to outline the different contributions to the development of the modern model of the atom.

WORKSHEET The development of the atomic model

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 the year 442 BCE, he hypothesised that if you take an object and cut it into smaller and smaller pieces, eventually you would reach a point where you could no longer cut it anymore. 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, bearing in mind he had no modern technology such as microscopes to view these substances.

Figure 7.6 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 amounts of these elements determined how materials behaved. Aristotle had such an influence over people at the time that it took about 2000 years for Democritus’s theory to be re-examined.

Figure 7.7 The Greek philosopher Aristotle proposed that all matter was made up four elements: earth, air, fire and water.

John Dalton 1766–1844

Dalton is credited for 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 were now arranged in the periodic table, contained atoms, and that atoms of the same element would be identical in size, shape and mass. This theory was called the ‘solid sphere model’ as Dalton believed the atom was a solid sphere. He also stated that compounds were a combination of elements. The question he could not answer, though, was why atoms behaved the way they do.

Figure 7.8 John Dalton was an English chemist, physicist and meteorologist. He is best known for initiating research into modern atomic theory.

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WORKSHEET
The gold foil experiment

Joseph John Thomson 1856–1940

Thomson was the first scientist to discover particles smaller than the atom, disproving Dalton's and Democritus's 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.

Figure 7.9 Thomson proposed the plum pudding model and is credited with discovering the electron.

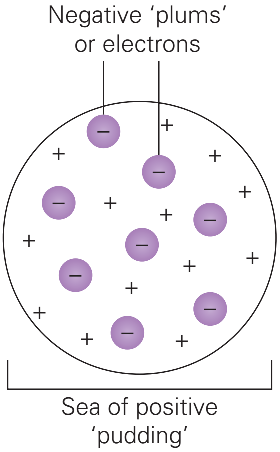

Figure 7.10 The plum pudding model consists of negative electrons (the plums) scattered through a sea of positive charge (the pudding).

The first model of the structure of the atom was proposed by Thomson, who named it the 'plum pudding' model (Figure 7.10). 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'.

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 radioactive decay (or disintegration) of an unstable atom

nucleus (plural: nuclei)
the central part of the atom containing its protons and neutrons

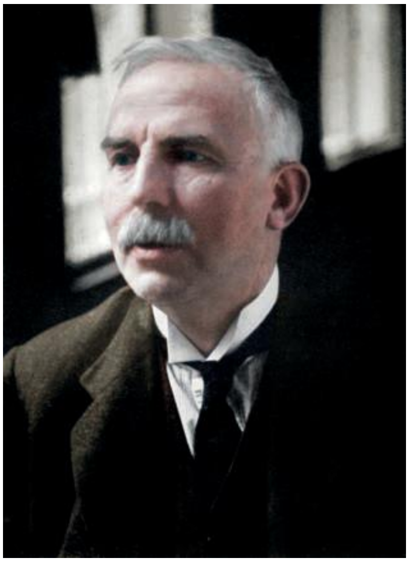

Figure 7.11 Rutherford stated that there was a large concentration of charge and mass situated in the centre of the atom and that most of the atom was empty space.

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! It was true that 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. However, surprisingly, some of the alpha particles bounced back or were deflected as if they had hit something (see Figure 7.12). 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 altogether.

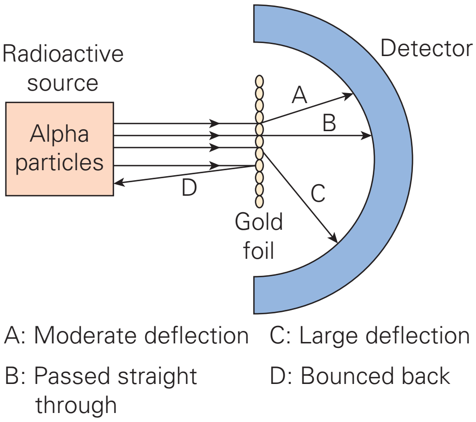

Figure 7.12 The gold foil experiment conducted by Rutherford and colleagues proved that most of the atom was empty space and that there was an area of charge and mass concentrated in the middle of the atom.

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 negative 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.

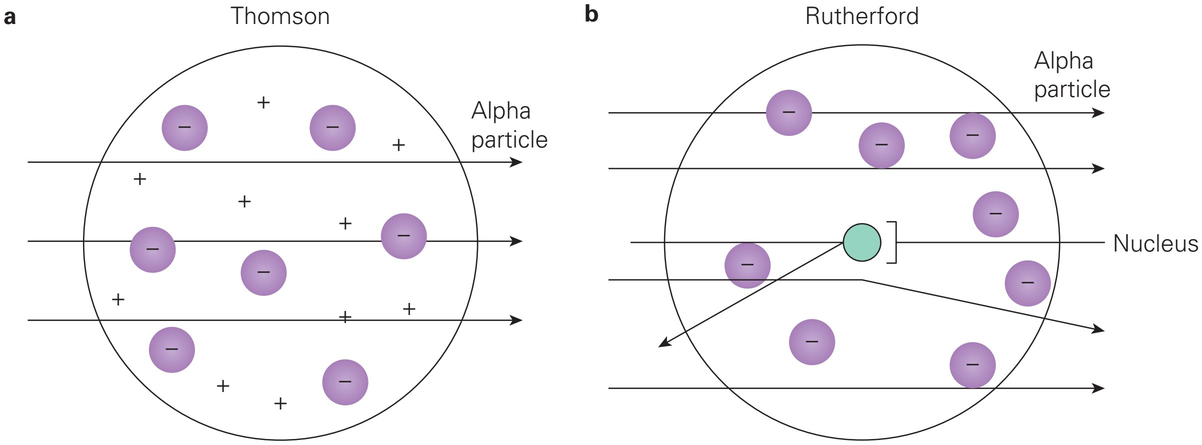

Figure 7.13 Comparison between atomic models: **(a)** Thomson's plum pudding and **(b)** Rutherford's central region of mass and charge

Quick check 7.3

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 the alpha particles ___________; however, a small number were deflected back. Rutherford hypothesised that the reason for this was that the alpha particles either passed through a region of ___________ or hit a central region of concentrated mass and positive charge, which he called the ___________, disproving the ___________.

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Practical skills 7.3: Teacher demonstration

Invisible spaces in water

Aim

To investigate the three-dimensional structure of molecules

Materials

- 100 mL propan-2-ol
- 250 mL beaker
- 100 mL measuring cylinder

Method

1. Draw the results table shown in the Results section.
2. Predict what will happen to the total volume when 100 mL of alcohol is added to 100 mL of water. Propose what the total volume of the solution will be.
3. Use the measuring cylinder to measure 100 mL of water and pour it into the beaker.
4. Using the same measuring cylinder, measure 100 mL of propan-2-ol and pour it into the beaker containing the water.
5. Note the actual total volume when the two solutions are mixed together.

Results

Copy and complete the following table .

Prediction of volume with 100 mL of water and 100 mL of alcohol	
Actual volume with 100 mL of water and 100 mL of alcohol	

Analysis

Discuss whether the actual final volume differed from your prediction, and why this was the case.

Explore! 7.1

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.

continued …

… continued

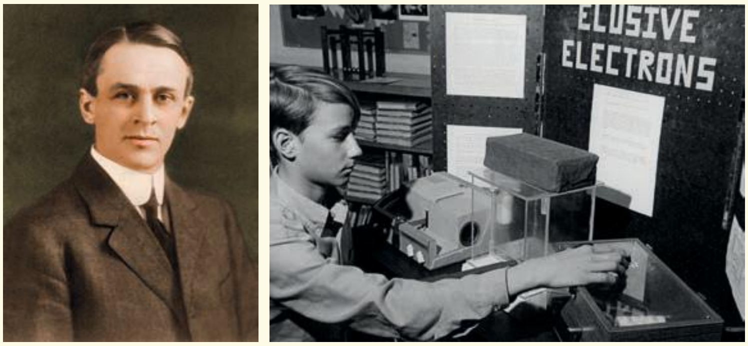

Figure 7.14 Nobel laureate Robert Andrews Millikan (left) and a student conducting the Millikan oil drop experiment (right)

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

Figure 7.15 Bohr proposed that electrons were not randomly spread across the atom but were arranged in discrete energy levels or shells.

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.

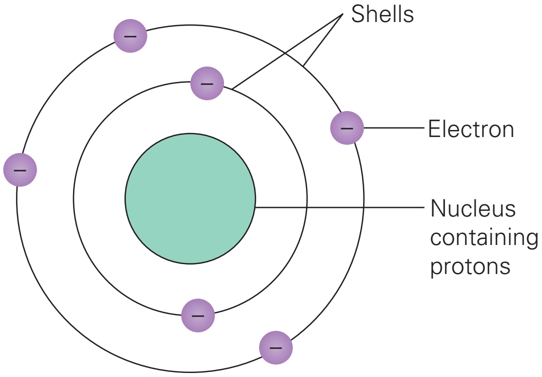

Figure 7.16 Bohr's model of the atom is sometimes called the planetary model. It shows electrons in fixed shells around a central nucleus.

Scientists now know that Bohr's model has some flaws, but it provided some important understanding about the behaviour of electrons. Perhaps more importantly, it is the model that you will recognise and use the most in your studies.

Erwin Schrödinger 1887–1961

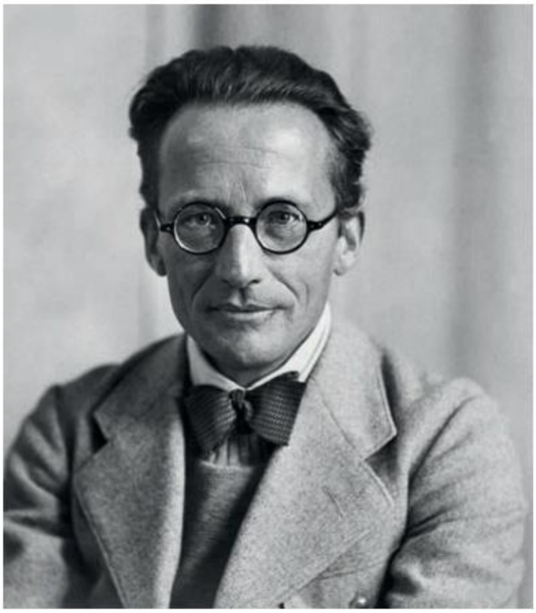

Figure 7.17 Schrödinger proposed the electron cloud model, contradicting Bohr's model of fixed electron shells.

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).

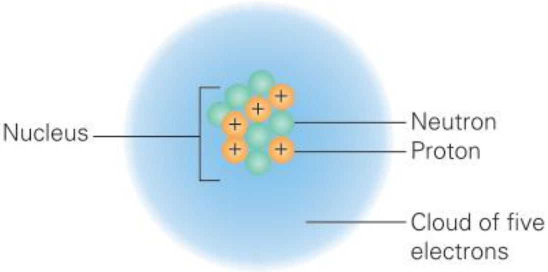

Figure 7.18 The electron cloud model of a boron atom

James Chadwick 1891–1974

Figure 7.19 Chadwick discovered the neutron, the last subatomic particle to be discovered. This completed the atomic model in use today.

There is one subatomic particle that was yet to be discussed. You may not be surprised that the neutron was the last of the three subatomic particles to be discovered. As it has no charge and does not repel the protons in the nucleus, it was relatively undetectable. This was the case 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. Often in high school, we use the Bohr model (protons in the nucleus) and shells of electrons; but we also include neutrons in the nucleus in our diagrams.

Quick check 7.4

1 a Recall the name Bohr gave to the structures that contained electrons.
  b Describe how this explanation of these structures differed from Rutherford's model.
2 Identify the subatomic particle that Chadwick discovered.

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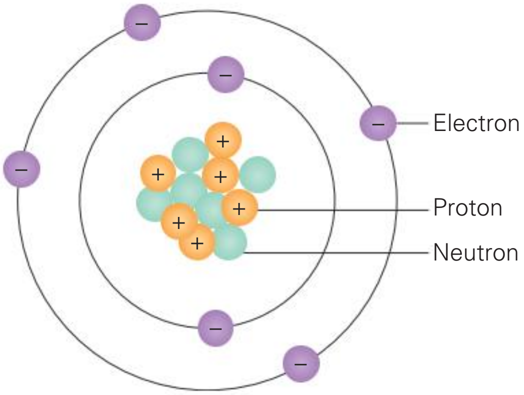

Figure 7.20 We use the Bohr model, also showing neutrons, because it is a simplification of the electron cloud model.

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. Figure 7.21 summarises the development of the modern atomic model.

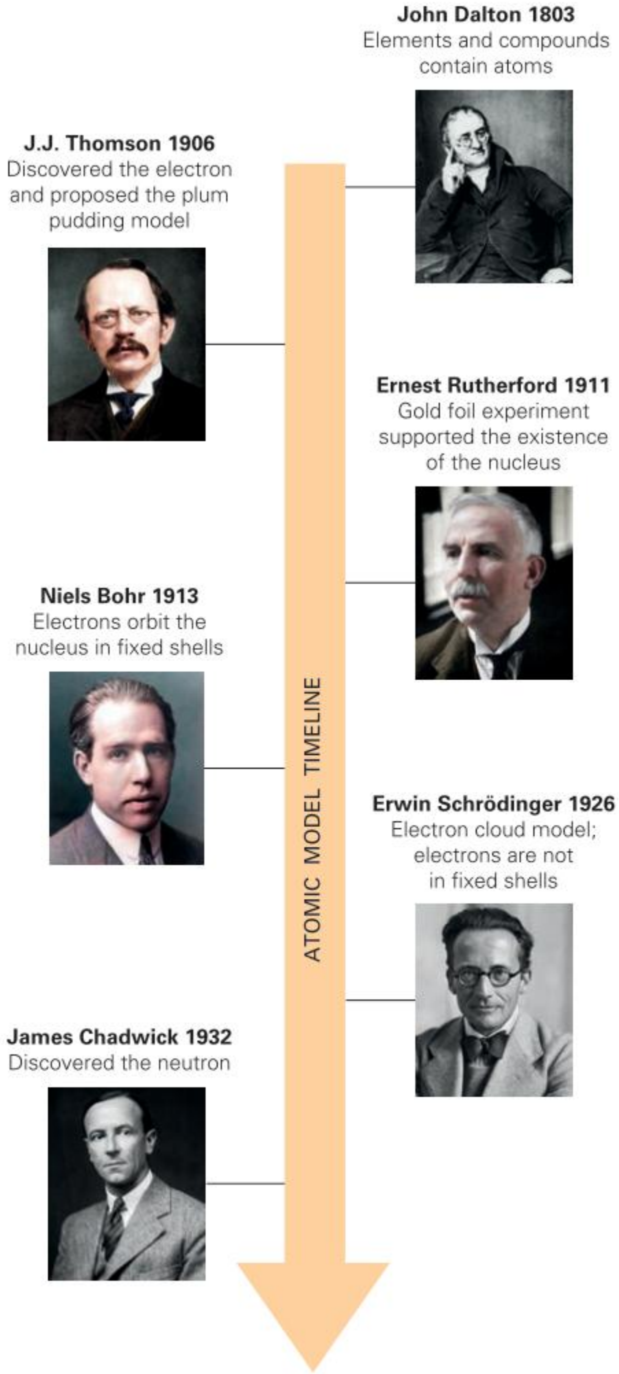

Figure 7.21 A summary of the development of the atomic model

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Science as a human endeavour 7.2

The Higgs boson

Figure 7.22 Professor Peter Higgs (1929–present) discovered the presence of a new particle, which was named 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 1960, British-born theoretical physicist Professor Peter Higgs proposed the existence of a particle that later was named after him: the Higgs boson.

The detection of this particle then became his goal and the goal of many other theoretical physicists.

In 2012, the European Organization for Nuclear Research (CERN) announced that 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, and 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 may eventually achieve your goals!

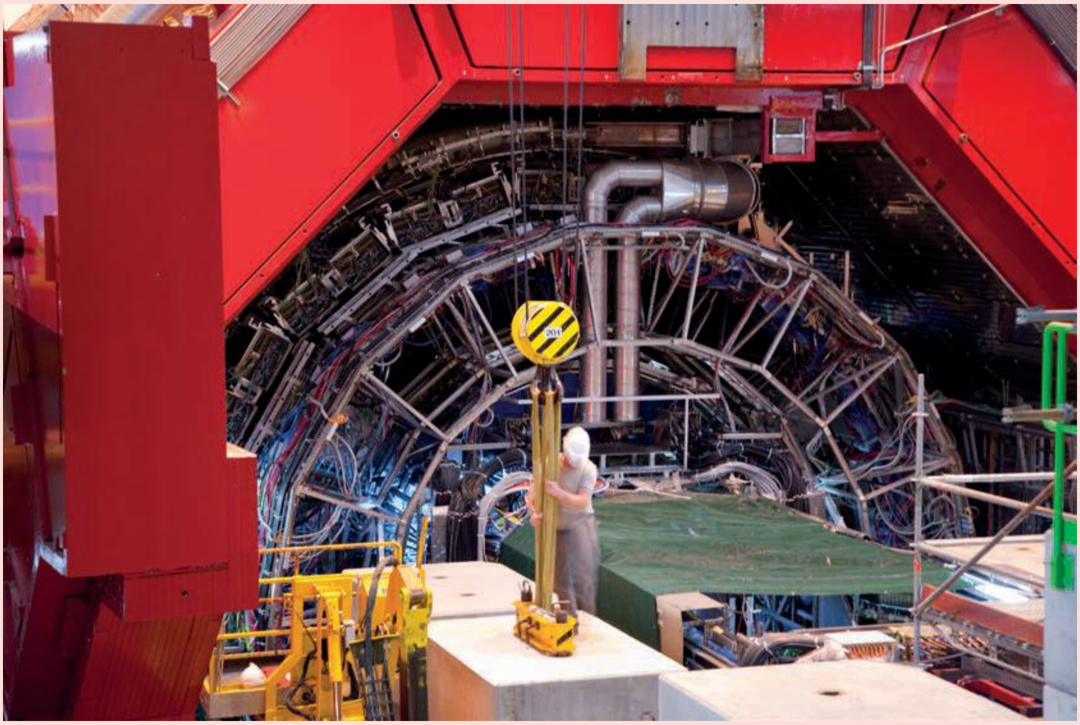

Figure 7.23 Engineers working on a part of the LHC at CERN where the Higgs boson was discovered

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Did you know? 7.1

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 when two or more atoms fuse together under extremely high temperature and pressure, such as the conditions on the Sun. Neutrinos are then emitted and travel through space, some reaching Earth. In 2015, Professors Takaaki Kajita and Arthur B. McDonald were awarded the Nobel Prize in Physics for their work, which provided evidence that neutrinos have mass, just like electrons.

Figure 7.24 Nobel Laureates Professors Arthur B. McDonald and Takaaki Kajita in 2015

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.

Figure 7.25 Professor Janet Conrad studies neutrinos.

Professor Conrad has been involved in the MicroBooNE experiment, which is designed to study low-energy neutrinos. Her work on this experiment has focused on measuring the properties of neutrinos and improving our understanding of their interactions with matter. This research has important implications for a wide range of fields, from particle physics to astrophysics.

Section 7.2 questions

QUIZ

Retrieval

1 **Recall** what the Greek word *atomos* means in English. How does this relate to the word 'atom'?

2 **Recall** who discovered the neutron.

Comprehension

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.

Analysis

5 **Compare** Rutherford's model of the atom with the plum pudding model.

6 **Analyse** the differences between Schrödinger's and Bohr's models of the atom.

Knowledge utilisation

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.

7.3 The modern structure of the atom

WORKSHEET
The structure of the atom

Learning goal
To be able to compare the relative mass and charge of protons, neutrons and electrons.

Subatomic particles

You have already learned that the word 'atom' comes from the Greek word *atomos*, meaning 'indivisible'. This idea, despite having a long history, only became widely accepted in the twentieth century. Even Dmitri Mendeleev, who many call the 'father of the modern periodic table', for a time refused to believe that atoms existed. The periodic trends he observed formed the basis of the table of the elements that he first published in 1869.

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

neutron
a subatomic particle with a neutral charge found in the nucleus of an atom

electron
a subatomic particle with a negative charge found outside the nucleus of an atom

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 will be discussed in more detail later in this chapter.

Did you know? 7.2

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!

Since 2008, physicists have learned a lot more about particles within atoms from studies using the 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 developed, 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.

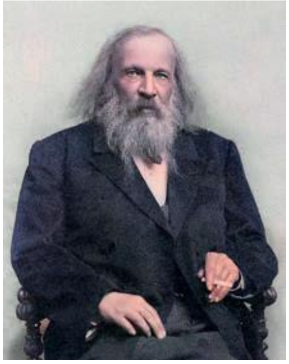

Figure 7.26 Mendeleev (1834–1907) is often referred to as the 'father of the modern periodic table'.

Figure 7.27 The Large Hadron Collider (LHC) is used by scientists to accelerate particles and then smash them together.

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Explore! 7.2

Particles smaller than the electron

Scientists once thought that the atom was the smallest particle that existed. You 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?

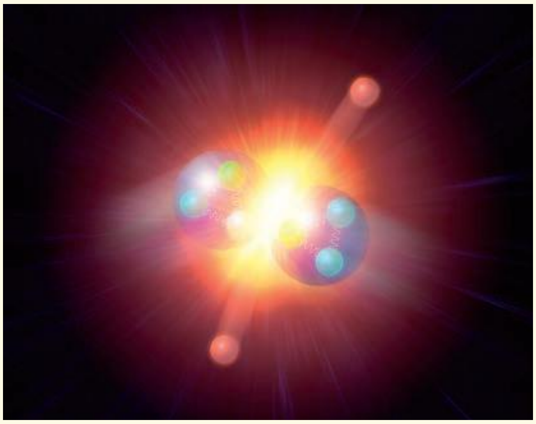

Figure 7.28 Two protons collide to emit two Higgs bosons. The protons are each made up of three smaller quarks.

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.

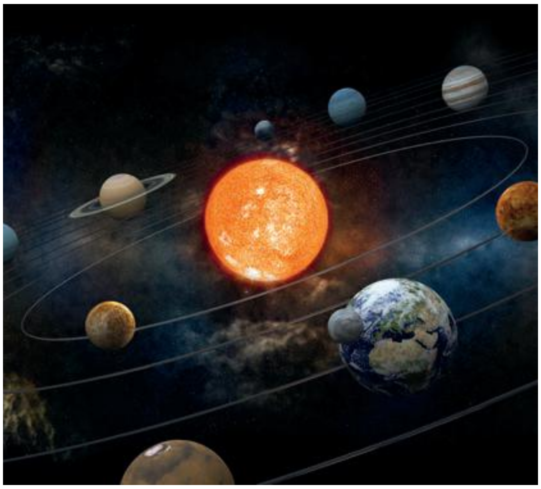

Figure 7.29 The solar system. The planetary model of the atom is based on the structure of our solar system.

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 or 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.

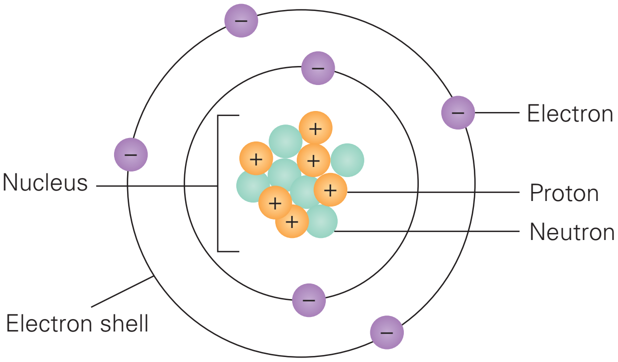

Figure 7.30 A Bohr diagram shows the positively charged nucleus (containing both protons and neutrons) and electrons orbiting in shells of different energy levels.

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 in the middle of it!

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Another model of the atom is the electron cloud model. As electrons are moving around the nucleus continuously, it is difficult to predict exactly where each electron will be at a given moment. Therefore, the electron cloud model shows large areas in the atom where electrons are most likely to be situated (orbitals) at any point in time.

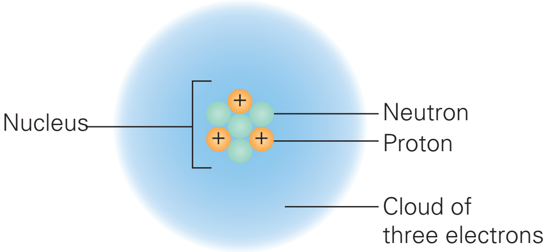


Figure 7.31 The electron cloud model shows the nucleus in the middle of a lithium atom surrounded by a cloud of electrons.

Did you know? 7.3

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.

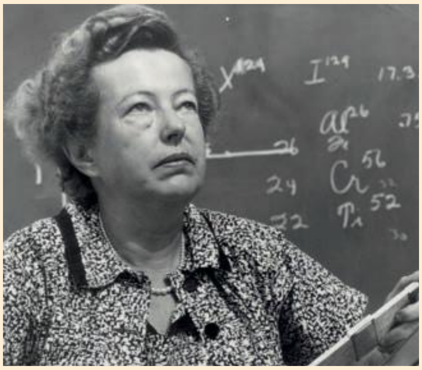


Figure 7.32 Goeppert Mayer's ground-breaking work on the nuclear shell model earned her the Nobel Prize in Physics in 1963, making her only the second woman to receive this honour after Marie Curie.

Quick check 7.5

1 What is the name of the structure at the centre of the atom and what does it contain?
2 Where are the electrons located?

Properties of subatomic particles

To understand more about atoms and how they behave, you 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. Remember, the protons in the nucleus in the middle of the atom have a positive charge (+1). Electrons orbiting the nucleus have a negative charge (−1). Positive and negative charges follow two basic rules of electrostatics: opposite charges attract and like (the same) charges repel. This means that the protons and electrons in an atom are attracted to each other, stopping the electrons from flying off into space. Neutrons are electrically neutral, which means they have relatively no charge (0). Table 7.1 summarises the relative charges of the subatomic particles.

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 $^{1}/_{1836}$ of a proton or a neutron. Table 7.2 summarises the relative masses of the three subatomic particles.

Subatomic particle	Relative charge
Proton	+1 (positive)
Neutron	0 (neutral)
Electron	–1 (negative)

Table 7.1 The relative charges of the three subatomic particles

Subatomic particle	Relative mass
Proton	1
Neutron	1
Electron	$^{1}/_{1836}$

Table 7.2 The relative masses of the three subatomic particles

VIDEO
Subatomic particles

Quick check 7.6

Copy and complete this table summarising 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^-			

Section 7.3 questions

QUIZ

Retrieval

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 atom where the protons and neutrons are located.

Comprehension

4 **Illustrate** a labelled diagram that shows the Bohr (or planetary) model of a beryllium atom that contains 4 protons, 5 neutrons and 4 electrons.

5 **Illustrate** a diagram of the electron cloud model of the atom.

Analysis

6 **Compare** the properties of protons, neutrons and electrons.

7 **Compare** the models you illustrated in Questions **4** and **5**.

Knowledge utilisation

8 **Propose** several reasons why models are useful in science. Explain the limitations of using models.

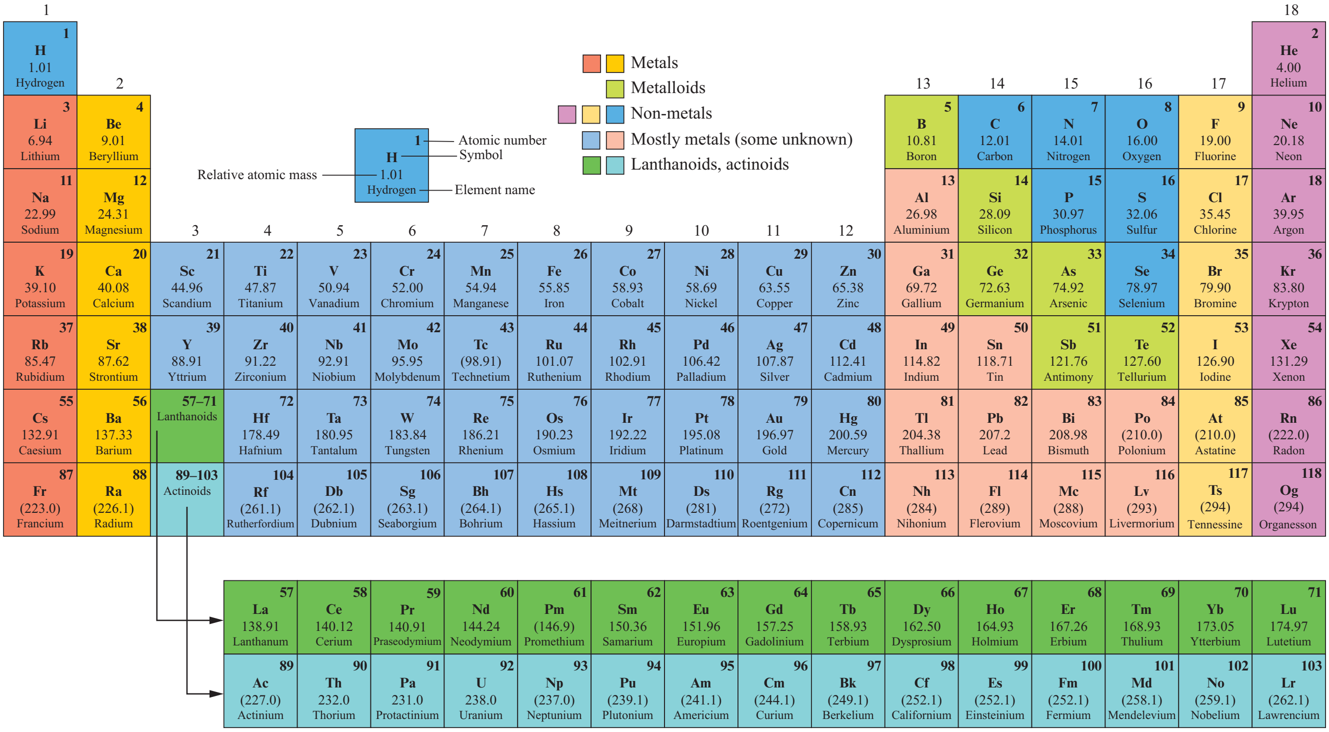
7.4 Atomic number and mass number

DOC

WORKSHEET
Numbers of subatomic particles 1

Learning goals

1. To determine the number of protons and electrons in an element.
2. To be able to calculate the mass of an atom from the number of protons and neutrons.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.01 Hydrogen																	2 He 4.00 Helium
3 Li 6.94 Lithium	4 Be 9.01 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.06 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.63 Germanium	33 As 74.92 Arsenic	34 Se 78.97 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.62 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.95 Molybdenum	43 Tc (98.91) Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.29 Xenon
55 Cs 132.91 Caesium	56 Ba 137.33 Barium	57–71 Lanthanoids	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Tl 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po (210.0) Polonium	85 At (210.0) Astatine	86 Rn (222.0) Radon
87 Fr (223.0) Francium	88 Ra (226.1) Radium	89–103 Actinoids	104 Rf (261.1) Rutherfordium	105 Db (262.1) Dubnium	106 Sg (263.1) Seaborgium	107 Bh (264.1) Bohrium	108 Hs (265.1) Hassium	109 Mt (268) Meitnerium	110 Ds (281) Darmstadtium	111 Rg (272) Roentgenium	112 Cn (285) Copernicum	113 Nh (284) Nihonium	114 Fl (289) Flerovium	115 Mc (288) Moscovium	116 Lv (293) Livermorium	117 Ts (294) Tennessine	118 Og (294) Organesson
			57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm (146.9) Promethium	62 Sm 150.36 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.93 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thulium	70 Yb 173.05 Ytterbium	71 Lu 174.97 Lutetium
			89 Ac (227.0) Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np (237.0) Neptunium	94 Pu (239.1) Plutonium	95 Am (241.1) Americium	96 Cm (244.1) Curium	97 Bk (249.1) Berkelium	98 Cf (252.1) Californium	99 Es (252.1) Einsteinium	100 Fm (252.1) Fermium	101 Md (258.1) Mendelevium	102 No (259.1) Nobelium	103 Lr (262.1) Lawrencium

Figure 7.33 The periodic table gives you information about each element's atoms.

atomic number
the number of protons in an atom of an element

The number of subatomic particles in an atom depends on the type of element being considered. Look at the periodic table 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.

Atomic number

The number on the top right of 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.

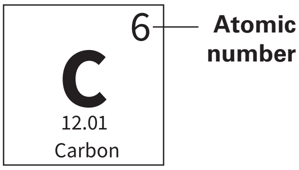


Figure 7.34 For the element carbon, the atomic number is 6. Therefore, you can conclude that it has six protons.

You will not find another element that contains six protons. This is because 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!

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 7.35 Carbon is a black solid with an atomic number of 6.

Figure 7.36 Liquid nitrogen is produced by cooling colourless nitrogen gas to –196°C. Nitrogen has an atomic number of 7.

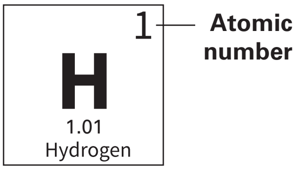


Figure 7.37 For the element hydrogen, the atomic number is 1, so you can conclude that it has one proton.

Quick check 7.7

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). So, the atomic number also tells you how many electrons an atom contains.

Changing the number of electrons in an element will not change the type of element, unlike changing the proton number, but it will change the chemical properties of the element. If the number of electrons in an atom changes, the atom is now referred to as an **ion** and is said to be charged. This is denoted by a superscript plus (+) or minus (–) sign after the chemical symbol. A plus sign indicates the atom has become more positive (lost negatively charged electrons), whereas a minus sign indicates the atom has become more negative (gained negatively charged electrons). For example, Mg^{2+} denotes a magnesium atom that has lost two electrons and now has an overall charge of 2+. It has 12 protons in the nucleus, but as it has lost two electrons so now only has 10 electrons.

ion
a charged version of an atom that has either gained or lost electrons

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Explore! 7.3

Charged particles

When the number of electrons in an atom changes, the properties of the element are affected. You are going to conduct some research on why this happens.

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 them 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 on what type of ions they 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. Consider whether it would be easier to donate one electron to have a full outer shell, or to try to gain seven. 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 the ion formed from:
   a sulfur
   b barium
   c iodine.

Investigation 7.1

Investigating which ions cause water hardness

Aim

To investigate the effect of different ions on water hardness

Planning

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 controlled variables as possible and describe how you will manage them to prevent any from affecting the measurements.
4 Develop a hypothesis to predict which ions will cause the hardest water.
5 Complete a risk assessment for this investigation, describing how any risks will be controlled.

Materials

- 8 test tubes
- 8 test-tube corks/bungs
- test-tube rack
- dropping pipettes
- 100 mL beaker
- marker pen

continued …

… continued

- 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 distilled or deionised water
- 10 mL sodium chloride, 0.1 mol/L
- 10 mL calcium chloride, 0.1 mol/L
- 10 mL magnesium chloride, 0.1 mol/L
- 10 mL potassium nitrate, 0.1 mol/L
- 10 mL sodium sulfate, 0.1 mol/L
- 10 mL iron(II) sulfate, 0.1 mol/L
- 10 mL magnesium sulfate, 0.1 mol/L

Method

1. 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.
2. Use a dropping pipette to transfer approximately 1 cm depth of soap solution to each test tube.
3. Seal the test tubes with a bung or cork and shake them well.
4. 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.

Analysis

Identify the ion(s) that cause the most water hardness. Justify your answer with data.

Evaluation

Reliability

1. Discuss the purpose of the test tube containing distilled water.

Limitations

2. Identify any potential sources of error in this experiment.

Improvements

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

Conclusion

Draw a conclusion from this experiment about ions and water hardness. Justify your answer with data.

Quick check 7.8

1. How does an atom become 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.

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DOC

WORKSHEET
Number 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

Mass number

The **mass number** of an atom is the sum of the protons and neutrons in the nucleus. The mass number is a whole number and is not found in the periodic table for any elements. It is not to be confused with the second number that is listed for every element in the periodic table, the relative atomic mass. Electrons are not considered when calculating the mass number because their mass is so small that it is considered negligible.

The second number listed for each element in the periodic table is called the **relative atomic mass** and it is seldom a whole number (see Figure 7.38). This is because 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 later in the chapter. The relative atomic mass shows the average mass of an element's atom when considering all natural isotope masses and their abundances.

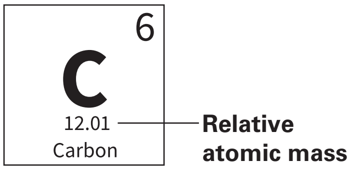

Figure 7.38 The atomic symbols for carbon showing the atomic number of 6 and relative atomic mass of 12.01. These numbers can be used to estimate the number of neutrons in a carbon atom.

Thus, for a single atom, the mass number can be calculated by the following equation:

Mass number = number of protons + number of neutrons

Unlike for protons, changing the number of neutrons in an atom of an element will not change the type of element, but it will change how it behaves.

Worked example 7.1

An oxygen atom has an atomic number of 8 (8 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 numbers (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 number of neutrons.

Quick check 7.9

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 7.4 questions

QUIZ

Retrieval

1 **State** the names of the two numbers that accompany each element on the periodic table.
2 **Identify** which of the numbers you named in Question **1** is always the largest.
3 **State** the name of the element that has an atomic number of 20.
4 An atom has a mass number of 45 and an atomic number of 16. **Calculate** how many neutrons it has. Show your working.
5 **Identify** the subatomic particles that have nearly the same mass.

Comprehension

6 **Explain** why the mass of the electron is not considered in the mass number.
7 Copy and complete the table using the information in the periodic table to **summarise** the structure of the different elements.

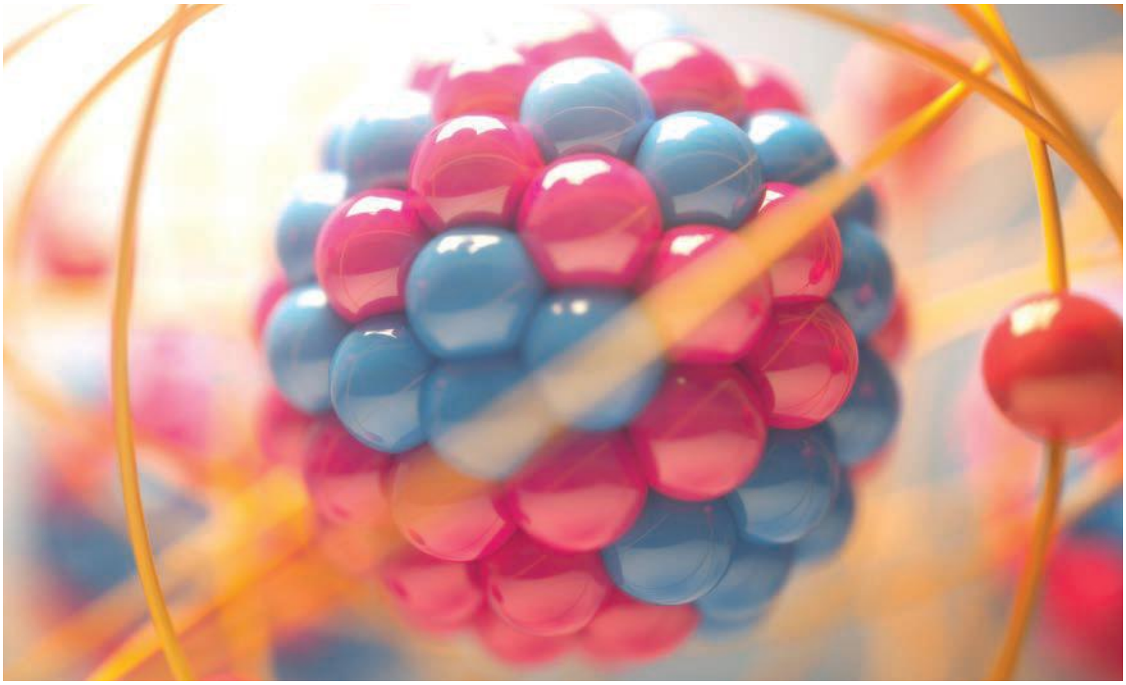
Name	Atomic number	Relative atomic mass	Number of protons	Number of neutrons	Number of electrons
Oxygen					
Helium					
Fluorine					

Analysis

8 **Compare** the mass number and the atomic number of an element.

Knowledge utilisation

9 'The mass number determines the identity of the element.' **Propose** whether this statement is true or false. Justify your answer.
10 **Justify** why no two elements on the periodic table have the same atomic number.
11 **Evaluate** the statement: 'Atoms are always neutral.'



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7.5 Isotopes

WORKSHEET
Isotopes

VIDEO
Uses of isotopes

Learning goals

1. To be able to define 'isotope' and 'radioactive half-life'.
2. To be able to describe three types of nuclear radiation.
3. To be able to compare the ionising and penetrating power of alpha, beta and gamma radiation.

Earlier in this chapter, you learned how changing the number of protons in an atom results in a different element identity. 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 but different mass numbers are called isotopes. This means that they have the same number of protons as each other (same atomic number; therefore, the same element), so their different mass numbers must be explained by having a different number of neutrons, as the mass of electrons is considered 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', as they were in the same place 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 (see Figure 7.40). All three of these forms are the element carbon because they all have an atomic number of 6 (6 protons).

Figure 7.39 In 1913, Frederick Soddy discovered isotopes in his work on uranium, which earned him the Nobel Prize in Chemistry in 1921.

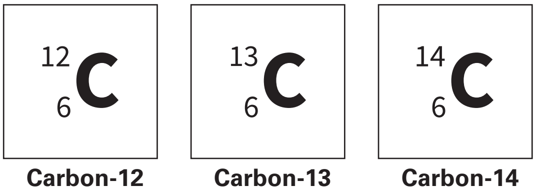

Figure 7.40 The three naturally occurring isotopes of carbon

Notice that the three forms of carbon have different mass numbers (12, 13 and 14). This difference in mass number is because they have 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, the first form of carbon has six neutrons, the second has seven and the third has eight. As they have different numbers of neutrons but the same atomic number, they are called isotopes of carbon.

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Note that 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 because most carbon atoms have a mass of 12, but a small number of atoms naturally occur with a mass of 13 or 14.

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 showing isotopes is to use a symbol notation. You will notice that on the periodic table the atomic number is written at the top; this is because the atomic number is used to define the element. When you write the symbols for isotopes, often a **nuclide notation** is used, whereby the mass number is written on the top left-hand side of the element symbol and the atomic number is written on the bottom left-hand side of the element symbol (see Figure 7.41).

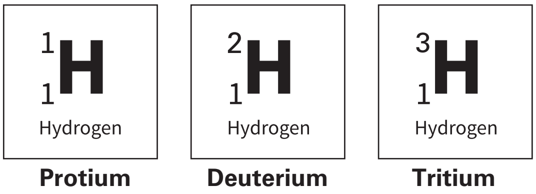

Figure 7.41 The three naturally occurring isotopes of hydrogen in nuclide notation

Stable and unstable isotopes

WIDGET
Nuclear equations

The stability of an isotope is based on whether it is likely to break down or decay into other elements. Often, heavy isotopes (that is, those that have many more neutrons than protons) are unstable compared to lighter isotopes (having similar numbers of neutrons and protons), which are stable. Unstable isotopes, such as the isotopes of the element uranium, are often 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 7.3 summarises the differences between stable and unstable 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 at the bottom left

radioactive decay
when an unstable nucleus emits radiation (alpha and beta particles or gamma waves) and breaks down to form another element

Stable isotopes	Unstable isotopes
Have a stable nucleus	Have an unstable nucleus
Not radioactive	Radioactive

Table 7.3 A comparison between stable and unstable isotopes

Explore! 7.4

Unusual mass numbers

The mass number of chlorine on the periodic table is 35.45. If you were to use this number to work out the number of neutrons, then it would have 18.45 neutrons. This is incorrect because 0.45 of a neutron cannot exist. Conduct some research as to why this is the case.

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?

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Quick check 7.10

1 Define 'isotope'.
2 How would you name an isotope of magnesium that has a mass number of 25?

WORKSHEET
Radioactive
decay

Did you know? 7.4

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, so they are very unstable. 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 7.42 Marguerite Perey was a French physicist who discovered the element francium, which is one of the rarest and most unstable elements on the periodic table. She was the first woman to be elected to the prestigious French Academy of Sciences.

Quick check 7.11

Recall the characteristics of unstable isotopes.

Radioactive decay

When a radioactive nucleus decays, some of the energy stored in the nucleus (nuclear energy) is transformed to different types of energy such as heat and light, but kinetic energy is also emitted. Energy is always conserved, so the decay of a nucleus converts some nuclear energy into other forms of energy. Emission from radioactive decay is commonly in the form of alpha (α) and beta (β) particle decay or emission of high-energy light in the form of gamma (γ) radiation.

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, the atomic number decreases by 2 and the 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 7.43 shows what happens when an atom of radon-222 undergoes alpha decay. Note: An alpha particle can be shown as either $^{4}_{2}\mathrm{He}$ or $^{4}_{2}\alpha$ and has a charge of 2+.

$$^{222}_{86}\mathrm{Rn} \rightarrow {}^{218}_{84}\mathrm{Po} + {}^{4}_{2}\mathrm{He}$$

$$^{222}_{86}\mathrm{Rn} \rightarrow {}^{218}_{84}\mathrm{Po} + {}^{4}_{2}\alpha$$

Figure 7.43 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.

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. The emitted He-4 is often described as an alpha particle.

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 altogether. The mass number of the remaining atom is not affected because it has lost a neutron but gained a proton. The equation in Figure 7.44 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 ${}^{0}_{-1}\beta$.

$$ {}^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e} $$

$$ {}^{131}_{53}\mathrm{I} \rightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\beta $$

Figure 7.44 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. The equation in Figure 7.45 shows the gamma decay of radioactive cobalt-60. As the cobalt-60 nucleus is unstable, it is said to contain more nuclear energy than 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.

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 that has high energy and a very short wavelength; produced when certain radioactive atoms decay

$$ {}^{60*}_{27}\mathrm{Co} \rightarrow {}^{60}_{27}\mathrm{Co} + {}^{0}_{0}\gamma $$

Figure 7.45 When an excited cobalt-60 nucleus decays, a gamma ray is emitted.

As previously discussed, 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! As you learned in Chapter 6, light can move in the form of a wave, even if our eyes cannot detect the wave form.

Explore! 7.5

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.

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 7.46 Marie Curie discovered the radioactive elements radium and polonium.

Did you know? 7.5

A Nobel Prize-winning family

Irène Joliot-Curie was a French physicist and chemist and the daughter of Marie Curie. She, along with her husband Frédéric Joliot-Curie, discovered artificial radioactivity in 1934. This discovery allowed scientists to produce new isotopes of elements that did not exist in nature.

Joliot-Curie's work on isotopes helped to advance our understanding of nuclear physics and chemistry, and she became the second woman to win a Nobel Prize after her mother.

Figure 7.47 Irène and Frédéric Joliot-Curie in their laboratory

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). Table 7.4 and Figure 7.48 summarise the properties of the three types of radiation.

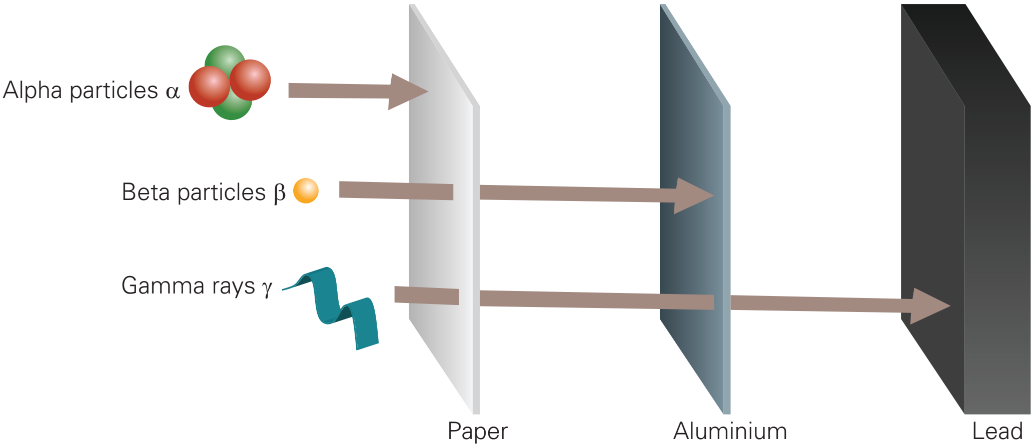

Figure 7.48 The penetrating powers of alpha, beta and gamma radiation

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 ${}^{4}_{2}\text{He}^{2+}$ ion; can cause the most damage, especially if they are 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 7.4 Properties of the three different types of radiation

Quick check 7.12

1. If an atom emits alpha radiation, what particle does it give off and how is the atom changed as a result?
2. If an atom emits beta radiation, what particle does it give off and how is the atom changed as a result?
3. Describe how gamma radiation differs from alpha and beta radiation.

Radioactive half-life

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 the **half-life** and 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. 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.

Uranium-238 is a naturally occurring isotope with a very long half-life of about 4.5 billion years, undergoing primarily alpha decay to form thorium-234. In contrast, 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!

Quick check 7.13

1. Define radioactive 'half-life'.
2. Write a nuclear equation for the:
   a. beta decay of C-14
   b. alpha decay of U-238.

Applications of radioactivity

There are about 90 naturally occurring elements with about 250 stable isotopes and about 3200 unstable radioisotopes. Stable isotopes and radioisotopes both have important uses.

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

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.

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 pipelines and materials used in aircrafts and spacecrafts. 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.

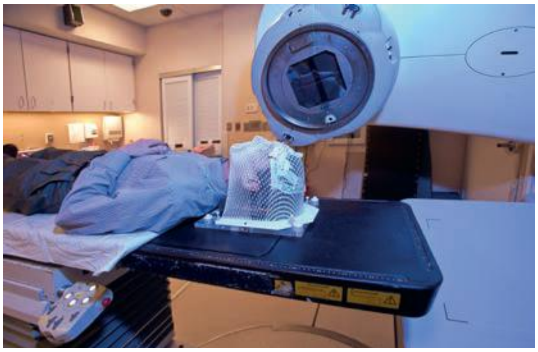

Figure 7.49 A patient undergoing radiotherapy for cancer

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Science as a human endeavour 7.3

Radiocarbon dating rock art

Carbon-14 is an isotope of carbon that primarily decays by beta radiation to nitrogen-14 on a consistent time scale. Scientists can predict the age of a fossil by examining the relative amounts of carbon-14 and nitrogen-14 in an organic fossil, in a technique known as radiocarbon dating. Carbon dating techniques are continuously improving, allowing for more accurate dating.

In early 2020, a team of researchers from across Australia collaborated on dating First Nations Australian rock art in the Kimberley region of Western Australia. Dating rock art can be challenging because much of the carbon in the organic ochre has degraded. However, the team of researchers instead radiocarbon dated overlying and underlying mud-wasp nest fossils to provide an age range for the paintings. A lot of the rock art in the area ranged from 10 000 to 12 000 years old with some being over 20 000 years old!

Figure 7.50 An example of the rock art that was radiocarbon dated

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Practical skills 7.4: 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, 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.

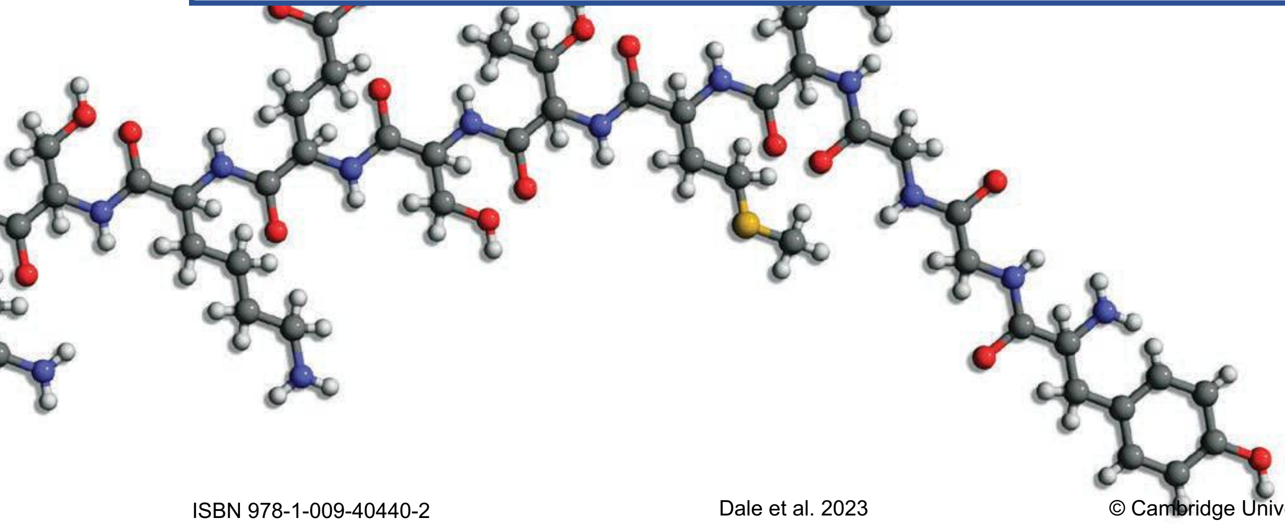
Radiation	Material that stops most of the radiation from passing through	Penetrating power
Alpha		
Beta		
Gamma		

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.

Evaluation

Discuss how the experiment could be modified to show the effectiveness of the radiation over different ranges and thickness of absorbing materials.



Science as a human endeavour 7.4

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 that smoke is 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:

$$^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\alpha$$
$$^{241*}_{95}\mathrm{Am} \rightarrow {}^{241}_{95}\mathrm{Am} + {}^{0}_{0}\gamma$$

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.

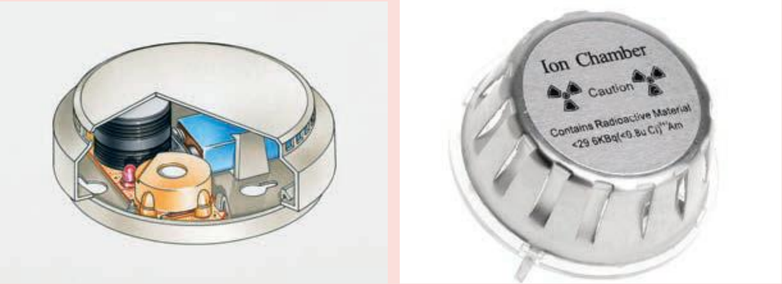


Figure 7.51 A cross-section of an ionisation chamber smoke detector (left). It shows a battery (blue), a piezoelectric sounder (yellow) and an ionisation chamber (black). An americium-241 ionisation chamber (right).

Section 7.5 questions

Retrieval

1 **Determine** the name of an isotope of barium with a mass number of 130.
2 **Determine** the name of an isotope of potassium with 22 neutrons.
3 **Name** three important uses of radioisotopes.

Comprehension

4 **Describe** the relationship between the mass of an isotope and its stability.
5 **Summarise** what happens to the nucleus of an element during alpha decay.

Analysis

6 **Contrast** stable isotopes and radioisotopes.
7 **Compare** these isotopes of sodium: Na-23 and Na-24.

Knowledge utilisation

8 **Construct** an equation to show the alpha decay of uranium-235 to thorium-231.
9 An element undergoes radioactive decay, but its atomic number and mass number are not affected. **Deduce** the type of decay.
10 During the radioactive decay of an isotope, a high-energy electron is released. **Deduce** the type of decay.

Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
7.1	I can distinguish between atoms, elements, compounds and molecules.	14	
7.2	I can discuss how the model of the atomic structure was developed.	7, 9, 19, 21, 22	
7.3	I can distinguish between protons, neutrons and electrons.	2, 4, 15	
7.4	I can determine the subatomic particles in an atom, using information from the periodic table.	10, 20	
7.5	I can describe how isotopes of an element differ from each other.	13	
7.5	I can discuss the different forms of radioactive decay.	6, 13, 17	
7.5	I can define 'radioactive half-life'.	3	

Review questions

SCORCHER

Retrieval

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 If a neutral atom has 18 protons, **state** how many electrons it has.

6 **Recall** the type of particle that is released during beta decay.

Comprehension

7 **Describe** the planetary model of the atom.

8 **Explain** why atoms of elements have a neutral overall charge.

9 **Explain** how Rutherford's gold foil experiment led to the discovery of the nucleus.

10 **Summarise** the three main isotopes of neon. You may do so in a table like the one shown here.

Isotope	Mass number	Number of protons	Number of neutrons	Number of electrons
$^{20}_{10}\text{Ne}$				
$^{21}_{10}\text{Ne}$				
$^{22}_{10}\text{Ne}$				

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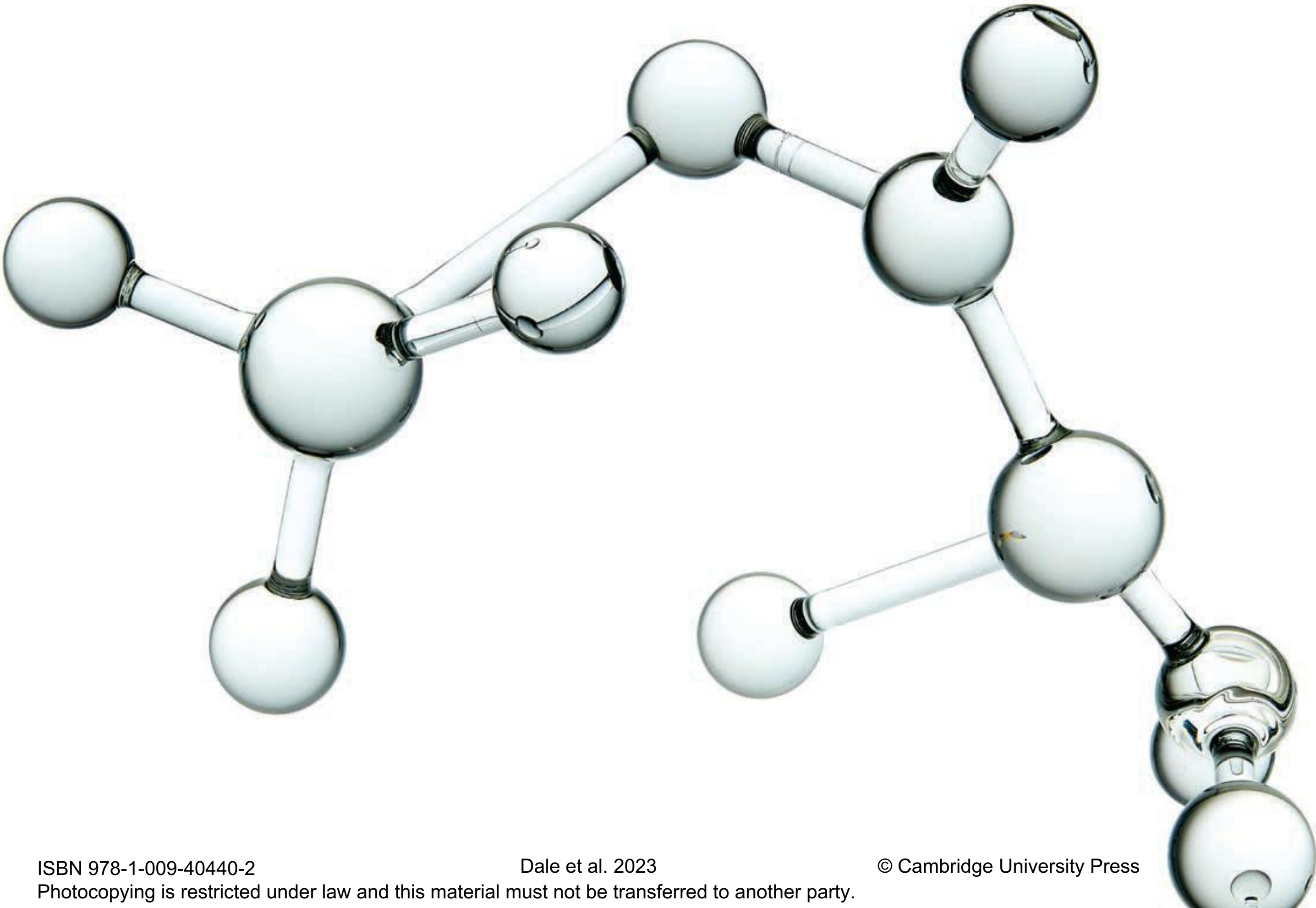
11 Apply your knowledge of the overall charge of an atom to **explain** what would happen to an oxygen atom if it had an extra electron (nine electrons).
12 **Explain** why the neutron was difficult to discover.
13 **Describe** the differences between isotopes of the same element.

Analysis

14 **Contrast** an element and a compound.
15 **Compare** the properties of the subatomic particles in terms of their mass and charge.

Knowledge utilisation

16 **Deduce** the relationship between the mass of an element and how stable it is.
17 Ionising radiation is used in smoke detectors. **Decide** which type of radiation you would choose for this use and why.
18 **Propose** why radioactive sources in schools must be stored in lead-lined boxes.
19 Democritus and Aristotle were philosophers, not modern scientists. In what ways were their thoughts ‘scientific’ and in what ways were they ‘not scientific’? **Discuss** how significant their contributions were to atomic theory.
20 **Write** a nuclear equation for the beta decay of iridium-192.
21 ‘The current atomic model is perfect and accurate.’ **Evaluate** the accuracy of this statement.
22 **Discuss** whether you expect the atomic model to change significantly in the future. Justify your answer.
23 **Deduce** why there is usually such a long period between a scientist proposing a theory and the theory being supported or refuted by valid scientific evidence.



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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 7.52. Scientists can predict the age of a fossil by analytical techniques that measure the relative abundances decay curves of carbon-14 and nitrogen-14 in the fossil.

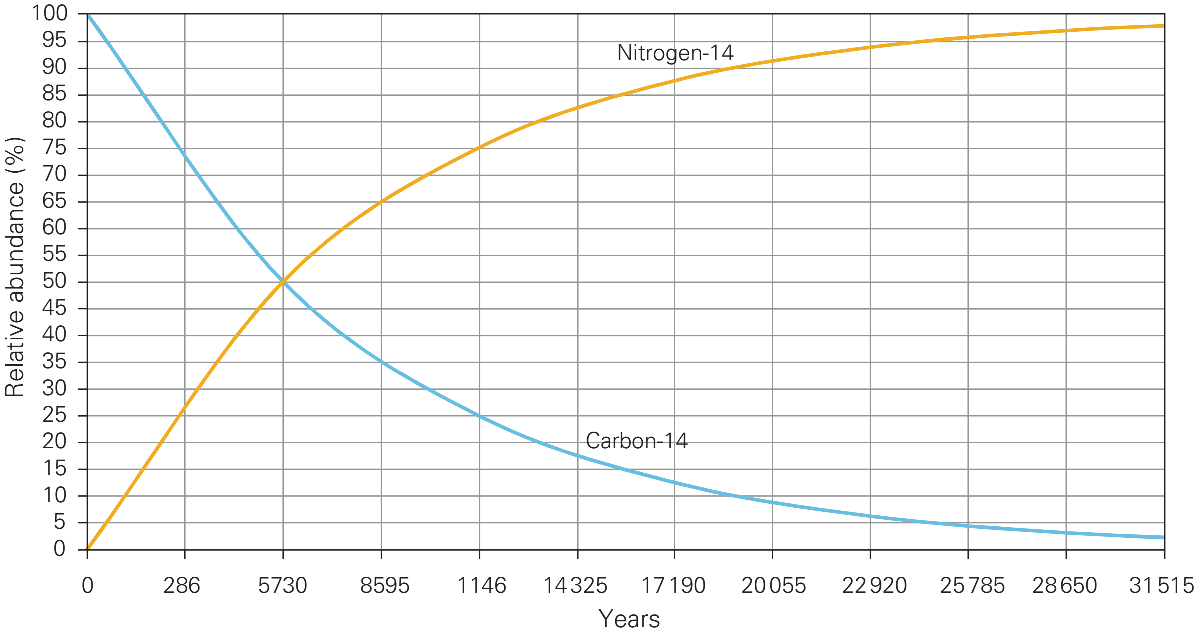


Figure 7.52 The relative abundance of carbon-14 (blue line) and nitrogen-14 (orange line) in an initial sample of carbon-14 over 31 515 years

Apply

1 A scientist has measured the relative abundance of carbon-14 in a sample of First Nations 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.

Analyse

4 **Contrast** the two curves and comment on the relative rate of decay of carbon-14 and growth of nitrogen-14.

Interpret

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.

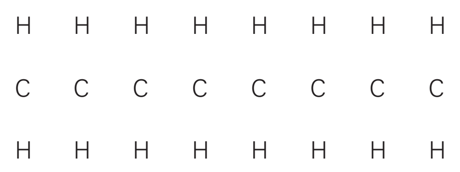
STEM activity: Designing and creating a product using bioplastics

Background information

Plastic is one of the most commonly used substances today. It is used for everything from food packaging to toys, from 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.

Design brief: Design and create a product using bioplastics.



$$\begin{array}{cccccccc} H & H & H & H & H & H & H & H \\ C & C & C & C & C & C & C & C \\ H & H & H & H & H & H & H & H \end{array}$$

Figure 7.53 Polyethylene is the simplest plastic, consisting 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 7.54 Plastic litter builds up on beaches.

Figure 7.55 An oil refinery in Brisbane

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.

bioplastic
a type of plastic made from renewable resources such as plants

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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.

Suggested materials

- corn starch
- vinegar
- glycerine
- water
- food dye (optional)
- saucepan
- wooden spoon
- hotplate
- non-stick/baking paper/aluminium foil and tray
- cookie cutters or moulds to shape the plastic
- safety glasses

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.

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 be set.

Evaluate and modify

9 Describe any difficulties you encounter when creating your product out of the 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.

Chapter 8
Chemical reactions

Chapter introduction

Chemical reactions occur when atoms in reactants undergo rearrangement, resulting in the formation of new products. The law of conservation of mass states that mass cannot be created or destroyed during a chemical reaction. 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. In this chapter, you will gain insight into the significance of balanced chemical equations, which provide essential information that is used to optimise and benefit industrial chemical syntheses.

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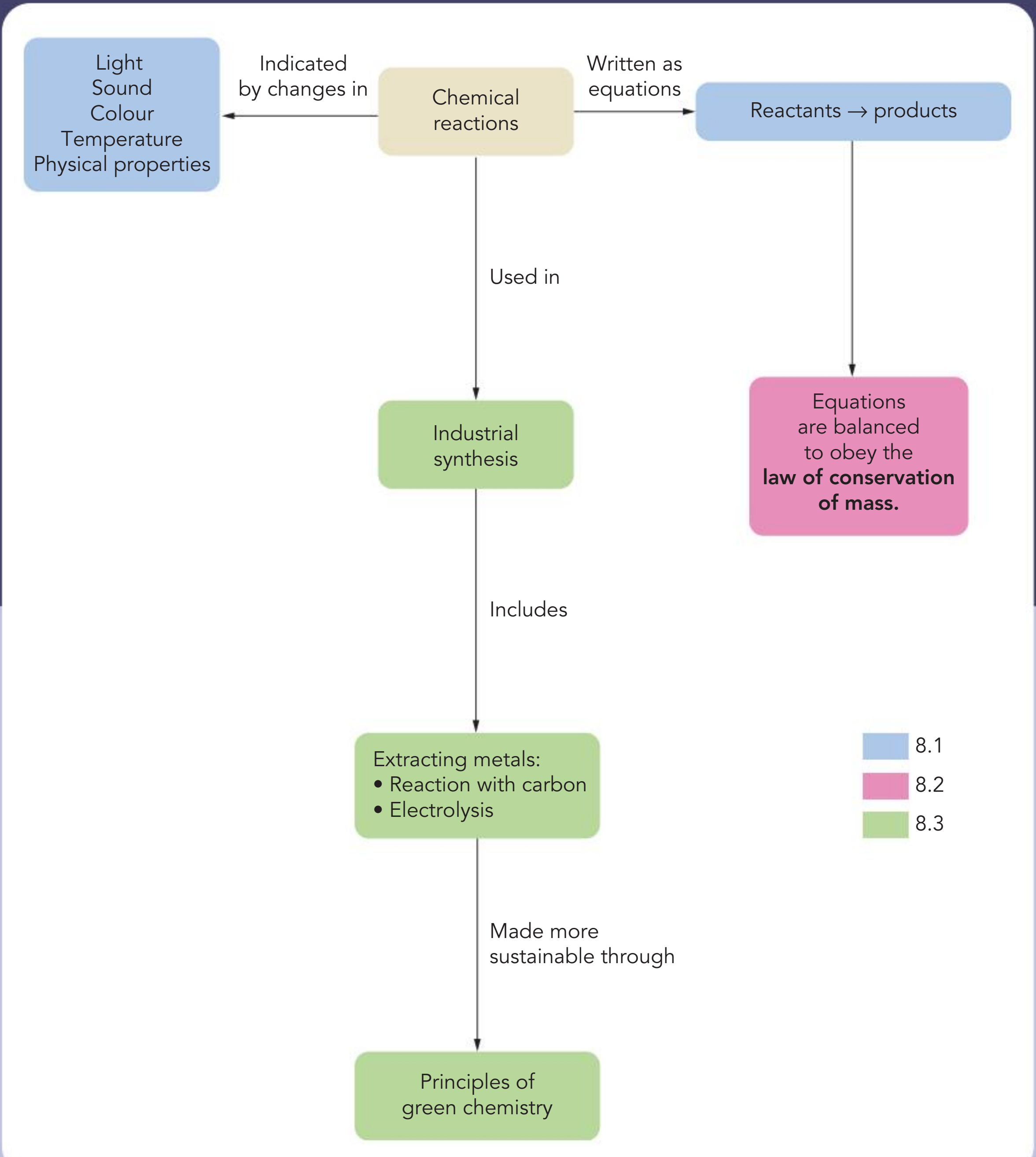
Concept map


Light
Sound
Colour
Temperature
Physical properties
Indicated by changes in
Chemical reactions
Written as equations
Reactants → products
Used in
Equations are balanced to obey the **law of conservation of mass.**
Industrial synthesis
Includes
Extracting metals:
• Reaction with carbon
• Electrolysis
8.1
8.2
8.3
Made more sustainable through
Principles of green chemistry

Curriculum

Model the rearrangement of atoms in chemical reactions using a range of representations, including word and simple balanced chemical equations, and use these to demonstrate the law of conservation of mass (AC9S9U07)	
identifying reactants and products in chemical reactions	8.1
using models and representations to show the rearrangement of atoms in chemical reactions	8.1
investigating chemical reactions in closed and open systems and relating data obtained to the law of conservation of mass	8.2
writing symbolic equations that are easy to balance and explaining, using the law of conservation of mass, and atoms, the rationale for investigating why most elements are not found in their elemental state and processes which are used to obtain the element	8.2, 8.3
predicting how ideas of green chemistry such as minimising the amount of unusable waste products, energy use and using more environmentally friendly chemical processes will affect the environment	8.3

Glossary terms

Balanced
Catalyst
Chemical change
Coefficient
Effervescence
Electrolysis
Law of conservation of mass
Native metal
Product
Reactant
Reaction conditions
Rearrange

8.1 Chemical reactants and products

Learning goals

1. To be able to recall the evidence of chemical change.
2. To be able to label reactants and products in a chemical equation.

WORKSHEET
Chemical reactions

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 reactants.

Figure 8.1 All the ingredients in your sandwich, from bread to salt, were made by chemical reactions.

What is a chemical reaction?

The easiest way to describe a chemical reaction is that starting substances are converted into new substances, but of course it is not as simple as that. 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 8.2 shows a chemical reaction in which compound 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. The arrow in the chemical reaction separates the starting substances that react together from the new substances produced by the reaction. The arrow indicates that a reaction is occurring and is normally said aloud as 'yields'. A chemical equation does not have an equals sign.

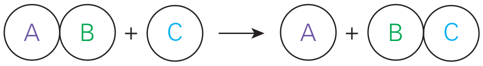


Figure 8.2 Rearranging atoms in a chemical reaction

Let's look at a real-life example. Figure 8.3 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.

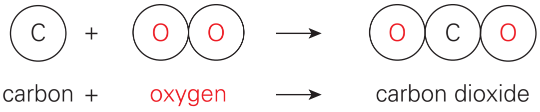


Figure 8.3 The formation of carbon dioxide is a chemical reaction.

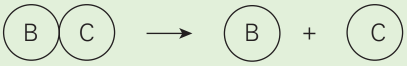
The rearrangement of the atoms can affect the properties of the substances in chemical reactions. Carbon is a solid at room temperature and oxygen is a gas. The compound formed in this reaction, carbon dioxide, is a gas at room temperature. The arrangement of the atoms within a compound determines the properties of a substance, which is why the properties of the compound formed in Figure 8.3 are so different from the starting substances.

rearrange
move things into a different order

Quick check 8.1

1 Explain how new substances are formed during a chemical reaction.

2 Describe what is happening to the substances in the following equation.



Making thinking visible 8.1

Think, puzzle, explore: Reactants and products

Think: What do you already know about how atoms rearrange in chemical reactions?

Puzzle: What questions do you have that puzzle you about the rearrangement of atoms in chemical reactions?

Explore: Conduct some research on how atom rearrangement can be demonstrated in word equations and balanced chemical equations.

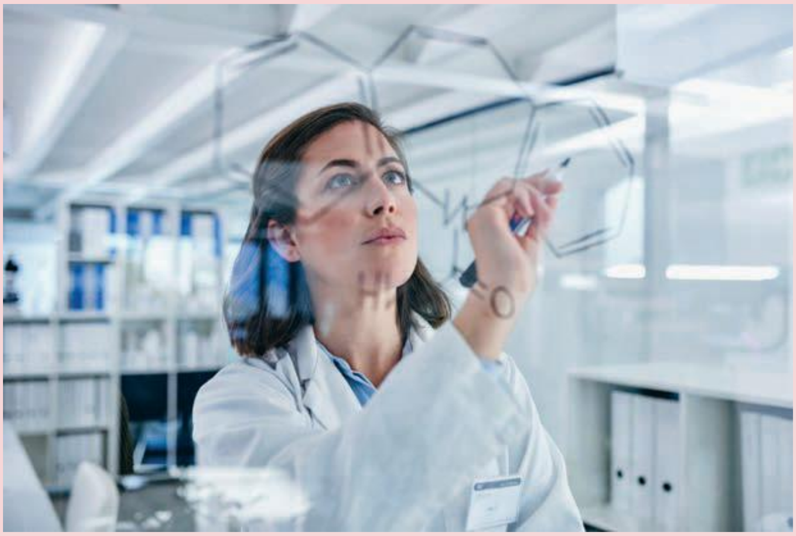


Figure 8.4 Scientists present chemical structures and reactions in a variety of different ways.

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

VIDEO
Chemical
reactions

Indicators of a chemical change

The difference in properties between the starting and new substances is one piece of evidence that a chemical reaction has occurred, but there are other distinctive ways in which this can be observed. In Year 8 you learned about the differences between a physical and a **chemical change**. Table 8.1 lists some observable evidence of a chemical reaction.

chemical change
a rearrangement of atoms that is often irreversible

A chemical change occurs when chemical species react to form new chemical species 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.

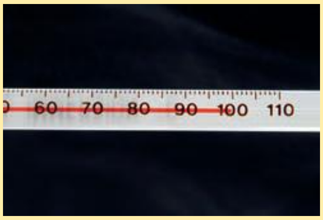
Indicator	Example
Sound produced	Hydrogen and oxygen reacting together to make water creates a loud bang. 
Change in colour	A grey-coloured iron nail reacting with oxygen and water forms red rust (iron oxide). 
Change in physical properties	Sodium (a soft metal) reacting with water (a colourless liquid) 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 8.1 Indicators of a chemical reaction

effervescence bubbles or fizzing in solution

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Figure 8.5 Ice melting and forming water is an example of a physical change, rather than a chemical change resulting in a change in physical properties.

Quick check 8.2

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. When a pan of water is heated on a cooker top, the water turns into steam. When the steam hits a cold window, it condenses back into liquid water. Is this an example of a physical change, chemical change or both?

How is a chemical equation written?

Reactants and products

In a chemical reaction, substances react with each other to form new substances. 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 8.6 shows a word equation for the reaction between magnesium and hydrochloric acid. A word equation shows reactant and product chemical species written in words with an arrow 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

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

Magnesium and hydrochloric acid are reactants, so they are written on the left-hand side of the arrow. Magnesium chloride and hydrogen are products, so they are written on the right-hand side of the arrow. The arrow denotes that a chemical change has occurred.

Reaction conditions

Not all chemical reactions happen spontaneously; that is, occur without us having to do anything to them. Some reactions require heat or light energy to get started, some require high pressures, some need a chemical called a **catalyst** to speed up the reaction. Some reactions happen spontaneously but require a longer period of time. These factors are called **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 do not get directly involved in the reaction (Figure 8.7b).

$$\underbrace{\text{magnesium} + \text{hydrochloric acid}}_{\text{reactants}} \rightarrow \underbrace{\text{magnesium chloride} + \text{hydrogen}}_{\text{products}}$$

Figure 8.6 A word equation for the chemical reaction between magnesium and hydrochloric acid

b $$\text{nitrogen} + \text{hydrogen} \xrightarrow[\text{450–500°C, 150–200 atmospheres (pressure)}]{\text{iron catalyst}} \text{ammonia}$$

Figure 8.7 **a)** Fertilisers are made from ammonia, a source of nitrogen. **b)** Ammonia in fertilisers is produced by the Haber process, which converts atmospheric nitrogen and hydrogen to ammonia in the presence of a catalyst and at high temperatures and pressures.

Quick check 8.3

1. On which side of a chemical equation are the products written?
2. On which side of a chemical equation are the reactants written?
3. Where should the reaction conditions be written in a chemical equation?

Did you know? 8.1

The perfect soufflé

A soufflé is a French sweet or savoury dish made with beaten egg whites. Its name comes from the French word *souffler*, which means 'to puff' in English. A well-prepared soufflé uses chemical reactions in cooking the base mixture at approximately 190°C to produce gases that help to 'puff' the mixture. If the temperature is too high or the mixture is cooked for too long, the gas can escape the soufflé, causing it to irreversibly collapse. A collapsed soufflé is certainly a French culinary faux pas!

Figure 8.8 A soufflé is 'puffed' by gases produced in cooking.

Types of chemical equations

Chemical equations can be presented in different ways. Word equations show the names of the reactants and products, while chemical equations show the chemical formulas of the reactants and products. Chemical reactions can also be represented using chemical structures (as shown for caffeine in Figure 8.9), which give shape and chemical bonding structure information; however, you will not use this type of presentation in Year 9. 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.

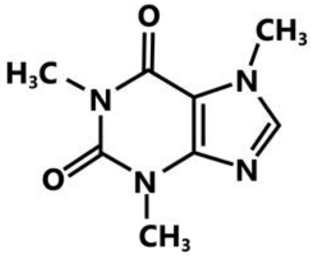

Figure 8.9 A caffeine molecule can be presented using a structural formula to provide more information about chemical bonding.

Section 8.1 questions

QUIZ

Retrieval

1 **State** what ‘→’ means in a chemical reaction.

2 **Name** 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 **Name** the products of each of the reactions in Question **2**.

4 **Select** the correct definition 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

Comprehension

5 **Describe** what happens to the atoms in reactants during a chemical reaction.

Analysis

6 **Compare** physical changes and chemical changes.

7 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.

8 **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

Knowledge utilisation

9 The following equation shows what happens during respiration in 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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8.2 The law of conservation of mass

Learning goals

1. To be able to define the 'law of conservation of mass'.
2. To be able to interpret a word equation and a balanced chemical equation for a chemical reaction.

WORKSHEET
Conservation of mass 1

Science as a human endeavour 8.1

Phlogiston theory and the discovery of oxygen

In the late 1700s, a theoretical element called phlogiston (from the Greek *phlox*, which means 'flame') was attributed to the flame produced during a combustion reaction. In 1774, scientist Joseph Priestley directly shone a beam of sunlight at a substance called 'red precipitate' (mercury oxide), which he considered to contain a large amount of phlogiston. As the red precipitate decomposed, it lost mass and Priestley collected a gas that was produced, which he called 'dephlogisticated air' (oxygen gas).

Priestley found that a candle burned for longer and a mouse lived for longer in the presence of the new type of air. Not only did Priestley make the first discovery of oxygen gas, but he had also built a foundation for the discovery of the law of conservation of mass that would come a decade later.

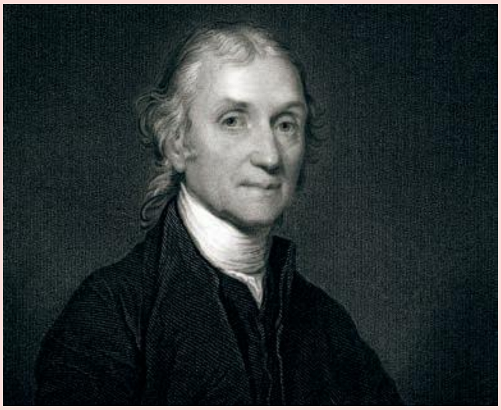

Figure 8.10 Joseph Priestley discovered oxygen.

One of the fundamental laws of chemistry is the **law of conservation of mass**. This law states that matter can be neither created nor destroyed in chemical reactions.

law of conservation of mass a scientific law that states that matter can be neither created nor destroyed

VIDEO
Law of conservation of mass

Historical understanding

In the late 1700s, scientists thought that for something to burn, it had to contain the element phlogiston (see Science as a human endeavour 8.1). 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.

Putting the law of conservation of mass into practice

The law of conservation of mass states that matter can neither be created nor destroyed – but what does this mean? Take the mass of all the ingredients used to make a pancake (flour, eggs and milk). When the pancakes have been cooked, the mass of all the pancakes made from the batter should equal the mass of the starting ingredients. This means that no matter is created or destroyed. However, as this is not a closed environment, there might be a difference between the two masses, as water evaporates from the batter during the cooking, meaning matter appears to be lost.

Figure 8.11 Antoine Lavoisier proposed the law of conservation of mass.

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Figure 8.12 The mass of the pancake batter should equal the mass of all the pancakes made from it. This is the law of conservation of mass in action.

DOC WORKSHEET Conservation of mass 2

If you leave a full glass of water outside on a hot day for long enough, it will become half full. The glass of water now had a smaller mass. You may conclude that this mass has been lost. But you know now that this is not the case. The water heats up, forming water vapour, which leaves the glass and goes into the air. Water vapour has mass. The water vapour has left the glass, which is why the mass of the glass decreases, but it is still present in the air somewhere. This example demonstrates why it is important to observe the conservation of mass in a closed system (one in which nothing can escape). In an open system, reactions that produce gases will appear to lose mass.

Figure 8.13 Leave a glass of water outside on a hot day and it will appear to lose mass.

Quick check 8.4

1. Who discovered the law of conservation of mass?
2. What is the definition of the law of conservation of mass?
3. If the mass of reactants is 30 g, what will the mass of products be?
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 8.14. Here, copper chloride ($CuCl_2$) is being broken down into its elements: copper (Cu) and chlorine (Cl_2).

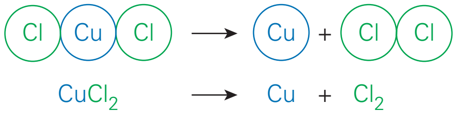
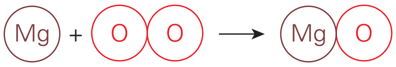


Figure 8.14 A particle representation and chemical equation showing the decomposition of copper chloride into its elements.

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. In the reactant, there is one atom of copper and two atoms of chlorine. In the products, there is one atom of copper and two atoms of chlorine. So, there is the same number of atoms on each side of the equation and therefore the same mass. The only difference is how the atoms are arranged.

Figure 8.15 shows a particle representation and chemical equation for the reaction between magnesium (Mg) and oxygen (O_2) to form magnesium oxide (MgO).

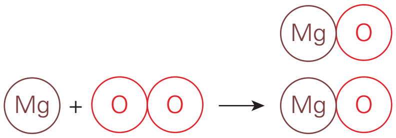


$Mg + O_2 \longrightarrow MgO$

Figure 8.15 The 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? The number of each type of atom in the reactants and the product is different. This means that the equation in Figure 8.15 is not obeying the law of conservation of mass. There is one magnesium atom on each side of the arrow, but the left-hand side of the equation has two oxygen atoms while the right-hand side has only one. This shows the product as having less mass than the reactants, which cannot happen. Therefore, the chemical equation must be altered to show that the law of conservation of mass is observed.

Figure 8.16 shows the equation adjusted so that it has two oxygen molecules on the right-hand side. This was done by adding another unit of magnesium oxide to the products. Notice that the chemical equation also now shows two magnesium oxide units in the products. However, adding the extra magnesium oxide unit to balance the oxygen atoms has also added another magnesium atom. The magnesium atoms are now unbalanced, with one on the left-hand side and two on the right-hand side of the equation. Adding one more magnesium atom to the left-hand side (reactants) makes the equation **balanced** (see Figure 8.17). Each side of the equation now has two magnesium atoms and two oxygen atoms. Again, notice that the chemical equation also reflects the addition of another magnesium atom. The numbers added to balance a chemical equation are called **coefficients**.

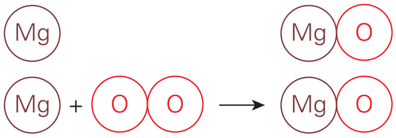


$Mg + O_2 \longrightarrow 2MgO$

Figure 8.16 This equation now has the correct number of oxygen atoms, but it is still not observing the law of conservation of mass.

balanced
when a chemical equation has an equal number of atoms of each element on both the reactant and product side of the equation

coefficient
a number placed in front of a chemical symbol to balance a chemical equation



$2Mg + O_2 \longrightarrow 2MgO$

Figure 8.17 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.

To show that a chemical equation obeys the law of conservation of mass, a balanced chemical equation provides more information than a word equation because the number of reactant and product atoms are presented. For now, you just need to concentrate on identifying whether equations observe the law of conservation of mass. In Year 10, you will learn how to balance chemical equations so that they follow this law.

Quick check 8.5

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.

Practical skills 8.1

Observing the law of conservation of mass (1)

Be careful

Do not stare directly at combusting magnesium.

Aim

To observe the law of conservation of mass by reacting magnesium and oxygen

Materials

- small piece of magnesium ribbon
- tongs
- crucible
- matches
- Bunsen burner
- clay triangle
- tripod
- heatproof mat
- safety glasses

Method

1 Copy the results table in the Results section.
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 Place a piece of magnesium ribbon in the crucible and weigh it again with the lid on.
5 Calculate the mass of magnesium by subtracting the mass of the empty crucible.
6 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.
7 Continue heating until the magnesium has fully reacted.
8 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.

Item	Mass (g)
Crucible + lid	
Crucible + lid + magnesium before heating	
Crucible + lid + compound after heating	
Magnesium	
Compound	

Analysis

1 Describe your observations when the magnesium reacted in the crucible. How did you know that a chemical change had occurred?
2 The formula for oxygen is O_2. Write a balanced chemical equation for this reaction.
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.

Evaluation

Limitations

1 Identify any potential sources of error in this experiment.

Improvements

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

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Practical skills 8.2

Observing the law of conservation of mass (2)

Aim

To observe the law of conservation of mass by reacting vinegar and baking soda

Materials

- 10 mL vinegar (acetic acid)
- 5 g baking soda
- balance
- small measuring cylinder
- small conical flask
- resealable plastic bag (big enough to fit 10 mL of vinegar and 5 g of baking soda, and with enough space for you to manipulate their containers)

Method

1. Copy the results table in the Results section.
2. Pour 10 mL of vinegar into the measuring cylinder.
3. Weigh out 5 g of baking soda into the conical flask.
4. Put the measuring cylinder and conical flask into the plastic bag. **Do not** spill any of the contents of the measuring cylinder or conical flask.
5. Measure the mass of the measuring cylinder, conical flask and plastic bag, using the balance. Record this in your results table.
6. Seal the plastic bag again, being careful not to spill any of the contents.
7. Without opening the bag, pour the vinegar into the conical flask containing the baking soda.
8. When you think the chemical reaction has finished, record the mass of the contents without opening the bag. Record this in your results table.
9. Calculate the change in mass using the initial mass and final mass results. Record these in your results table.

Results

Copy and complete the following table.

Initial mass (g)	Final mass (g)	Change in mass (g)

Analysis

1. Describe your observations when the vinegar and baking soda reacted in the plastic bag. How did you know that a chemical change had occurred?
2. The gas produced in the reaction is the same as one of the gases you breathe out. What is the name and formula of this gas?
3. When vinegar (acetic acid) reacts with baking soda (sodium bicarbonate), sodium acetate, water and carbon dioxide are produced.
   Write a word equation for this reaction.
4. This experiment was carried out in a closed system. Deduce what you think this means.

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Section 8.2 questions

QUIZ

Retrieval

1 **Recall** the law of conservation of mass.

2 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. **Demonstrate** that the mass of the second reactant must equal 13 g to obey the law of conservation of mass.

3 **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

Comprehension

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

Analysis

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 **Distinguish** between an open system and a closed system.

Knowledge utilisation

7 **Decide** whether an open system or a closed system is better to observe the law of conservation of mass. Justify your choice.

8 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.

9 Joy 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. Joy 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 **Develop** an experiment to prove who was correct.

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8.3 Industrial synthesis

Learning goals

1. To describe types of chemical reactions used to produce elements.
2. To be able to explain how manufacturers can improve chemical synthesis by using green chemistry principles.

WORKSHEET
Comprehension exercise

Chemical reactions occur naturally to produce a range of naturally occurring chemical compounds. 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.

Figure 8.18 Copper is a less reactive metal, which is why it can be found in its pure form in nature, i.e. it is a native metal.

native metal
a metal that exists in its elemental form in the environment

Extracting metals

As most metals in their elemental states are reactive, many of them are found naturally as compounds, known as ores. Ores contain metal atoms as chemical compounds mixed with other impure substances, but for some very unreactive metals, they may be found in the native elemental state.

Native 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 (Figure 8.18) metals can be found in their elemental form.

Reaction with carbon

Most relatively reactive metals 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 carbon dioxide and the pure form of the metal. The reaction below is an example of this form of extraction:

$$\text{iron oxide} + \text{carbon} \rightarrow \text{iron} + \text{carbon dioxide}$$

$$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$$

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Figure 8.19 Molten iron spews out of a blast furnace where iron ores are reacted with carbon to form pure iron metal.

Figure 8.20 An open cut gold mine in Ravenswood, Queensland

Practical skills 8.3

Extracting iron using a matchstick

Be careful

Wear appropriate personal protective equipment.

Aim

To extract iron from iron oxide

Materials

- 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
- cling wrap

Method

1 Copy the table shown in the results section.
2 Run the magnet over the iron(III) oxide powder, sodium carbonate powder and match head. Record whether they are magnetic.
3 Moisten the head of the match by dipping it into a beaker of water.
4 Place a small amount of sodium carbonate powder in a watchglass. Do the same with the iron(III) oxide powder.
5 Roll the head of the match in the sodium carbonate powder and then in the iron(III) oxide powder.
6 Using the pair of tongs, hold the head of the match into a blue Bunsen burner flame – only let it burn halfway down the match.
7 Allow the match to cool.
8 Use the spatula to crush the charred head of the match into the weighing boat.
9 Run the magnet underneath the weighing boat and record what you see. If you wrap the magnet in cling wrap, then it can be directly dipped into the match remains.

Results

Copy and complete the following table.

Substance	Magnetic?
Iron(III) oxide powder	
Sodium carbonate powder	
Match head (before heating)	
Charred remains (after heating)	

continued …

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… continued

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.

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 sodium and potassium.

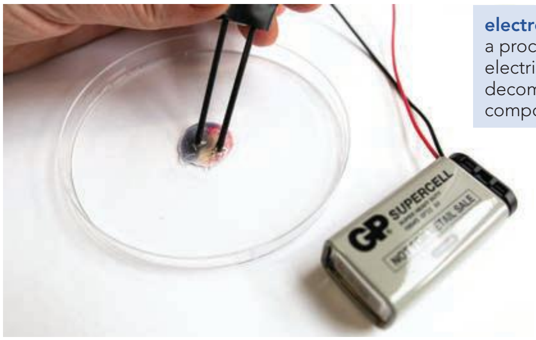

Figure 8.21 A small-scale electrolysis of molten sodium chloride to produce sodium metal.

electrolysis
a process in which an electric current is used to decompose a chemical compound

Explore! 8.1

Green hydrogen fuel stations

Green hydrogen fuel stations that are being constructed across Queensland store high-pressure hydrogen gas (H_2) or, in some cases, water (H_2O) that can be converted to hydrogen gas by electrolysis. Some green hydrogen fuel stations have solar panels and/or wind turbines, which generate electricity that is then used to power the electrolysis reaction that converts water into hydrogen and oxygen gases.

Do some research on the internet to answer the following questions.

Figure 8.22 Green hydrogen fuel is produced by the electrolysis of water.

1 Write a word equation and a balanced chemical equation for the electrolysis of water, also known as 'water splitting'.

2 Why is a hydrogen fuel station regarded as 'green hydrogen'?

Quick check 8.6

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.

VIDEO
Green chemistry

Principles of green chemistry

From an environmental perspective, industrial synthesis of metals can be considered as 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, which provides a framework for chemical manufacturers to produce products in a more sustainable way. These principles are considered by manufacturing companies all over the world to optimise their chemical reactions. A few of these principles of green chemistry are described in Table 8.2.

Chemical manufacturers produce a variety of products that we use every day, which include 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 (see Explore! 8.3). For example, you might already use eco-friendly biodegradable products such as toothbrushes, cutlery and cups. The future of all chemical syntheses is heading towards a more sustainable future.

Figure 8.23 Bamboo toothbrushes are made from renewable feedstocks and are biodegradable.

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 high amounts of energy which are often produced from other 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 8.2 Principles of green chemistry

Explore! 8.2

Controlled firestick farming

Figure 8.24 Rangers working with the Queensland Indigenous Women's Ranger Network conduct a controlled burn at Archer Point in far north Queensland.

At first glance, green chemistry and firestick farming may not seem similar, but the two are actually deeply intertwined.

Green chemistry is a philosophy and set of practices aimed at minimising the environmental impact of chemical processes, while firestick farming is a traditional land management technique used by First Nations Australians to promote biodiversity and maintain healthy ecosystems. Both approaches prioritise sustainability and aim to minimise harm to the natural world, making them powerful tools for preserving Earth's health and resilience.

For thousands of years, First Nations Australians have used fire to sustain Australian bushland and plant growth. Conduct some research on the benefits of firestick farming or cultural burning practice and answer the following questions.

1 What is cultural burning?
2 At what time of year, in the *north* of Australia, is cultural burning most effective and why?
3 What are the products of combusting plant material in excess oxygen?
4 How are local First Nations Australians' fire management practices informing and being adopted in Queensland's fire management?
5 Consider whether cultural burning follows green chemistry principles and why is it considered a sustainable practice.

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Explore! 8.3

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 a quick reference.

Head to the ACS website and explore the details of each of the 12 principles of green chemistry.

Green Chemistry Pocket Guide

The 12 Principles of Green Chemistry

Provides a framework for learning about green chemistry and designing or improving materials, products, processes and systems.

1. Prevent waste
2. Atom Economy
3. Less Hazardous Synthesis
4. Design Benign Chemicals
5. Benign Solvents & Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis (vs. Stoichiometric)
10. Design for Degradation
11. Real-Time Analysis for Pollution Prevention
12. Inherently Benign Chemistry for Accident Prevention

www.acs.org/greenchemistry

ACS Chemistry for Life®

ACS Green Chemistry Institute®

Figure 8.25 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/greenchemistry/principles/12-principles-of-green-chemistry.html

Did you know? 8.2

Green chemistry education

Dr Amy S. Cannon is recognised as the first person to earn a PhD in green chemistry. As the cofounder and executive director of Beyond Benign, a 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.

Figure 8.26 Dr Amy Cannon has received many awards for her leadership in promoting environmentally responsible chemistry practices.

Section 8.3 questions

QUIZ

Retrieval

1 **Define** ‘electrolysis’.

2 **List** three metals that can be found in the earth as native metals.

Comprehension

3 **Describe** what is meant by the use of renewable feedstocks in green chemical synthesis.

Analysis

4 **Explain** why extraction of iron using a blast furnace is not an energy-efficient chemical synthesis.

5 **List** three household objects in your house that may have been synthesised according to green chemistry principles.

Knowledge utilisation

6 **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

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

Success criteria		Linked questions	Check
8.1	I can identify indicators of chemical changes.	1	
8.1	I can identify the reactants and products in a chemical equation.	2	
8.2	I can recall the law of conservation of mass.	3, 5	
8.2	I can interpret a word equation and a balanced chemical equation for a chemical reaction.	5, 8	
8.3	I can recall some types of chemical reaction used to produce elements.	7	
8.3	I can explain how manufacturers can improve chemical syntheses using green chemistry principles.	4, 9	

Review questions

SCORCHER

Retrieval

1 **List** five indicators of chemical change.

2 **Describe** what is happening in the following reaction. Use these keywords: reactants, product, reaction conditions.

$$\text{hydrogen} + \text{oxygen} \xrightarrow{\text{heat}} \text{water}$$

3 **State** the law of conservation of mass.

Comprehension

4 **Describe** the green chemistry principle ‘design for degradation’.

5 **Explain** how a balanced chemical equation can provide evidence of the law of conservation of mass.

6 **Write** a word equation for the reaction of nitrogen gas and hydrogen gas to produce ammonia.

Analysis

7 **Compare** the conditions required for the reaction of a metal with carbon and an electrolysis reaction.

8 **Analyse** the following word equation and formula equation.

$$\text{hydrochloric acid} + \text{magnesium} \rightarrow \text{magnesium chloride} + \text{hydrogen}$$
$$2HCl + Mg \rightarrow MgCl_2 + H_2$$

Identify:

a the reactants

b the products

c whether it observes the law of conservation of mass

d the chemical formula of magnesium chloride

Knowledge utilisation

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 made to include the 12 green chemistry principles.

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.

11 **Discuss** whether cultural burning follows any principles of green chemistry.

Data questions

A variety of fuel sources is shown in Table 8.3, 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 8.27.

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 8.3 The relative number of carbon atoms per fuel molecule and the mass produced by burning 1 kg of fuel

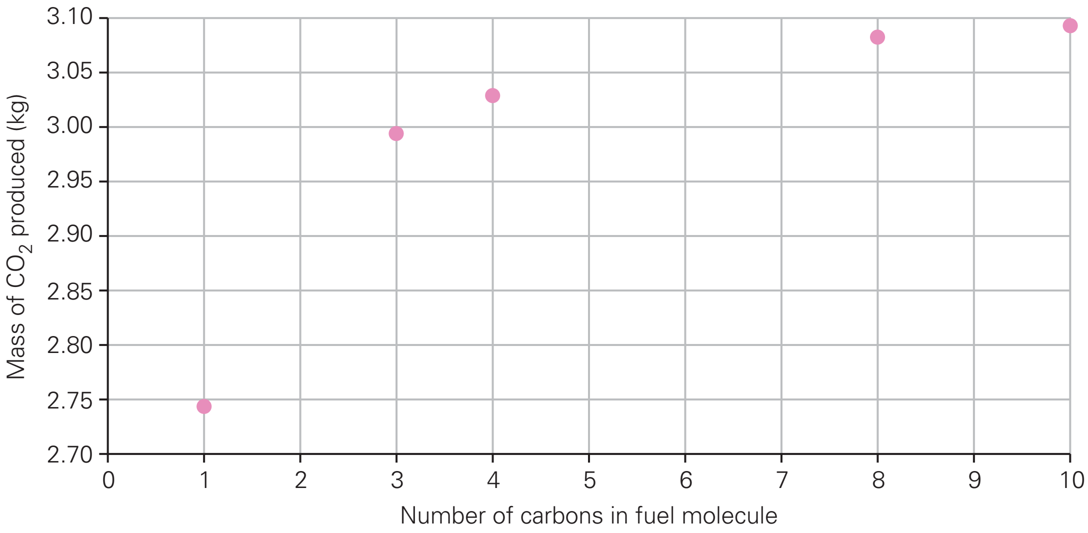

Figure 8.27 The relative number of carbon atoms per fuel molecule versus the mass of CO_2 produced by burning 1 kg of fuel

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Apply

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 their 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 the mass of carbon dioxide produced by burning 1 kg of their fuel is less than 1 kg more than that produced from natural gas. **Determine** whether the evidence from Table 8.3 supports this claim.

Analyse

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 8.3 as gas, liquid or solid.

Interpret

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

Science has applications in all industries, including medicine, technology and business. Did you know it is also key to the food and beverage industry?

Baristas in Australian coffee shops have felt the frustration of milk curdling. They want to be able to offer their customers rice milk, almond milk, coconut milk, lactose-free milk, soy milk and cow's milk, but all these products respond differently when heated and when they are added to tea and coffee.

What is curdling and why would milk curdle? 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.

Sometimes you might want curdling; for example, when you make yoghurt or cheese. But if you are trying to make a soy latte, curdling is very undesirable.

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 8.28 An Australian flat white coffee (left) and lumpy curdled milk (right)

Design brief: Create an infographic for baristas, based on your experimentation results, for best practice with 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. To do this, you will need to design several tests or trials. Be sure your milk samples are fresh, 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.

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Note: An infographic is a visual representation of information, designed to make the data and information easy to understand. Infographics are different from graphs, which are meant to be analysed. An infographic is simple, understandable, and meant to communicate messages quickly.

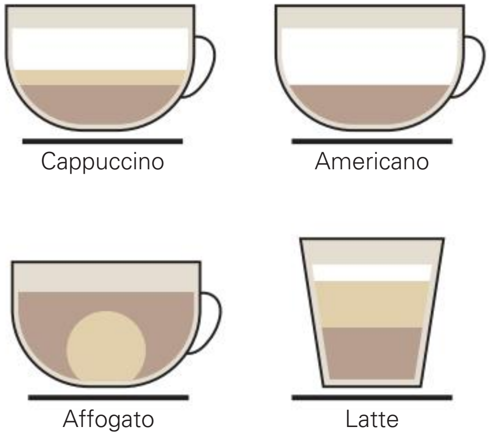

Figure 8.29 An infographic showing the various coffee, milk and froth ratios for different types of coffee drinks

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

Be careful

Do not consume any of the food.

Take care when handling boiling water.

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.

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.

Glossary

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 radioactive decay (or disintegration) of an unstable atom

Alternating current a form of electricity in which the current reverses direction in regular cycles

Ammeter a device for measuring electric current

Ampere the unit of electrical current, usually shortened to amp (A); 1 amp = 1 coulomb per second

Amplitude the distance (height) of a wave crest or the depth of a wave trough from the centre line of the wave

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

Atom the building block 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

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 a portable source of power; made up of two or more cells

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 genetic information is copied and the cell splits in half

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

Budding a type of asexual reproduction by organisms such as yeast and hydra, in which the daughter offspring grows off the side of the parent and drops off

Carbon sequestration the process of storing carbon in a carbon sink

Carbon sink an area where carbon is stored (e.g. ocean, 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

Cell a single electrical energy source that produces a current

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

Circuit a structure through which charges can move

Circuit breaker a device that carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

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

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

Component a part of a circuit

Compound a substance formed by the chemical combination of two or more different elements in a fixed proportion

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 material that allows electric current to flow through it easily

Conductor (heat) a substance that allows heat to pass through it easily

Confounding variable a factor that can affect the outcome of a study, making it difficult to know if the relationship observed is due to the variables being studied or to another factor

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

Convection the transfer of thermal energy due to the movement of particles in a liquid or gas

Coulomb the amount of charge transferred in 1 s with a current of 1 amp

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

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 and back to its starting position; the length of a cycle is the wavelength

Decomposer a living organism, such as bacteria and fungi, that breaks down dead organic matter

Differentiation the process by which cells become specialised

Direct current a form of electricity in which the current flows in one direction

Displacement the position of a particle when it has moved away from its rest position on the centre line of the wave

Double insulated having two levels of insulating materials between the electrical parts of an appliance and any parts on the outside that you touch

Dry cell a battery in which the electrolyte is absorbed in a solid to form a paste

Earthed having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

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

Effervescence bubbles or fizzing in solution

Efficiency the percentage of input energy that is converted to useful energy by a machine

Electricity a form of energy that results from the accumulation or the flow of charge

Electrocution when electric current passes through the body

Electrolysis a process in which an electric current is used to decompose a chemical compound

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

Electron a subatomic particle with a negative charge found outside the nucleus of an atom

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

Enrichment the process of increasing the purity of a particular isotope in a substance

Ethics the study used to guide what is considered to be right or wrong

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

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

Extrapolation extending a trend, pattern or relationship observed in a limited range of data to make predictions or to estimate values beyond that range

Fossil fuel a non-renewable energy source, such as oil, coal or natural gas, that has formed underground from plant and animal remains millions of years ago

Fragmentation a type of asexual reproduction in which a parent organism splits into multiple fragments, each of which can potentially develop into a new, 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)

Fuse a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

Gamete a sex cell (egg or sperm), which contains half the genetic material required to make an organism

Gamma ray a type of electromagnetic radiation that has high energy and a very short wavelength; produced when certain radioactive atoms decay

Geosphere all Earth's geological materials, including magma, lava, rocks and minerals

Geothermal energy thermal energy that originates from inside Earth

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

Global warming the long-term rise in the average temperature on Earth, primarily caused by the increase of greenhouse gases in the atmosphere

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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 for males and ovary for females

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 in 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

Hydroelectric power a renewable source of energy that harnesses the gravitational potential energy of water to generate electrical energy

Hydrosphere all of the water found on Earth (e.g. lakes and rivers)

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

Infrared radiation a type of electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

Insulator (electricity) a material that does not allow current to flow through easily

Insulator (heat) a substance or material that does not allow heat to pass through easily

Insulin a hormone secreted by the pancreas that triggers cells to take up glucose from the bloodstream and the liver to store glucose as glycogen, lowering blood glucose levels

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)

Ion a charged version of an atom that has either gained or lost electrons

Ionic compound a compound generally made up of both metal and non-metal atoms

Ionising radiation higher-frequency ultraviolet rays, X-rays and gamma rays, which can turn atoms and molecules into ions, which can potentially damage living cells

Isotopes atoms of the same element with the same number of protons but a different number of neutrons

Kinetic energy the energy of moving matter

Law of conservation of energy a scientific law that states that energy can be neither created nor destroyed, only converted from one form of energy to another

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

Load something that uses energy in a circuit

Longitudinal wave a wave with vibrations in the direction of travel instead of transversely; e.g. sound waves

Mains electricity the electricity that is supplied to homes

Mass number the sum of the protons and neutrons in the nucleus of an atom

Mean the average of a set of data, calculated by adding up all the values in the set and dividing by the total number of values

Mechanical wave a disturbance in a medium that transfers energy through that medium

Median the middle value in a set of data when they are arranged in order

Medium the matter through which a mechanical wave travels

Menstrual cycle a cycle controlled by hormones to prepare a woman's 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

Microwave a type of electromagnetic radiation used for cooking, communications and Wi-Fi; lies between radio waves and infrared radiation

Mode the value that appears most frequently in a set of data

Molecule a chemical species generally made up of two or more non-metal atoms; 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

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

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

Non-renewable cannot be replenished in a human lifetime

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 at the bottom left

Ohm the unit of electrical resistance (Ω)

Ohm's law a scientific law that states that the current that flows through most conductors is directly proportional to the voltage applied

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

Oscillating moving back and forth with periodic motion somewhat like vibration

Osmoregulation the regulation of water levels in the blood/body

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 in which the female gamete is produced and where seeds develop

Ovum an egg, or female gamete

Parallel circuit a circuit in which each component is connected in a separate conducting path

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

Peer review a process where work is examined and approved by experts before being published

Periodic motion a movement of a particle or an object that returns to its starting position and repeats in the same time interval, like a swing

Photon an electromagnetic wave carrying a specific amount of energy related to its frequency or wavelength

Pitch how high or low a sound seems to our ears on a music scale

Plagiarism the process or practice of using another person's idea or work and pretending that it is your own

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

Potential difference the difference in electrical potential energy between the negative and positive terminals in an electric circuit

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

Primary data data that researchers collect themselves for a specific purpose; obtained from observations, experiments, surveys or interviews

Product a substance that is formed in a chemical reaction

Proton a subatomic particle with a positive charge found in the nucleus of an atom

Puberty the time of transition from juvenile form to adult form

Radiation the transfer of energy without the presence of particles

Radio wave a type of electromagnetic radiation that has the longest wavelength

Radioactive decay when an unstable nucleus emits radiation (alpha and beta particles or gamma waves) and breaks down to form another element

Random error an unpredictable error that occurs in different directions each time a measurement is made; caused by external factors that affect the measurement process

Randomised controlled trial a study design that randomly assigns participants to either an experimental group or a control group; the only expected difference is the variable being studied

Range the difference between the largest and smallest values in a set

Rarefaction the part of a longitudinal wave where the particles are spread apart

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

Renewable can be replenished within a human lifetime

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

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

Resistance the degree to which a substance resists the flow of current; measured in ohms (Ω)

Response the reaction to a stimulus

Sankey diagram a flow chart that represents the flow of energy through a system

Scrotum a sac that encloses the testes

Secondary sexual characteristic any physical characteristic developing at puberty that distinguishes 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 and is 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

Series circuit a circuit in which the batteries and other components are all connected one after the other

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

Short circuit when current is allowed to flow from one conductor to another with little or no resistance

Significant figures the number of digits used to indicate how accurate a measurement or calculation is

Solar energy a renewable source of energy that converts the light energy from sunlight directly into another useable type of energy

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

Static discharge a sudden transfer of electrostatic charge

Static electricity an imbalance of charge on objects

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 containing the ozone layer

Subatomic particle one of the particles that make up an atom

Sustainable causing little or no damage to the environment, and therefore able to continue for a long time

Sustainable ecosystem a biological environment that can support itself without outside assistance

Synapse the junction between two neurons

Systematic error a consistent and predictable error that occurs in the same direction each time a measurement is made; caused by issues in the measurement system or experimental set-up

Target cell a cell affected by a specific hormone

Temperature a measure of the average random kinetic energy of the particles in an object

Testes the male reproductive glands that produce sperm

Thermal energy the total kinetic energy of all particles in a system

Transverse wave a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

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

Ultraviolet light a type of electromagnetic radiation that lies between visible light and X-rays; is needed by our bodies to make vitamin D; short-wavelength ultraviolet light can cause sunburn and cancer

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Useful energy the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it produces

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

Visible light the part of the electromagnetic spectrum that we can see

Voltage the potential difference between two points in an electric circuit; measured in volts (V)

Voltage drop the reduction in voltage that occurs across a component or section of an electric circuit because of the resistance of the conductive material

Voltmeter a device for measuring voltage between two points on an electric circuit

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)

X-ray a type of electromagnetic radiation that has short wavelengths and that can pass through flesh to give images of bones; hazardous and can cause cancer

Zygote a fertilised egg cell

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