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Tori Shaw
Erin Checkley
Sarah Chuck
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.

Cambridge University Press & Assessment acknowledges the Aboriginal and Torres Strait Islander Peoples of this nation. We acknowledge the traditional custodians of the lands on which our company is located and where we conduct our business. We pay our respects to ancestors and Elders, past and present. Cambridge University Press & Assessment is committed to honouring Aboriginal and Torres Strait Islander Peoples' unique cultural and spiritual relationships to the land, waters and seas and their rich contribution to society.

About the authors

Tori Shaw

Lead author

Tori Shaw has been committed to sharing her love for science with Year 7–12 students for over 20 years. She has worked in both government and independent schools, has been an assessor for the VCAA and IBO, and co-authored Cambridge's VCE Biology series. Her greatest joy comes from making science accessible, exciting and fun for all students. She is currently the Head of Science at Kingswood College in Melbourne.

Erin Checkley

Erin Checkley has taught Science and Mathematics across Years 7–12 for the past 12 years. Transferring from a career in physiotherapy, she discovered a passion for curriculum development through studying her Master of Education at the University of Melbourne and a strong desire to build students' critical thinking skills. Erin is currently teaching as a science specialist in Years Prep–4 at Ballarat Clarendon College.

Sarah Chuck

Sarah Chuck has taught 7–10 Science and VCE Biology for eight years. Having taught in an all-girls context for most of her career, she is passionate about increasing female engagement in STEM and fostering a sense of confidence and belonging among her students. Sarah has been a VCAA assessor and STAV council member, and she is currently Head of Science at a Catholic secondary college in Melbourne.

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Special thanks to Sharon Davis and Julie Bover of Goorlil Consulting and to Kingswood College.

About the cover

The Helmeted Honeyeater (*Lichenostomus melanops cassidix*) is Victoria's bird emblem and is only found in a small area within the Yellingbo Nature Conservation Reserve. Its habitat is primarily swamp forests, and it nests in a variety of understorey shrubs, including Scented Paperbark (*Melaleuca squarrosa*), which is also featured on the cover of this publication. Its population is under threat primarily from habitat loss, but also climate change and competition from other birds. It is listed as Critically Endangered on Victoria's *Flora and Fauna Guarantee Act 1988* Threatened List.

Contents

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Answers are available online in the Interactive Textbook and the Online Teaching Suite.

How to use this resource

Elements in the print book

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

Explore!

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

Quick check

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

Learning goals

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

Did you know?

These are short facts that contain interesting information.

Science as a human endeavour

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

Section questions

Question sets at the ends of sections are categorised under five headings: Remembering, Understanding, Applying, Analysing and Evaluating. Cognitive verbs appear in bold.
These questions are also available as Word document downloads in the Interactive Textbook.

Hands-on activities

Try this

Classroom activities help explore concepts that are currently being covered.

Making thinking visible

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

Practical/Investigation

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

Worked example

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

End-of-chapter features

Chapter review

Chapter checklist

Success criteria		Linked question
1.1	I can recall the steps of the scientific method.	9
1.1	I can define primary and secondary sources of information, and utilise the CRAAP test to assess secondary sources.	1, 4
1.1	I can construct a scientific hypothesis, including independent and dependent variables.	2
1.2	I can construct a step-by-step experimental method.	11a
1.2	I can describe the importance of a risk assessment.	11b
1.2	I can suggest some ethical guidelines a scientist must follow when using human and animal participants in experiments.	8a
1.2	I can outline how experimental errors can be minimised.	6
1.3	I can classify quantitative data as either continuous or discrete.	8b, 8c
1.3	I can calculate the mean, median, mode and range of data.	8d
1.3	I can plot a line graph and a line of best fit.	5, 10a, 10b, 10c
1.3	I can identify trends present in graphical representations of data.	7a, 7b, 7c, 7d, 10d
1.4	I can discuss the reliability and validity of experimental results.	3, 8e
1.4	I can communicate findings by constructing a scientific conclusion.	7e, 10e

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

Chapter review question sets are categorised under five headings: Remembering, Understanding, Applying, Analysing and Evaluating. Cognitive verbs appear in bold. These questions can be completed in the Interactive Textbook or downloaded as Word documents.

Data questions

Applying

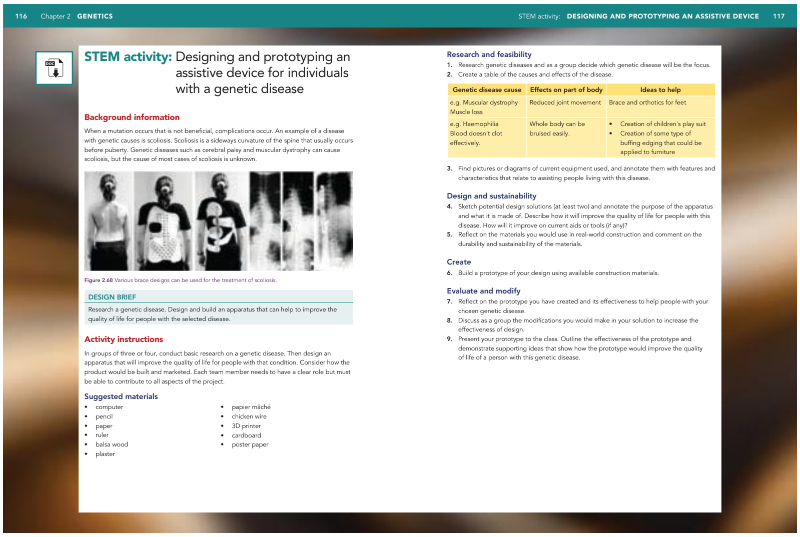
1. The table below shows the effect of changing the pH of a pond on the number of tadpoles in the pond.

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

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

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

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



116 Chapter 2 GENETICS

STEM activity: DESIGNING AND PROTOTYPING AN ASSISTIVE DEVICE 117

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

Background information

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

Figure 2.68 Various brace designs can be used for the treatment of scoliosis.

DESIGN BRIEF

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

Activity instructions

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

Suggested materials

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

Research and feasibility

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

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

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

Design and sustainability

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

Create

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

Evaluate and modify

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

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

Links to the Interactive Textbook (ITB)

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

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

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

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

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

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

Overview of the Interactive Textbook

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

Definitions pop up for key terms in the text.

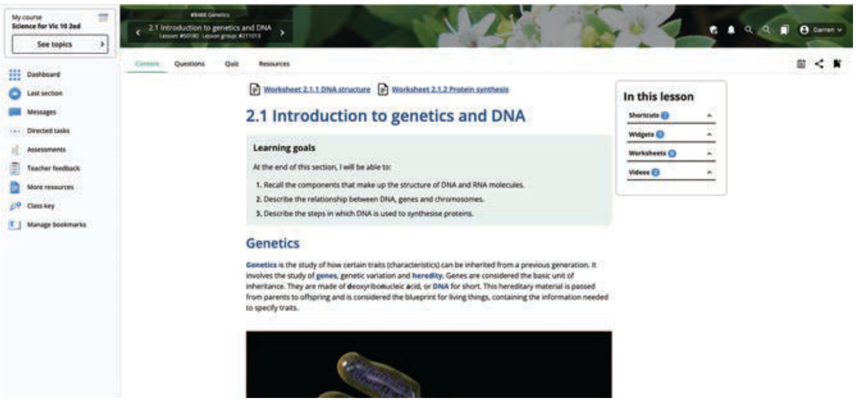
Quizzes contain automarked questions that enable students to quickly check their understanding.

Worksheets are provided as downloadable Word documents.

Videos summarise, clarify or extend student knowledge.

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

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



2.1 Introduction to genetics and DNA

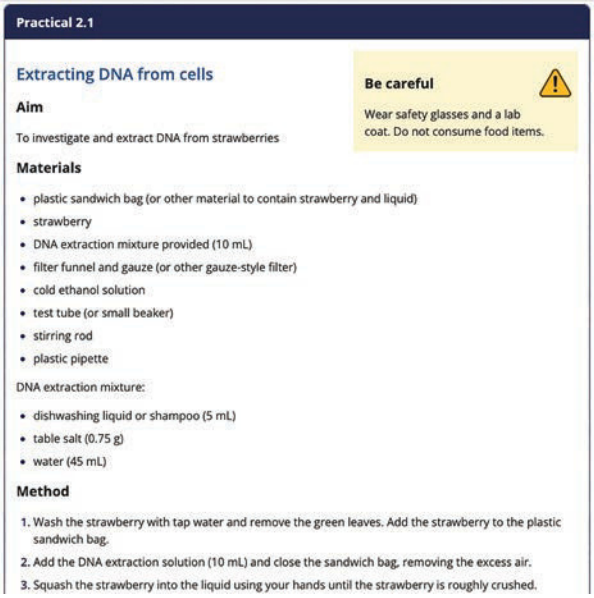
Learning goals

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

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

Genetics

Genetics is the study of how certain traits (characteristics) can be inherited from a previous generation. It involves the study of genes, genetic variation and heredity. Genes are considered the basic unit of inheritance. They are made of deoxyribonucleic acid, or DNA for short. This hereditary material is passed from parents to offspring and is considered the blueprint for living things, containing the information needed to specify traits.



Practical 2.1

Extracting DNA from cells

Be careful

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

Aim

To investigate and extract DNA from strawberries

Materials

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

DNA extraction mixture:

- dishwashing liquid or shampoo (5 mL)
- table salt (0.75 g)
- water (45 mL)

Method

1. Wash the strawberry with tap water and remove the green leaves. Add the strawberry to the plastic sandwich bag.
2. Add the DNA extraction solution (10 mL) and close the sandwich bag, removing the excess air.
3. Squash the strawberry into the liquid using your hands until the strawberry is roughly crushed.

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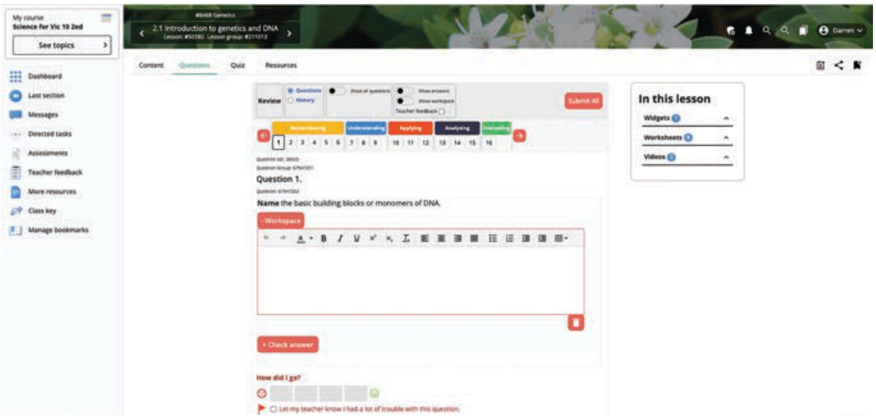
Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

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.



Question 1.

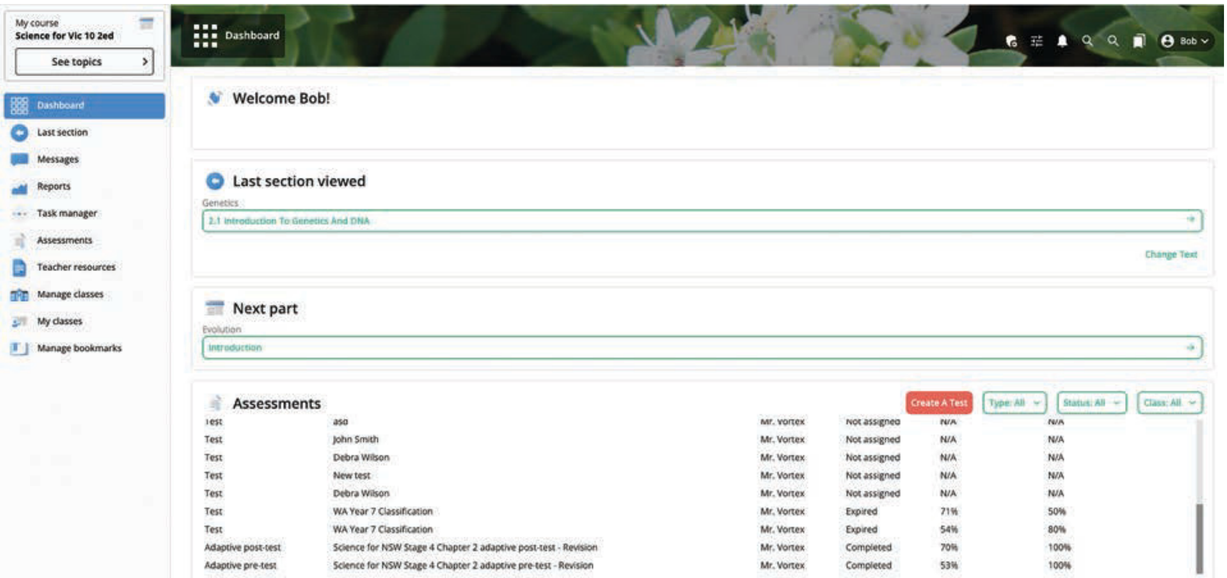
Name the basic building blocks or monomers of DNA.

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

Overview of the Online Teaching Suite (OTS)

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

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



Test	asd	Mr. Vortex	Not assigned	N/A	N/A
Test	John Smith	Mr. Vortex	Not assigned	N/A	N/A
Test	Debra Wilson	Mr. Vortex	Not assigned	N/A	N/A
Test	New test	Mr. Vortex	Not assigned	N/A	N/A
Test	Debra Wilson	Mr. Vortex	Not assigned	N/A	N/A
Test	WA Year 7 Classification	Mr. Vortex	Expired	71%	50%
Test	WA Year 7 Classification	Mr. Vortex	Expired	54%	80%
Adaptive post-test	Science for NSW Stage 4 Chapter 2 adaptive post-test - Revision	Mr. Vortex	Completed	70%	100%
Adaptive pre-test	Science for NSW Stage 4 Chapter 2 adaptive pre-test - Revision	Mr. Vortex	Completed	53%	100%

Chapter 1

Science skills

Chapter introduction

Scientists use a systematic approach, known as the scientific method, when conducting experiments. Researchers can analyse the patterns in their data and identify relationships between variables. Scientists must validate their claims with scientific evidence. In this chapter, we will discuss how to conduct an effective experiment, how to process and analyse data, and how to communicate your results with the world.

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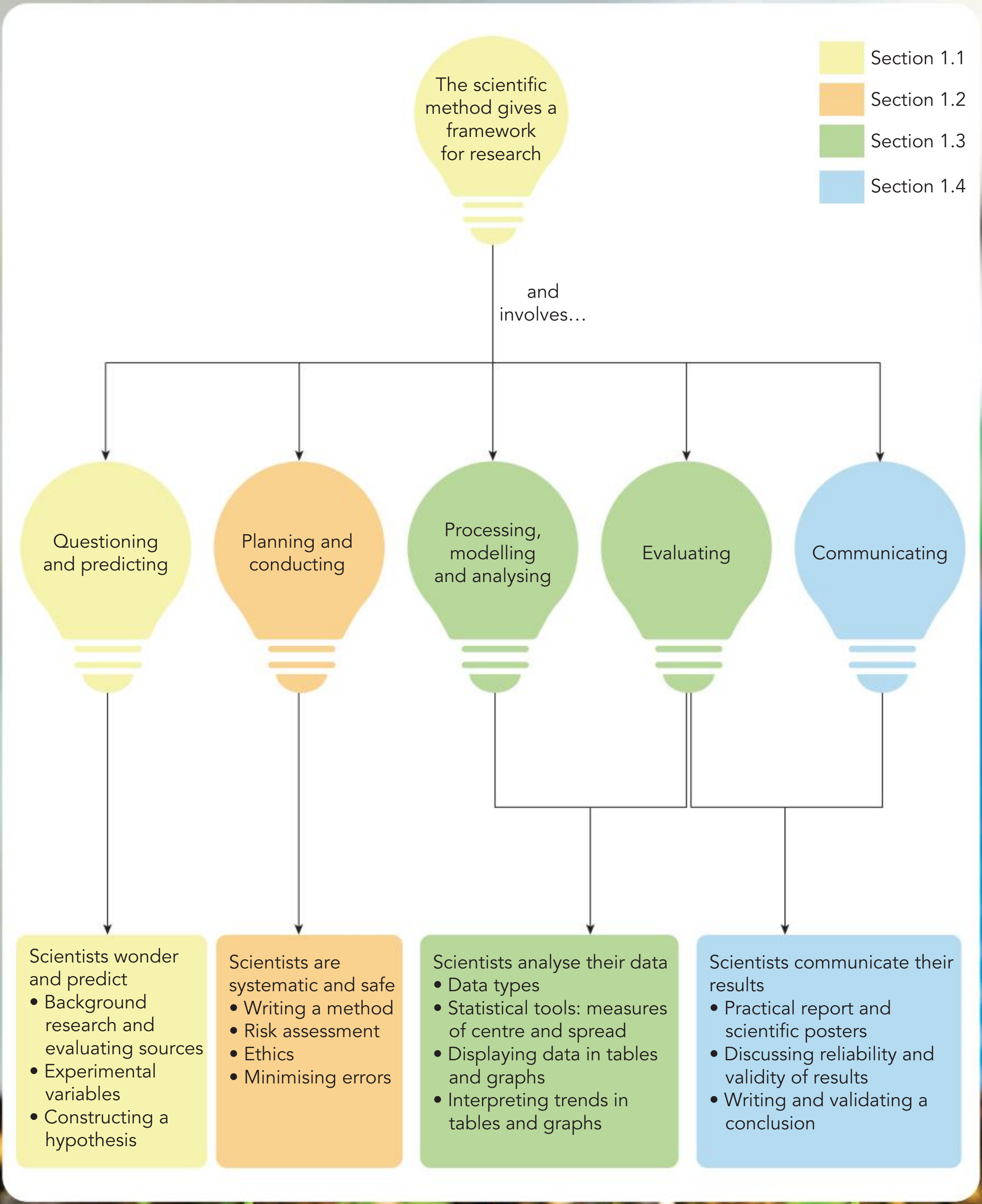
Concept map



🟨 Section 1.1
🟧 Section 1.2
🟩 Section 1.3
🟦 Section 1.4

The scientific method gives a framework for research

and involves…

- Questioning and predicting
- Planning and conducting
- Processing, modelling and analysing
- Evaluating
- Communicating

Scientists wonder and predict
- Background research and evaluating sources
- Experimental variables
- Constructing a hypothesis

Scientists are systematic and safe
- Writing a method
- Risk assessment
- Ethics
- Minimising errors

Scientists analyse their data
- Data types
- Statistical tools: measures of centre and spread
- Displaying data in tables and graphs
- Interpreting trends in tables and graphs

Scientists communicate their results
- Practical report and scientific posters
- Discussing reliability and validity of results
- Writing and validating a conclusion

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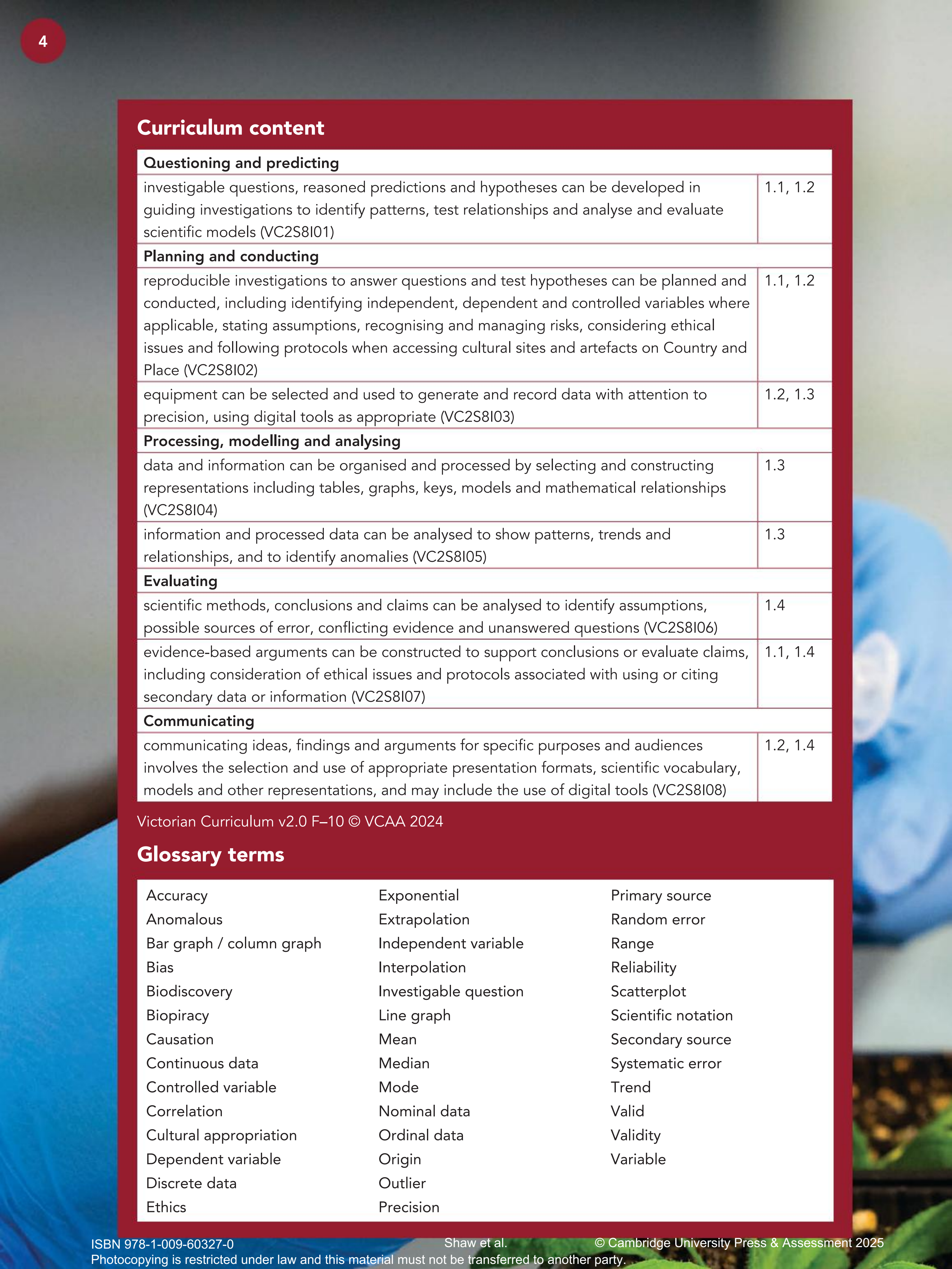

Curriculum content

Questioning and predicting	
investigable questions, reasoned predictions and hypotheses can be developed in guiding investigations to identify patterns, test relationships and analyse and evaluate scientific models (VC2S8I01)	1.1, 1.2
Planning and conducting	
reproducible investigations to answer questions and test hypotheses can be planned and conducted, including identifying independent, dependent and controlled variables where applicable, stating assumptions, recognising and managing risks, considering ethical issues and following protocols when accessing cultural sites and artefacts on Country and Place (VC2S8I02)	1.1, 1.2
equipment can be selected and used to generate and record data with attention to precision, using digital tools as appropriate (VC2S8I03)	1.2, 1.3
Processing, modelling and analysing	
data and information can be organised and processed by selecting and constructing representations including tables, graphs, keys, models and mathematical relationships (VC2S8I04)	1.3
information and processed data can be analysed to show patterns, trends and relationships, and to identify anomalies (VC2S8I05)	1.3
Evaluating	
scientific methods, conclusions and claims can be analysed to identify assumptions, possible sources of error, conflicting evidence and unanswered questions (VC2S8I06)	1.4
evidence-based arguments can be constructed to support conclusions or evaluate claims, including consideration of ethical issues and protocols associated with using or citing secondary data or information (VC2S8I07)	1.1, 1.4
Communicating	
communicating ideas, findings and arguments for specific purposes and audiences involves the selection and use of appropriate presentation formats, scientific vocabulary, models and other representations, and may include the use of digital tools (VC2S8I08)	1.2, 1.4

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Glossary terms

Accuracy
Anomalous
Bar graph / column graph
Bias
Biodiscovery
Biopiracy
Causation
Continuous data
Controlled variable
Correlation
Cultural appropriation
Dependent variable
Discrete data
Ethics
Exponential
Extrapolation
Independent variable
Interpolation
Investigable question
Line graph
Mean
Median
Mode
Nominal data
Ordinal data
Origin
Outlier
Precision
Primary source
Random error
Range
Reliability
Scatterplot
Scientific notation
Secondary source
Systematic error
Trend
Valid
Validity
Variable

1.1 Scientists wonder and predict

Learning goals

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

1. Recall the steps of the scientific method.
2. Define primary and secondary sources of information, and use the CRAAP test to assess secondary sources.
3. Construct a scientific hypothesis, specifying independent and dependent variables.

Review of the scientific method

Using a shared scientific method allows scientists to follow a systematic approach. The scientific method, outlined below, provides a framework for planning, conducting and analysing the results so that they may be communicated more broadly.

Step 1. Observe and ask questions
Develop a good (investigable) research question that can be tested.

↓

Step 2. Do background research
Find as much information as you can on the question. You should consider the quality and reliability of your sources of information.

↓

Step 3. Define variables and state a hypothesis
Construct a hypothesis. This is an educated guess about the possible answer to the research question from your research. A well-constructed hypothesis will lead to a prediction, which is a statement that describes what is expected to happen if the hypothesis is true. You should also state your independent, dependent and controlled variables.

↓

Step 4. Test the hypothesis with an experiment
You will need to write a method that can test a prediction from the hypothesis. It should include the materials and apparatus used and the procedure in easy to follow steps. You should also write a risk assessment.

↓

Step 5. Collect and record the data
During the experiment, you will collect data. It might be quantitative or qualitative data. You will display these data in a meaningful way, using graphs, tables or diagrams.

↓

Step 6. Analyse the data
Examine the tables and graphs of data. Analysing data can reveal relationships, trends and patterns. Discuss your results in relation to your research hypothesis.

↓

Step 7. Evaluate the data
This is a discussion of the reliability and validity of the experimental process, including any improvements you would make or extensions that you would do if you were to repeat the experiment.

↓

Step 8. Form a conclusion
This is an insightful interpretation of the data through a justified conclusion that is linked to the hypothesis.

↓

Step 9. Communicate your findings
Scientists share their findings with the broader scientific community by writing a practical report or presenting a scientific poster. Sometimes the conclusions raise more questions and can lead to further research.

WORKSHEET
Conducting research

investigable question
a research question that can be answered by conducting a scientific experiment

primary source
(of information) a first-hand record or account

secondary source
(of information) a second-hand account; a source that summarises, analyses or interprets primary sources

Background information research

The starting point of every scientific experiment is developing an **investigable question**, conducting background research and forming a prediction that can be tested.

In Year 7, you learned about the types of observations and inferences that can be used to formulate investigable questions about the world around you. The question must be relevant, practical (you have the time and necessary equipment) and able to be answered by conducting a scientific experiment.

Explore! 1.1

Ethical research

As well as being practical and relevant, investigable questions must also be ethical. When research involves experimenting on humans or other organisms, there are ethical guidelines that must be followed. This is discussed in more detail in *Section 1.2*.

For example, your question might be 'Does eating food that has been left unrefrigerated cause an upset stomach?'. Consider the experiment. Would you be allowed to purposely cause a participant harm by feeding them food that has gone off?

Figure 1.1 Is deliberately feeding someone food that has gone off an ethical experiment?

Use the internet to research the terms 'informed consent' and 'non-maleficence'.

Once a research question has been decided upon, it is important that scientists do some background research. This helps them to identify existing knowledge, and what similar questions have already been answered by other scientists.

Scientists might review some **primary sources** of information. These might be data or information that a researcher generated, or that the researcher collected directly from observations and surveys. Primary sources of information are a first-hand record or account of information.

Secondary sources of information are more likely to be reviewed in background research. Secondary sources summarise, analyse or interpret primary sources. When scientists refer to secondary sources of information, they have access to the research and questions that have been answered all over the world. However, when accessing secondary sources of information, particularly those on the internet, it is important to evaluate the credibility of sources. The CRAAP test (outlined later in this section) is one such tool for doing so.

When using secondary sources of information, it is essential that you cite the original source. This not only keeps a record of where the original data or information came from, but it also acknowledges the original owners of the work. A scientist can quote, review and discuss the findings and ideas of another researcher. However, when it comes to publishing data, images or text exactly as they were presented in a primary or secondary source, it is most likely that permission must be sought from the original owners of the work.

Aboriginal and Torres Strait Islander Peoples are the rightful holders and knowledge-keepers of their cultures, histories and ways of knowing. This means they are the primary source for this knowledge.

Their voices and expertise must be central when engaging with Aboriginal and Torres Strait Islander knowledge, practices and cultural sites.

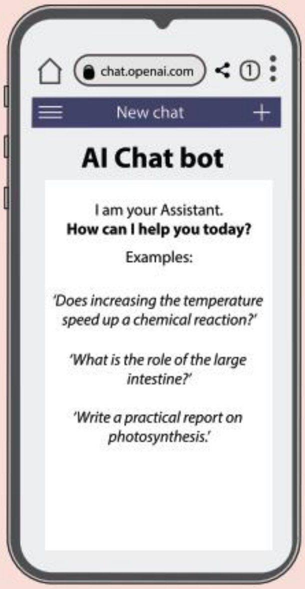
It is essential that scientists recognise and respect the significance of this knowledge and work in partnership with Aboriginal and Torres Strait Islander communities. This means following ethical guidelines, ensuring free, prior and informed consent, and upholding community authority over how their knowledge is used. By doing so, scientists contribute to meaningful collaboration rather than engaging in **cultural appropriation**, where knowledge is taken without permission or used in ways that disconnect it from its cultural context.

cultural appropriation	use of cultural knowledge, stories or traditions without acknowledgement or consent, often in ways that ignore their cultural meaning and disconnect them from the communities they belong to
biodiscovery	the collection and use of native biological material (e.g. plants and animals) for commercial applications
biopiracy	when naturally occurring, biological material is commercially exploited

Science as a human endeavour 1.1

Science as a 'non-human' endeavour

The internet is an amazing tool for sharing and searching for information. Unlike search engines which return links to existing websites, AI (artificial intelligence) powered chatbots such as ChatGPT, use Large Language Models to understand a question or prompt you enter and provide a response. It might be tempting to conduct background research using AI programs such as this, but beware: these programs don't just search, they create. This means the accuracy of the responses they provide is not always high. It is dishonest to use the words or ideas of others in your work and claim it is your own, without referencing your sources. This is known as plagiarism. Schools and universities have access to software to inspect work for plagiarism and have strict rules to ensure students are acting with academic integrity.



I am your Assistant.
How can I help you today?
Examples:

'Does increasing the temperature speed up a chemical reaction?'

'What is the role of the large intestine?'

'Write a practical report on photosynthesis.'

Figure 1.2 AI programs can provide answers fast, but can we trust them?

Science as a human endeavour 1.2

Biodiscovery and traditional knowledge

Aboriginal and Torres Strait Islander Peoples' ancestral knowledge often has commercial applications, such as the use of medicinal plants in drugs and naturally occurring insecticides in the development of products for use in agriculture. **Biodiscovery** acts govern the collection and use of native biological material to prevent **biopiracy**, which is the commercial exploitation of these resources. The United Nations (UN) has stated that Indigenous people around the world have a right to benefit from their biological resources and ancestral knowledge. While Australia recognises Aboriginal and Torres Strait Islander Peoples' intellectual property, it has not been formally established in laws.

Uncle Steve Kemp, a Ghungalu elder, runs a 'bush pharmacy' in Queensland, treating locals with ancestral medicines. He uses the gumby gumby plant, or native apricot, which has been used for thousands of years. The leaves can be boiled and drunk as a tea to treat colds and skin irritations. In 2017, two non-Indigenous people unsuccessfully applied for a trademark to exclusively use the name 'gumby gumby'. One of them already owns the patent (a legal protection for an invention) for the process of making products from the leaf, but academics are now calling for this patent to be reviewed in light of the trademark application being rejected. This case highlights the challenges in regulating biodiscovery, the importance of Traditional Owners maintaining their intellectual property and the right to commercially benefit from it.

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Search techniques

A web-based search of your question might turn up an overwhelming amount of information. You can refine your search by following the steps below:

1. Identify key words

A simple technique you can use to break down an investigable question is reading with a pen. See *Try this 1.1* for ways to do this.

Try this 1.1

Reading with a pen

Read your investigable question closely, underlining key phrases and circling words or phrases you don't understand. Put a question mark (?) next to something that sparks a question and an exclamation mark (!) next to something that surprises you. Write important thoughts in the margin or in a mindmap around the research question. These can inform your mini questions and guide your research.

For example:

How does palm oil farming affect biodiversity in Indonesia?

2. Break down your investigable question and develop specific and relevant mini questions to answer

For example, some mini questions you could research based on the investigable question in *Try this 1.1* might include:

1. What is palm oil?
2. What is palm oil used for?
3. Where is palm oil farmed?
4. How have palm oil practices changed over time?
5. Which animals are native to Indonesia?
6. What are the effects of palm oil farming?
7. What does biodiversity mean?
8. Who is responsible for monitoring environmental change in Indonesia?

3. Access sources of information

The internet is an effective resource for global sharing of information, but there are skills required to use it effectively. You need to ensure the information you access (whether it is text, images or videos) is correct and without **bias**. Consider whether the information is provided as an opinion or a fact, and who the source is. For example, an oil company is likely to provide very different information about the use of petroleum oil compared to a renewable energy organisation!

bias
when a source of information is influenced by personal opinion or judgement

Table 1.1 and Table 1.2 show some search techniques and common file types that might assist in your research.

Search technique	How?	Example
Finding exact matches for grouped words	Use quotation marks to group search words together.	"palm oil farming"
Search for exact matches in titles or headings	Type: intitle:"search word"	Intitle:"farming palm oil"
Search for a file type (see Table 1.2)	Type: filetype:abbreviation for file type "search word"	Filetype:pdf"palm oil"
Try different spellings	Sometimes words are spelled differently on US websites, so try spelling search words the American way.	*Colour* (on Australian and UK websites) is spelled *color* on US websites
Try a variety of sources	Google is not designed to bring the most scientific pages to the front of your search, so try other search engines and databases.	Google Scholar Library search engines World Book Databases to which your school subscribes

Table 1.1 Search techniques

Use	File type
Presentations	pptx, pages, key, pez
Images	jpeg, psd, png, tiff
Documents	pdf, doc, pub

Table 1.2 Common file types and their uses

Evaluating secondary sources

You should evaluate the credibility of secondary sources you access, such as books, articles and websites, before you use the information. The CRAAP test takes into account the currency, relevance, authority, **accuracy** and purpose of the source. When you use the CRAAP test, you give each of these factors a score of 0, 1, 2 or 3. You then add up all the scores. You should aim to use sources that have total scores of at least 13. Table 1.3 explains how to apply the CRAAP test.

DOC
WORKSHEET
CRAAP test

accuracy how well a measuring instrument determines the variable it is measuring; it refers to how close a measurement is to the true value

Figure 1.3 Secondary sources of information include physical resources such as books and journals, and online resources.

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	Description	Score			
		0	1	2	3
C	**Currency:** How old the information is • When was the information published or posted? • When was the last time the information was updated? • Is any of the information out of date or does it use old terms? • Do the links work?	No date is given.	The information is over three years old; no date of revision or update is given.	The information has been created or updated within the last three years.	The information was created less than two years ago. Sources referenced are current.
R	**Relevance:** How well the information matches what you are researching Does the information answer your question or link to the topic? Who is the information aimed at? Is the information worded at an appropriate level for you to understand?	There is no relevance to the topic I'm researching.	It has a small amount of information about the topic I'm researching.	It has a large amount of information about the topic I'm researching.	It can fully help me understand the topic I'm researching.
A	**Authority:** The writer of the information Who is the author/publisher/source/sponsor? Have the authors stated why they are experts? (Dr/Professor/experience) What are the author's qualifications in the topic? Is contact information provided, such as a publisher or email address? Does the URL reveal anything about the author or the source? Is the information linked to a biased organisation?	No author is identified.	The author is identified, but no credentials are given.	The author is named, and their contact details are given. The publisher is identified.	The author and publisher are identified and respected, and all contact details and credentials are listed.
A	**Accuracy:** How correct or truthful the content is Where does the information come from? Is the information supported by evidence? Has the information been reviewed or refereed by an expert? Can you verify any of the information by checking another source? Is the writing free of emotion? Are there spelling, grammar or other errors in the writing?	There are no links to sources or a citation list. Information is difficult to understand, contains errors and may be incomplete.	There are no links to sources or a citation list. Information contains spelling and grammar errors.	There are links to sources or a citation list. Information is easy to understand and contains only minor spelling issues.	There are links to sources or a citation list. Information is corroborated with other sources. It contains no errors and is written well and in a concise way.

Table 1.3 Applying the CRAAP test for evaluating sources

	Description	Score			
		0	1	2	3
P	**Purpose:** The reason the information exists What is the purpose of the information? Do the authors make their intentions or purpose clear? Is the information fact, opinion or propaganda? Is the information biased? Does the writer's point of view appear objective and neutral?	The purpose is biased and therefore is personal. There may be too much advertising.	The purpose is to persuade or sell something to a reader.	It offers some factual information, but there may be some advertising.	The purpose is to present factual information in a balanced way.

Table 1.3 *(continued)*

Try this 1.2

Using the CRAAP test

The aim of this activity is to use the CRAAP test to assess the credibility of resources you find when researching some mini questions. Use a search engine to investigate the following mini questions:

- What does adaptation mean?
- Why is it important for animals to have adaptations?

1. Copy and complete the following table.

Australian animal characteristics	Animal 1	Animal 2
Common name		
Scientific name		
Where found in Australia		
Description of habitat		
Description of adaptation		
How adaptation improves survival in habitat		

2. List three examples of the search terms you used.
3. Compile a list of sources you used.
4. Choose three of the sources and score them using the CRAAP test.
5. Identify the best and worst sources of information you accessed.

Writing an aim

When writing a practical report, your research question may be rewritten as an aim. The aim is a short statement that tells the reader the purpose of the experiment, and it should make reference to the experimental variables. For example:

Research question: 'Does the amount of water a plant receives affect how well it grows?'

Aim: To determine if the volume of water a plant receives affects its growth.

Variables

All the aspects or factors of an experimental procedure that could change are **variables**. The factor you do change (or allow to change) is the **independent variable**, and the **dependent variable** is the one that is measured due to the change in the independent variable. All other variables, known as the **controlled variables**, must stay the same. If they are not appropriately controlled (kept constant), then the changes observed in the dependent variable may not have been caused by the independent variable, and you have not conducted a fair test.

variable
a factor in an experiment with a value that varies or can be changed

independent variable
the variable in an experiment that you change or allow to change, so it causes change in the dependent variable (which you measure)

dependent variable
the variable in an experiment that you measure (to see if the changes to the independent variable have caused it to change)

controlled variable
a variable in an experiment that is kept constant so that it does not cause a change in the dependent variable

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Figure 1.4 A seed sprouts and grows in length

For example, an experimenter might be interested to see if the volume of water affects the growth of a seed sprout. Three seeds are planted and placed in a well-lit room. One seed is provided with weekly water, one with daily water, and one with no water at all after the initial planting. After two weeks, their height is measured.

The variables in this experiment are as follows:

- Independent variable: volume of water provided (in millilitres)
- Dependent variable: length of a seed sprout (in millimetres)
- Controlled variables: level of sunlight exposure, seed type, soil type, amount of soil/pot size, time interval between planting and measurement of length.

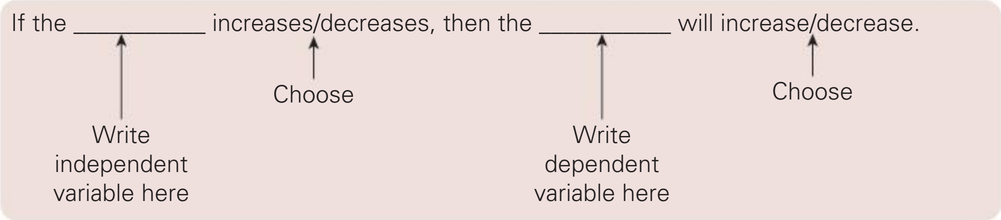
When considering variables, it is important to think critically about assumptions you may have made. Variables such as room temperature or humidity are often assumed to be constant, but they may fluctuate over the course of an experiment. Unless you are actively monitoring and controlling the temperature of the room, then you cannot state that it is a controlled variable. If you're not sure if the variable is fluctuating, then you should err on the side of caution and measure, record and control the variable in question. This makes a good point of discussion when evaluating your results.

Note that some scientific investigations may consist of collecting data by observation of the independent and dependent variables as they occur naturally in the environment. This is known as fieldwork and is not considered an experiment. For example, if the research question is 'Do soldier crabs inhabit rocky shorelines?', the independent variable is the nature of the shoreline – rocky or not – and the dependent variable is soldier crabs – present or not.

WORKSHEET
Variables and hypotheses

Constructing a hypothesis

Once you have defined your research question/aim, conducted your background research and defined your variables, then you can construct your hypothesis. This is a short 'If … and then …' statement that makes a prediction regarding the relationship between the independent and dependent variables. This prediction can be tested with an experiment.



If the ___________ increases/decreases, then the ___________ will increase/decrease.

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Section 1.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 1.1 questions

Remembering

1. **Define** a primary source of information and give an example.
2. **Define** a secondary source of information and give an example.

Understanding

3. **Outline** the effect of a poorly controlled experimental variable.
4. **Explain** the domains a CRAAP test assesses by copying and completeing this table:

Domain	What is being assessed?
Currency	
	Does the information address your research question? Is it written for the right audience?
Authority	Who is the author and are they appropriately qualified?
Accuracy	
	Is the information fact or opinion? Are the author's intentions clear? Is the information free from bias?

Applying

5. A student wants to see if writing all his homework in his diary every day will increase his homework scores. For one term, he records all homework in his diary daily. In the next term, he does not record any homework. He compares his homework scores for each term. **Identify** the:
   a) independent variable in this experiment
   b) dependent variable in this experiment.
6. **Sequence** these steps of the scientific method in the correct order:
   - test the hypothesis with an experiment
   - define variables and state a hypothesis
   - analyse the data
   - evaluate the data
   - observe and ask questions
   - form a conclusion
   - do background research
   - collect and record the data
   - communicate your findings
7. Read the following description of an experiment:
   Two beakers were labelled A and B.
   10 g of crumbled marble powder was added to beaker A, along with 20 mL of hydrochloric acid. The experimenter recorded the time taken in seconds until the marble powder completely dissolved.
   10 g of marble chunks were added to beaker B along with 20 mL of hydrochloric acid. The experimenter recorded the time taken in seconds until the marble chunks completely dissolved.
   a) **Identify** the independent variable.
   b) **Identify** the dependent variable.
   c) **Identify** three variables that should be controlled.
   d) **Construct** a hypothesis for this experiment.

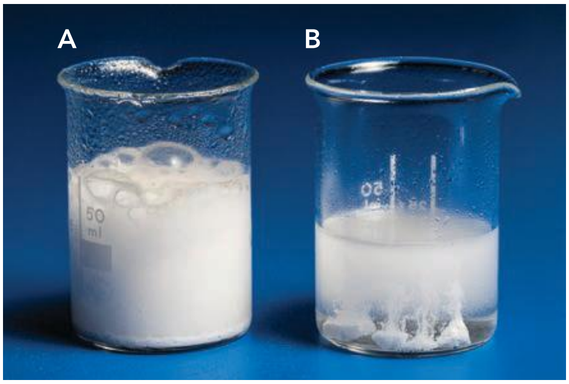

Figure 1.5 Beaker A shows a faster reaction rate than beaker B.

Analysing

8. **Identify** the error in this hypothesis:
   If the room temperature (in °C) increases, this can affect a plant.

Evaluating

9. **Justify** why a website would be considered biased if it reported on the health effects of consuming sugar but was sponsored by a snack food company. Refer to the CRAAP test domains in your answer.

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1.2

Scientists are systematic and safe

Learning goals

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

1. Construct a step-by-step experimental method.
2. Describe the importance of a risk assessment.
3. Suggest some ethical guidelines a scientist must follow when using human and animal participants in experiments.
4. Outline how experimental errors can be minimised.

So far, you have learned about how scientists define a research question, conduct background research and make predictions about relationships between variables. We will now consider the methodical ways in which a scientist conducts their investigation to ensure a fair test and valid experimental results.

WORKSHEET
Writing a method

Writing a scientific method

Writing a method for the experiment that you are going to carry out is not just for your reference; it is for the reference of all other scientists who might want to carry out an experiment similar to yours in the future. Because of this, a method must be a clear procedure of actions that can be carried out in the exact same way anywhere in the world.

Some conventions to follow when writing a method for your experiment:

- Write each step in order.
- Number the list of steps, starting with 1.
- Include names of specific equipment used.
- Include exact measurements of quantities used, for example, mass or volume.
- Indicate how the independent variable is changed and the dependent variable measured.
- Indicate key variables that are controlled.
- Include the number of repeat trials carried out.
- Use the third person passive voice and past tense.

Explore! 1.2

The passive voice

Professional scientists communicate their experimental and investigative findings in peer-reviewed journal articles. These articles undergo a rigorous evaluation process by experts in the field before being published, ensuring the reliability and quality of the research. The style of writing that all scientists have in common is they use the past tense passive voice and write in the third person, particularly when writing an experimental method.

For example, a high school student might write:

- You need to fill a 100 mL measuring cylinder with water.

However, the style of writing used in contemporary journal articles would be:

- A 100 mL measuring cylinder was filled with water.

Use the internet to identify the grammatical rules for writing in the passive voice and third person. Can you see those rules followed in the example above?

Conducting safe experiments

Even if you perform experiments carefully, they all carry an element of risk. It is not sufficient to just 'be safe' in the science laboratory. Before you begin conducting your experiment, you should complete a risk assessment to demonstrate your knowledge of the risks and your consideration around how they can be avoided or minimised.

Risk assessments

An example risk assessment is shown in Table 1.4. Many risks will be obvious to you: you will already know the hazards associated with using glassware or electricity in the lab, but you may not be fully aware of how dangerous different chemicals are. When writing your risk assessment, you will have to use a safety data sheet (SDS) to provide information about the risks associated with every chemical you use. This sheet outlines any dangers the chemical presents, how you can minimise or avoid any risk to yourself when using it and the appropriate action to take if you are exposed to the chemical (such as recommended first aid). Table 1.5 shows some of the information that can be found on the safety data sheet for hydrochloric acid.

Hazard	Risk	Risk management
Broken glass	Cuts from handling	Keep glassware away from the edge of tables. Ensure care is taken when handling glass equipment. If any glass is broken, inform a teacher. Do not try to clear it up yourself.
Bunsen burner	Burns	Ensure appropriate personal protective equipment is worn. Do not leave the flame unattended. Ensure it is cool before handling. Check that the gas valve is off when you have finished with it.

Table 1.4 An example of a simple risk assessment

Substance	Hazard	Explanation of hazard
Hydrogen chloride gas	 Corrosive, health hazard	Adverse effects if inhaled. May cause irritation of respiratory tract, shortness of breath, chest pain and even death.
Concentrated hydrochloric acid (>6.8 mol L^{-1})	 Corrosive, irritant	Corrosive to skin and eyes. Vapour or aerosols (droplets in air) may irritate the respiratory tract and lungs. It may also cause serious burns.

Table 1.5 An example of a simple SDS for hydrochloric acid. Usually, companies will have a much more detailed and extensive SDS accompanying chemical products.

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Substance	Hazard	Explanation of hazard
Moderate concentrations of hydrochloric acid (2.7 mol L^{-1} – 6.8 mol L^{-1})	 Irritant	May cause irritation of eyes, skin and the respiratory tract.
Dilute hydrochloric acid (<2.7 mol L^{-1})	 Potential irritant, low hazard	May cause irritation of eyes and any existing cuts in the skin.

Measures for reducing risk

- Use the lowest concentrations required.
- Use the smallest volume necessary.
- Wear personal protective equipment: gloves, protective clothing, eye protection, face protection.
- Do not breathe in the vapour.
- Use in a well-ventilated area, e.g. use a fume cupboard for concentrated solutions.

Emergency response

- If inhaled: assist person(s) affected to fresh air and ensure breathing is comfortable.
- In eyes: rinse thoroughly with water for several minutes.
- On skin: remove all contaminated clothing. Rinse skin with water or shower.
- If swallowed: rinse mouth.
- Call 000 if the person is feeling unwell.

Table 1.5 *(continued)*

Quick check 1.1

1. **Recall** what SDS stands for.
2. **Assess** whether the following statements regarding an SDS are true or false:
   a) An SDS will tell you if the chemical is appropriate for the experiment.
   b) An SDS will outline some of the physical properties and dangers of the chemical.
   c) An SDS will outline suggested first aid if you are exposed to the chemical.

Conducting ethical experiments

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

Ethical guidelines provide some standards that scientists must adhere to in order to conduct themselves in a culturally and socially acceptable manner. Managing risk involves making sure no harm comes to the experimenter or participants in the experiment (including psychological harm from being deceived during the experiment). This is just one ethical principle that must be adhered to when scientific investigations involve humans and animals.

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Some other specific principles that apply include:

- **Informed consent.** Participants are informed about the procedures and risks involved in the experiment. Scientists must ensure that information is presented in ways that participants can understand, so that their consent is fully informed.
- **Voluntary participation and the right to withdraw.** Participants agree to participate without being pressured to do so and can choose to exit the experiment or have their data removed at any stage. For Aboriginal and Torres Strait Islander participants, ensure that power inequalities between researchers and participants are addressed. Power inequalities including racism impact the actions of Aboriginal and Torres Strait Islander participants.
- **Confidentiality.** All data should be deidentified (e.g. assigned to a label like 'Participant 4' rather than the person's name) and stored securely.

Experiments involving human or animal participants will require approval from an ethics board before they can be conducted. Ethical considerations for Aboriginal and Torres Strait Islander participants should involve Aboriginal and Torres Strait Islander representation on ethics boards.

When conducting fieldwork, it is critical that scientists display respect for both the natural environment, and for Aboriginal and Torres Strait Islander Peoples' heritage sites. In the event that an artefact of cultural significance is found, it is mandated by law that you leave it undisturbed and report the finding to the Victorian Aboriginal Heritage Council.

Did you know? 1.1

Destruction of sacred sites

Mining company Rio Tinto faced widespread criticism and condemnation in 2020, after the destruction of two 46 000-year-old Aboriginal cultural sites and Juukan Gorge in the Pilbara region of Western Australia. The blasting of the sites for mining purposes was approved in 2013, prior to the significant archaeological discovery of the oldest example of bone tools found in Australia, made in 2014. This decision ignored the cultural knowledge expressed by Puutu Kunti Kurrama and Pinikura Peoples. Aboriginal communities, along with the Australian Government and other organisations, have called for a review of the Biodiversity Conservation Act to ensure greater protections for sacred sites and prevent further tragedies.

Figure 1.6 An open-cut iron ore mine in the Pilbara region of Western Australia

Making thinking visible 1.1

Think, pair, share: Environmental impact

Scientists are engaged in fieldwork to monitor water quality in Antarctica. There is the potential for local environmental impacts through travel, pollution and disturbing wildlife populations such as nesting areas and breeding sites.

1. **Think** of some ways a scientist or research team might minimise the impact they have on the environment. Consider travel to the region, practices at the research station and how they conduct themselves during fieldwork.
2. **Pair** up with a partner and share your thoughts.
3. **Share** as a class and identify five top tips that a research team should implement.

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

Figure 1.7 This scientist working on the Antarctica Peninsula must take reasonable steps to minimise their environmental impact.

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Conducting valid experiments

valid
the experiment suitably addresses the research question and measures what it intends to measure

causation
one event is caused by another event occurring

correlation
a measurement of the relationship between two variables; how one changes relative to the other

precision
how close measurements repeated under the same conditions are to each other

Experiments must be conducted in a safe and ethical manner, but they must also yield **valid** results. In Year 7, you learned about the concept of a fair test: a well-designed experiment where only the independent variable is changed, and all the other variables that might have an impact are controlled. This is essential if scientists are to claim there is a causal relationship between the independent and dependent variables.

Many research questions are a question of **causation**. For example, we have previously considered whether the volume of water provided to a seed sprout influences its growth. The research question is whether increasing water volume *causes* the seed sprout to grow longer. All other experimental factors (such as the level of sunlight and duration of growth) must be controlled to ensure it is not their impact that is affecting the dependent variable. If they are not kept constant, then the scientist's claim is not credible. Establishing definitive causation is very difficult. Even if there is an obvious pattern in the data, there is always the chance that it arose due to chance or the influence of a third variable that was either not controlled or not even considered! The mathematical term **correlation** measures the association between two variables and describes how one variable changes in relation to another. You can observe a strong correlation between variables when there is a consistent pattern in the data: for example, sprout height increases as the volume of water provided increases. This statement does not imply a causative relationship.

Minimising errors

Selecting appropriate equipment

It is important to select and use equipment with the necessary **precision** for accurate observations and measurements. For instruments with finer graduations, rounding up or down can be done to record data with the required precision. In cases where graduations are coarser, an intermediate value needs to be estimated.

Figure 1.8 This measuring device features fine gradations of 0.1 mL. The observer must correctly read the position of the meniscus (curved surface of the liquid) to accurately determine the precise volume. In this example, the bottom of the curved meniscus indicates a volume of 20.0 mL.

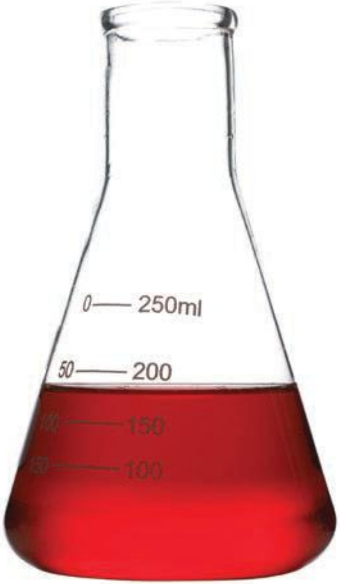

Figure 1.9 A conical flask has coarse gradations, where each line represents a scale of approximately 50 mL. It is estimated that the volume shown here is 180 mL.

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Digital tools, such as digital microscopes, simulations and video-recording devices, have improved scientific observations and measurements. Digital microscopes provide enhanced capabilities for qualitative and quantitative data collection. Simulations and video recordings help capture and analyse phenomena that may be difficult to observe directly. It is important to carefully evaluate simulations and models to ensure they are designed well and are relevant to the experiment. If a simulation is programmed incorrectly or set up poorly, it may mean the entire experiment is not valid.

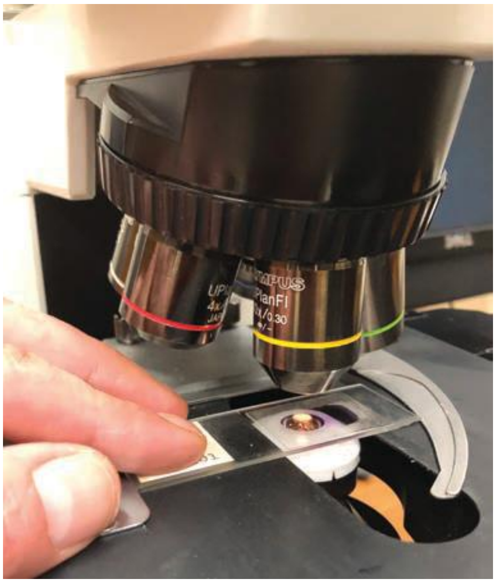

Figure 1.10 When observing cell structures under a microscope, adjusting the magnification to the appropriate level allows specific details to be clearly observed. Recording the magnification used is also necessary for other scientists to replicate the experiment and validate the findings.

Try this 1.3

Testing the strength of shapes

Background

In this experiment, you will be measuring the strength of paper sheets folded into vertical stands of different shapes. You may choose any shapes you wish, but they must all be the same height and made of the same materials (one sheet of A3 paper). You will measure the strength under compression – that is, the ability to support mass without collapsing.

Aim

To measure the strength under compression of different shapes of paper stands

Hypothesis

State your hypothesis using the "If … then …" framework.

Materials

- A3 sheets of paper × 3
- piece of cardboard
- several 50 g and bigger masses
- sticky tape
- scissors

Method

1. Define your variables for this experiment and list them in a table.

Independent variable	
Dependent variable	
Controlled variables	

2. Construct and number your paper stands, each one made from a sheet of A3 paper, and the same height. Use sticky tape if required to hold the shape.
3. Place cardboard horizontally on the first stand.
4. Add 50 g masses until the stand collapses. Record the total mass added that collapses the stand.
5. Repeat three times for each stand (i.e. do three trials).

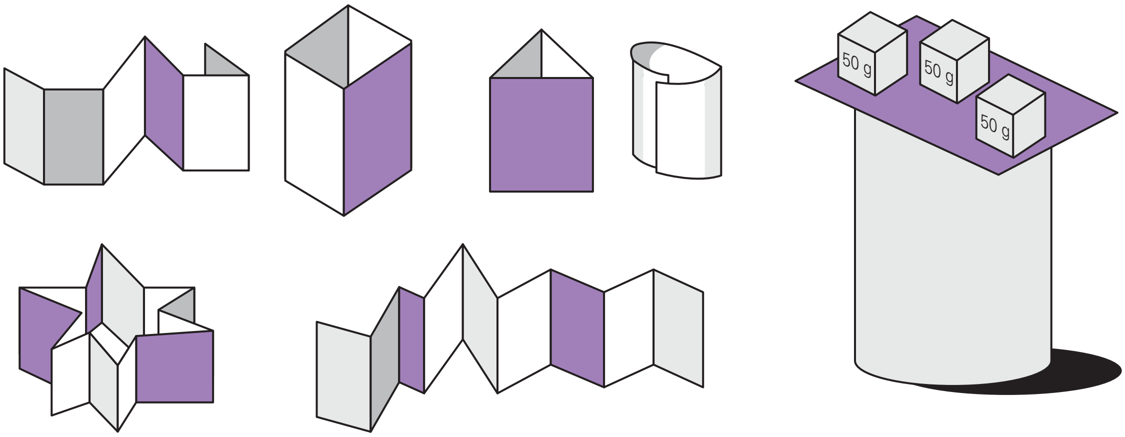

Figure 1.11 Some possible shapes to test are shown on the left. On the right is an example of testing the strength of a cylinder using three 50 g masses.

Results

Record your results in a table, using the table below as a guide. Give your table an appropriate title that describes what data it is displaying.

Put your independent variable here (and state units of measurement)	Put your dependent variable here (and state units of measurement)			
	Trial 1	Trial 2	Trial 3	Trial 4

Discussion: Analysis

1. Identify the strongest shape you tested.
2. Did anyone in the class have a stronger shape?
3. Were you able to identify a causal relationship between the independent and dependent variables?
4. Suggest one more variable you controlled or should have controlled.

Discussion: Evaluation

1. Explain why adding more trials and calculating the mean of the results would increase the reliability of the results you collected.

Conclusion

Draw a conclusion from this experiment about the strength of different shapes of paper, by copying and completing this statement in your science book.

From this activity it can be claimed that __________. This is supported by the observations that ____________. Therefore, the hypothesis *is/is not* supported by these findings.

Error types

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

There are potential sources of error in all experiments. **Systematic errors** arise when the measurements vary in a consistently incorrect way. For example, if your scale is faulty or poorly calibrated, it might overstate the mass by 1 g every time. The environment can also have an effect on an experiment if variables are not controlled. For example, the high ambient temperature of the room might speed up the rate of chemical reactions. We can avoid systematic errors by carefully controlling variables in the experiment and using equipment that has been tested against a known value (calibrated). It is important to use the same measurement tools for the entire experiment and not switch back and forth between different rulers, stopwatches or scales.

Even when we are extremely careful, there are **random errors** that can still affect the accuracy of a measurement. These are unpredictable errors that don't follow a regular pattern, such as problems with how the observer estimates a volume that falls between two gradations on a beaker or conical flask. This type of error can be reduced by repeating the experiment many times and taking average values.

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

Section 1.2 review

Online quiz	Section questions	Teachers can assign tasks and track results

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Section 1.2 questions

Remembering

1. **State** which type of error is represented in each of the following scenarios:
   a) A set of scales is faulty and regularly overestimates the mass of objects by 10 g
   b) A beaker only has gradations of 50 mL marked with lines, meaning observers need to estimate volumes that fall in between the markings on the scale
2. **Recall** what SDS stands for.
3. **Define** 'informed consent'.

Understanding

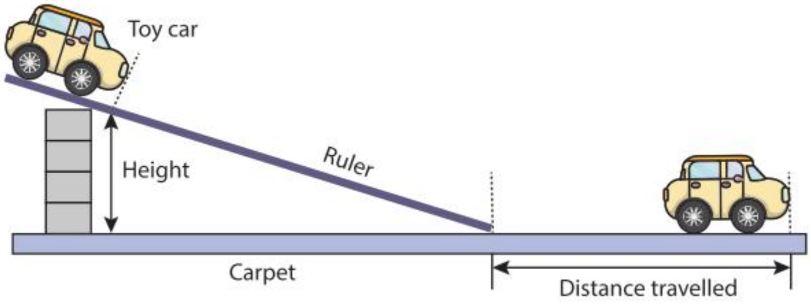
4. **Classify** these statements regarding a scientific method as true or false:
   a) The method should be written in the first person.
   b) The method should outline how variables are controlled, changed and measured.
   c) The method should have sufficient detail such that someone else could replicate the experiment.
   d) The method does not need to specify exact equipment used.

Applying

5. **Describe** how an experiment can be considered a fair test. Use an appropriate example in your response.

Analysing

6. A group of students conduct an experiment investigating ramp height and the distance a toy car will travel along the ground.



   a) **State** two variables that would need to be controlled in order for this to be a fair test.
   b) The measuring tape used to measure the distance travelled only has markings in centimetres. If students take turns recording the distance and rounding to the nearest centimetre, **suggest** what type of error this introduces.

Evaluating

7. Repeating an experiment multiple times and averaging the results is an effective way to minimise the effect of random errors. **Justify** why conducting multiple trials has no impact on reducing systematic error.

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1.3 Scientists analyse their data

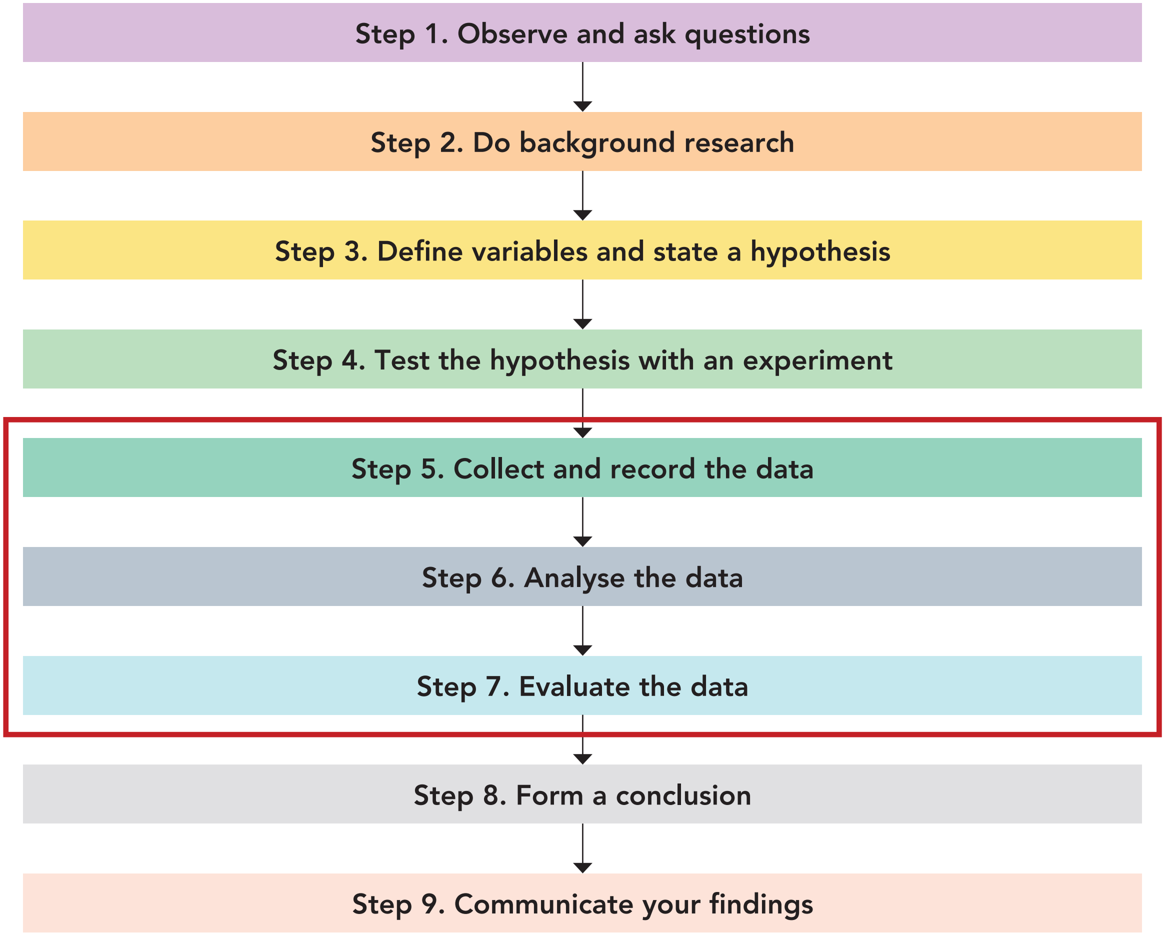
Learning goals

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

1. Classify quantitative data as either continuous or discrete.
2. Calculate the mean, median, mode and range of data.
3. Plot a line graph and a line of best fit.
4. Identify trends present in graphical representations of data.

Processing and displaying different data types

You will recall that several steps within the scientific method outlined earlier in the chapter relate the collection and processing of experimental data. There is simply no point designing and conducting a brilliant experiment unless the findings are correctly analysed and valid conclusions can be made. This is as true for science students as it is for career scientists.



To find meaning in the data, it should be analysed and presented in ways that allow possible causal relationships between variables to be evaluated. In this section you will learn about calculating measures of central tendency as well as presenting your data in tables and graphs.

The type of analysis that is appropriate depends on the type of data you have collected. Quantitative data is data that is numerical in nature and can be categorised as either continuous or discrete. **Continuous data** tends to include all numerical values within a range and is often measured. **Discrete data** considers exact values such as integer numbers (whole numbers) and is often counted.

Qualitative data is data that is worded, descriptive or categorical in nature. **Ordinal data** has a clear order to the categories, whereas **nominal data** has no clear order to the categories. Some examples are shown in the diagram below.

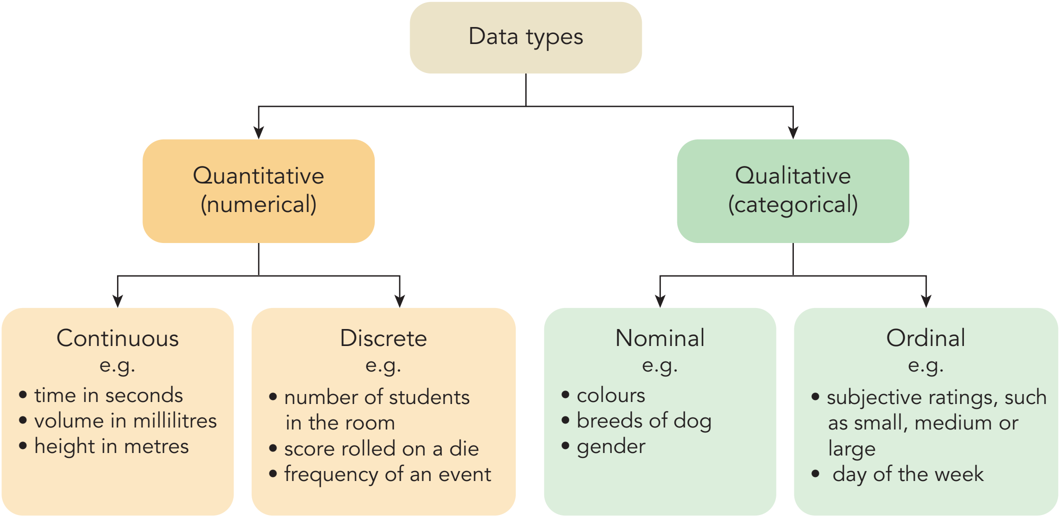


Figure 1.12 Classifying types of data

continuous data quantitative (numerical) data points that have a value within a range; this type of data is usually measured against a scale that includes decimals or fractions, e.g. length in metres = 1.21, 1.7, 1.89 …

discrete data quantitative (numerical) data points that tend to have whole numbers; this type of data is usually counted, e.g. number of pets = 0, 5, 1, 2

ordinal data qualitative (categorical) data where the categories have an order, e.g. slow, moderate, fast

nominal data qualitative (categorical) data where the categories have no clear order, e.g. red, yellow, green

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

Quick check 1.2

1. **Categorise** the following data as quantitative or qualitative, and then as either continuous/discrete or ordinal/nominal:
   a) size of plant (small/medium/large)
   b) reaction speed in milliseconds
   c) favourite food
   d) number of siblings

Measures of centre and spread

When analysing quantitative data that have been collected, measures of centre, or central tendency, are often calculated.

Measures of central tendency allow scientists to approximate a typical data point. In real life, you may hear this referred to as ‘finding the average’ as it gives you an idea of the middle or most common data value. The **mean** (average) is a commonly used measure of centre and is calculated as follows:

$$\text{mean} = \frac{\text{sum of all data values}}{\text{number of data values}}$$

median
the middle value in a dataset that is arranged in order of size

mode
the most commonly occurring value in a dataset

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

The **median** is the 'middle number' when the data is arranged in numerical order. When there are two middle numbers (i.e. when there is an even number of data values), you calculate the mean of the two middle numbers.

The **mode** is the most frequently occurring number in a dataset. Scientists can also gain an understanding of the spread of the data by calculating the **range**:

range = highest data value – lowest data value

Worked example 1.1

Six students were asked 'How many hours of screentime do you spend on your phone each day?'

The data values were as follows: 2, 9, 8, 5, 2, 4

Calculate the mean, median, range and mode.

Working	Explanation
Calculating the mean	
mean $= \frac{\text{sum of all data values}}{\text{number of data values}}$ $= \frac{2 + 9 + 8 + 5 + 2 + 4}{6}$ $= 5$	Divide the sum of the data values (total hours) by the number of data values (number of students). The mean screen time is 5 hours.
Calculating the median	
2, 2, 4, 5, 8, 9 $\frac{4 + 5}{2} = 4.5$	Arrange the date values in numerical order. Because there is an even number of data values, the middle number is between two data values (4 and 5). In this case you find their mean, so the median is 4.5 hours.
Calculating the mode	
2, 2, 4, 5, 8, 9 mode = most frequently occurring data value = 2	Count how many times each data value is repeated. The mode is the most frequently occurring data value. In this case, only '2' is repeated, so the mode is 2 hours.
Calculating the range	
range = highest data value – lowest data value = 9 – 2 = 7	Subtract the lowest data value from the highest data value. The range is 7 hours.

Measures of central tendency and spread can give us an overview of the dataset. For example, we could say that for the students surveyed in Worked example 1.1, the mean number of hours of screen time was 5 hours, but that student responses varied by 7 hours.

Your teacher probably calculates the mean test score for your class and compares with other classes to gain an understanding about how your class is performing. However, statistical measures need to be interpreted carefully. The mean can be drastically affected by the presence of just one extreme value (known as an outlier). When this occurs, it is no longer very useful. For example, if a seventh student was surveyed in Worked example 1.1 and they reported 23 hours of screen time, this would increase the mean, and it would no longer be a good indication of the centre. The same can be said for the mode: sometimes the most common response is not a good measure of the centre of the dataset. It is more useful in qualitative datasets, where you might be interested in the most common category.

Try this 1.4

Collecting smartphone data usage

As a class, collect data about the number of hours each student spends on their smartphone per week. Look for the 'Screen Time' or 'Digital Wellbeing' feature. It might be located under the 'Usage' or 'Battery' section. Depending on your device and operating system, you may find a weekly summary or a detailed breakdown of your smartphone usage.

1. Collate data from the class to create a summary of this data. Consider the different ways you might want to analyse the data, perhaps based on gender or age or type of phone.
2. Put the data into a spreadsheet software program and explore how you can determine the mean, median, mode and range of the data by using formulas/functions within the program.

Figure 1.13 Your phone tracks usage data.

Quick check 1.3

1. Consider the following dataset: 22, 23, 23, 24, 25, 26, 27, 29, 31
   For the data, **calculate** the:
   a) mean
   b) median
   c) mode
   d) range.

Recording data with precision

When presenting any numerical values, it is important to determine the appropriate level of precision. This may involve stating values to a certain number of decimal places, depending on the significance of the data and the level of accuracy obtained during the experiment. There should be consistency in the number of decimal places used when recording data. However, it is essential to avoid excessive rounding that may result in the loss of important information.

Positive and negative signs are particularly important when dealing with standard units that involve both positive and negative values. For example, when measuring temperature changes, including the appropriate positive or negative sign indicates whether the temperature has increased or decreased relative to a reference point.

In cases where very large or very small numbers are encountered, **scientific notation** can be used to represent the data concisely. This involves expressing numbers as a coefficient multiplied by 10 raised to a power.

scientific notation a way of writing very large or very small numbers by putting one number before the decimal point, then multiplying by a power of 10

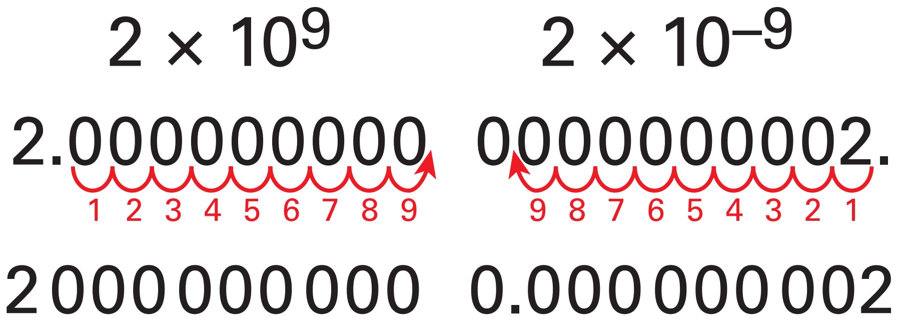


Figure 1.14 Scientific notation helps simplify the presentation of very large or small numbers, making it easier to compare values.

Displaying data in tables

Presenting data in tables allows information to be organised and effectively communicated. Setting up the table of results prior to conducting your experiment means that you can record data easily as you go. Some guidelines for setting up a results table:

- The table should be ruled in pencil with an appropriate title stating the independent and dependent variables.
- The independent variable's values or categories should be listed in the first column.
- The second column lists the dependent variable measurements. If more than one trial is completed, then there will be more than two columns, and potentially a column showing the average (often the mean) of the values (see Figure 1.15).
- Each column needs a heading, and units of measurement should be specified here, NOT rewritten after every measurement.
- All values are stated to the same number of decimal places.

Clear title

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

Unit of measurement specified in heading

Independent variable placed in first column (yellow), one column of dependent variable results for each trial (blue)

Consistent number of decimal places

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

Figure 1.15 An example of a well set-out table of results

Displaying data in graphs

Once data is processed it can be presented in a graph. When experiments involve multiple trials (like in Figure 1.15) it is common practice to only graph the last column showing the mean values of the trials.

The type of data you collect informs the way it which it is represented. If your independent variable is qualitative (e.g. species of animal) and your dependent variable is quantitative (such as heart rate in beats per minute) then a **bar graph** or **column graph** is an appropriate way to represent the data.

A common way of displaying quantitative data is using a **scatterplot**, which maps how the dependent variable changes in response to the independent variable. Each pair of observations is represented with a single data point. If the variables are something continuous – such as distance, length or time – then you can connect each data point to the one either side, creating a **line graph**.

bar graph / column graph a type of graph used to display the frequency of a qualitative variable, or a relationship between a qualitative independent variable and a quantitative dependent variable

scatterplot a type of graph used to display the relationship between two quantitative variables

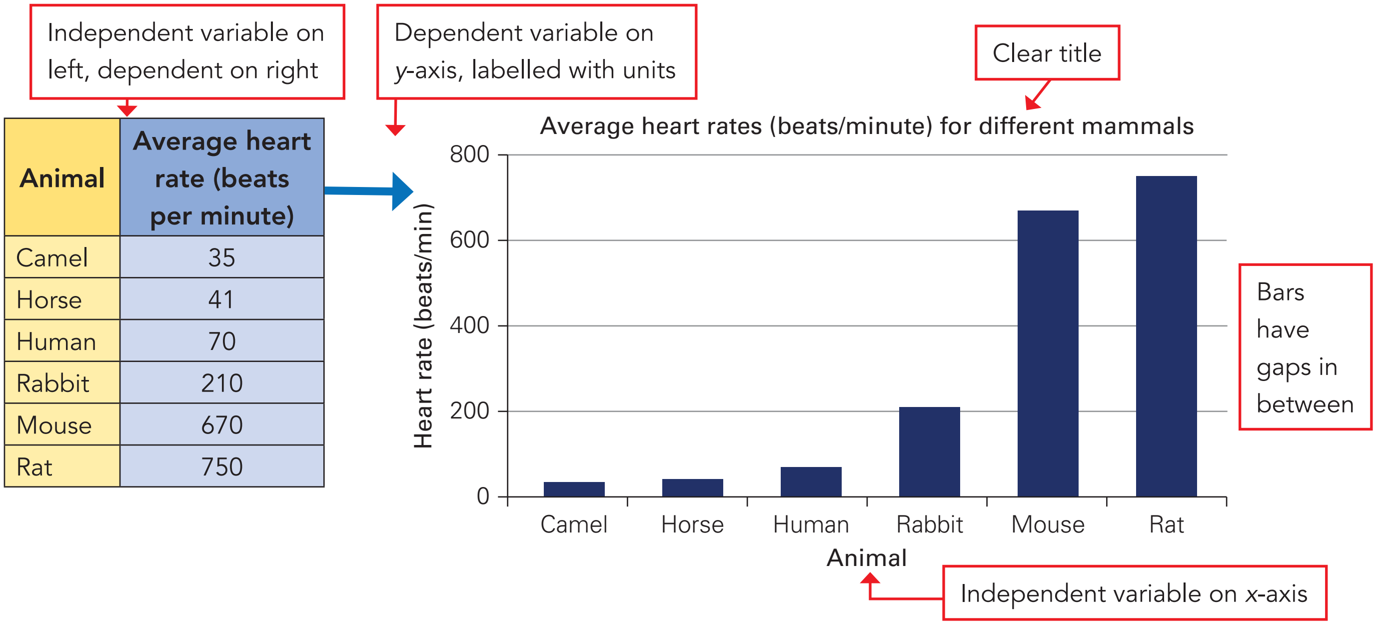
line graph a type of graph used to display how a continuous quantitative variable changes over time, or in reference to the independent variable

Constructing a column graph

A column graph is a visual representation of data from a table. Some guidelines for constructing a column graph:

- The graph should be ruled in pencil with an appropriate title stating the independent and dependent variables.
- The independent variable is placed on the *x*-axis (the horizontal axis) and the dependent variable is placed on the *y*-axis (the vertical axis). Units of measurement (where appropriate) are specified in the labels in brackets.

- The graph should cover the full width of the page. Consider how many categories of independent variable you need to display.
- The *y*-axis should have an evenly increasing scale, preferably in multiples of 1, 2, 5 or 10. You cannot have breaks in the scale. You should choose a scale that spreads your data values out enough to be clearly interpreted. Your scale does not need to start at 0 if this doesn't suit your data. For example, if your dependent variable values are 800, 819, 920 and 950, then an appropriate scale for the *y*-axis might begin at 700 and extend up to 1000 in intervals of 20 or 50.
- The bars should have a gap in between them that is roughly equal to the width of each bar.



Independent variable on left, dependent on right

Dependent variable on *y*-axis, labelled with units

Clear title

Bars have gaps in between

Independent variable on *x*-axis

Animal	Average heart rate (beats per minute)
Camel	35
Horse	41
Human	70
Rabbit	210
Mouse	670
Rat	750

Figure 1.16 A table of data showing the average heart rates (quantitative) of different species of animal (qualitative) can be represented graphically with a column graph

Constructing a scatterplot/line graph

A scatterplot is a visual representation of the relationship between two quantitative variables. When the independent variable is something continuous, such as time, the data points can be connected to form a line graph.

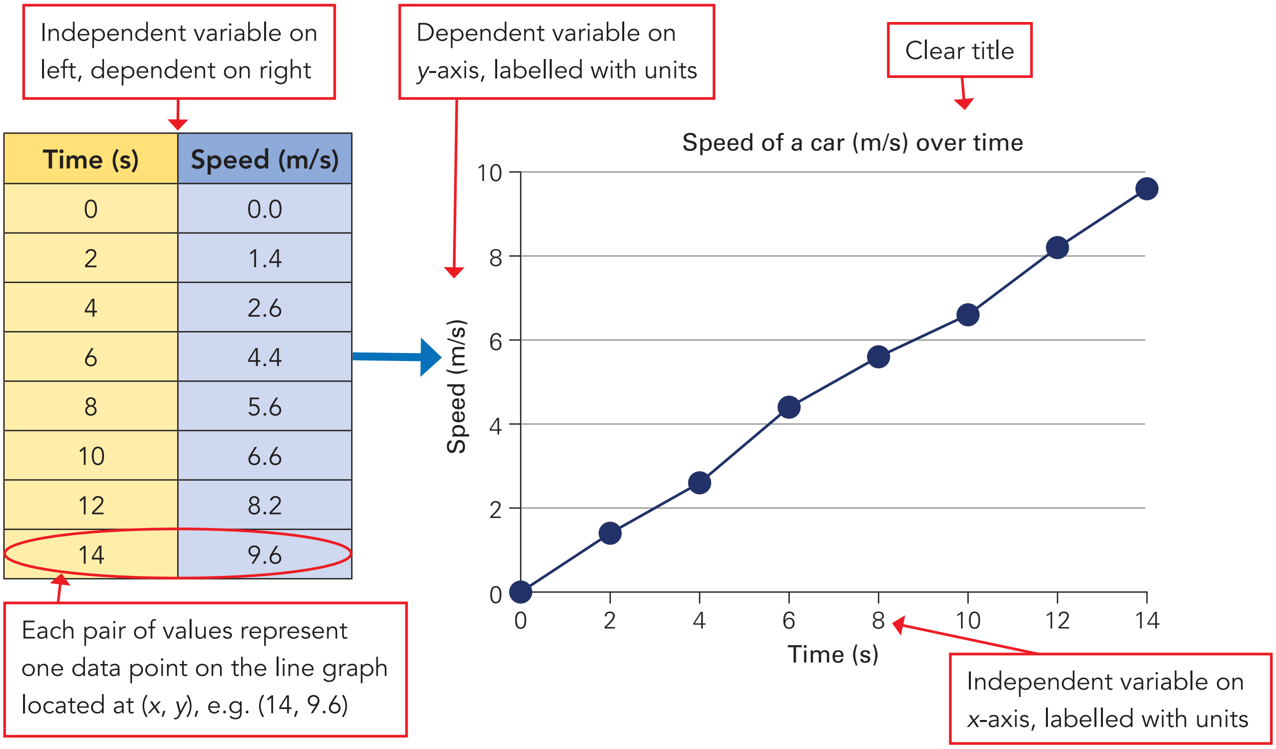
- The graph should be ruled in pencil with an appropriate title stating the independent and dependent variables below the graph.
- The independent variable is placed on the *x*-axis and the dependent variable is placed on the *y*-axis. Units of measurement are specified in the labels in brackets.
- Axes are marked with a scale that increases evenly, preferably in multiples of 1, 2, 5 or 10. You cannot have breaks in the scale. For example, you can't show 0 to 20 in intervals of 5 and then skip straight to 60 *even if* this is what your data values do. You need to choose a scale that spreads your data values out over the full width of the graph (usually the full width of a page). Your scale does not need to start at 0 if this doesn't suit your data. If your values are between 85 and 115, then it would make sense to construct an axis with a starting point at 80 extending to 120, perhaps in intervals of 5. If both the *x*-axis and the *y*-axis extend to 0, then this point where they meet (0, 0) is called the **origin**.
- Data points are typically represented with a dot or an 'X'. If you are plotting multiple sets of data on the same graph, use different-coloured points for each dataset, and add a legend.
- Circle any **outlier** results. These are any data point that is clearly **anomalous** and are potentially the result of an error or mistake in recording. You cannot simply remove the data point even if it doesn't seem to fit with the other results. Scientists must communicate all the experimental data including outlier results.

origin
the point (0, 0) where the *x*-axis and *y*-axis intercept when both axes start from zero

outlier
an anomalous data point, likely the result of an error or a mistake in data collection

anomalous
a result that differs from the expectations suggested by scientific theory

- If it is appropriate to convert the scatterplot into a line graph, use a ruler to connect each data point (dot) to the next one with a straight line. In Figure 1.17 this allows us to see how the dependent variable (speed) changes over time (the continuous independent variable).



Independent variable on left, dependent on right

Time (s)	Speed (m/s)
0	0.0
2	1.4
4	2.6
6	4.4
8	5.6
10	6.6
12	8.2
14	9.6

Dependent variable on *y*-axis, labelled with units

Clear title

Each pair of values represent one data point on the line graph located at (*x*, *y*), e.g. (14, 9.6)

Independent variable on *x*-axis, labelled with units

Figure 1.17 A table of results showing how the speed of a car changing over time can be represented graphically with a line graph

Practical 1.1

Pendulum swing practical

Background information

In this practical, you will gather continuous data and convert it into a line graph.

Aim

To test the effect of string length on the time it takes a pendulum to complete one swing

Hypothesis

State your hypothesis using the 'If … then …' framework.

Materials

- retort stand
- bosshead and clamp
- 120 cm of string
- weight for pendulum
- protractor
- Blu Tack®
- stopwatch
- graph paper or graphing application, such as Excel

Method

1. Define your variables for this experiment and record them using the table below.

Independent variable	
Dependent variable	
Controlled variables	

2. Write a risk assessment for this experiment.

continued …

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3. Attach the weight to the bottom of the piece of string.
4. Tie the string to the bosshead and clamp attached to the retort stand and measure 20 cm from the join of the bosshead to the base of the weight, as shown in Figure 1.18.
5. Using the protractor, hold the string tight at 45 degrees and release the pendulum.
6. Start the stopwatch as soon as you release the pendulum and count three full swings (across and back), as shown in Figure 1.18.
7. When the pendulum returns for the third time, stop the stopwatch and divide the time by 3 to get the time for one swing.
8. Record the time for one swing in the results table. Repeat for two more trials.
9. Repeat steps 4–8 for different lengths of string.

Results

Create a results table for your experiment.

Use the mean of all trials to produce a line graph. Remember the following points:

- Plot the independent variable on the *x*-axis.
- Plot the dependent variable on the *y*-axis.
- Label each axis with the variable name and the unit of measurement.
- Write a title for the graph.
- Use an even scale (equal spaces between the numbers on the axes).

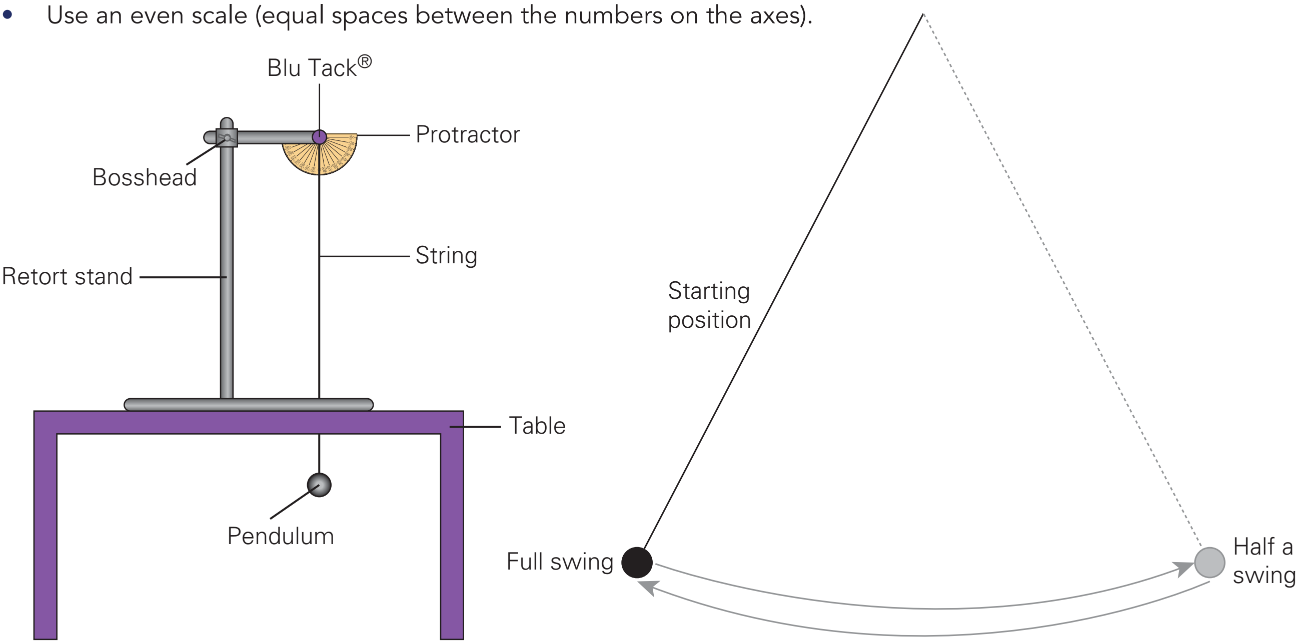

Figure 1.18 Experimental set-up. Setting up the pendulum (left) and timing the swing of the pendulum (right).

Discussion: Analysis

1. Identify any trends you see in your graph.
2. Compare your collected data to data from another group. How do their results compare to yours?

Conclusion

Draw a conclusion from this experiment about the effect of string length on pendulum swing, by copying and completing this statement in your science book.

From this activity it can be claimed that __________. This is supported by the observations that _____________. Therefore, the hypothesis *is*/*is not* supported by these findings.

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Practical 1.2

Insulation of water

Be careful

Ensure protective equipment is worn at all times. Keep hands clear of the boiling water to avoid burns. Pour slowly to avoid spilling.

Background information

In this practical, you will gather data to produce a bar graph. You will test the effect of foil, paper and cotton wool as insulating materials and measure how this affects the cooling rate of water.

Aim

To test the effect of different materials on the cooling rate of water

Hypothesis

State your hypothesis using the 'If … then …' framework.

Materials

- 500 mL graduated conical flasks × 4
- kettle
- thermometers
- foil
- cotton wool
- paper
- stopwatch
- elastic bands

Method

1. Complete some background research to write a brief rationale on insulation.
2. Define your variables for this experiment and record them using the table below. Also include the type of data that each variable will yield.

		Variable yields what type of data?
Independent variable		
Dependent variable		
Controlled variables		NA

3. Cover the sides of three conical flasks with either cotton wool, paper or foil, and use elastic bands to secure the covers in place. Leave one conical flask without covering.
4. Place one thermometer in each of the conical flasks.
5. Boil the kettle and carefully pour boiling water into each of the conical flasks up to the 200 mL mark. Start the stopwatch immediately.
6. Time for 5 minutes using the stopwatch and then measure and record the temperature of the water in each beaker.
7. Gather data from two more trials from other groups in your class. Add these to the results table and calculate the mean temperature after 5 minutes for each insulating material.

continued …

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Results

Copy and complete the following table to record your results. Give your table an appropriate name that describes what data it is displaying.

Cover material	Temperature after 5 minutes (°C)			
	Trial 1	Trial 2	Trial 3	Mean
Foil				
Paper				
Cotton wool				
No cover				

Create a bar graph for the mean data in your results table. Put the independent variable (insulating material) on the *x*-axis and the dependent variable (temperature after five minutes) on the *y*-axis.

Discussion: Analysis

1. Suggest a reason for using a conical flask with no cover material.
2. Suggest a reason for putting your data into a bar graph rather than just leaving it in a table.

Discussion: Evaluation

1. Identify potential sources of measurement uncertainties or experimental faults in this experiment.
2. Suggest one way you could improve the experimental design if you were to repeat this experiment in the future.
3. Can you identify evidence that supports the causal relationship between the independent and dependent variables?

Conclusion

Draw a conclusion from this experiment about the effect of different materials on the cooling rate of water, by copying and completing this statement in your science book.

From this activity it can be claimed that __________. This is supported by the observations that ______________.

Therefore, the hypothesis *is*/*is not* supported by these findings.

Analysing the data by interpreting tables and graphs

Tabulating and representing data graphically allows for analysis of any **trends** (patterns in the data) and identification of unexpected results.

WORKSHEET
Analysing
data

trend
a pattern in a graph that shows the general direction/shape of the relationship between the dependent and independent variables

Describing trends

Table 1.6 summarises some common trends you might observe and describe.

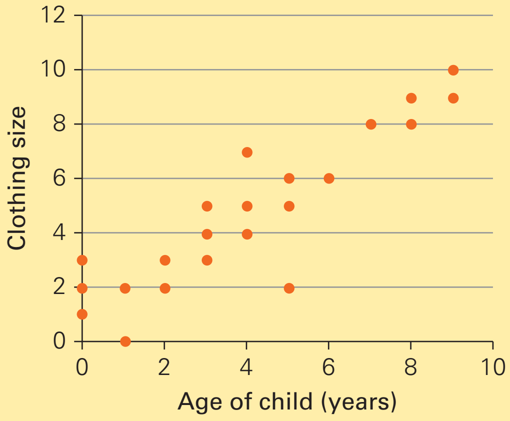
Graph	Explanation
 **Figure 1.19** The effect of child age on clothing size	The data in the scatterplot (Figure 1.19) shows a steady increase. You would describe this by saying, 'As the age of the child (in years) increases, the size of clothing also increases'.

Table 1.6 Common trends in data

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

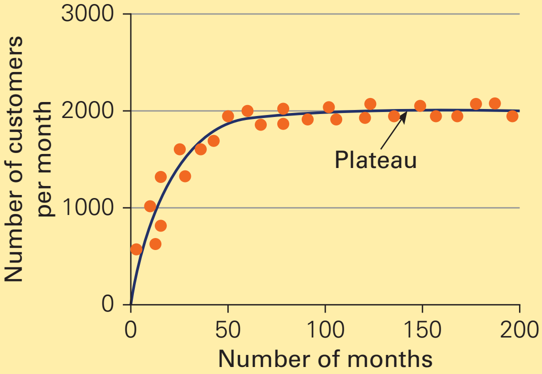
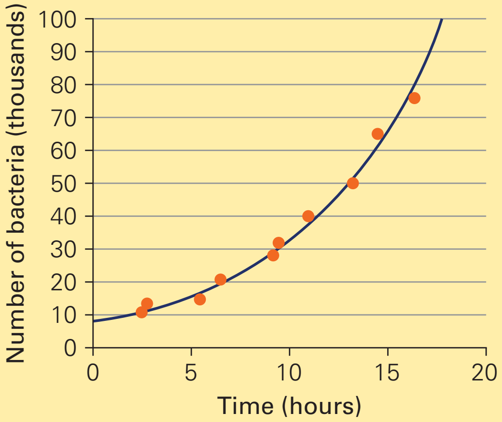
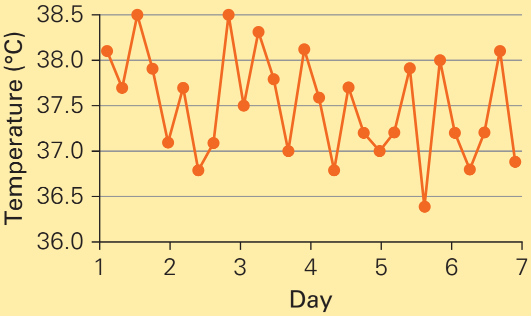
Graph	Explanation
 **Figure 1.20** The number of customers per month, over 200 months	In Figure 1.20, the data shows a rapid increase in customers that reaches a plateau (flat line) and then remains constant. You would describe this by saying, 'Initially, during approximately the first 60 months, as the number of months increases, the number of customers per month increases rapidly from 0 to 2000. Then, for the next 100 months, the number of customers per month remains constant at around 2000'.
 **Figure 1.21** The effect of time on number of bacteria	The data in Figure 1.21 shows an **exponential** increase. You would describe this by saying, 'For the first 10 hours, the number of bacteria increases slowly from 10 000 to 30 000. After 10 hours, the number of bacteria increases more rapidly' (by commenting on the steepness of the gradient).
 **Figure 1.22** Temperature fluctuations over a seven-day period	In the line graph in Figure 1.22, the data do not show a clear pattern. There are seemingly random fluctuations over time. You should still highlight that the data points appear to be scattered or randomly distributed without a clear pattern or correlation.

Table 1.6 *(continued)*

Drawing a line of best fit

After plotting your data as points, you may notice one of the trends discussed previously. To highlight this pattern in the data, you can draw in a line of best fit. This can be a straight line or a curve – whichever suits the data better and approximates the relationship between the independent and dependent variables. When drawing a line of best fit, you do not connect every data point. Instead, you draw a line/curve with approximately as many data points on one side of the line as there are on the other (e.g. half above, half below) *without* including outliers. The line of best fit is like an 'average' that runs smoothly through the middle of the data and makes the trend obvious. Figures 1.20 and 1.21 in the table above demonstrate curved lines of best fit.

Your line of best fit should:

- be continuous, and it can be straight or curved or any other shape that averages the data points. Do not try to draw a straight line over data that is clearly curved.
- not be forced through the origin (0, 0) if one is used on the graph
- be drawn within the range of data points. If extended beyond the original dataset, it can be dotted/dashed, as shown in Figure 1.23.

Figure 1.23 is a scatter plot with a line of best fit, drawn in red. Note how the line runs through the 'middle' of the data, like an average. The dotted regions are where the line has been continued beyond the original dataset.

As discussed, the line of best fit is not always a straight line. The graph in Figure 1.24 shows how 100 mL of water cools over 100 minutes. As you can see, a straight line would not fit the dots very well. In this case, the line of best fit is a curved line.

You can use the line of best fit to predict:

- missing measurements within the original dataset (this is called **interpolation**)
- measurements beyond the original dataset (this is called **extrapolation**).

In Figure 1.25, some data has been collected and graphed to show the relationship between temperature and number of mosquitoes. It appears the data was collected for temperatures ranging from 18°C to 46°C. If the scientist wanted to predict the number of mosquitoes when the temperature is 31°C (as shown with the purple dotted line), this would be an example of interpolation. If they wanted to predict the number of mosquitoes when the temperature is 8°C (as shown with the green dotted line), this is extrapolation. It is less reliable as it assumes the relationship, shown by the line of best fit, continues beyond the original dataset.

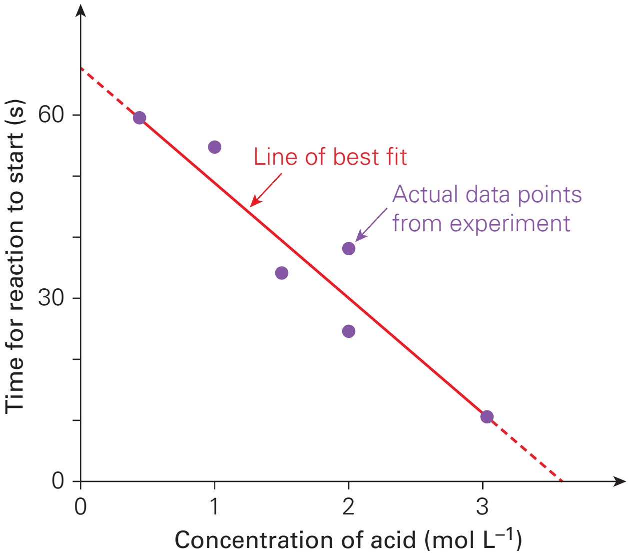


Figure 1.23 The effect of acid concentration on the time taken for a reaction to start

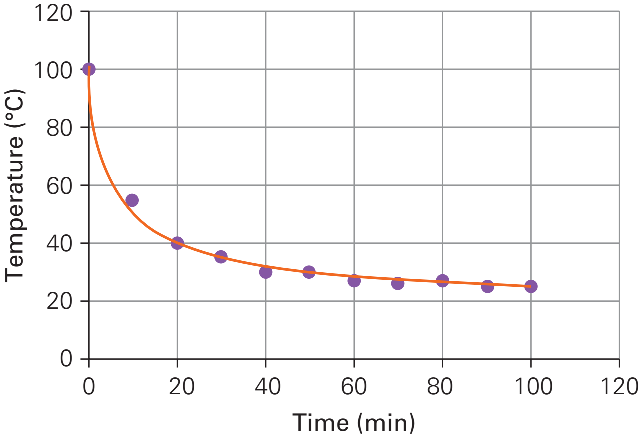


Figure 1.24 The effect of time on the temperature of 100 mL of water

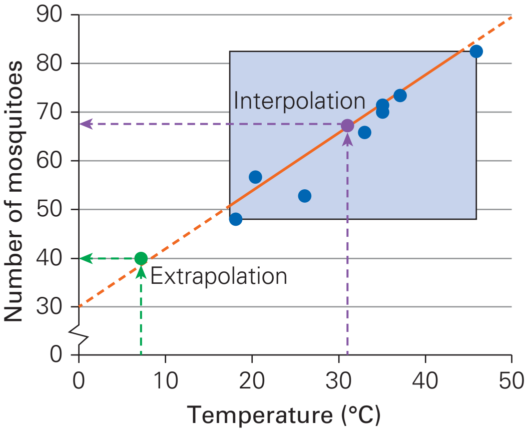


Figure 1.25 A scatterplot of data. A line of best fit can be used to predict measurements both within and beyond the original dataset.

interpolation
using existing data (such as a line of best fit) to make a reliable prediction within the original dataset

extrapolation
using existing data (such as a line of best fit) to make a less reliable prediction beyond the original dataset

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Try this 1.5

Balloon popping

Be careful
Safety glasses must be worn during this practical.

Background information
In this activity, you will gather data that can be turned into a line graph.

Aim
To test the effect of number of breaths on the circumference of a balloon

Materials
- balloon
- string
- permanent marker
- ruler

Method
1. Lie the balloon flat on the workbench. Using the string, measure the circumference at the widest part of the balloon.
2. Using a permanent marker, draw a line on both sides of the balloon to indicate where you took the first measurement.
3. Use one breath to inflate the balloon and hold it tight to prevent air escaping. Without tying the balloon, use the string to measure new value of the circumference along the line you have already drawn.
4. Repeat step 3, adding more volume to the balloon by one breath at a time, making sure no air escapes, recording your results until the balloon pops.

Results
Create a results table for this experiment.

Draw a line graph. Number of breaths should be on the *x*-axis and balloon circumference on the *y*-axis.

Discussion: Analysis
Identify one trend that you observed in your graph.

Discussion: Evaluation
1. Suggest possible experimental uncertainties and faults in this experiment.
2. Suggest one way to improve the experimental design if you were to conduct this experiment again in the future.

Conclusion
1. Draw a conclusion from this experiment about the effect of number of breaths on the circumference of a balloon, by copying and completing this statement in your science book. From this activity it can be claimed that __________. This is supported by the observations that _____________. Therefore, the hypothesis *is*/*is not* supported by these findings.

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Section 1.3 review

Online quiz

Section questions

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Section 1.3 questions

Remembering

1. **State** which type of graph should be used to display continuous quantitative data.
2. **Determine** the mean, median and mode of the following dataset: 1, 2, 3, 4, 5, 5, 8

Understanding

3. **Explain** why it is important to include outliers when reporting your data, but to remove outliers when analysing data.
4. **Describe** where the independent and dependent variables should be placed on a graph.

Applying

5. **Contrast** qualitative and quantitative data.
6. **Contrast** discrete and continuous data.

Analysing

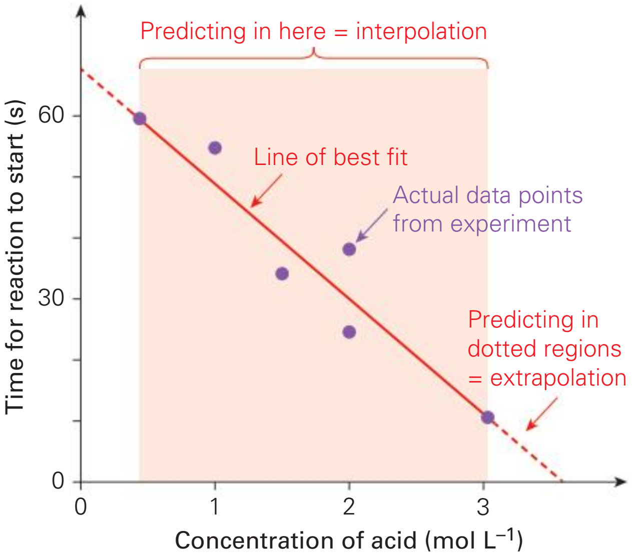
7. Martin had a bag of lollies of different colours. He found that, when he offered them to friends, he was always left with purple lollies. He decided to conduct an experiment to test people's favourite lolly colours. He shared a bag that had 20 of each colour and recorded what was left at the end. From this he worked out how many of each colour had been eaten. The results are shown in the table.

Lolly colour	Number of lollies eaten
Purple	4
Green	13
Yellow	18
Red	20

   a) **State** which type of graph should be used to represent this data.
   b) **Propose** which variable is the independent variable and which is the dependent variable.

Evaluating

8. Tahnee uses the following graph to make a prediction about the time taken for a reaction to start when using 0.1 mol L^{-1} acid. She estimates it would be around 68 seconds. **Justify** whether this prediction is reliable or not.



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1.4 Scientists communicate their results

Learning goals

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

1. Discuss the reliability and validity of experimental results.
2. Communicate findings by constructing a scientific conclusion.

Scientists must communicate effectively when they share their research findings. This means that the presentation format should be tailored to suit the audience. For example, a scientist may present their findings on the effect of climate change through an oral presentation and poster display at a conference. Their findings may be documented in an article in a peer-reviewed journal, which follows a similar formal structure to the practical reports you might create at school. When informing members of the general public, scientists need to communicate in a way that people can easily understand, and make use of graphs, diagrams and infographics that summarise their results concisely.

Science educators and influencers run school programs, and appear on social media platforms, television and radio. This enables important research findings to find a wider audience and engages and inspires people to see the relevance and importance of science to society. When science is communicated effectively, it promotes more informed decision-making at all levels, from the government to communities to individuals.

Explore! 1.3

Science influencers

When communication of science is done well, scientists have the ability to enthuse and harness the curiosity of the general population and encourage young people to pursue study and careers in the sciences.

Use the internet to explore what topics the following science communicators present and to what audience. Consider how these influencers describe causal relationships in experiments.

- Doctor Karl Kruszelnicki
- Professor Lisa Harvey-Smith

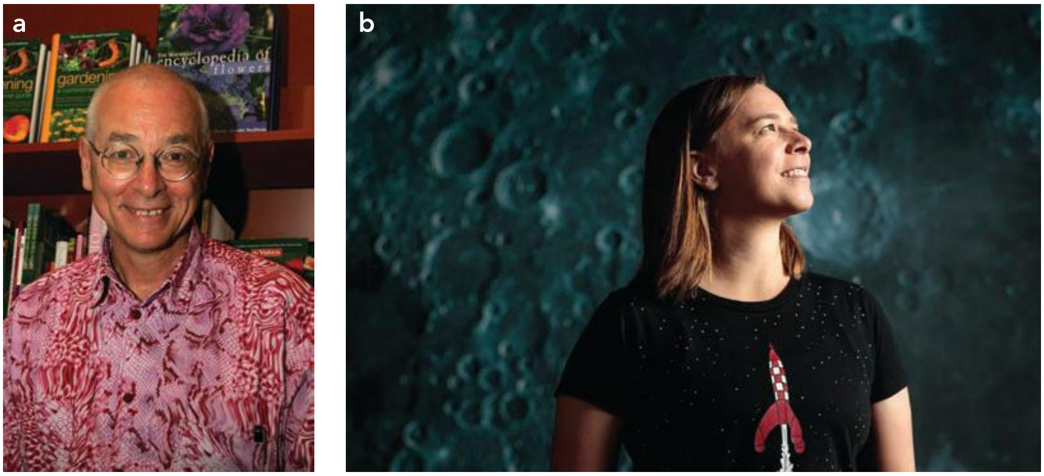

Figure 1.26 Science influencers **(a)** Doctor Karl Kruszelnicki and **(b)** Professor Lisa Harvey-Smith

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Making thinking visible 1.2

Tug for truth: Protecting endangered species

It is claimed that effective science communication regarding endangered species has informed the policies and regulations related to fishing catch and hunting limits. Use the internet to research this claim and complete the activity below:

- What is your personal opinion on this statement?
- Draw a tug of war diagram on the board. Use different-coloured post-it notes to add evidence that supports the claim on one side, and evidence that refutes the claim on the other side.
- Do you have any new ideas or questions about the claim?

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

Practical reports and scientific posters

Two common ways of presenting the findings from an experiment are practical reports and scientific posters. In Year 7 you discovered that the sections of a practical report closely align with the steps of the scientific method (Figure 1.27).

A scientific poster has a standardised format with headings that mirror a practical report. While it contains less detail, it offers a summary of the experiment and can be more engaging – particularly for people who are not from a scientific background. An example of a scientific poster is shown in Figure 1.28. It has been annotated to guide you through the process of creating one.

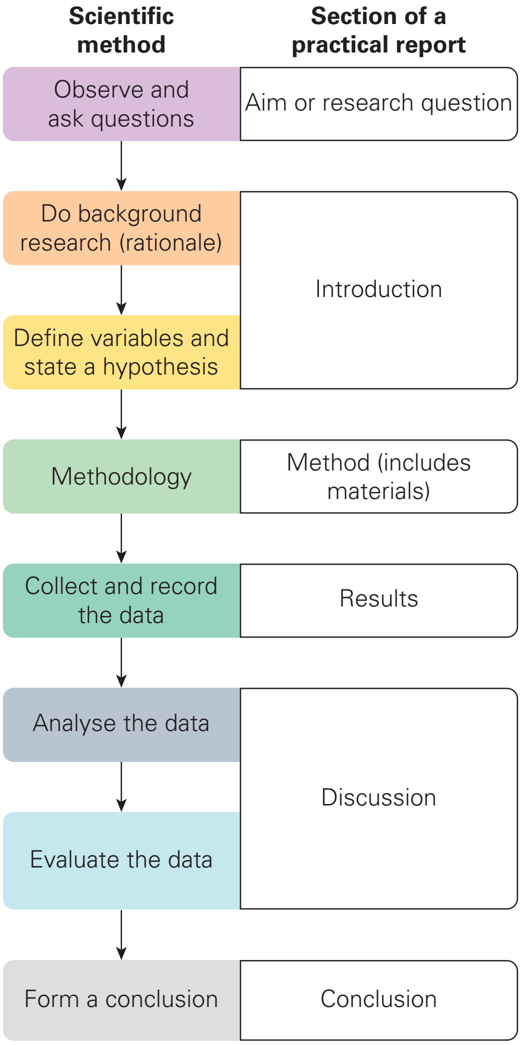

Figure 1.27 Steps of the scientific method matched to sections of a practical report

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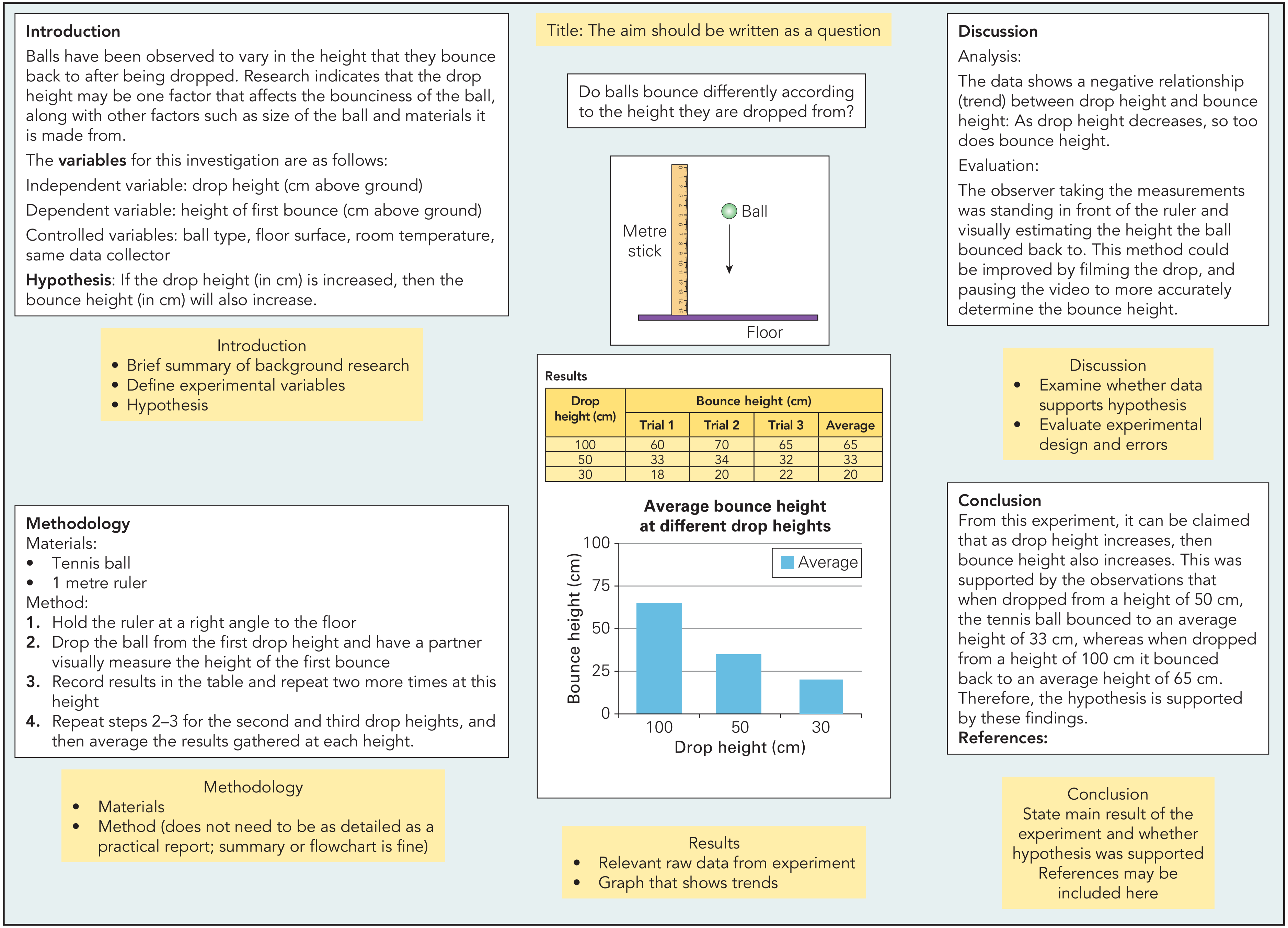


Introduction

Balls have been observed to vary in the height that they bounce back to after being dropped. Research indicates that the drop height may be one factor that affects the bounciness of the ball, along with other factors such as size of the ball and materials it is made from.

The **variables** for this investigation are as follows:

Independent variable: drop height (cm above ground)

Dependent variable: height of first bounce (cm above ground)

Controlled variables: ball type, floor surface, room temperature, same data collector

Hypothesis: If the drop height (in cm) is increased, then the bounce height (in cm) will also increase.

Introduction
- Brief summary of background research
- Define experimental variables
- Hypothesis

Methodology

Materials:
- Tennis ball
- 1 metre ruler

Method:
1. Hold the ruler at a right angle to the floor
2. Drop the ball from the first drop height and have a partner visually measure the height of the first bounce
3. Record results in the table and repeat two more times at this height
4. Repeat steps 2–3 for the second and third drop heights, and then average the results gathered at each height.

Methodology
- Materials
- Method (does not need to be as detailed as a practical report; summary or flowchart is fine)

Title: The aim should be written as a question

Do balls bounce differently according to the height they are dropped from?

Results

Drop height (cm)	Bounce height (cm)			
	Trial 1	Trial 2	Trial 3	Average
100	60	70	65	65
50	33	34	32	33
30	18	20	22	20

Results
- Relevant raw data from experiment
- Graph that shows trends

Discussion

Analysis:

The data shows a negative relationship (trend) between drop height and bounce height: As drop height decreases, so too does bounce height.

Evaluation:

The observer taking the measurements was standing in front of the ruler and visually estimating the height the ball bounced back to. This method could be improved by filming the drop, and pausing the video to more accurately determine the bounce height.

Discussion
- Examine whether data supports hypothesis
- Evaluate experimental design and errors

Conclusion

From this experiment, it can be claimed that as drop height increases, then bounce height also increases. This was supported by the observations that when dropped from a height of 50 cm, the tennis ball bounced to an average height of 33 cm, whereas when dropped from a height of 100 cm it bounced back to an average height of 65 cm. Therefore, the hypothesis is supported by these findings.

References:

Conclusion
State main result of the experiment and whether hypothesis was supported
References may be included here

Figure 1.28 Example of a scientific poster

Writing a scientific discussion

The discussion section of your practical report or scientific poster is typically broken into two parts: analysis and evaluation.

Analysis

This is where you interpret the results (the raw data in tables, or processed data in graphs). Any relationships between the variables, as shown by trends, should be highlighted and described.

Evaluation

This is where you critique the results and method. It is also a section of the report where you would outline any problems you faced during the experiment and offer suggestions for improvements or extensions to the method. This includes possible errors or mistakes encountered in experimentation. Any suggested improvements should include the following information:

- a brief description of the problem encountered
- a description of how the problem affected the results
- a description of how you could improve the experimental method (e.g. use different equipment or change the order of the steps)
- an explanation of how this would improve the **reliability**, **validity**, precision and accuracy. Table 1.7 provides more detail on the difference between these four aspects.

reliability
the degree of consistency of your experimental measurements; a test is reliable if it gives the same result when it is repeated under the same conditions

validity
a measure of how closely the results of an experiment reflect what they should

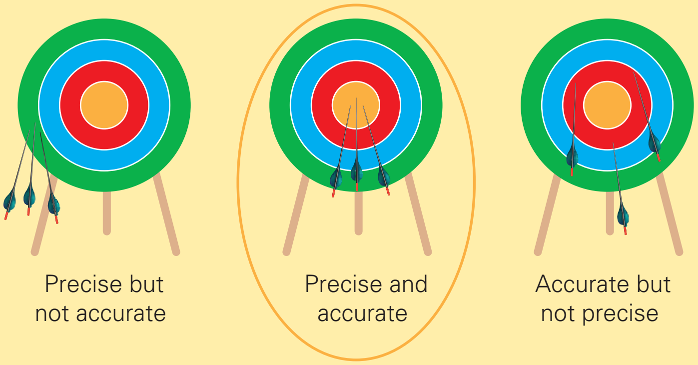
Critique	What does it tell you?	How is it assessed?	How are they related?
Reliability	The extent to which the results can be reproduced when the experiment is repeated under the same conditions (by the same scientist or another scientist)	Check how consistent the results were across time, between different observers	A reliable result is not always valid. It might be reproducible, but this doesn't mean it is correct. A valid measurement may not be reliable if the conditions of the experiment are not consistently reproducible.
Validity	The extent to which the results really measure what they intend to measure	Check that only the independent variable changes and the controlled variables were kept constant. Check the method was followed properly and is suitable.	
Precision	How close two or more measurements are to each other	Are the measurements similar in repeated trials?	A measurement can be precise but not accurate. A measurement can be accurate but not precise.  Precise but not accurate Precise and accurate Accurate but not precise
Accuracy	How close a measurement is to the correct value	Are the measurements close to a standard measurement?	

Table 1.7 The difference between reliability, validity, precision and accuracy

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Some students investigated the effect of salt on the boiling point of water. They used a thermometer to measure the temperature at the boiling point after salt had been added. Here is an example of how they might structure the evaluation section of their practical report. Note: they would not include the italicised headings; the evaluation would be a paragraph or two.

Step 1: Describe a problem that was encountered.

The thermometer did not allow accurate readings because it is difficult to judge exactly when the water starts boiling – it is not when the first bubbles are seen. The boiling point should be taken as when the temperature stays the same for a period of time, even though more heat is added. Secondly, depending on the type of thermometer and the size of the gradations, it may be difficult to see the small changes in boiling point on a thermometer.

Step 2: Describe how the problem affected the results.

It was unclear whether the temperature was staying the same, so the students had to make a judgement about when the boiling point had been reached. This judgement could vary from person to person. Students also had to make an estimation of the temperature due to the gradations on the thermometer, so the level of their eye and their own judgement could result in variations between experimenters.

Step 3: Explain how it could be improved.

Using a temperature probe, a data logger or an electronic thermometer could allow more accurate measurements.

Step 4: Explain how this would improve accuracy, reliability, validity and precision.

The data collected would be digital and more accurate, as there would be fewer measurement uncertainties and less chance of introducing human error. A digital output would show more clearly what the temperature was when it stopped changing.

Effectively, the evaluation allows you to consider the types of error that might have been present in your experiment. You should ask yourself:

- Were systematic errors avoided?
- Did you identify all the variables that needed to be controlled? For example, was the concentration of salt the same each time (same mass of salt added to same volume of water)?
- Were all controlled variables actually controlled in the experiment?
- Were measurement tools functioning correctly and calibrated against a known value?
- Were random errors minimised?
- Is a modification to the method necessary to improve reliability or accuracy? For example, if the original method involved measuring the pH of a solution using pH paper, a modification could be made to use a pH meter instead. This change would be made because pH paper measurements may introduce random errors due to colour interpretation by the observer and limited precision.
- Were there any errors that are unavoidable in the experiment?
- Was there a problem with the method? For example, if the original method required a specific incubation time for a reaction, but it was found that the reaction did not proceed as expected within that time frame, the incubation time could be extended to allow for complete reaction. This modification is based on the recognition of an error in the original method and the need to ensure accurate data collection.

Figure 1.29 By using a pH meter instead of pH paper, more accurate and precise pH measurements can be made.

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Quick check 1.4

1. **Define** the terms ‘precision’ and ‘accuracy’.
2. **Suggest** which type of error is minimised by controlling variables.
3. **State** whether controlling variables improves the reliability of the experimental results or the validity of the results.

Writing a conclusion

WORKSHEET
Evaluating conclusions

A conclusion is a short paragraph in a scientific report and should always include three key ideas:

- the claim of causation that can be made from the experiment regarding the independent and dependent variables
- the evidence from your data that supports this claim (specific data should be stated)
- an explanation of whether the data supports or does not support the hypothesis.

It is important that when scientists have evaluated their data, they are very careful in describing claims of causal relationships. Remember, a trend in data doesn’t necessarily mean that there is causation. Reliability and validity both need to be considered when making concluding claims.

Here is an example of an experiment along with the conclusion that was made:

Annabel conducted an experiment to see if taking her very anxious dog Les for more walks reduces the number of socks Les destroys.

Annabel’s hypothesis was: ‘If Les takes more walks per day, then Les will chew a smaller number of socks’.

Annabel collected her data and represented it in a scatterplot, shown in Figure 1.30. From analysis of the trend in the graph, Annabel developed the following conclusion:

‘This experiment provided evidence that there is a possible causal relationship between the number of walks Les has per day and the number of socks he chews. The data shows that as the number of walks per day increased (from 2 to 6), there was a decreasing trend in the number of socks chewed (from 5 to 0). The evidence from this experiment supports the hypothesis that if Les takes more walks per day, then Les will chew a smaller number of socks.’

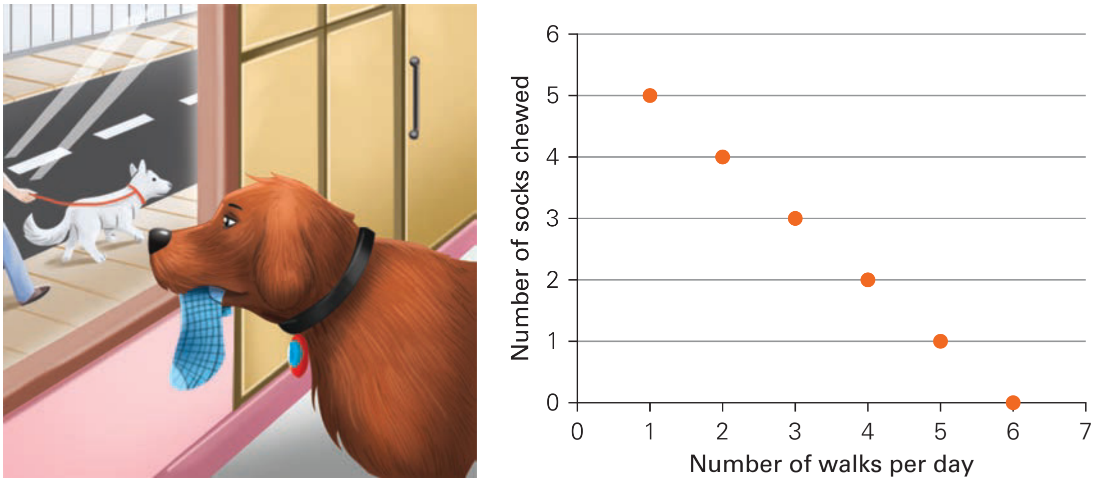

Figure 1.30 The effect of walks on the number of socks chewed

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Validating a conclusion

Comparing results with other groups or secondary sources is a valuable practice to assess the consistency of your findings. If there are discrepancies or conflicting results, the potential reasons behind them can be analysed, such as differences in methods, sample size or experimental conditions. Such conflicts may lead to further investigation or discussion to understand the underlying factors causing the variations. Sometimes, this comparison may produce additional questions that need to be explored to verify the validity of those claims. When conducting experiments in class, your teacher might collate the results from multiple groups and instruct you to use this combined data in your discussion. This is a practical way of comparing the consistency of results and identifying errors. However, combining groups' data can cause issues too: If groups have interpreted and conducted the method differently, then this can reduce the reliability of the data collected.

Remember, when validating any conclusion, it is important to look for facts or ideas that have been taken for granted to be true, and to question scientific practices that have become standard. For example, in experiments that involve motion of a projectile (such as throwing a ball), the effect of wind resistance is so small that it is often left out of the calculations of forces, making the equations easier to solve. Discussing these assumptions and practices with others helps determine if they are reasonable and supported by evidence. This process helps in developing a stronger understanding of the topic and promotes a more thorough examination of your experimental results and the conclusions you draw from them.

Try this 1.6

Writing a conclusion

Gen conducted an experiment to see if the distance from a window would affect the growth of her potted plants.

Gen's hypothesis was: 'It is hypothesised that as distance from the window increases, the growth of the plants will decrease'.

Gen measured her plants before the experiment, placed them at different distances from the window and measured them two months later. She then graphed her results and obtained a line of best fit.

1. Develop a conclusion based on Gen's results. Your conclusion should reference the aim, briefly summarise the data and state whether the hypothesis was supported or not.
2. Suggest three controlled variables that Gen would have used to make this a fair test.
3. Propose two possible causes for the increase in plant height for the plant that was placed 6 m from the window.

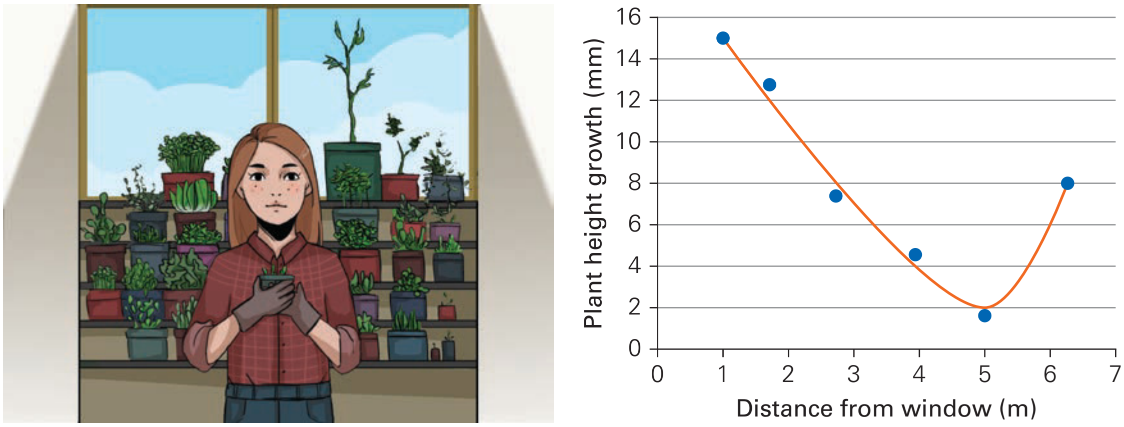

Figure 1.31 How the distance from a window affects plant height growth

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Section 1.4 review

Online quiz	Section questions	Teachers can assign tasks and track results

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Section 1.4 questions

Remembering

1. **State** the part of a scientific report that states whether the hypothesis was supported.
2. **State** the part of a scientific report where you can talk about problems you faced and changes you would make.

Understanding

3. **Outline** the three key components of a scientific conclusion.
4. **Describe** one advantage and one disadvantage of displaying your research in a scientific poster as opposed to a practical report.

Applying

5. **Contrast** validity and reliability.

Analysing

6. **Suggest** a way to validate your conclusion.
7. Use this table of data to answer the questions below.

Time elapsed (minutes)	Temperature (°C) of the solution			
	Trial 1	Trial 2	Trial 3	Mean temperature
1	80	83	82	
2	63	65	66	
3	30	32	65	

   a) **Calculate** the mean temperature for each time.
   b) **Determine** the outlier in the results.
   c) **Evaluate** the data.
   d) **State** a conclusion for this experiment.

Evaluating

8. Students measure the mass of zinc powder three times and obtain the following readings: 10.20 g, 10.20 g, 10.19 g. Unfortunately, they later discover that the scales are faulty. **Justify** whether these results could be considered precise, accurate or neither.

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Chapter review

Chapter checklist

Success criteria		Linked question
1.1	I can recall the steps of the scientific method.	9
1.1	I can define primary and secondary sources of information, and utilise the CRAAP test to assess secondary sources.	1, 4
1.1	I can construct a scientific hypothesis, including independent and dependent variables.	2
1.2	I can construct a step-by-step experimental method.	11a
1.2	I can describe the importance of a risk assessment.	11b
1.2	I can suggest some ethical guidelines a scientist must follow when using human and animal participants in experiments.	8a
1.2	I can outline how experimental errors can be minimised.	6
1.3	I can classify quantitative data as either continuous or discrete.	8b, 8c
1.3	I can calculate the mean, median, mode and range of data.	8d
1.3	I can plot a line graph and a line of best fit.	5, 10a, 10b, 10c
1.3	I can identify trends present in graphical representations of data.	7a, 7b, 7c, 7d, 10d
1.4	I can discuss the reliability and validity of experimental results.	3, 8e
1.4	I can communicate findings by constructing a scientific conclusion.	7e, 10e

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **State** the difference between a primary source and a secondary source when conducting background research.
2. **Recall** what should be included in a hypothesis.
3. **Define** the terms ‘reliability’ and ‘validity’.
4. The CRAAP test assesses the quality of sources of information. **State** what each of the letters stands for.

Understanding

5. **List** the features of a well-constructed line graph.
6. **Describe** one way to reduce systematic errors in an experiment, and one way to reduce random errors.

Applying

7. Several students were timed on how long each spent on chapter review questions, and then the next exam score for each was recorded. The results were graphed and are shown in Figure 1.32.

- a) **Identify** the independent variable and the dependent variable.
- b) **Analyse** the data and identify which data point appears to be an outlier.
- c) **Describe** the outlier's performance in terms of the independent and dependent variables.
- d) **Describe** the pattern evident in the data.
- e) **Construct** a conclusion based on the data.

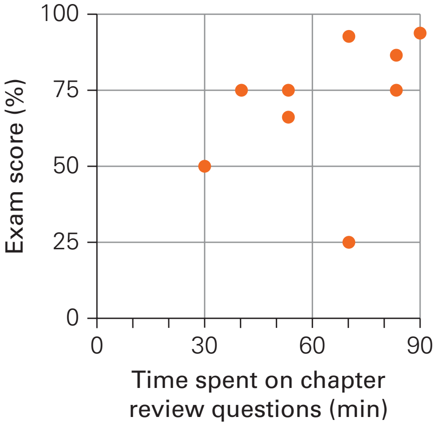

Figure 1.32 How time spent on chapter review questions affects exam scores

8. Scientists were conducting an investigation into household water use. Participants were recruited for the study by mailing out invites with information about the study. If they wanted to participate, they had to collect data relating to the duration of their showers (in minutes) and the volume of household water use (in megalitres). The data would be anonymous, and they could withdraw from the study at any time.

- a) **Identify** two ethical practices that the experimenters adhered to.
- b) **Classify** the variable 'shower duration (in minutes)' as continuous or discrete data.
- c) **Classify** the variable 'household water use (in megalitres)' as continuous or discrete data.
- d) **Calculate** the mean, median, mode and range of the following shower duration data:

Participant responses (in minutes)	2, 5, 6, 10, 5, 2, 4, 12, 18, 14, 7, 8, 5, 9, 7

- e) Participants were asked to estimate the duration of their showers to the nearest minute. **Discuss** one way the experimental method could be improved, outlining the effect this would have on the accuracy, reliability, validity and precision of the data.

Analysing

9. **Sequence** the following steps of the scientific method:

- do background research
- observe and ask questions
- test the hypothesis with an experiment
- define variables and state a hypothesis
- analyse the data
- communicate your findings
- evaluate the data
- form a conclusion
- collect and record the data

10. Answer the following questions using Figure 1.33.
    a) **Determine** the masses of the two bandicoots captured after three months.
    b) **Identify** when a 500 g bandicoot was captured for the first time.
    c) **Draw** a line of best fit for the data. Use this line of best fit to **predict** the mass of a bandicoot captured after six months.

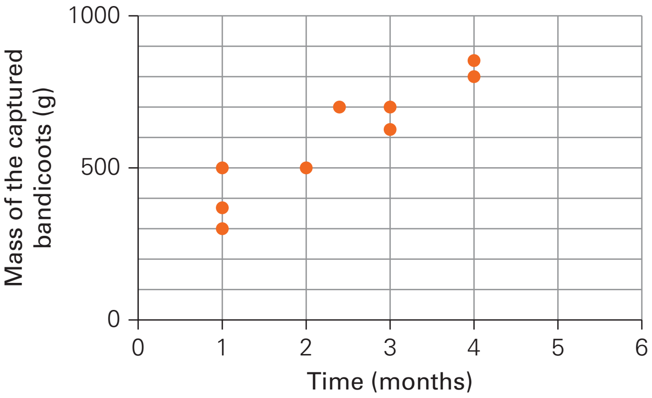

Figure 1.33 How time affects the mass of captured bandicoots

    d) **State** whether your prediction in part **d** was an example of interpolation or extrapolation.
    e) **Propose** a reason why there appears to be a trend of increasing mass with time.

Evaluating

11. The 'squeaky pop' test involves the reaction of an acid and a metal.
    a) **Correct** this student's description of their experimental method so that is follows conventions.
    'First you get the equipment you need out of the cupboard. Then you measure out 20 mL of hydrochloric acid and add it to the test tube. Drop in the magnesium ribbon but be very careful because the acid is corrosive and dangerous. Then hold a burning match near the top of the test tube and listen for a pop.'
    b) **Suggest** a source of information you could refer to regarding the risks and safety precautions required when using hydrochloric acid.

Data questions

A scientist was investigating the relationship between the volume that a certain mass of gas would occupy at different temperatures (while the pressure was constant) and the volume that the same mass of gas would occupy at different pressures (while temperature was constant).

Applying

1. **Identify** the pressure exerted by a volume of 19 L of gas at 20°C by referring to Figure 1.35.
2. **Identify** the dependent, independent or controlled character of each variable (volume, temperature, pressure) for the data presented in Figure 1.34.
3. **Identify** the volume occupied by a gas at a pressure of 101 kPa and a temperature of 10°C by referring to Figure 1.34.

Analysing

4. **Identify** the general relationship between the volume the gas occupies and the temperature, and the volume the gas occupies and the pressure.
5. **Analyse** whether the volume that the gas occupies is doubled when the temperature is doubled in Figure 1.34.

Evaluating

6. Use the two graphs to **deduce** the volume that the gas will occupy at 20°C and 101 kPa.
7. Extrapolate the data to **predict** the volume that the gas will occupy at 110°C and 101 kPa.
8. In Figure 1.34, **predict** whether a new line will be higher or lower than the original if the pressure was increased to a constant 150 kPa.
9. Use Figure 1.34 and Figure 1.35 to **deduce** whether an increase in temperature at atmospheric pressure would affect the volume occupied by the gas.

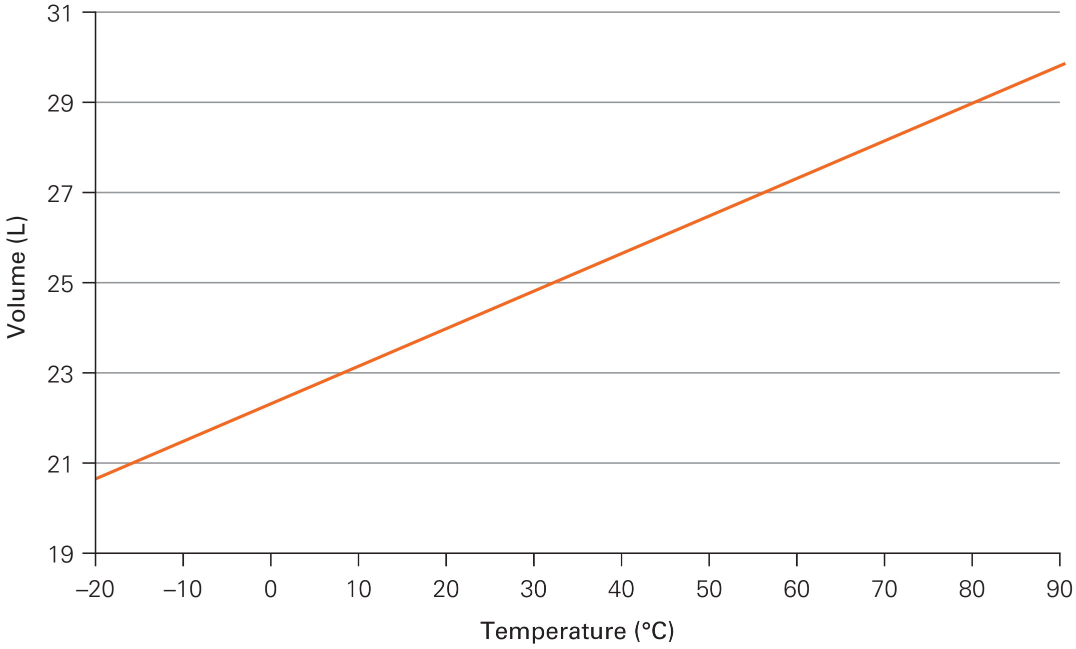

Figure 1.34 Variation of the volume of a gas at atmospheric pressure (P = 101 kPa) when temperature is changed

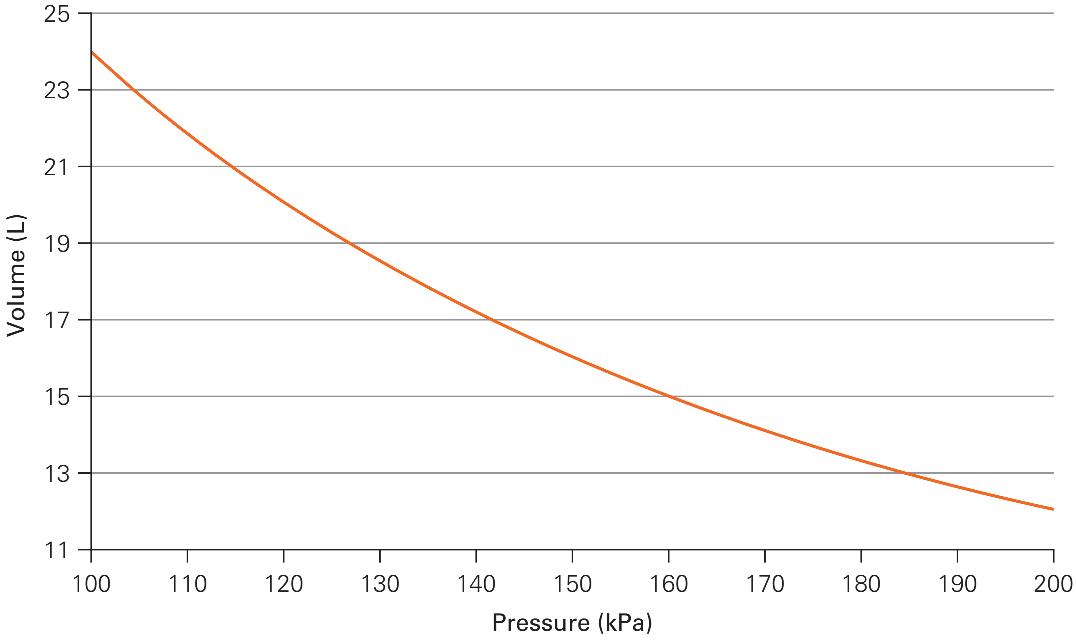

Figure 1.35 Variation of the volume of a gas at ambient temperature (T = 20°C) when pressure is changed

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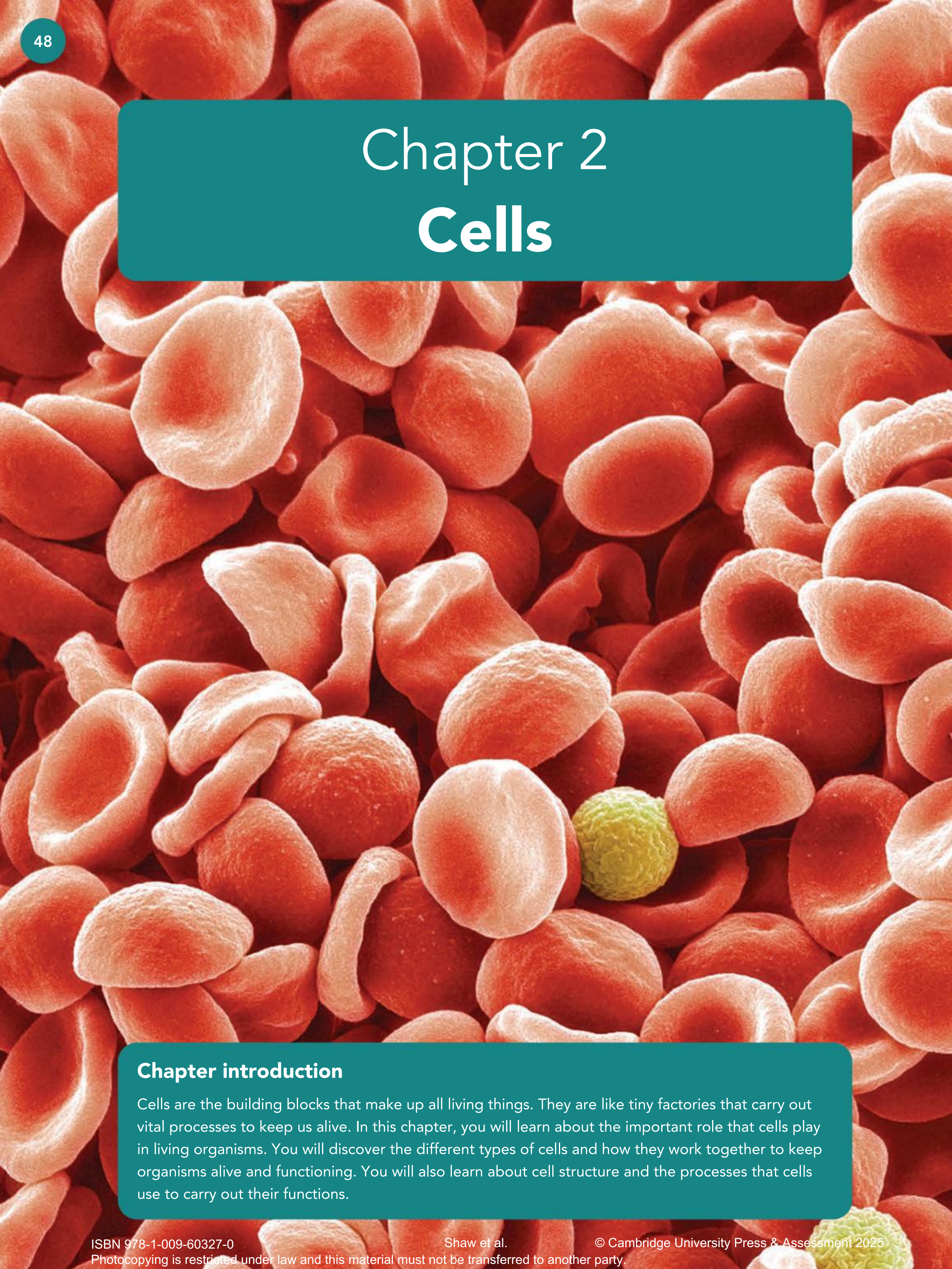


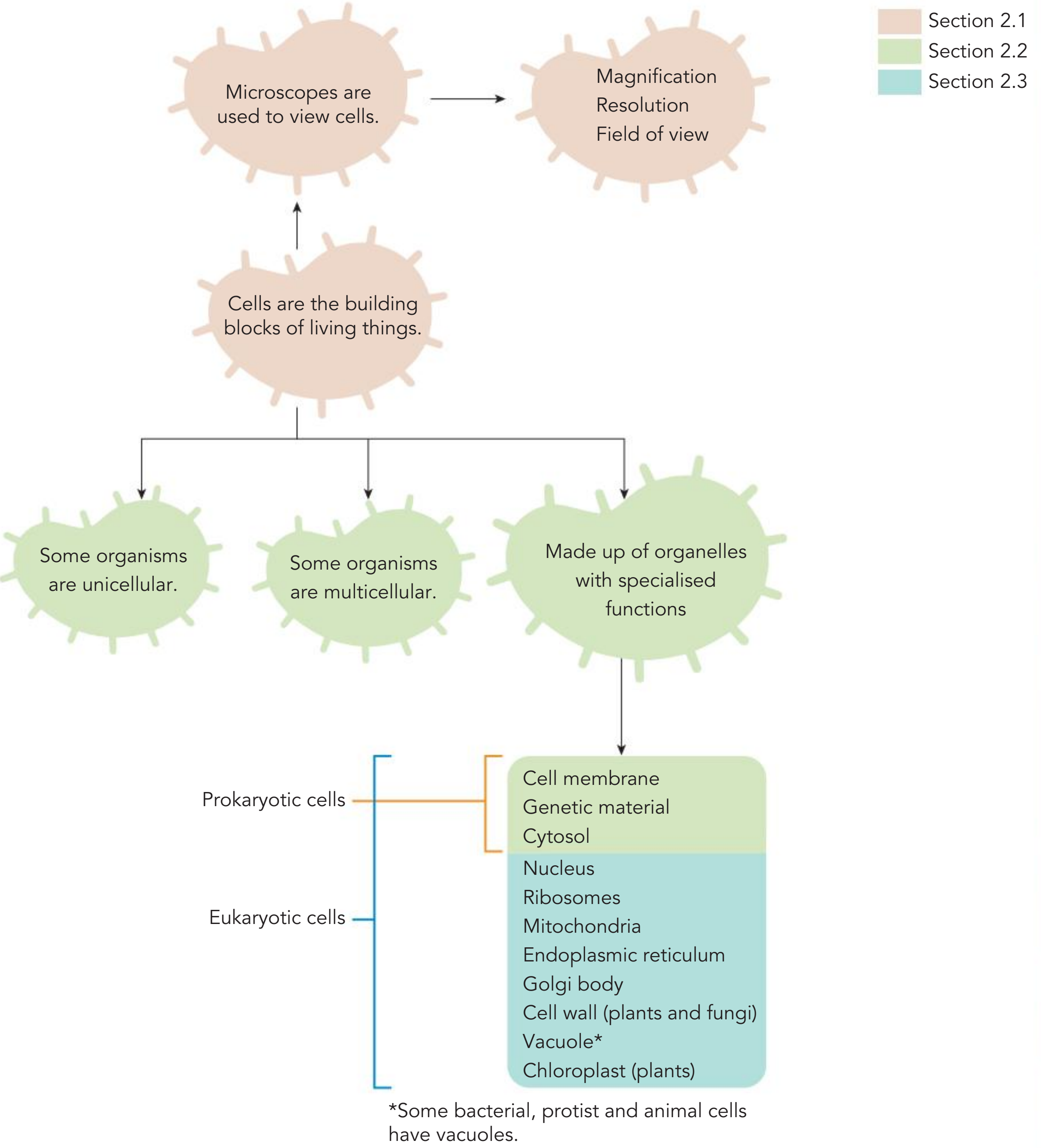
Chapter 2

Cells

Chapter introduction

Cells are the building blocks that make up all living things. They are like tiny factories that carry out vital processes to keep us alive. In this chapter, you will learn about the important role that cells play in living organisms. You will discover the different types of cells and how they work together to keep organisms alive and functioning. You will also learn about cell structure and the processes that cells use to carry out their functions.

Concept map



*Some bacterial, protist and animal cells have vacuoles.

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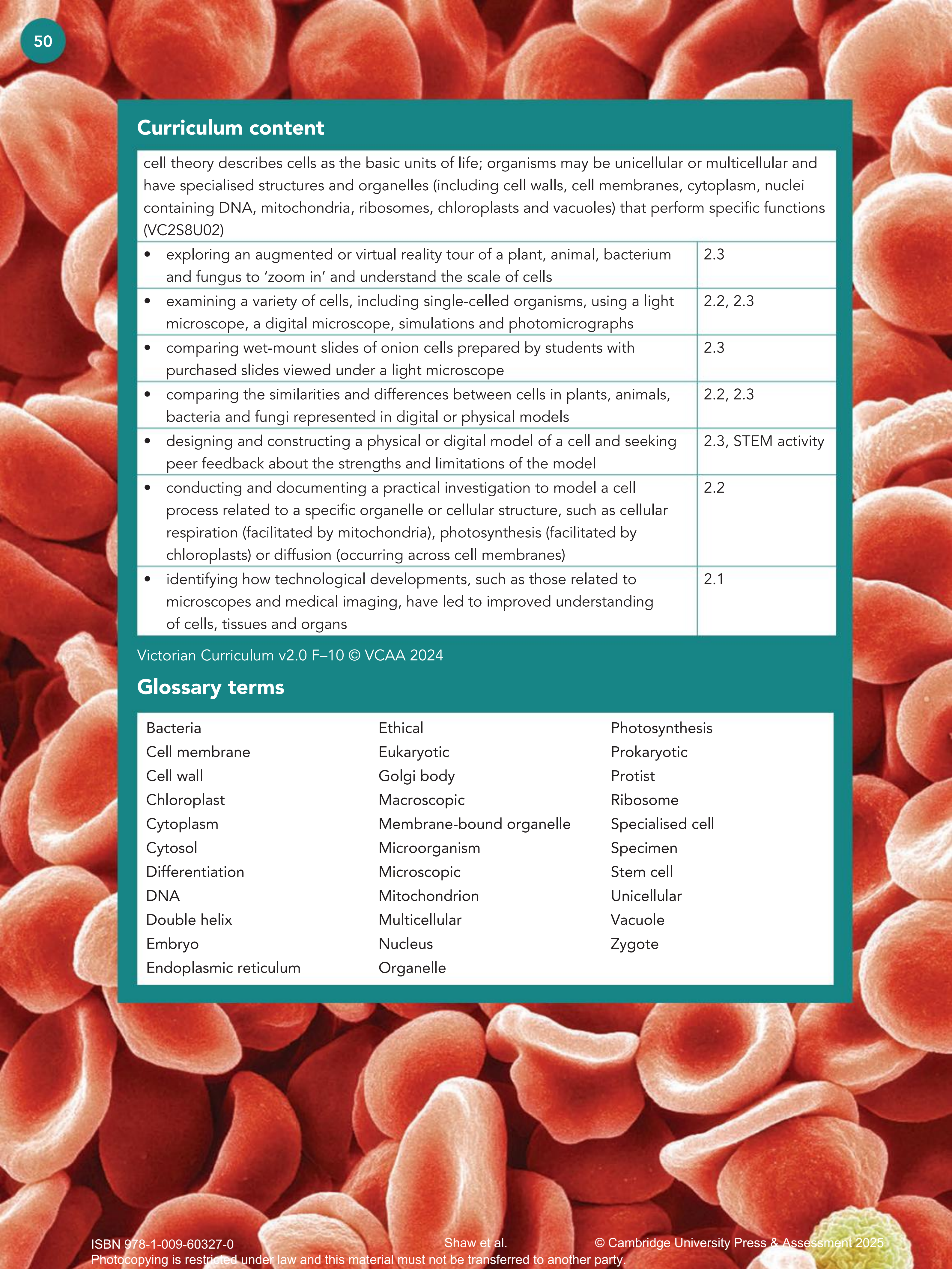

Curriculum content

cell theory describes cells as the basic units of life; organisms may be unicellular or multicellular and have specialised structures and organelles (including cell walls, cell membranes, cytoplasm, nuclei containing DNA, mitochondria, ribosomes, chloroplasts and vacuoles) that perform specific functions (VC2S8U02)	
• exploring an augmented or virtual reality tour of a plant, animal, bacterium and fungus to 'zoom in' and understand the scale of cells	2.3
• examining a variety of cells, including single-celled organisms, using a light microscope, a digital microscope, simulations and photomicrographs	2.2, 2.3
• comparing wet-mount slides of onion cells prepared by students with purchased slides viewed under a light microscope	2.3
• comparing the similarities and differences between cells in plants, animals, bacteria and fungi represented in digital or physical models	2.2, 2.3
• designing and constructing a physical or digital model of a cell and seeking peer feedback about the strengths and limitations of the model	2.3, STEM activity
• conducting and documenting a practical investigation to model a cell process related to a specific organelle or cellular structure, such as cellular respiration (facilitated by mitochondria), photosynthesis (facilitated by chloroplasts) or diffusion (occurring across cell membranes)	2.2
• identifying how technological developments, such as those related to microscopes and medical imaging, have led to improved understanding of cells, tissues and organs	2.1

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Glossary terms

Bacteria
Cell membrane
Cell wall
Chloroplast
Cytoplasm
Cytosol
Differentiation
DNA
Double helix
Embryo
Endoplasmic reticulum
Ethical
Eukaryotic
Golgi body
Macroscopic
Membrane-bound organelle
Microorganism
Microscopic
Mitochondrion
Multicellular
Nucleus
Organelle
Photosynthesis
Prokaryotic
Protist
Ribosome
Specialised cell
Specimen
Stem cell
Unicellular
Vacuole
Zygote

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2.1 Microscopes and cells

Learning goals

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

1. Consider how the invention of the microscope has contributed to understanding of cell structure.
2. Label the parts of a microscope.
3. Examine a variety of cells, including single-celled organisms, using a light microscope, a digital microscope, simulations and photomicrographs.

WORKSHEET Parts of a microscope

The microscope

Cells are the basic building blocks of all living things. They are the smallest unit of life that can carry out all the functions necessary for an organism's survival. To study cells, scientists use microscopes. Microscopes allow us to see and study the tiny details of cells that are invisible to the naked eye by making them appear larger. Five hundred years ago, scientists used hand-held magnifying glasses to view small **macroscopic specimens** – these were large enough to be visible to the naked eye. Scientists soon found that using two lenses together enabled them to see even smaller specimens. This discovery led to the invention of the first light microscope.

macroscopic visible to the naked eye

specimen an object being observed under a microscope

Explore! 2.1

The history of the microscope

In 1665, Robert Hooke published a book based on his observations of the microscopic world. He was able to do this because he had built a compound microscope with a twist-operated focusing mechanism – this had never been seen before. He further improved the microscope by placing a water flask beside the microscope to focus light from an oil lamp onto his specimens to illuminate them brightly.

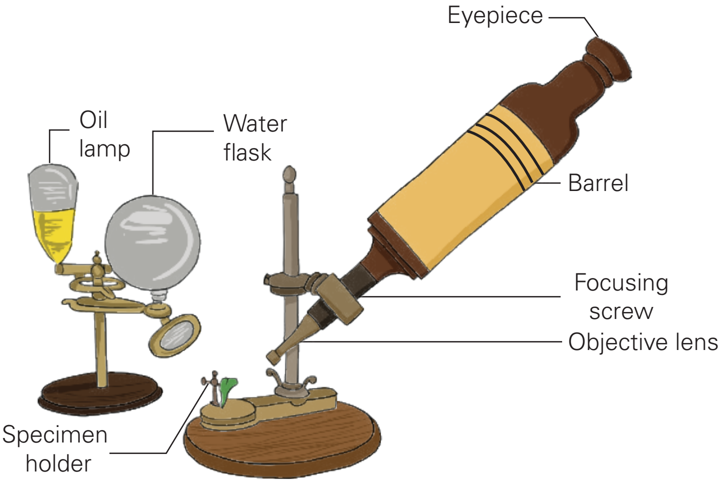

Figure 2.1 The Hooke microscope (circa 1660)

1. Find out about the roles of the following scientists in the development of the microscope and how their discoveries have led to an improved understanding of cells and organs: Professor Pratibha Gai-Boyes, Professor Ed Boyes and Professor Ian Wright; Robert Hooke; Antonie van Leeuwenhoek; Doctor Gertrude Rempfer; Frits Zernike; Marvin Minsky; Ernst Ruska; and Gerd Binnig and Heinrich Röhrer.
2. Using A3 paper, draw an annotated timeline showing who developed what and when.

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VIDEO Leeuwenhoek and his simple microscope

Did you know? 2.1

The discovery of microorganisms

Antonie van Leeuwenhoek was a Dutch scientist who is often credited with being the first person to see and describe **microorganisms**. He is considered one of the pioneers of microbiology, and his discoveries were made possible by his remarkable skill in building and using microscopes. Van Leeuwenhoek created his own microscopes, which were simple, single-lensed instruments that he could use to magnify objects by up to 300 times. With these microscopes, he was able to observe and describe the shape and movements of single-celled organisms, including bacteria. He called these organisms 'animalcules', meaning 'little animals'.

Figure 2.2 Antonie van Leeuwenhoek

microorganism an organism that is too small to be seen with the naked eye

microscopic anything that can only be seen clearly with the use of a microscope

The light microscope used in schools today is similar to those used by scientists hundreds of years ago, but the technology used to produce today's lenses is more advanced and enables us to see things at higher magnifications. Anything that can only be seen clearly with the use of a microscope is described as **microscopic**.

There are different types of microscopes, which vary in their level of magnification and the types of images they produce. The most commonly used microscope in schools is the light microscope. Light microscopes have at least two lenses: the eyepiece (ocular) lens and the objective lens. They also have a light source, a stage on which to place specimens and knobs to adjust the focus. The monocular microscope shown in Figure 2.3 is for use with one eye. Binocular microscopes can be used with both eyes.

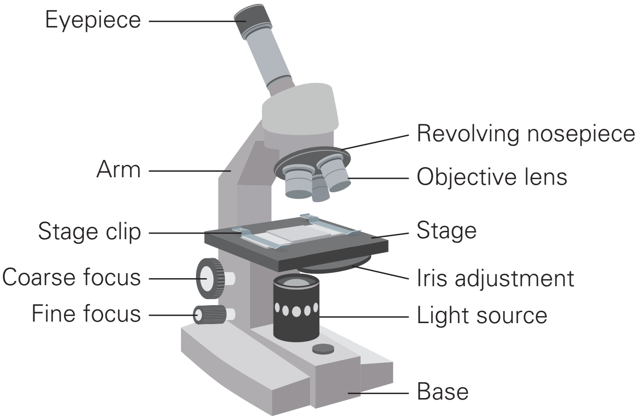

Figure 2.3 The parts of a monocular microscope

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Try this 2.1

Parts of the microscope

Draw up a table with the parts of a microscope in the left column. Find out the function of each part and put this information in the right column.

Microscope terms

Special terms are used to describe the way an object appears under a microscope. Table 2.1 summarises some key terms.

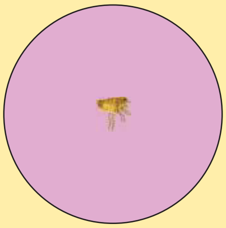
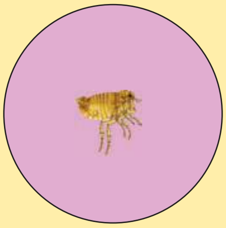
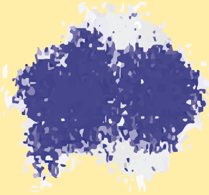
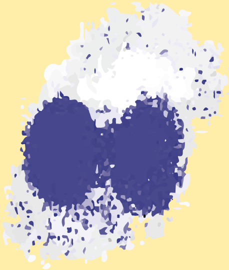
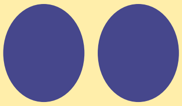
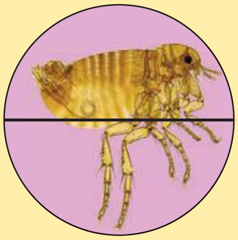
Term	Definition	Image
Magnification	How much the image of the specimen or object is increased in size (i.e. how much you are zooming in). Viewing an object under 10× magnification means that the object appears 10 times larger.	 40× magnification  100× magnification  400× magnification
Resolution	How detailed and clear the image is (i.e. how easy it is to tell two separate objects apart)	 Poor resolution  Better resolution  Best resolution
Field of view (FOV)	How much of the object you can see when you look through the eyepiece. When the magnification increases, less of the object can be seen.	 Human flea

Table 2.1 Some key terms used in microscopy

Binocular microscopes have an eyepiece for each eye. There are two types: compound binocular and stereoscopic. Compound binocular microscopes split one path of light from the specimen between the two eyepieces, so each eye has the same view. Therefore, the image looks flat (two-dimensional). Stereoscopic ('stereo') microscopes, which are much more expensive, direct two separate light paths from the specimen to each eye, so they have different views. The image has depth (three-dimensional). This is useful for manipulating or dissecting specimens, and the magnification does not have to be very large. There are also trinocular microscopes that have an additional eyepiece that a camera can be attached to.

Figure 2.4 An image of a cucumber green spider taken with a camera mounted on a trinocular microscope

Light microscopes can magnify a specimen up to 1500×, which, on some microscopes, is enough to make bacteria visible. However, the resolution at this magnification is not very high, and so light microscopes do not enable you to view anything smaller than bacteria in any detail.

Figure 2.5 Light microscope images taken of the heads of a **(a)** caterpillar, **(b)** ant and **(c)** beetle

VIDEO
Electron microscope

Advances in technology

To observe things that are smaller than bacteria in much higher detail, scientists use an electron microscope. This microscope uses tiny particles called electrons, instead of light, to view an object. Electron microscopes have a magnification of around 10 million times and very high resolution. Since the invention of the electron microscope in 1933, scientists have been able to observe the structure of extremely small objects in high detail. There are now two types of electron microscope:

- transmission electron microscope (TEM) – The specimen to be viewed is sliced very finely and the internal structure can be seen because images are created from electrons transmitted (passing) through the specimen.
- scanning electron microscope (SEM) – The specimen to be viewed is not sliced, and the external surface can be viewed. Images are created from reflected electrons.

Electron microscopes are extremely expensive, and all specimens that are observed must be prepared in a way that requires them to be killed first. However, the advantages electron microscopes have over light microscopes, and the wide range of applications in both research and medicine, far outweigh the high cost of the technology. Using TEM, scientists can observe small structures inside cells and use this information to develop new drugs that target specific molecules involved in diseases such as cancer. It can also be used to identify the presence of heavy metals or harmful toxins in human tissues, which can cause disease.

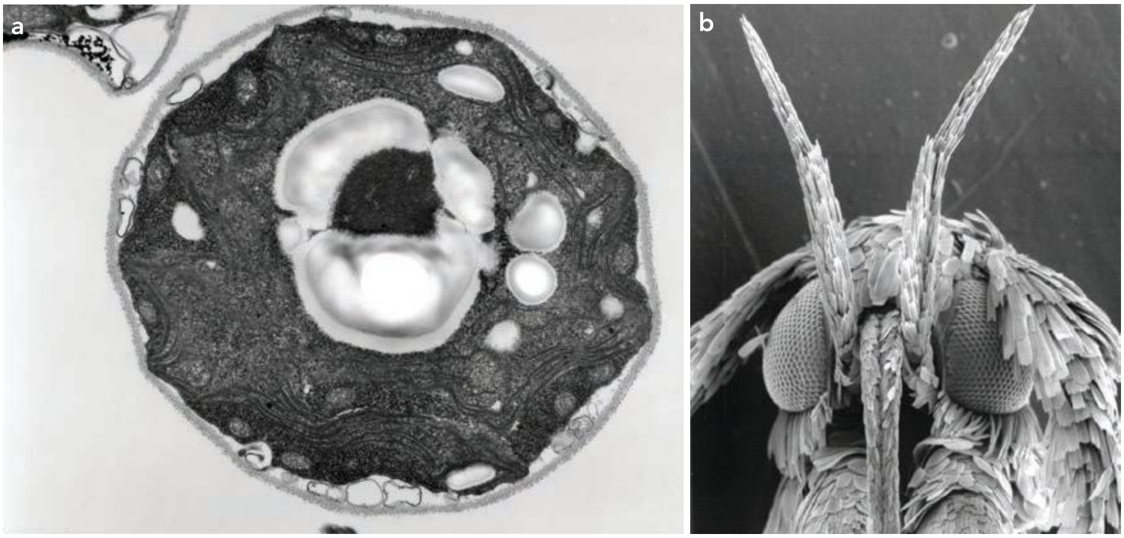


Figure 2.6 Examples of a **(a)** green algal cell as seen through a TEM and **(b)** moth head through an SEM

Try this 2.2

Using a scanning electron microscope

Use *MyScope Explore Scanning Electron Microscope* to observe many everyday objects and biological samples under an SEM. Choose one to share with the class.

Explore! 2.2

Types of microscopes

Research the different types of microscopes that are used today: monocular microscope, stereo microscope and electron microscope.

Copy and complete the following table.

Type of microscope	Magnification	Resolution	Advantages	Disadvantages	Example of what can be seen
Monocular light microscope					
Stereoscopic light microscope					
Scanning electron microscope					
Transmission electron microscope					

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Quick check 2.1

1. **State** the maximum magnification of the monocular microscope, the stereo microscope and the electron microscope.
2. **State** what microorganisms were originally called.
3. **Define** the following key terms, in your own words: magnification, resolution, field of view.
4. **Organise** the different types of microscopes, in order from most powerful to least powerful.

Making thinking visible 2.1

See, feel, think, wonder: SEM images

The following images have been produced from an SEM.

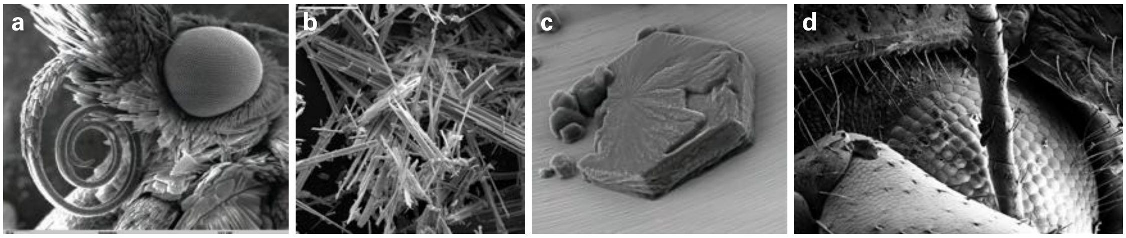


Figure 2.7 **(a)** Head of a moth, **(b)** asbestos, **(c)** partially melted ice crystal and **(d)** ladybird eye

- **See**: describe what you see in these images.
- **Feel**: how do these images make you feel?
- **Think**: what do the images make you think about? Explain your reasoning.
- **Wonder**: what questions do you have about these images?

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

Science as a human endeavour 2.1

Using smartphones to detect disease

Smartphone cameras are not designed to produce high-resolution microscopic images. However, devices that are designed to convert smartphones into microscopes have been developed. They increase the resolution and the visibility of tiny details of the images, which they take down to a scale of approximately one-millionth of a metre, and have the potential to make mobile medical diagnosis of diseases affordable and accessible.

The detection of diseases often requires changes in cells being detected using optical microscopy. This involves staining the cells with chemicals in a laboratory and the use of specialised phase-imaging microscopes. These microscopes are expensive and bulky and so are inaccessible to remote or disadvantaged medical centres in developing countries.

This new smartphone technology could lead to in-home disease detection, where a person could obtain their own saliva or pinprick blood sample and then send an image to a laboratory that could analyse and diagnose the disease.

Practical 2.1

Using a microscope

Be careful

Ensure that the microscope is carried appropriately. Carry it with one hand holding the arm and one hand under the base. Do not use the coarse focus knob to cause the objective lens to touch the glass slide and damage it.

Aim

To focus a microscope to view the letter 'e'.

Materials

- light microscope
- scissors
- sticky tape
- newspaper
- glass microscope slide

Method

1. Cut a 1 cm × 1 cm square of text out of a newspaper.
2. Attach the square to the centre of a glass slide, using sticky tape.
3. Set the lowest magnification or smallest objective lens in place. Turn the coarse focus knob until it is as close to the stage as it will go.
4. Place the slide on the stage of the microscope and secure it in place with the clips. Ensure that the text is the right way up when it is placed on the stage.
5. Using the coarse focus knob, lower the stage until the words on the newspaper are focused.
6. Move the slide so that a letter 'e' is in the centre of the field of view.
7. Using a pencil, draw your observation of the letter 'e' at this lowest magnification. Record the overall magnification next to your drawing. To calculate the overall magnification, you will need to multiply the magnification of the eyepiece (ocular) lens by the magnification of the objective lens. For example, if the eyepiece is 10× magnification and the objective lens is 4× magnification, then the overall magnification is 10 × 4 = 40×.

RULES FOR DRAWING OBJECTS VIEWED UNDER A MICROSCOPE

Include a title for your image and the overall magnification used to view the specimen.

Always use a pencil.

Label your diagram, using a ruler for the lines.

8. Try moving the slide left and right, forwards and backwards, and note what you observe about the movement of the image of the letter 'e' in the field of view.
9. Repeat steps 3–7 for each of the objective lenses. You no longer use the coarse focus knob to focus now; use only the fine focus knob to focus your specimen.

Results

Your results will consist of:

- your drawings of the field of view using the different objective lenses. Include the magnification of each drawing.
- your notes about what happens when you move the stage left and right, forwards and backwards.

Discussion: Analysis

1. Explain what happened to the letter 'e' when viewed under the microscope at low magnification.
2. Describe what happened when you increased the magnification using the different objective lenses.
3. Describe what you observed as you moved the slide – did the 'e' go in the same direction as the direction in which you moved the slide?
4. What did you notice about the orientation of the letter 'e'? Was it the right way up? Back to front? Explain.
5. As the magnification of an image increases, the resolution decreases. State the magnification at which you would have had the lowest resolution.
6. Explain what happened to the field of view as you increased the magnification of the objective lens.
7. Outline a safety precaution you would use when observing a specimen using the objective lens with the highest magnification.

continued …

Discussion: Evaluation

1. Summarise the advantages and disadvantages of using a light microscope.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Cell theory

Cells are extremely small, and most cells cannot be seen with the naked eye. It wasn't until 1665, when Robert Hooke built a compound microscope that lit up the specimen he was viewing, that we even knew cells existed. Because of his improvement of the microscope, he was able to observe that a dead cork plant appeared to be made of small blocks. He named these blocks 'cells' because they looked like the small identical 'cells' that monks lived in at the time.

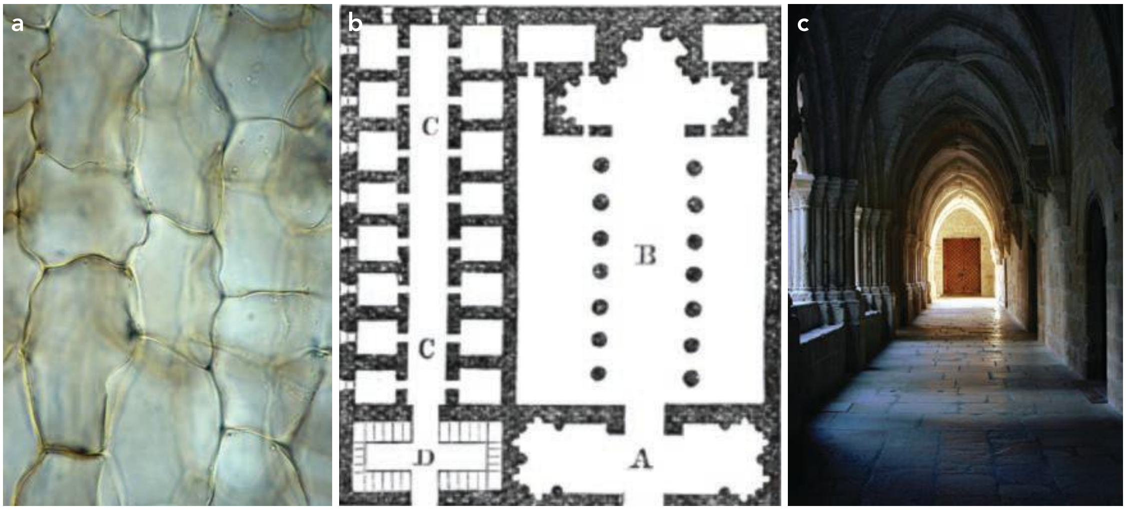


Figure 2.8 **(a)** The cork cells Hooke observed looked like the monks' cells in the **(b)** building plans of **(c)** monasteries.

Nearly 200 years later, after many other scientists had observed and catalogued many more types of cells, a *cell theory* was proposed.

This first cell theory stated that:

- Cells make up all living things.
- Cells are the basic building blocks of all living things.
- All cells form spontaneously from their environment, in a similar way to crystals forming.

We now know that the third part of this theory is incorrect, as cells do not just pop into existence. Modern cell theory clarifies this:

CELL THEORY

- Cells make up all living things.
- Cells are the basic building blocks of all living things.
- All new cells are produced from existing cells.

Did you know? 2.2

Skin

You lose about 40 000 skin cells every minute of every day. This means that, over a lifetime, you will lose at least half of your body weight in skin cells. Have you ever wondered where dust comes from? Most of the dust in your house is made up of your dead skin cells.

Try this 2.3

Cell size

In science, it is important to use appropriate units when measuring different objects. You would not measure the size of a bedroom in kilometres or the size of an ant in metres. Therefore, when you measure cells, it is important to use a very small unit. This is usually a micrometre (μm). A micrometre is 1000 times smaller than a millimetre (mm).

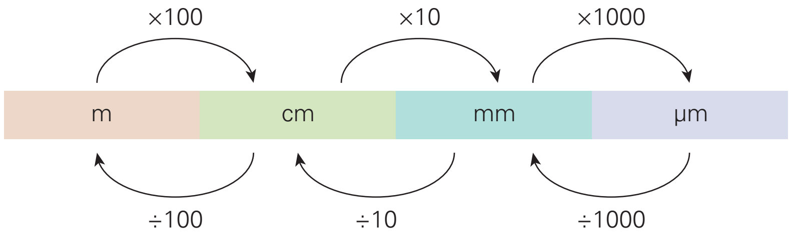
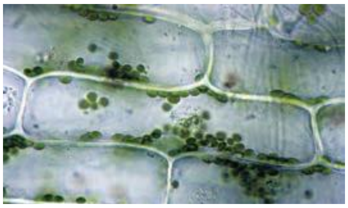


Figure 2.9 Conversions needed for different measurements

Using Figure 2.9, convert the cell sizes below into millimetres (mm) or micrometres (μm).

Cell type	Size (mm)	Size (μm)
 **Figure 2.10** Red blood cells	0.0065	
 **Figure 2.11** Plant cells on a leaf's surface		100
 **Figure 2.12** Sperm cells	0.05	

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Did you know? 2.3

Egg cells

Cells come in many sizes. The main reason is simple: their size and structure depend on their function. Ova, also known as eggs, are some of the largest cells in the animal kingdom. They are typically much larger in size than other cells, such as red blood cells and muscle cells. This size is necessary for the egg to contain all the nutrients and genetic material required for the initial stages of the development of a new organism. The size of an egg varies greatly depending on the species, with some bird eggs being over 100 times larger than a human egg. This large size allows the egg to provide enough sustenance and protection to the developing embryo until it hatches.

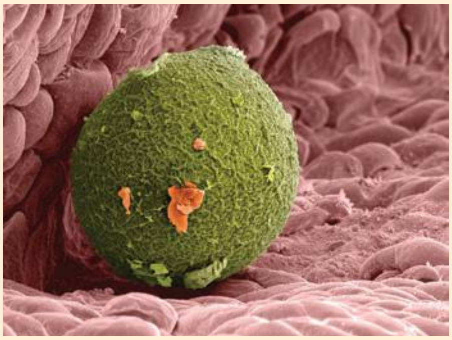

Figure 2.13 A scanning electron micrograph of a human ovum in the fallopian tube, which has been edited to add colour. Ova are 'macro' cells. Macro means 'large-scale', and so they can be seen with the naked eye – that is, without a microscope. These cells are about 0.12 mm in size.

Quick check 2.2

1. **Name** the largest cell in the human body.
2. **Contrast** the terms 'micro' and 'macro'.
3. **Explain** why cells come in many shapes and sizes.

Practical 2.2

Estimating size

Aim

To use a microscope to calculate the size of small objects

Materials

- light microscope
- transparent ruler
- tweezers
- different types of small seeds × 4
- concave glass slides × 4

Be careful

Ensure that the microscope is carried appropriately. Carry it with one hand holding the arm and one hand under the base. Do not use the coarse focus knob to cause the objective lens to touch the glass slide and damage it.

Method

Part 1: Calculating the field of view (FOV)

1. Place the transparent ruler on the stage of the microscope.
2. Starting on the lowest magnification, record the overall magnification in Table 2.2.
3. Focus on the ruler. Using the ruler, measure the diameter of the area you can see under the microscope in millimetres (mm). Record this measurement in the 'FOV (mm)' column in Table 2.2.
4. Calculate the FOV size in micrometres (μm) by multiplying the measurement in millimetres you recorded in step 3 by 1000. Record this measurement in the 'FOV (μm)' column in Table 2.2.
5. Calculate the FOV for each of the higher magnifications, by repeating steps 3 and 4.

Part 2: Measuring the size of seeds

6. Estimate the size of each of the seeds using your naked eye and record your estimate in the 'estimated size' column in Table 2.3.
7. Using a ruler, attempt to measure each seed to the closest millimetre (mm), and record your measurement in the 'measured size' column in Table 2.3.

continued …

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8. Place your first seed on a glass slide and then place the slide on the stage of the microscope.
9. Focus on the object using the objective lens with the lowest magnification. Increase the magnification if necessary, but the seed should not take up the whole field of view. Use Table 2.2 to identify the FOV for your chosen magnification and record this in the 'FOV diameter size' column in Table 2.3.
10. Estimate how many of those objects would fit in a straight line across the middle of the FOV. For example, perhaps 20 poppy seeds look like they would fit across the centre in a line. Record this number in Table 2.3.
11. Divide the total FOV size that you have already calculated (in Part 1) by the estimated number that will fit across the FOV in μm. For example, if in Part 1 you found the FOV at the low magnification was 10 mm, which you converted to 10 000 μm, then your calculation would be $\frac{100\,000}{20} = 500$. That is, each poppy seed is 500 μm in size.
12. Record the actual size of your seed in results Table 2.3.
13. Repeat steps 8–12 for each seed.

Results

Copy the two tables below and use them to record your results. Give your tables appropriate titles that describe what data it is displaying.

Total magnification	Field of view diameter (mm)	Field of view diameter (μm)

Table 2.2 Field of view measurements

Seed	Estimated size	Measured size	Number of times it would fit across the FOV	FOV diameter size	Calculated size of seed (FOV/ number of times seed fits across)
1					
2					
3					
4					

Table 2.3 Seed measurements

Discussion: Analysis

1. Describe what happened to the FOV as the magnification increased.
2. List your seeds in order from smallest to largest, using data from the 'calculated size of seed' column in Table 2.3.

Discussion: Evaluation

1. Compare the estimated size and measured size of your seeds to the calculated size.
2. Describe the sources of error in your measurements.
3. Explain how you could increase the accuracy of your results.
4. Sometimes FOV is calculated using a mini-grid instead of a ruler. A mini-grid has extremely thin lines that can show μm. Suggest why a mini-grid would produce more accurate results than a ruler when estimating size.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Go online to access the interactive section review and more!

Section 2.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 2.1 questions

Remembering

1. **Define** the term ‘microscopic’.
2. **Recall** the three points of modern cell theory.
3. **State** the function of each of the following parts of the microscope.

Part	Function
Stage	
Eyepiece	
Objective lens	
Coarse focus knob	
Fine focus knob	

4. **Recall** the contribution of Robert Hooke to our understanding of the cell.

Understanding

5. **Summarise** the advantages of using:
   a) a monocular light microscope
   b) a stereo light microscope
6. **Explain** why it is important to turn the coarse focus knob until it is as close to the stage as it will go, before putting the slide on the stage. (Think about the risk assessment.)

Applying

7. **Calculate** the magnification of the microscope when using the following objective lenses.

Eyepiece	Objective lens	Magnification of specimen
× 10	× 10	
× 10	× 5	
× 10	× 80	

8. A nanometre (nm) is 1000 times smaller than a micrometre (μm). Generally, a virus is around 0.0225 μm in size. **Calculate** this size in nanometres.
9. Copy and complete the following table to **calculate** the sizes of the different specimens.

Specimen	Size		
	Nanometres (nm)	Micrometres (μm)	Millimetres (mm)
Atom	0.1		
Bacterium		1	
Virus	35		
Animal cell		10	
Chicken egg			50

10. **Describe** how you would determine the size of a cell.

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Analysing

11. Distinguish between a TEM and an SEM.

12. Classify the following specimens into three groups: those that can be seen easily with the naked eye, those that can be seen with a light microscope, and those that can be seen only with an electron microscope. (Some might belong in more than one group.)

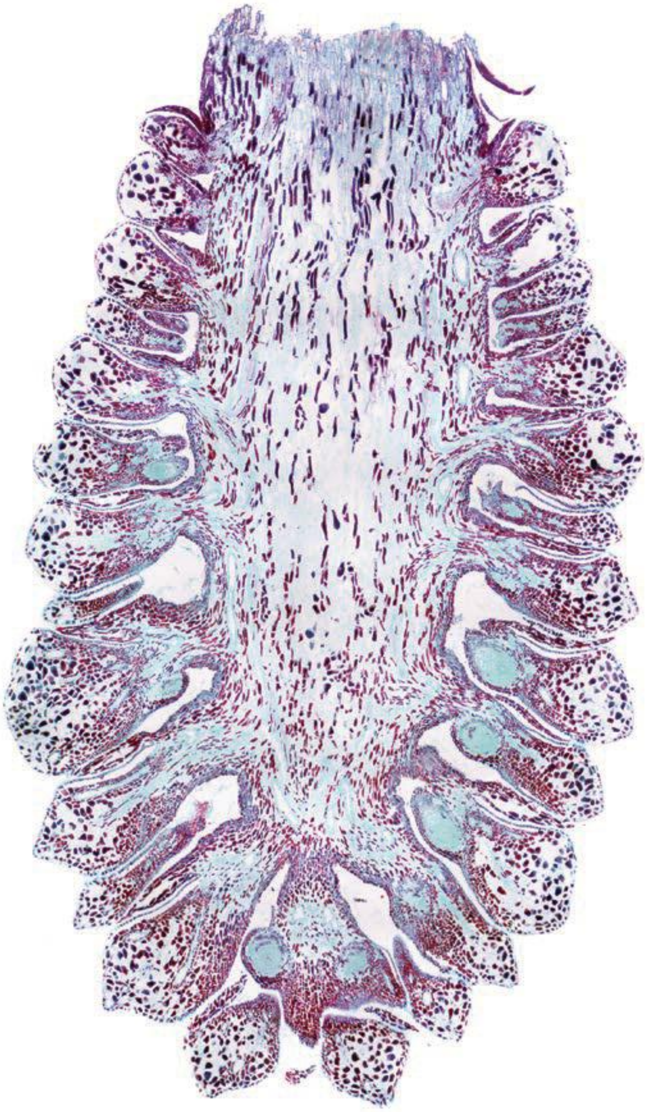
- plant cell (100 µm)
- frog egg (1 mm)
- red blood cell (7 µm)
- phytoplankton (2 µm)
- chicken egg (50 mm)
- virus (35 nm)
- bacterium (1 µm)

Evaluating

13. Propose the reason that different units are used to measure different-sized objects.

14. Create a detailed set of step-by-step instructions for a year 7 student on how to use a microscope safely.

15. Justify the statement 'the development of microscopes has changed our understanding of cells'.



2.2 Organelles

WORKSHEET
Cell types and structure

Learning goals

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

1. Distinguish between prokaryotic and eukaryotic cells.
2. Identify the structure and function of organelles in cells.

What do all cells have in common?

All living things are made up of one or more cells. People, trees, fish and mushrooms are made up of many different cells working together and are known as **multicellular** organisms. These cells depend on each other and cannot survive alone. Organisms in the kingdoms Bacteria, Protista and Archaea are made of single cells and are referred to as **unicellular** organisms. Each of these single cells carries out all the processes needed to stay alive by itself. Generally, unicellular organisms are quite simple and are similar to some of the oldest forms of life found on Earth, whereas the cells of multicellular organisms are specialised and much more complex.

All cells, no matter how simple, contain the following three components:

- a **cell membrane**
- genetic material in the form of **DNA**
- **cytosol**.

multicellular
made of many cells

unicellular
made of just one cell

cell membrane
the barrier that separates the inside of the cell from the external environment

DNA
the material containing the code that allows a cell to produce copies of itself and regulates the functions within the cell

cytosol
the water-based mixture that fills a cell, containing different molecules; many chemical processes that happen within a cell occur in the cytosol

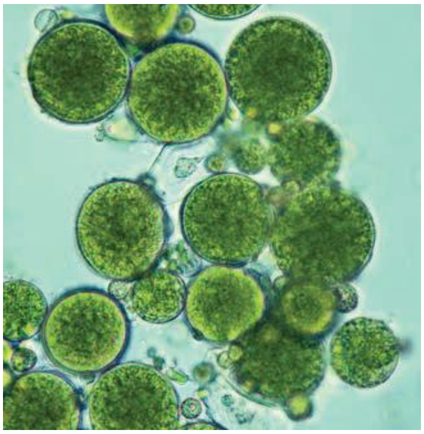


Figure 2.14 Unicellular algae

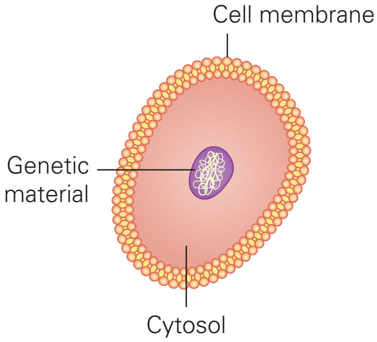


Figure 2.15 All cells, no matter how simple or complex, contain these three components.

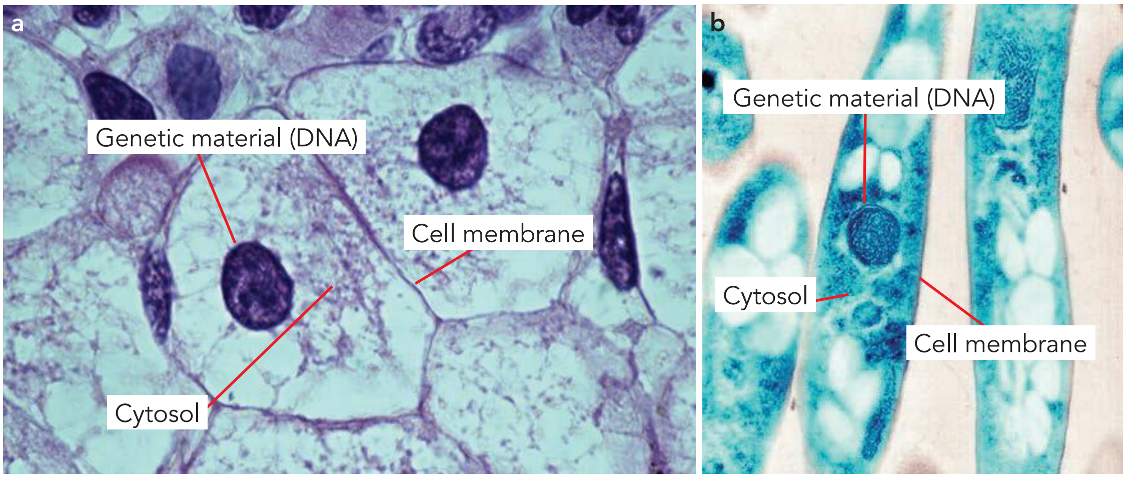


Figure 2.16 (a) Human liver cells; **(b)** *Bacillus anthracis* bacteria, which are unicellular organisms

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Quick check 2.3

1. **Define** these terms and include examples of each: unicellular, multicellular.
2. **Recall** the three components that all cells have in common.

Simple and complex cells

All cells can be grouped into two main domains of life: **prokaryotic** (simple) and **eukaryotic** (complex). Prokaryotes are simple unicellular organisms such as **bacteria**, while eukaryotes are organisms composed of eukaryotic cells and can be unicellular or multicellular. Examples of eukaryotes are animals, plants, fungi and protists. The two categories of cell type are based on the structures found inside the cell. All cells have a membrane, cytosol and genetic material. You may have heard the term '**cytoplasm**' be used instead of cytosol, but they are not the same thing. The cytosol is the fluid component of the cytoplasm, whereas cytoplasm refers to everything within the cell membrane. Eukaryotic cells are more complex and also have many **membrane-bound organelles**, including a nucleus, that carry out specific functions. Prokaryotic cells do not have a nucleus or any membrane-bound structures.

The term 'prokaryote' means 'before (*pro*) nut/kernel (*karyon*)', meaning they were present before eukaryotic cells. The specialised structures inside cells are known as **organelles** because they are like 'mini' organs with specific roles.

VIDEO
Cells of living things

prokaryotic
a cell that lacks membrane-bound organelles and a nucleus

eukaryotic
a cell that possesses membrane-bound organelles and a nucleus

bacteria
very small prokaryotic organisms that have cell walls but lack membrane-bound organelles and a nucleus

cytoplasm
the internal contents of a cell

membrane-bound organelle
an organelle that is surrounded by an outer covering made of fat

organelle
a specialised structure in a cell that has a specific function or role

Try this 2.4

Observing 'friendly' prokaryotes under the microscope

Using your microscope and wet mount preparation skills, look at some bacteria under the microscope. You will need the stain called methylene blue and a sample of yoghurt or probiotic drink containing live bacteria strains. Look at the size and structure of the bacterial cells and consider their similarities and differences.

Explore! 2.3

Fighting antibiotic-resistant bacteria

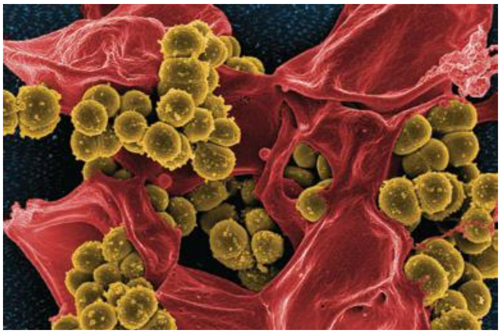

Figure 2.17 Methicillin-resistant *Staphylococcus aureus* bacteria (coloured yellow) and a dead white blood cell (coloured red)

Usually antibiotics are prescribed when someone is suffering from an infection caused by bacteria. But some bacteria cannot be killed using antibiotics, and this results in a phenomenon called antibiotic resistance. According to the World Health Organization, around 700 000 people die every year from infections with antibiotic-resistant bacteria, and it is predicted that this number could increase to 10 million deaths by 2050. However, in 2023, scientists gained a greater understanding of an antibiotic derived from a plant toxin, and the discovery has the potential to improve these statistics. Albicidin is produced by *Xanthomonas albilineans*, a bacterium that causes leaf scald disease in sugarcane. The bacteria use albicidin to attack the plant, but it has also been found to destroy other bacteria. Laboratory tests have shown that bacteria find it very hard to develop resistance towards albicidin. This could lead to the development of different antibiotics and help overcome antibiotic resistance. Complete some research to find out what other new discoveries scientists have recently made in the fight against antibiotic-resistant bacteria.

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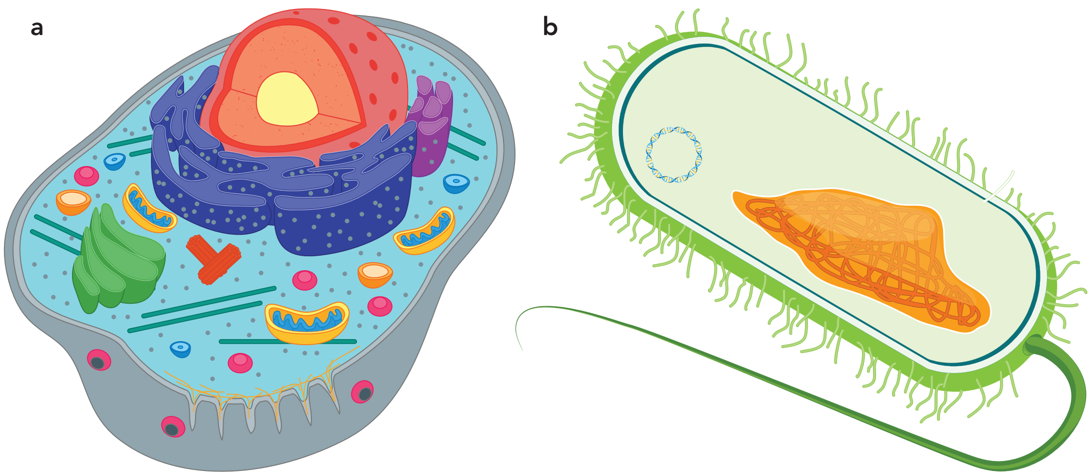

Figure 2.18 Three-dimensional representations of **(a)** a eukaryotic cell versus **(b)** a prokaryotic cell. Note that these images aren't to scale, and prokaryotic cells are typically much smaller than eukaryotic cells. Can you identify the cell membrane, genetic material and cytosol in each cell type?

Try this 2.5

Prokaryotes versus eukaryotes

For the following list of organisms, identify which are examples of prokaryotes and which are examples of eukaryotes.

mushrooms
grass
Archaea
potatoes
Cyanobacteria
fruit flies
tapeworms
Escherichia coli

The cell city

Although all cells contain the three structures described previously, only complex eukaryotic cells contain the specialised membrane-bound organelles covered in this section. These organelles have a membrane around the outside that helps to compartmentalise them (separate them into defined compartments) and allows them to do their jobs more efficiently. It is helpful to compare the cell to a city. A city has many needs, and each organelle caters for one or more of those needs. This idea is developed further in the STEM activity for this chapter.

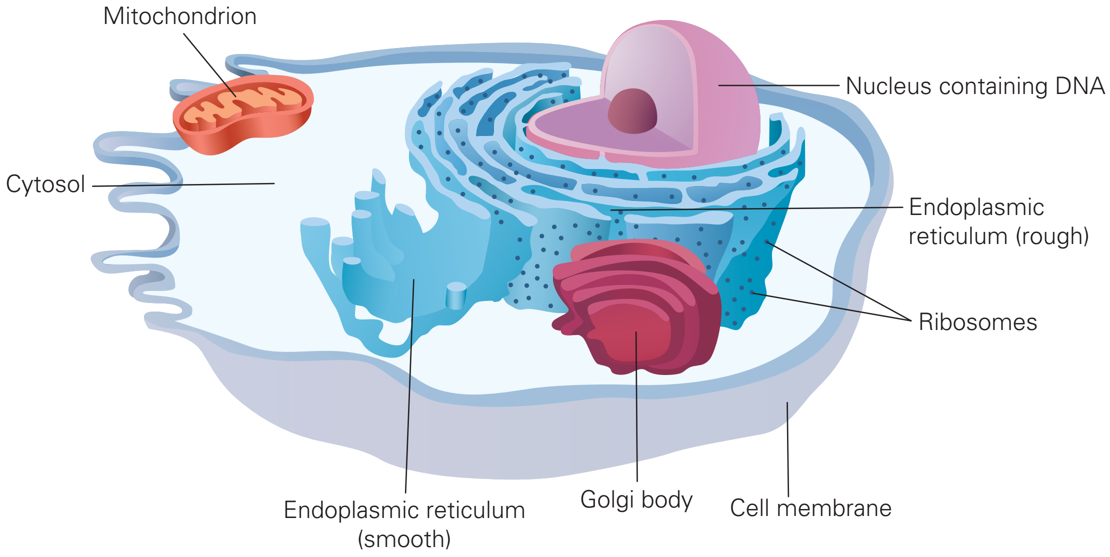

Figure 2.19 A eukaryotic cell with labelled organelles

Nucleus

The **nucleus** is the largest structure in the cell and holds the DNA. It is like the brain of the cell and controls all its functions. In a city, the nucleus would be the top level of government, which keeps all the plans and blueprints and makes all the important decisions.

nucleus
part of a cell that contains the genetic material

double helix
a description of the structure of DNA where two strands wind around each other like a twisted ladder

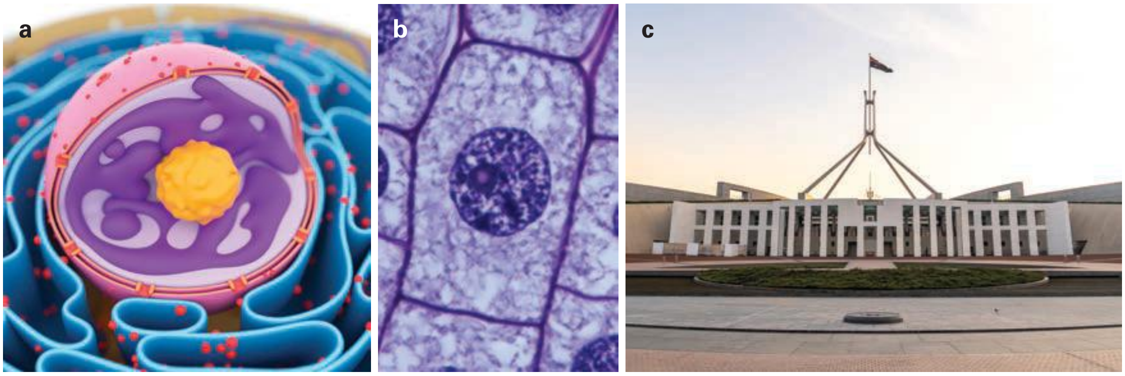

Figure 2.20 (a) Graphical representation of a nucleus. **(b)** A light microscope image of a nucleus within a plant cell. **(c)** Parliament House, Canberra. The nucleus makes all the major decisions for the cell city.

Did you know? 2.4

Missing nucleus

Human red blood cells lose their nucleus as they mature in the bone marrow. The nucleus is expelled from the cell while other organelles are retained. This process allows the red blood cells to transport more oxygen, as the absence of a nucleus provides them with more room for haemoglobin, the molecule that binds to oxygen. It also increases their flexibility to squeeze through narrow blood vessels called capillaries. The lack of a nucleus means that red blood cells have a lifespan of around 120 days, after which they are removed from circulation by the spleen and liver. The bone marrow continuously makes new red blood cells to replace the old ones.

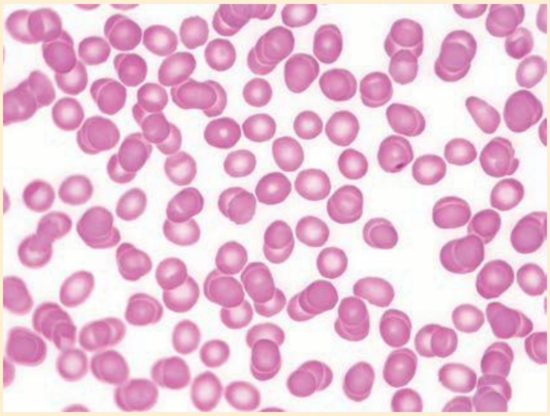

Figure 2.21 Red blood cells lack a nucleus. This light micrograph is of human red blood cells that have been stained so that they are easier to see.

Genetic material

The genetic material found in the nucleus is called deoxyribonucleic acid (DNA). DNA contains the coded information that makes you who you are and tells every cell what to do. The code has all the instructions that a living organism needs to grow, reproduce and function. A DNA molecule is shaped like a twisted ladder, and this shape is called a **double helix**. In the cell city, DNA would be the plans and laws that the government (the nucleus) uses to keep everything running smoothly.

Figure 2.22 Graphical representation of a DNA molecule

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Did you know? 2.5

The Moon and back

If you stretched the DNA in one cell all the way out, it would be over two metres long! This means if you lined up the DNA from all your cells, it would reach to the Moon and back approximately 1500 times!

Cell membrane

The cell membrane is a thin double layer that separates the inside of a cell from its external environment. It contains molecules such as fats and proteins that play a role in controlling which substances can enter or exit a cell. The process of substances crossing the cell membrane is called diffusion. The cell membrane is like a border checkpoint of the cell city, controlling who enters and leaves.

Figure 2.23 (a) The cell membrane controls and checks what moves into and out of the cell, similar to **(b)** border security at an airport.

Cytosol

The cytosol is the liquid part of the cytoplasm, the substance that fills the interior of all cells. It is a mixture of water and other molecules that plays a crucial role in many cellular processes. Although it appears mostly transparent under a light microscope, it has a very complex structure, with regions that vary greatly in composition, so parts of it may resemble jelly. Many of the chemical reactions that cells require to function take place between molecules dissolved in the water of the cytosol, controlled by proteins called enzymes. Many nutrients and other materials may be stored in the cytosol.

Using the city analogy, the cytosol makes the cell city like Atlantis, an underwater city.

Ribosomes

ribosome
a structure in a cell that reads genetic information to assemble proteins

Ribosomes are very small structures that ‘read’ the codes sent to them from the DNA and use these to produce proteins that the cell needs to build structures and carry out different functions. They are one of the few organelles that are not membrane-bound, so they are found in all cells, including prokaryotes. Ribosomes would be the factories of the cell city, producing bricks, cars and different tools for the city to use.

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Mitochondria

Mitochondria (singular: mitochondrion) are where food is turned into energy, in a process called *cellular respiration*. Cells use this energy for many tasks, such as moving things into and out of the cell, and cell growth, repair and reproduction. The mitochondria can therefore be thought of as the power station of the cell.

Figure 2.24 **(a)** Graphical representation of the inside of a mitochondrion. **(b)** An electron microscope image of mitochondria. **(c)** The mitochondria produce energy from food, much like power stations can produce electricity from coal.

mitochondrion a structure in a cell that converts the energy from food into the form needed by the cell during cellular respiration

endoplasmic reticulum an organelle that is involved in making fats, carbohydrates and proteins

Golgi body a structure in a cell involved in the modification, packaging and transport of proteins and lipids

Endoplasmic reticulum

The **endoplasmic reticulum** (ER) is a folded membrane attached to the nucleus. The name ‘endoplasmic reticulum’ is a description of what it does: *endo* (inside), *plasmic* (cytoplasm), *reticulum* (network). There are two types of ER in the cell. The rough ER is where ribosomes are attached, and it is involved in the building and transport of proteins. If no ribosomes are attached, then it is smooth ER, which is involved in the making of carbohydrates and fats. The ER is like a highway that produces, connects and delivers substances to different parts of the cell.

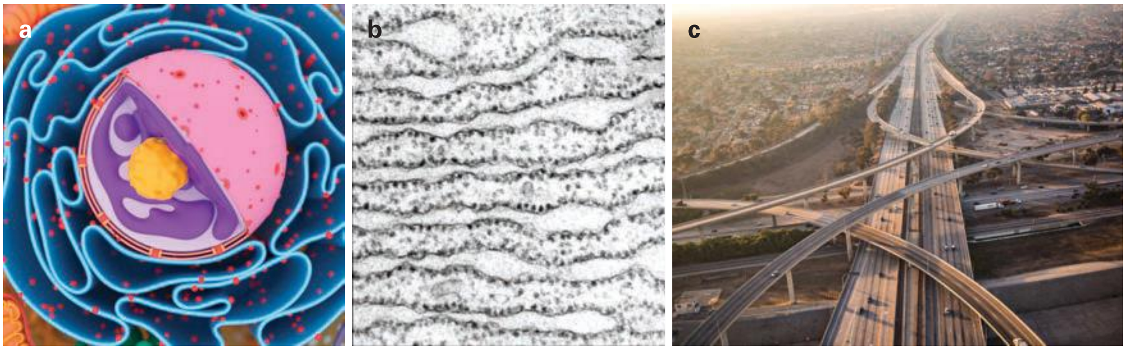

Figure 2.25 **(a)** Graphical representation of the endoplasmic reticulum around the outside of the nucleus. **(b)** An electron micrograph of the rough endoplasmic reticulum. Note the ribosomes attached to the membrane of the endoplasmic reticulum. **(c)** The endoplasmic reticulum is the highway network of the cell city.

Golgi body

The role of the **Golgi body** (also known as the Golgi apparatus) is to modify and package the proteins and lipids made by the endoplasmic reticulum then export them to their destination. Golgi bodies are like the post office of the cell. They place proteins and lipids into small sacks of membrane, called vesicles (the ‘postal vans’), and send them to where they are required.

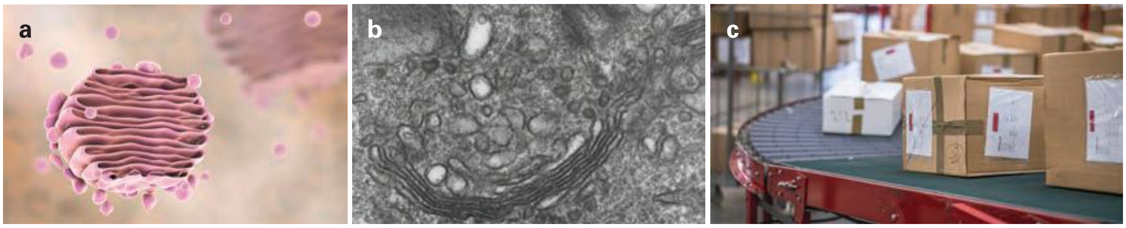

Figure 2.26 **(a)** Graphical representation of a Golgi body. **(b)** An electron micrograph of a Golgi body. **(c)** Golgi bodies act as the postal system of the cell city.

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Practical 2.3

Modelling diffusion in gummy bears

Introduction

The cell membrane is responsible for allowing substances into and out of cells in a process called diffusion. Some substances can pass straight through the cell membrane, while others need special proteins to aid their movement across. Whether substances are moving into or out of a cell depends on many factors. Using gummy bears as a model for cells, this experiment will investigate the movement of water.

Aim

To model the process of diffusion of water using gummy bears

Materials

- gummy bears × 3
- 100 mL beakers × 3
- measuring cylinder
- 0% salt solution (pure water)
- 50% salt solution
- spatula
- scales

Method

Lesson 1

1. Label the three beakers 1, 2 and 3.
2. Using the measuring cylinder, measure 20 mL of water into beaker 1 and 20 mL of 50% salt solution into beaker 2. Leave beaker 3 empty.
3. Use the scales to weigh each of the three gummy bears. Record the mass of each gummy bear in the 'initial mass' column of results table.
4. Add one gummy bear to each solution, ensuring that gummy bear 1 is placed in beaker 1 and so on.
5. Leave the beakers overnight.

Lesson 2

6. Carefully remove each gummy bear from the beakers and gently pat each of them dry with a paper towel.
7. Use the scales to weigh each of the three gummy bears and record the mass of each in the 'final mass' column of the results table.
8. Subtract the initial mass from the final mass to determine whether water has passed into or out of the gummy bears. Record your calculation in the 'change in mass' column of the results table.

Results

Table showing the different masses of gummy bears before and after diffusion

Gummy bear	Initial mass (g)	Final mass (g)	Change in mass (g)
1			
2			
3			

Discussion: Analysis

1. In which solution did the gummy bear gain mass and in which did it lose mass?
2. Describe what you think caused the gummy bears to change mass after being left in each solution overnight.
3. State which part of a cell controls the entry and exit of substances.

Discussion: Evaluation

1. Describe the limitations of using gummy bears as a cell model.
2. Describe the purpose of the gummy bear in beaker 3.

continued …

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Try this 2.6

Organelles

Draw up a table with three columns. List all the organelles covered in this section in the left column. Give a description of their role in a cell in the middle column and provide a simple picture or diagram in the right column.

Quick check 2.4

1. **State** the terms used for simple and complex cells.
2. **Define** the term 'organelle'.
3. Copy Figure 2.27 and **label** the following organelles: cell membrane, cytosol, nucleus (includes genetic material), ribosomes, smooth and rough endoplasmic reticulum, Golgi bodies, mitochondria.

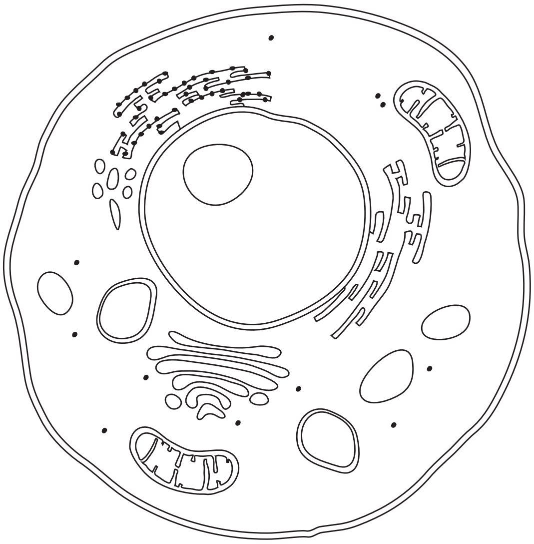

Figure 2.27 Diagram of a eukaryotic cell

Explore! 2.4

The cell's internal scaffolding

Eukaryotic cells have a cytoskeleton. A cytoskeleton is a structure that helps the cell maintain its shape and internal organisation. It also provides mechanical support that enables things to move around inside the cell. Research and summarise the roles of the following structures within cells: microtubules, intermediate filaments, microfilaments. These are tricky terms to understand and explain, so keep your answers simple.

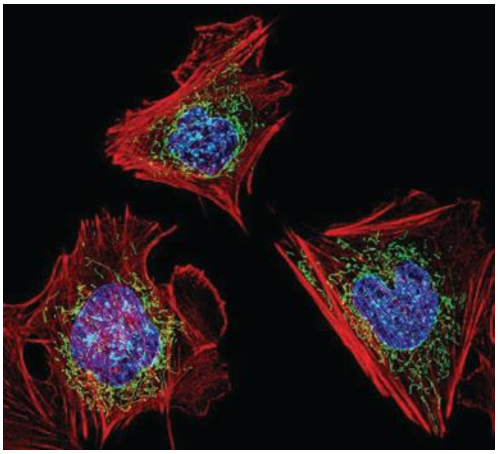

Figure 2.28 Mouse connective tissue cells. DNA in the nucleus is shown in blue, mitochondria are green and the cytoskeleton is red.

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Science as a human endeavour 2.2

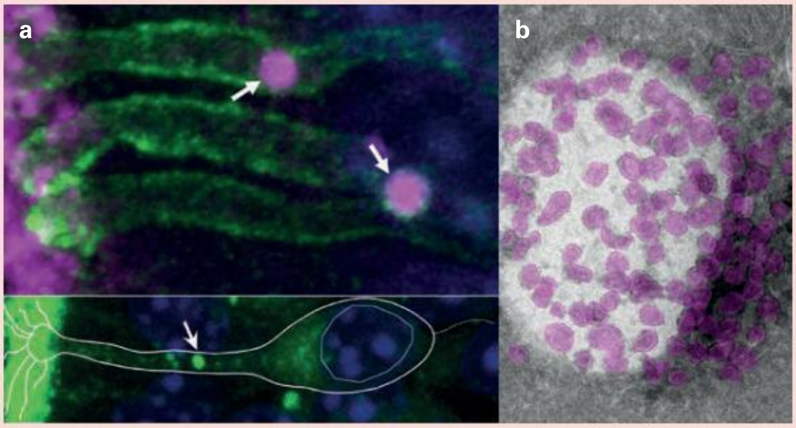

Figure 2.29 (a) The silhouette of an olfactory nerve cell with transducosomes shown with arrows. **(b)** A magnified image of the release of transduction proteins from a transducosome.

Discovery of a new cell organelle

Olfactory nerve cells, found in the nose, are responsible for our sense of smell. They have long projections called cilia that stick out into the nasal cavity and contain special proteins that bind to odour molecules, which then trigger a nerve signal to the brain. This process of converting odour into nerve signals is called transduction.

In 2022, scientists discovered a structure called the transducosome, which contains transduction proteins. When we smell something, the outer membrane of the transducosome breaks, releasing the transduction proteins. These proteins reach the cilia of the nerve cell, allowing us to perceive the smell.

Go online to access the interactive section review and more!

Section 2.2 review

Online quiz	Section questions	Teachers can assign tasks and track results

Section 2.2 questions

Remembering

1. **State** three structures found in all cells.
2. **State** three organelles found only in eukaryotic cells.
3. **Identify** the correct organelle from the description.
   a) produces energy for cells
   b) a barrier between the inside and the outside of cells that controls what enters and leaves
   c) a water-based mixture that fills the cell, and where many chemical processes happen
   d) makes proteins using the instructions provided by the genetic material of the cell

Understanding

4. **Explain** the function of the nucleus.
5. **Summarise** why the Golgi body can be thought of as the post office of the cell.

Applying

6. **Distinguish** between unicellular and multicellular, using examples.

Analysing

7. **Compare** the roles of the rough endoplasmic reticulum and the Golgi body.
8. **Compare** the function of the cell membrane with that of the nucleus.

Evaluating

9. Different cells have different numbers of mitochondria. **Propose** a reason why muscle cells contain more mitochondria than skin cells do.

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2.3 Eukaryotic cells

Learning goals

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

1. Compare plant, animal, protist and fungi cells.
2. Design a physical or digital model of a cell and explain how the representation models the cell.

WORKSHEET
Plant and animal cells

VIDEO
Eukaryotic cells

Eukaryotic organisms are made of eukaryotic cells and therefore have many organelles in common. Eukaryotes can be found in the kingdoms Animalia, Plantae, Fungi and Protista. In this section, you will look at the differences between the cells of the organisms found in these kingdoms.

Figure 2.30 Plants, animals and fungi living together

specialised cell
a cell that has undergone structural changes that allow it to perform a specific task

zygote
a fertilised egg cell

differentiation
the process by which stem cells become specialised

embryo
a fertilised egg in the early stages of growth and differentiation

stem cell
a cell that can develop into many different types of cells

Animal cells

Animal cells typically contain all the organelles discussed in the previous section, although the number of each may vary depending on the specific cell type.

In multicellular organisms, various **specialised cells** perform specific functions to ensure proper body function. All cells in the body come from a single fertilised egg known as a **zygote**, which undergoes division and **differentiation** into different specialised cells, forming an **embryo**.

Cells that have the potential to turn into different types of cells are called **stem cells**. Once a stem cell differentiates into a specific cell type, such as an intestinal cell, it can only replicate into cells of the same type.

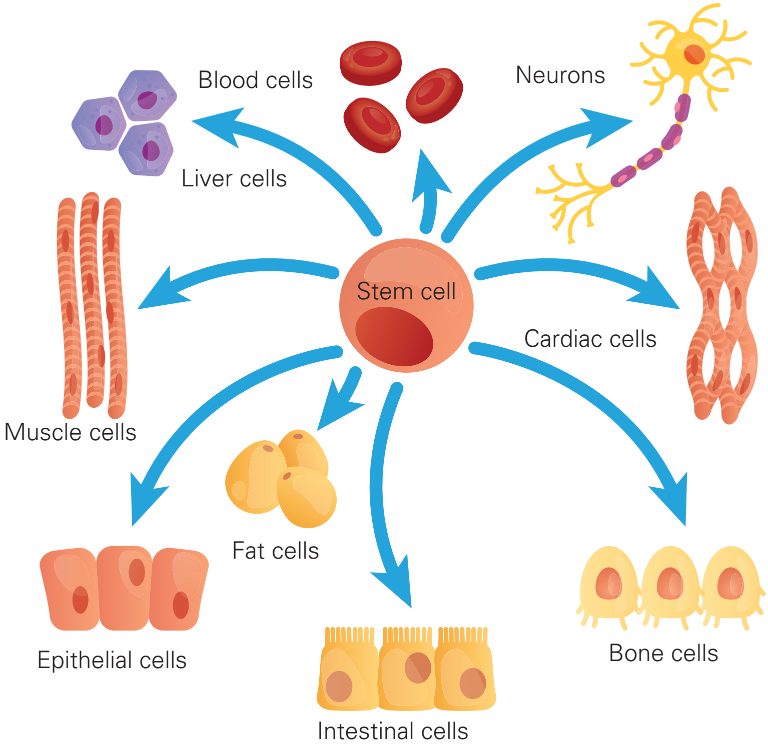

Figure 2.31 Embryonic stem cells (stem cells found in embryos) can become many types of cells in a process known as cell differentiation.

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Stem cells don't only exist in embryos. There are still some stem cells in your body today that are ready to turn into any type of cell you need. They can be found in different tissues around your body and are activated by certain triggers, such as an injury. For example, if you cut yourself, stem cells below the layers of your skin turn into skin cells to help replace the damaged cells. This replacement is not always perfect and, if the damage is too extreme, it can leave a scar.

The tissue that makes up a scar is made of the same material as normal skin, a protein called collagen. In normal tissue, collagen has a cross-weave structure where the fibres are oriented randomly. However, in scar tissue, it has a parallel alignment where all fibres run in the same direction. There is a simple reason for this: open wounds are dangerous and need to be healed as soon as possible. Parallel alignment is the faster way of repairing this tissue.

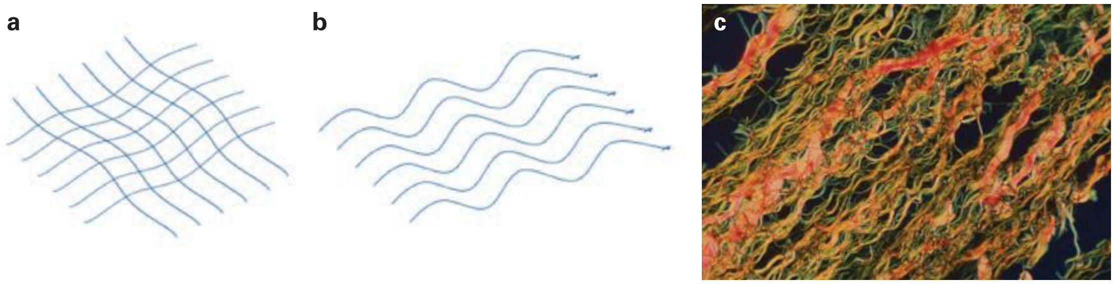

Figure 2.32 **(a)** Collagen fibre structure in normal tissue, **(b)** scar tissue and **(c)** a micrograph of collagen fibres in scar tissue

Explore! 2.5

Stem cell therapy

Because stem cells can turn into different types of cell, they have the potential to be used in treating and curing many types of diseases and conditions. These treatments are known as stem cell therapy.

1. Research the blood cancer called leukaemia.
2. Investigate how stem cell therapy is used to treat leukaemia and summarise your findings.

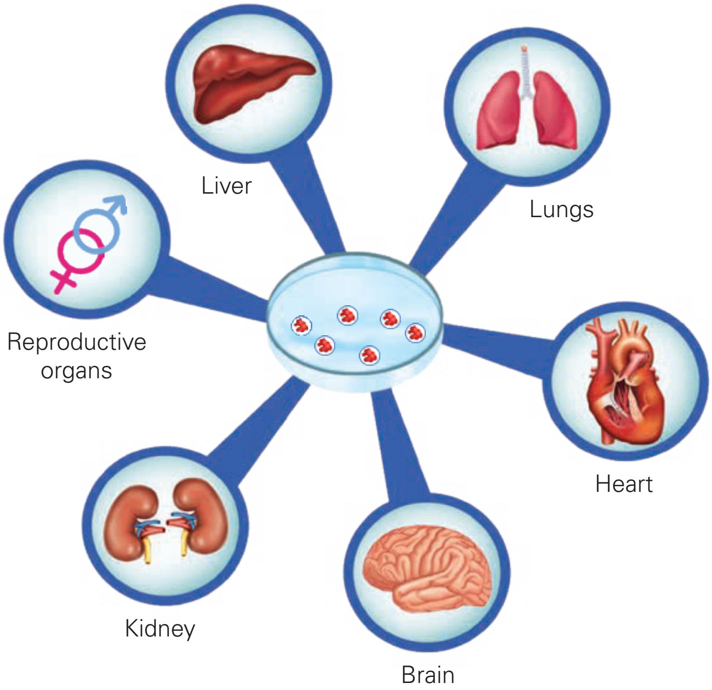

Figure 2.33 A stem cell can replicate and become one of the 200-plus types of cells in the body.

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Science as a human endeavour 2.3

Spray on skin

Figure 2.34 Professor Fiona Wood

Professor Fiona Wood is a British-born Australian plastic surgeon specialising in burns. In the 1990s, she began working with Marie Stoner, and together they made significant advances in the field of tissue engineering. They decreased the amount of time it took to grow skin cells in culture from 21 days to 5, which helps to reduce the extensive scarring that affects burn victims. They pioneered the spray-on-skin technique, which involves collecting and culturing healthy skin cells from the patient and then spraying them onto the wound to grow more skin. In 2002, Fiona led a team that saved the lives of 28 burn victims from the Bali bombings using spray-on-skin. She was named Australian of the Year in 2005 for her work with these patients and her contributions to the field of reconstructive medicine.

Explore! 2.6

Growing synthetic organisms

In 2022, researchers grew fully synthetic (no sperm or egg cells involved) mouse embryos outside the womb using stem cells. The embryos were able to grow to day 8.5, developing the beginnings of a brain, intestinal tract and a beating heart. This breakthrough will tell scientists a lot about embryo development and organ growth, including how to grow whole replacement organs from scratch. Discuss with your class how this new technology may address the **ethical** issues that arise from organ transplantation.

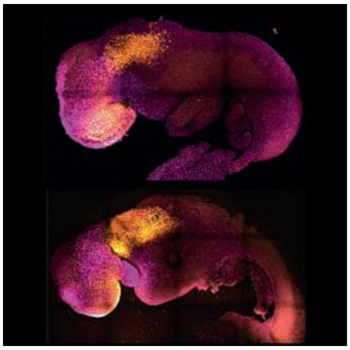

Figure 2.35 A naturally formed mouse embryo (top) compared with a synthetic embryo grown using stem cells (bottom)

ethical relating to ethics, the field of considering what is right and wrong

Quick check 2.5

1. **State** the organelles that are found in animal cells.
2. Multicellular organisms are often made up of specialised cells. **Describe** what the term 'specialised cells' means.
3. Use the term 'differentiation' to **explain** how specialised cells form.
4. **Describe** what stem cells are and why they are useful in medicine.

Plant cells

photosynthesis the process of creating sugar and oxygen from carbon dioxide and water in the presence of sunlight

chloroplast a structure in a plant cell that contains chlorophyll and conducts photosynthesis

cell wall a rigid structure that surrounds each plant cell, shaping and supporting the cell

vacuole a structure in a cell that stores water and nutrients

Plants are different from all other eukaryotic organisms in many ways. They are autotrophic, which means they can make their own food in a process called **photosynthesis**. This difference means that plant cells have some organelles that animal and fungi cells lack. The special organelle in plants that carries out photosynthesis is called a **chloroplast**.

Chloroplasts contain a green pigment called *chlorophyll* which captures the Sun's light, a requirement for photosynthesis to occur. It is because of this pigment in chloroplasts that plants appear green. Chloroplasts are found in plant cells that are exposed to light (e.g. leaf cells) but not in cells of the roots.

Photosynthesis involves creating simple sugar molecules (glucose) from carbon dioxide and water in the presence of sunlight. This process also produces oxygen. Although this requires many chemical reactions, the overall inputs and outputs can be simplified into a worded equation:

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

Plants do not require a skeleton or muscles because they don't move around, but they still need to be able to support their weight so they can grow tall, towards the light from the Sun. This is why plant cells have a **cell wall**. The cell wall is a rigid structure that surrounds each cell (sitting outside the cell membrane) and maintains shape and provides support for the plant. The cell wall is made of a substance called *cellulose*.

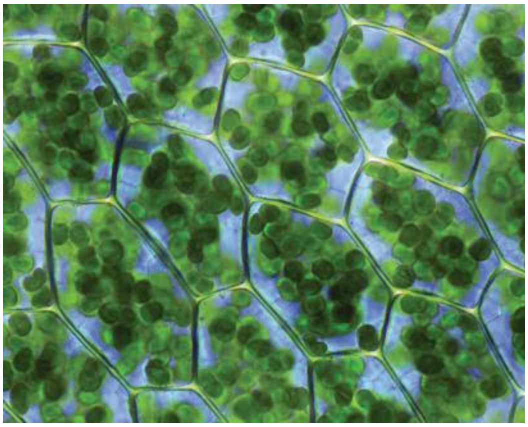

Figure 2.36 In the plant cells shown, the green blobs are chloroplasts. Note the thick cell wall that surrounds each cell.

Figure 2.37 Eucalyptus trees grow as tall as they do because of the rigid cell wall that surrounds each of their cells.

Plant cells also contain an organelle called a **vacuole**. This organelle stores water and other nutrients for the plant. It also works with the cell wall to help support the plant and give it shape. If you have ever forgotten to water your plants at home, you might have noticed that they droop and wilt, becoming floppy. This is because the vacuoles in each cell lose so much water that the cells become flaccid, and so the plant cannot hold its shape. Plants rely on the large amounts of water stored in the vacuoles of their cells to create the pressure needed to stand upright.

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Try this 2.7

Cell exploration

Use the internet to find a free online interactive three-dimensional model that will allow you to understand the scale and scope of animal, plant, bacteria and fungi cells. You may want to consider *Cell Anatomy Viewer Game* by Ask a Biologist or *Cell Size and Scale* by Learn.genetics.

WIDGET
Eukaryotic organelles

Animal cells also contain vacuoles, but they are much smaller and are mainly used for storage of nutrients. The cells of some fungi, protists and bacteria may also have vacuoles.

Figure 2.38 A thirsty plant; the vacuoles are no longer full of water and so they cannot help to support the plant in standing upright.

Distinguishing animal cells from plant cells

You have seen that animal cells and plant cells have many organelles in common, as they are both comprised of eukaryotic cells that have many processes in common. However, you have also learned about the additional organelles that plant cells have due to their different structures and functions.

It is generally easy to identify plant cells under the microscope, because the cell wall usually gives them a shape with rigid straight lines and a thick outline, whereas animal cells have a less uniform shape and a much thinner outline.

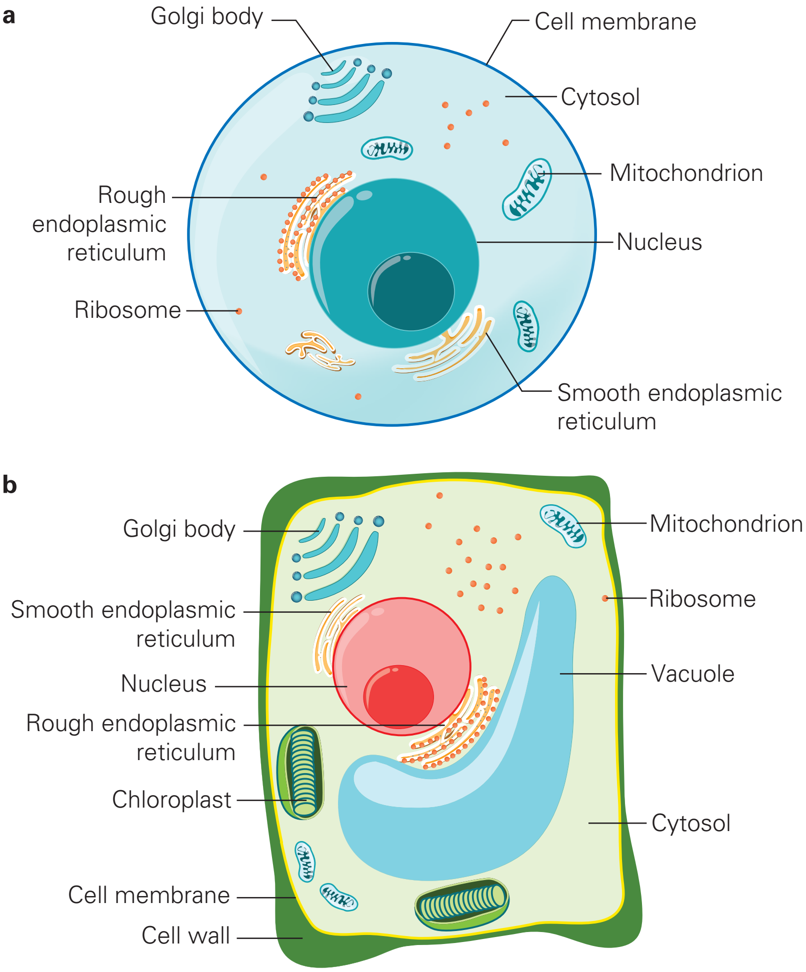

Figure 2.39 (a) Graphical representations of animal cell and **(b)** plant cell showing the major structures and organelles

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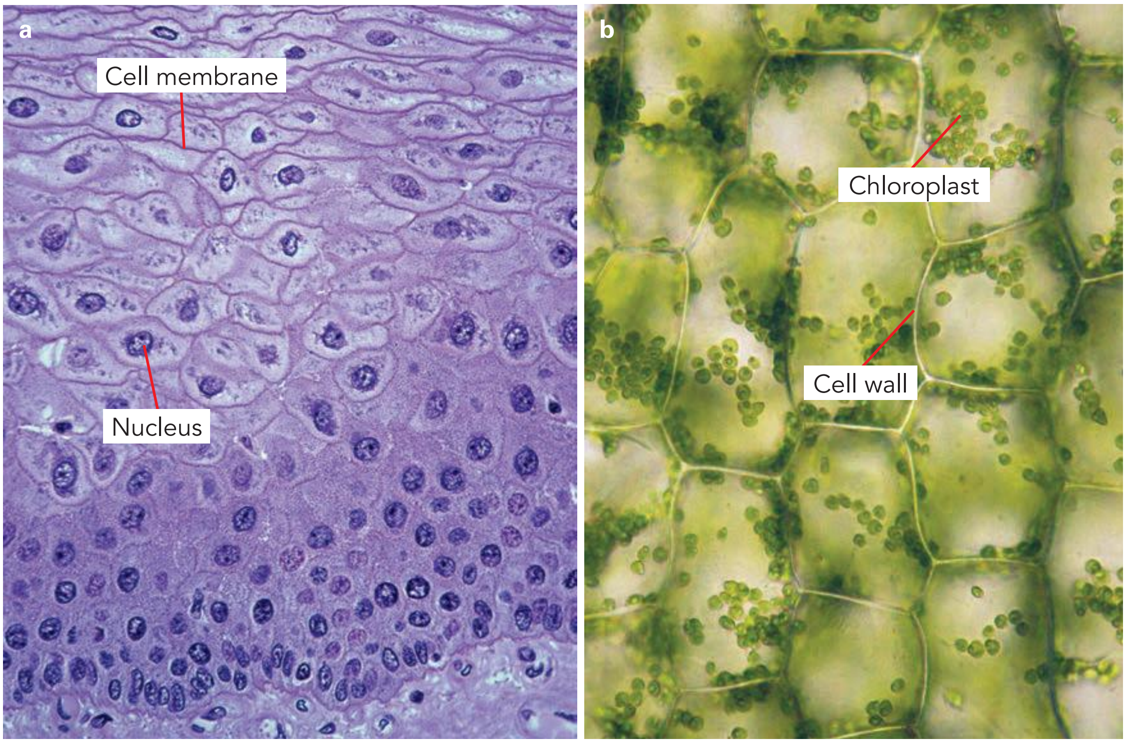

Figure 2.40 (a) Animal (oesophagus) cells at 100× magnification. **(b)** Plant cells at 100× magnification.

Quick check 2.6

1. **Name** the organelles in a plant cell that an animal cell does not have.
2. **Explain** why plant cells have each of the organelles named in Question 1.

Try this 2.8

Making a wet mount

When you want to observe cells under a microscope, you need to prepare what is called a wet mount. Let's practise using pond water.

Use a pipette to place a drop of pond water in the centre of a glass slide. Then gently lower a cover slip onto the water, as shown in Figure 2.41. If the cover slip drops too quickly, it can trap air bubbles and then you won't be able to see your specimen as easily. After laying the cover slip down, use a tissue or blotting paper on the edge of the cover slip to soak up any extra liquid.

Note: Some specimens may be dry, and so you would need to add a drop of water. Some may be transparent, so you would need to add a stain instead of (or in addition to) water.

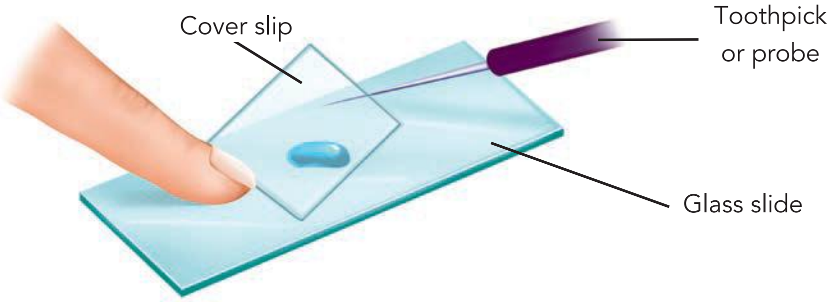

Figure 2.41 Lowering the cover slip slowly is very important when preparing a wet mount.

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Practical 2.4

Observing cells under a microscope

Be careful

Ensure that the microscope is carried appropriately. Carry it with one hand holding the arm and one hand under the base. Do not use the coarse focus knob to cause the objective lens to touch the glass slide and damage it. Do not consume food items in the laboratory.

Aim

To observe the characteristics of plant and animal cells

Materials

- light microscope
- glass slides and cover slips
- toothpick
- onion and celery
- iodine solution
- ripe and unripe bananas
- prepared animal cell slides

Method

1. Prepare wet mounts:
   a) Peel a translucent (partially see-through) piece of tissue from the onion.
   b) Place the piece of onion tissue on a glass slide and add a drop of water on the glass slide before carefully laying the onion tissue on top. Be careful not to fold the onion over on itself. Add a drop of iodine solution.
   c) Cover the slide with a cover slip, using your wet mount technique.
   d) Repeat steps a–c for the celery.
   e) Use the toothpick to collect some ripe banana cells and smear them as thinly as you can across a glass slide.
   f) Add a drop of iodine solution and then cover with a cover slip.
   g) Repeat steps e–f for the unripe banana.
2. Observe the cells:
   a) Starting with the microscope on the lowest magnification, turn the coarse focus knob until it is as close to the stage as it can go.
   b) Place your first slide on the stage and focus using the coarse focus knob. Once focused, turn to the next objective lens. Use only the fine focus knob to focus now.
   c) Once focused, move to the highest magnification and focus using only the fine focus knob.
3. Draw a diagram:
   a) Using a pencil, draw diagrams of an onion cell, a celery cell, a ripe banana cell, an unripe banana cell and four animal cells from the prepared slides.
   b) Label all the organelles you can see, using a ruler and labels at the side of the diagram. Record the name of the specimen and the magnification of the drawing.

RULES FOR DRAWING OBJECTS VIEWED UNDER A MICROSCOPE

Include a title for your image, the overall magnification used to view the specimen, and the stain used.

Always use a pencil.

Label your diagram, using a ruler for the lines.

Results

Your results will be in the form of four plant cell diagrams and four animal cell diagrams. Remember to use a pencil and ruler when drawing and labelling scientific diagrams, and include a title and the overall magnification for each.

continued …

Discussion: Analysis

1. Explain why stains are needed.
2. Compare the onion and celery cells: what similarities and differences did you observe?
3. Compare the ripe and unripe banana cells: what similarities and differences did you observe? Can you explain the differences?
4. What characteristics did you observe in the plant cells? In the animal cells? What did they have in common? Explain why there are differences.
5. Are the plant and animal cells all the same size and shape? If there are differences, can you explain why?
6. Which organelles could be viewed under the microscope? Which organelles are present but could not be seen?

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered, and include potential sources of error.

Try this 2.9

Observing photosynthesis

When plants perform photosynthesis, they produce oxygen. Terrestrial plants (plants that live on land) release this oxygen into the atmosphere for us to breathe. We can observe this in aquatic plants by observing the formation of oxygen bubbles.

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

Place a piece of *Elodea* (pondweed) in a test tube. Submerge your piece of *Elodea* in a 0.2% bicarbonate solution and place it in front of a bright lamp. As *Elodea* starts to photosynthesise, you will be able to see the oxygen being produced in the form of bubbles!

Complete a virtual simulation of this practical using *Biology Simulations Cell Energy Simulation*, which measures the amount of oxygen produced by *Elodea*. Choose one variable to alter and copy the graph of dissolved oxygen produced into your science book. The amount of dissolved oxygen is a measure of how much photosynthesis is occurring under different conditions.

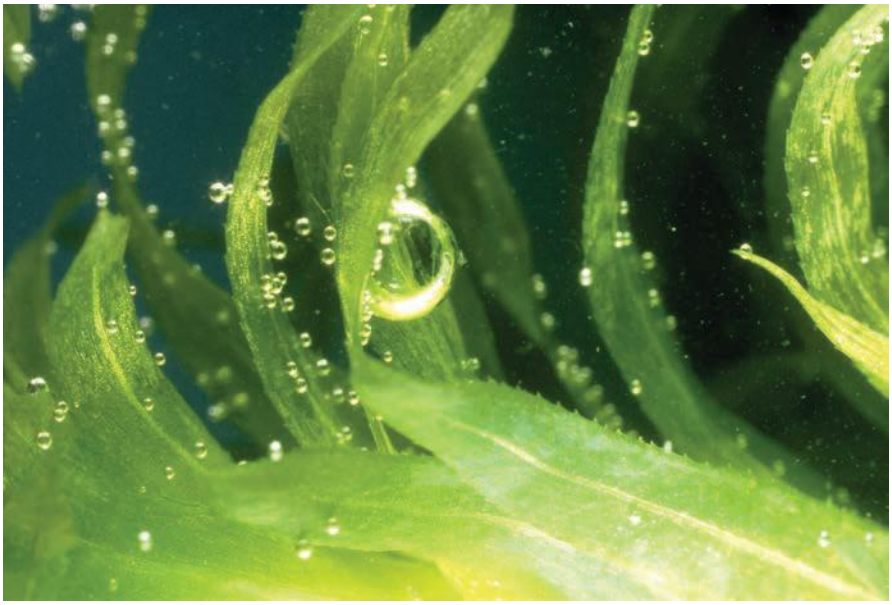

Figure 2.42 *Elodea* releases bubbles of oxygen during photosynthesis.

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Try this 2.10

Making a model: Three-dimensional cell

Aim

Create a three-dimensional model of a plant cell and an animal cell using the materials provided

Materials

- black beans
- white beans
- ping pong balls
- zip lock bags
- red food colouring
- green food colouring
- takeaway food container
- poppy seeds
- balloons
- glue and tape

Method

1. Look at the materials your teacher has provided for you and decide what you are going to use to represent each part of the plant cell and the animal cell.
2. Copy and complete the table below to indicate how each organelle is going to be represented in your model.
3. Construct your three-dimensional model of the cell.

Results

Plants		Animals	
Cell	**Materials used**	**Cell**	**Materials used**
Nucleus		Nucleus	
Cell membrane		Cell membrane	
Mitochondria		Mitochondria	
Ribosomes		Ribosomes	
Golgi body		Golgi body	
Endoplasmic reticulum (rough)		Endoplasmic reticulum (rough)	
Endoplasmic reticulum (smooth)		Endoplasmic reticulum (smooth)	
Cytosol		Cytosol	
Large vacuole		Small vacuoles	
Chloroplast			
Cell wall			

Discussion: Analysis

1. Explain how your model represents all the parts of a cell.
2. Explain why models are used in science.

Discussion: Evaluation

1. Assess two strengths and two limitations of your model.
2. Propose a way to make your model more accurate.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered, and include potential sources of error.

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Fungi

Fungi are similar to both plants and animals, and most are multicellular.

Fungi are heterotrophs, like animals, which means they must digest other organisms in order to gain nutrients. Fungal cells therefore don't have chloroplasts like plant cells do. They are like plants in that they have a cell wall, but their cell wall is made of *chitin*, a similar molecule to cellulose.

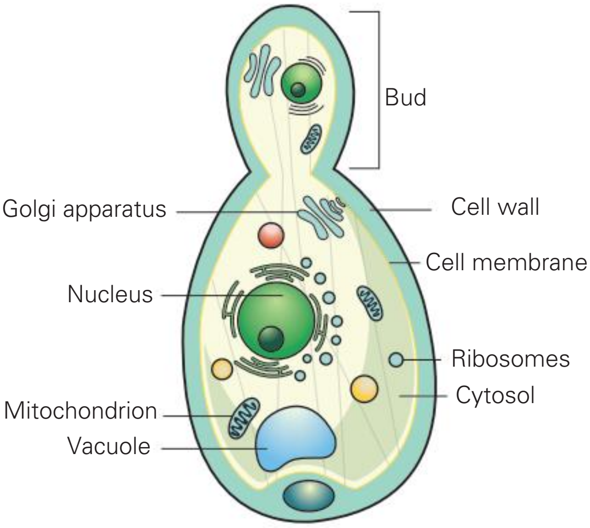

Figure 2.43 A yeast cell showing major structures and organelles. Yeasts are a type of fungal cell.

Did you know? 2.6

Fungi and beetles

The cell wall of fungal cells is made of chitin, and this is the same material that makes up the exoskeleton of insects such as beetles.

Figure 2.44 Beetle exoskeletons and fungal cell walls are made of the same substance: chitin.

The main body of a fungus is called the *mycelium*. This is a large network of small filaments, called *hyphae*, that can stretch for over 10 kilometres! You don't often see hyphae, as they are very small, and you only really notice a fungus when it develops a fruiting body when conditions are perfect. This fruiting body can be seen as a mushroom or a toadstool, a truffle or a puffball. This is why you often see mushrooms appear soon after heavy rainfall. The fungus makes these fruiting bodies to produce spores to reproduce.

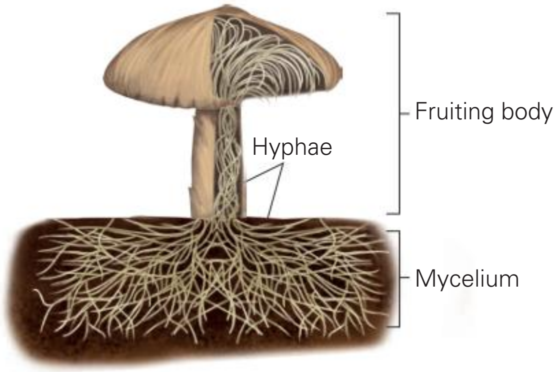

Figure 2.45 Diagram of a fungus

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Figure 2.46 Fungi: **(a)** toadstool, **(b)** chanterelle mushrooms, **(c)** puffball

Quick check 2.7

1. **State** whether fungi are prokaryotic or eukaryotic.
2. **Contrast** the cell wall of a plant with the cell wall of a fungus.
3. **Explain** the function of the cell wall.

Investigation 2.1

Fungi-fighting bacteria

Be careful

Ensure benches are cleaned and hands are washed before leaving the laboratory. Do not open the Petri dishes after sealing.

Background information

Some bacteria produce an antifungal substance – a substance that can kill fungi. Soil is a good source of antifungal bacteria that can help protect plants from harmful fungal infections and diseases.

Aim

To test the effectiveness of different soil dilutions on the growth of fungi

Materials

- Four dilutions of soil: 1 g soil, 2 g soil, 3 g soil and 4 g soil with water added up to the 10 mL mark of a measuring cylinder for each dilution
- yeast solution (1 tablespoon yeast in 250 mL warm water)
- an agar plate per group × 1
- sterile swab
- plastic pipettes × 4
- measuring cylinders × 4
- beaker
- balance
- sticky tape
- disposable gloves

Method

1. Write a rationale about fungi and the factors that affect fungal growth.
2. Write a specific and relevant research question for your investigation.
3. Identify the independent, dependent and controlled variables.
4. Write a hypothesis for your investigation.
5. Write a risk assessment for your investigation.
6. Draw a cross on the bottom of the agar plate, creating four quadrants.
7. Thoroughly swab the agar plate with the yeast solution, horizontally and then vertically, to get full coverage.

continued ...

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8. Using a pipette, place a few drops of each soil dilution in a separate quadrant and label the agar plate lid. Ensure the drops of different dilutions do not touch each other, as they may mix together and affect your results.
9. Allow time for the drops to be fully absorbed into the agar.
10. Cover the agar plate with the lid and with two to four pieces of sticky tape, taping down opposite edges of the plate. Label the outside edge of the plate on the agar side.
11. Place in an incubator at 30°C for two days.
12. Observe the growth of the yeast in each quadrant and record the results.

Results

Draw a results table for your experiment.

Produce a suitable graph for your experiment.

Discussion: Analysis

1. Describe any patterns, trends or relationships in your results.
2. Explain any trends you have identified.
3. Suggest two ways that your results could be useful for controlling fungal growth.

Discussion: Evaluation

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

Conclusion

1. Draw a conclusion from this experiment about the effect of different soil dilutions on the growth of fungi, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that _____________.
   Therefore, the hypothesis *is/is not* supported by these findings.

Try this 2.11

Observing different cell types

Using a virtual microscope simulator such as *BSCS Science Learning Virtual Microscope*, select an animal cell, plant cell and a microorganism to draw. Remember to include a title and record the level of magnification used in the simulation.

Protists

Protista is a kingdom that consists mostly of unicellular organisms; however, there are a few multicellular examples, such as kelp. They are eukaryotic, so they contain the membrane-bound organelles that you learned about in the previous section. However, scientists have changed the classification of many of these organisms several times because they display characteristics of both plants and animals. All **protists** need to live in a moist environment and so are very common in most aquatic environments. If you look at a sample of pond water under the microscope in the warmer months of the year, you will likely see many types of protists, such as *Euglena* and *Amoeba*. Each of these types of protists is slightly different in structure, depending on its function.

protist
a eukaryotic organism that is part of the kingdom Protista

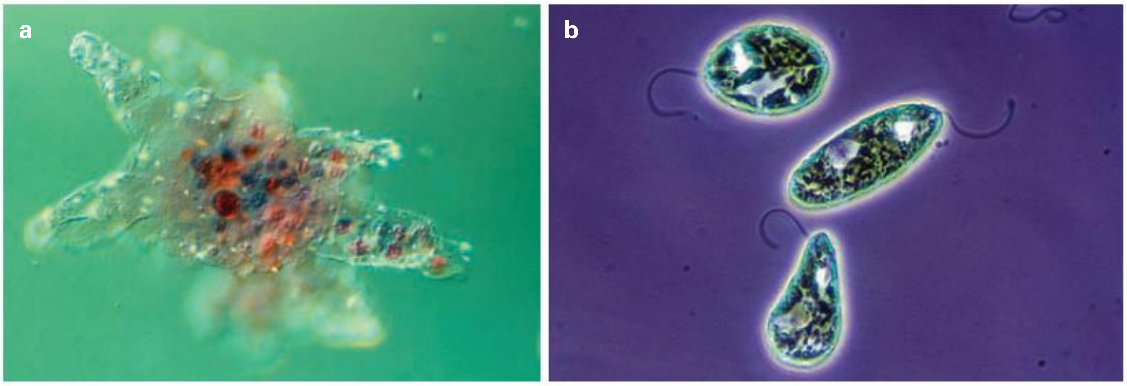

Figure 2.47 Protists: **(a)** *Amoeba*, **(b)** *Euglena*

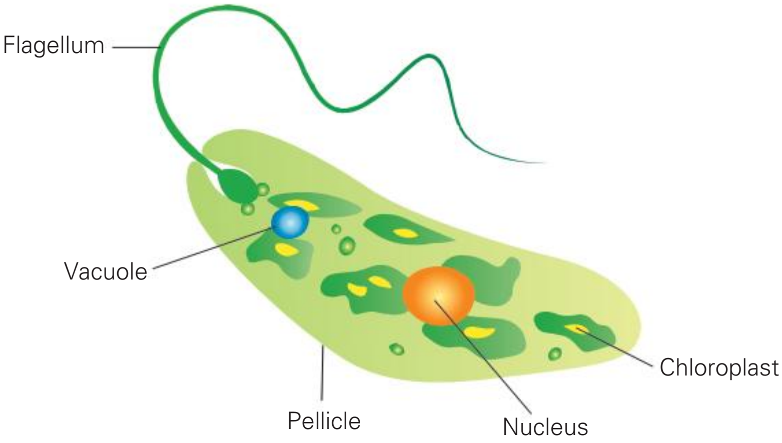

Figure 2.48 *Euglena* have chloroplasts, which are typically considered a plant cell organelle, but they also have a flagellum, which is more typical of an animal cell.

Section 2.3 review

Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 2.3 questions

Remembering

1. **State** the organelle involved in photosynthesis.
2. **Name** the three key differences between plant cells and animal cells in terms of their organelles.
3. **Recall** two examples of protists.
4. **Define** the term ‘specialised cells’ and provide examples.
5. **Identify** the two parts of a plant cell that provide support and explain how they work together.
6. **Identify** where you are most likely to find protists.

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Understanding

7. **Explain** why fungi are known as heterotrophs.
8. **Summarise** the steps you need to take when preparing a wet mount.
9. Stem cells are currently of significant interest to scientists. **Explain** why this is the case, using what you have learned about their use in therapy and other medicinal applications.

Applying

10. a) **Name** the organelles labelled A to E in the eukaryotic cell shown in Figure 2.49.
    b) **Identify** the type of cell shown in Figure 2.49. Explain your answer.

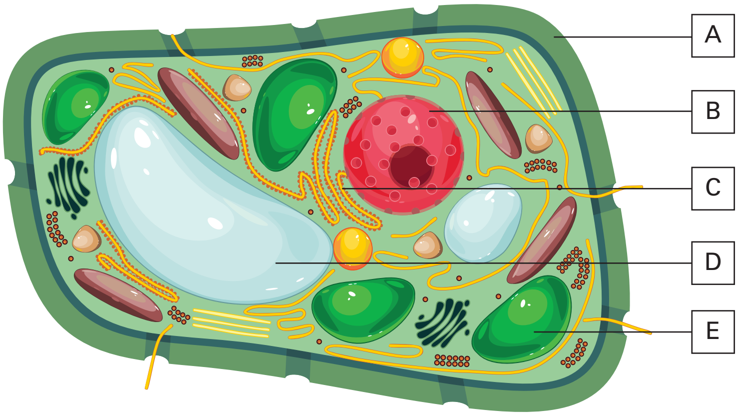

Figure 2.49 Eukaryotic cell

Analysing

11. a) Draw a Venn diagram to **compare** an animal cell with a fungal cell in terms of the cell's structure and organelles.
    b) Draw a Venn diagram to **compare** a plant cell with a fungal cell in terms of the cell's structure and organelles.
12. Yeast are unicellular eukaryotic cells and belong to the kingdom Fungi. A student conducted an experiment to test the effect of temperature on the activity of yeast, which will produce a gas when added to a solution of sugar in water. The student placed 2 g of yeast and 10 g of sugar into a glass apparatus full of water, designed to trap any gas produced in a narrow closed vertical tube at the top. The amount of gas can be measured by the height of the column of gas that collects in the tube. They did the experiment three times with the apparatus containing water at three different temperatures and measured the height of the column of gas produced after one minute.

Table showing the amount of gas produced at different temperatures

Temperature (°C)	Height of column of gas produced in the tube (mm)			
	Trial 1	Trial 2	Trial 3	Mean
10	60	64	62	62
30	102	98	100	100
60	20	14	17	17

a) Using the student's results, **identify** the effect of temperature on yeast function.
b) **Identify** the best temperature for yeast activity.
c) **Infer** the effect that an even higher temperature, such as 100°C, would have on the yeast being tested.

Evaluating

13. **Justify** this statement: 'Fungi are all around us, but you can't always see them'.
14. **Propose** reasons why humans need muscles and a skeleton, whereas plants do not.

Chapter review

Chapter checklist

Success criteria		**Linked questions**
2.1	I can describe how the invention of the microscope has contributed to the understanding of cell structure.	7, 11
2.1	I can label the parts of a microscope.	4
2.1	I can examine a variety of cells, including single-celled organisms, using a light microscope, a digital microscope, simulations and photomicrographs.	Section 2.1 activities
2.2	I can distinguish between prokaryotic and eukaryotic cells.	15
2.2	I can identify the structure and function of organelles in cells.	5, 8, 9
2.3	I can compare the similarities and differences of plant, animal, protist and fungi cells.	1, 8c, 10
2.3	I can design a physical or digital model of a cell and explain how the representation models the cell.	12, 16

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. Of the four kingdoms – Animalia, Plantae, Fungi, Protista – **state** which have unicellular organisms and which have multicellular organisms.
2. **Name** two examples of protists.
3. **Name** three types of specialised cells.
4. **Name** the common components of the monocular light microscope.
5. **Recall** the role of the mitochondria in cells and why they are so important.
6. **Identify** the type of cell that can turn into any other type of cell.
7. **Identify** two disadvantages of the electron microscope.

8. a) **Recall** the role of the following organelles in the cell.

Organelle	Role in the cell
Nucleus	
Cytosol	
Golgi body	
Ribosomes	

b) Using Figure 2.50, **identify** the organelles listed in part **a**.

c) Is the cell shown in Figure 2.50 a plant cell or an animal cell? **Explain** how you know.

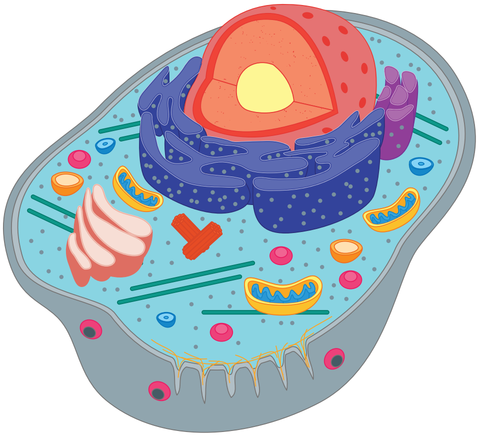

Figure 2.50 Eukaryotic cell

Understanding

9. After going on holiday, you come home to find that all your plants are wilted. **Explain** why this has occurred, referring to parts of the cell.

10. Use 'yes' or 'no' to **summarise** the organelles that are found in each cell type in the table below.

	Animals	Plants	Fungi
Nucleus			
Cell wall			
Large vacuole			
Cytosol			
Cell membrane			
Chloroplast			

Applying

11. **Identify** the type of microscope that needs to be used to view objects smaller than a cell.

12. Peroxisomes are small organelles found in eukaryotic cells. Their job is to break down waste in the cell. Using the 'cell as a city' model, **select** an appropriate analogy for peroxisomes.

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Analysing

13. **Organise** the following microscope instructions in order by numbering the steps in the left column. Step 1 has been done for you.

Step	Description
	Check that the iris adjustment is open
	Draw a diagram
	Return to low magnification objective lens
	Centre your specimen slide on the stage
	Rotate the objective lenses until the low-magnification lens is in place
	Turn on the power
1	Carry the microscope with two hands to the bench
	Carry the microscope with two hands back to the cupboard
	Turn off the power and let the lamp cool
	Using the coarse focus knob, focus away from the slide
	Lower the lowest-magnification objective lens until it is close to the stage
	Swing a higher-magnification objective lens into place
	Remove the cover and plug in the microscope
	Unplug the microscope, pack it up and place on the cover
	Use only the fine focus knob

14. **Contrast** the terms ‘resolution’ and ‘magnification’.
15. Draw a Venn diagram to **compare** prokaryotic cells (such as bacteria) with eukaryotic cells (such as plant and animal cells).

Evaluating

16. **Evaluate** the use of models when explaining the structure of the cell.

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Data questions

The human body is composed of trillions of cells that work together to carry out various functions necessary for life. Estimating the total number of cells in an adult human body is a challenging task, but researchers have made significant progress in recent years. By studying individual organs and tissues and using various methods, such as microscopy, scientists have developed estimates for the number of cells in the human body, divided by cell type. These are shown in Figure 2.51.

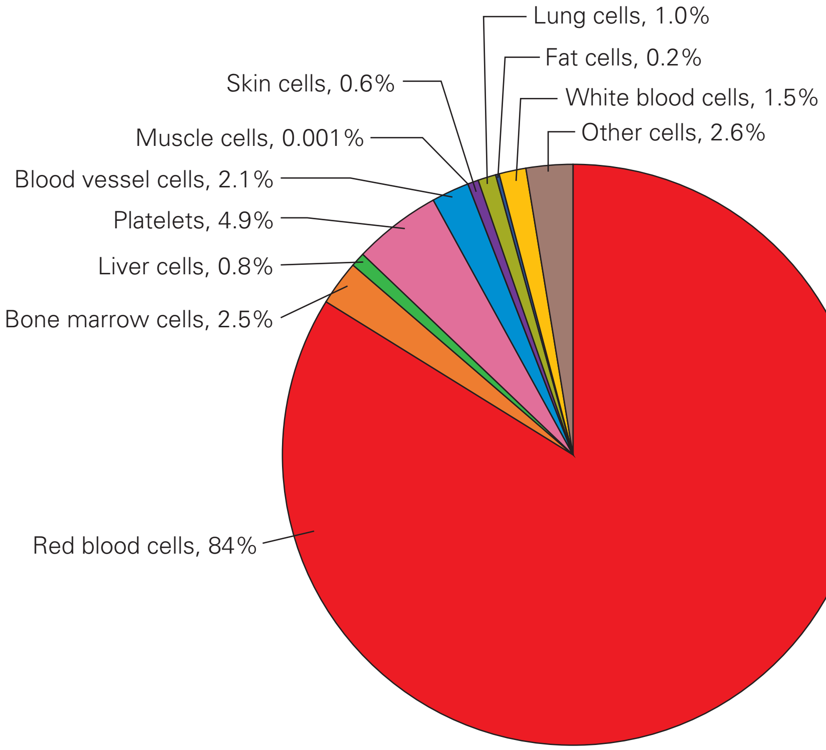

Figure 2.51 Estimated cell numbers in an average adult human, divided by cell type

Cell turnover refers to the ongoing process of breaking down and recycling cellular components like proteins, fats and organelles, while also creating new molecules to build fresh cells. This continuous renewal is essential for maintaining good health and proper bodily function. The speed of cell turnover varies depending on the specific cell, tissue and organ. For instance, skin cells have a short lifespan of a few weeks, while liver cells can endure for years.

Figure 2.52 shows the mean lifespan of different cell types and their total mass in an adult human.

Applying

1. **Identify** the most common cell type, using Figure 2.51.
2. **Identify** the least common cell type, using Figure 2.51.
3. If the estimated total number of cells in an adult human is 30 × 10^{12} (30 trillion), **calculate** the total number of red blood cells, using Figure 2.51.

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4. **Identify** the cell type that has the highest total cell mass, using Figure 2.52.
5. **Identify** the cell type that has a mass turnover of 0.08 g per day, using Figure 2.52.

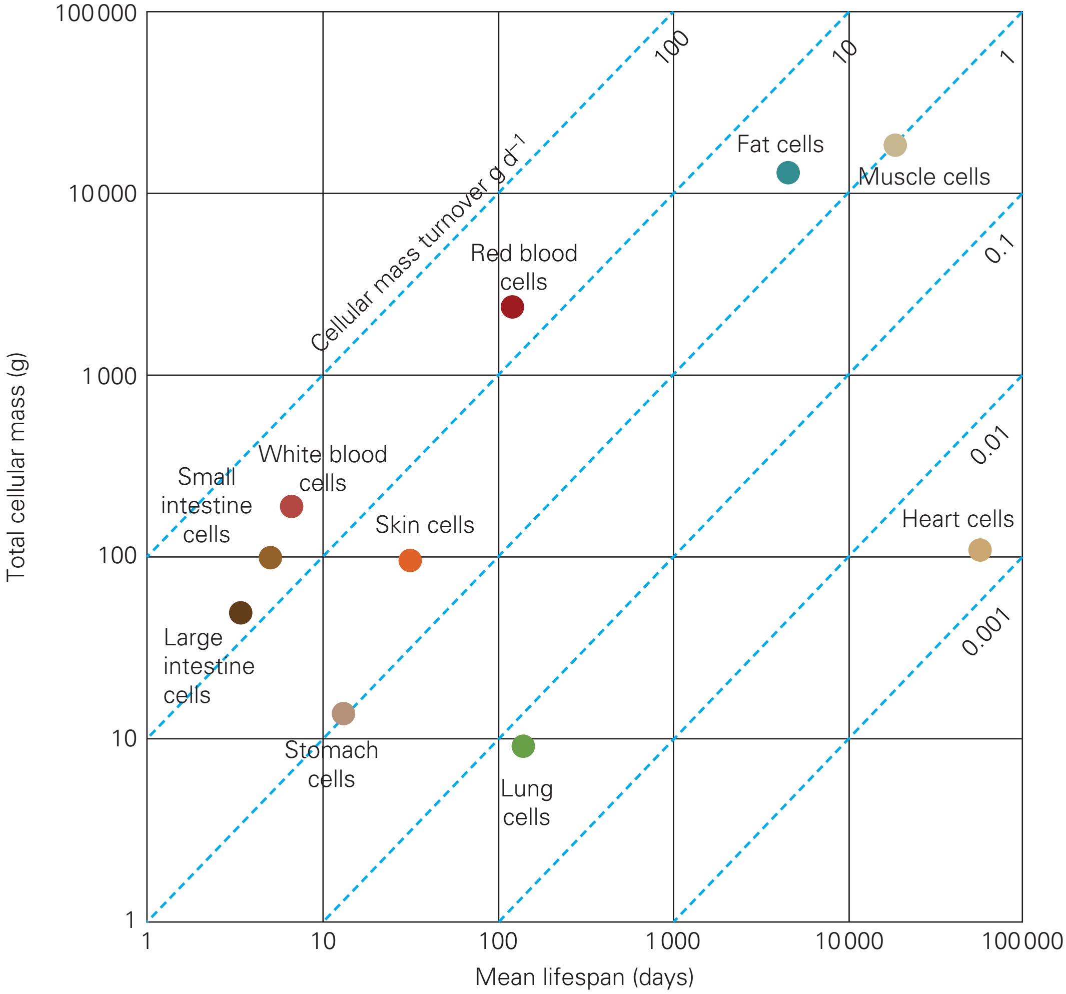

Figure 2.52 The mean lifespan (days) and total cell mass (grams) of different cell types in an adult human. Note that both the *x*-axis and the *y*-axis increase by a factor of 10 at each interval.

Analysing

6. **Contrast** small and large intestine cells, using Figure 2.52.
7. **Categorise** the following cells as having either a high turnover rate or a low turnover rate, using Figure 2.52: *heart cells, white blood cells, red blood cells, lung cells*.

Evaluating

8. **Compare** stomach cells and muscle cells, using Figure 2.52.

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STEM activity: Design a city

Background information

All living things, from humans to insects, trees and bacteria, are made up of cells. Cells are the smallest unit of life, and most are too small to see without a microscope. While some organisms, such as bacteria, are made up of only one cell, multicellular organisms can be made up of trillions of cells. Cells work together to form organs, which work together to form body systems (e.g. respiratory, circulatory), which are vital in working together to form complex multicellular organisms.

Although cells are small, they are complex. Today we use microscopes to see inside a cell and observe even smaller components of the cell, called organelles. These organelles all have different functions and work together to keep the cell alive.

An *analogy* is a comparison with something familiar. Analogies are often used in science to explain, in simple terms, how processes work. The way in which organelles in a cell function together can be compared with the way in which the components of a city work together to make the city function well. Cities all need to have structures and processes in place, to manage functions such as transport, sanitation, utilities, housing, construction and food production. There also needs to be a governing body that oversees all these activities.

DESIGN BRIEF

Design a city using cells as a model.

Activity instructions

Your task is to design a city, based on the structure and functions of a cell. You will use your knowledge of the functions of cells and make comparisons with the functions of a city to create a modern city design that addresses some of the challenges we face in modern cities (e.g. transportation, overcrowding). You can present your work to the class through a poster, PowerPoint presentation or vlog/video.

Figure 2.53 Three-dimensional model of a cell

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Suggested materials/presentation formats

- poster
- PowerPoint
- video

Research and feasibility

1. List all the major organelles and their functions. As a group, research the issues/resources faced by a city such as Melbourne (or any major capital city) and then match the issues/resources required with the organelle.

Organelle	Function	City issue/ resource	How the organelle provides the solution
e.g. Mitochondria	Provides energy for the cell	Cities need energy from a power plant.	The mitochondria provide energy for the cell; they are like a power plant that gives energy to the whole city.

Design and sustainability

2. Discuss in your group which type of cell you are going to model your city on and sketch a diagram of this type of cell. Then, as a group, label the organelles with the name and corresponding city resource.
3. Discuss in your group the sustainability of the city you have designed. How could the city be self-sufficient for ALL its resources?

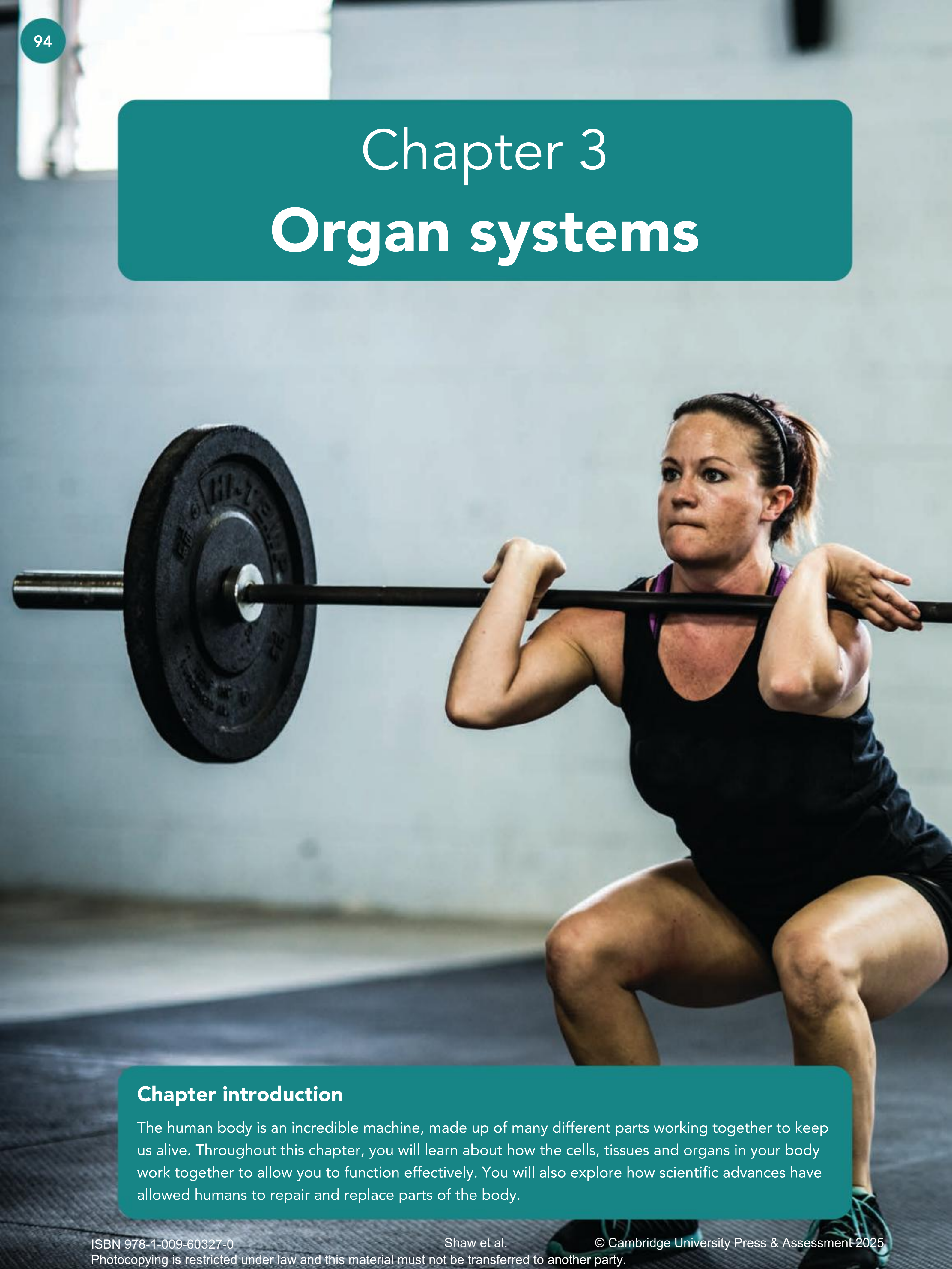
Create

4. Reflect on your basic design and as a group start building a larger drawing that uses all your ideas, making annotations on your drawing or using your vlog. As you are creating, keep thinking about all the issues faced by a city and how they are managed/solved, including the sustainability of your city.

Evaluate and modify

5. Analyse the solutions you have come up with and comment on how achievable they would be in the real world today.
6. Explain any problems that might be encountered when implementing your solutions in the real world today. What types of technologies could be incorporated into your solutions (e.g. artificial intelligence, renewable energy)?
7. Evaluate the effectiveness of your analogies by examining what features of how a city works are different from how a cell works. For example, if you have mentioned that chloroplasts are like solar panels, explain how the process of photosynthesis is different from the process of converting light energy into electricity.

Chapter 3
Organ systems



Chapter introduction

The human body is an incredible machine, made up of many different parts working together to keep us alive. Throughout this chapter, you will learn about how the cells, tissues and organs in your body work together to allow you to function effectively. You will also explore how scientific advances have allowed humans to repair and replace parts of the body.

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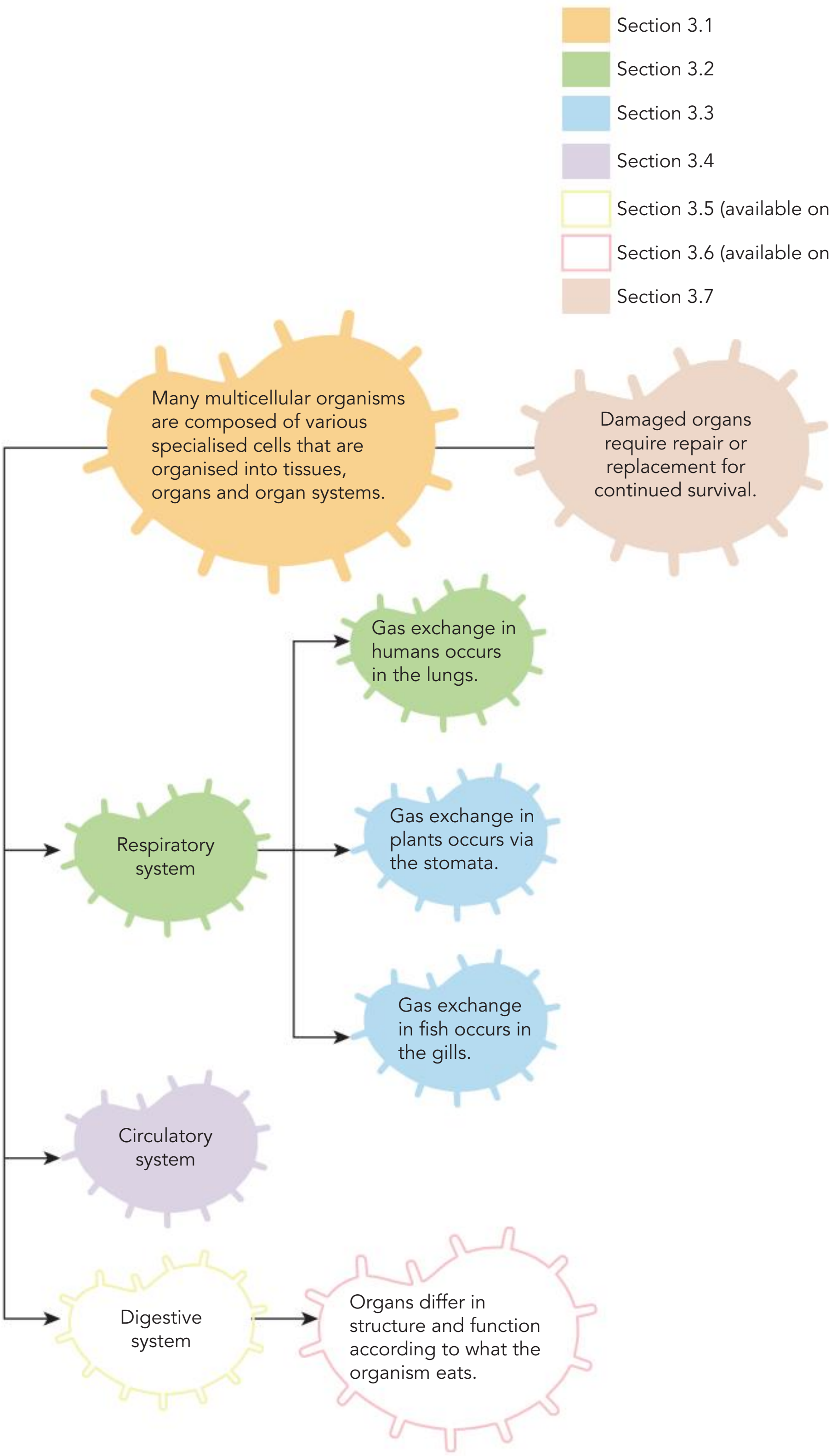
Concept map



🟧 Section 3.1
🟩 Section 3.2
🟦 Section 3.3
🟪 Section 3.4
⬜ Section 3.5 (available online)
⬜ Section 3.6 (available online)
🟫 Section 3.7

Many multicellular organisms are composed of various specialised cells that are organised into tissues, organs and organ systems.

Damaged organs require repair or replacement for continued survival.

Gas exchange in humans occurs in the lungs.

Gas exchange in plants occurs via the stomata.

Gas exchange in fish occurs in the gills.

Organs differ in structure and function according to what the organism eats.

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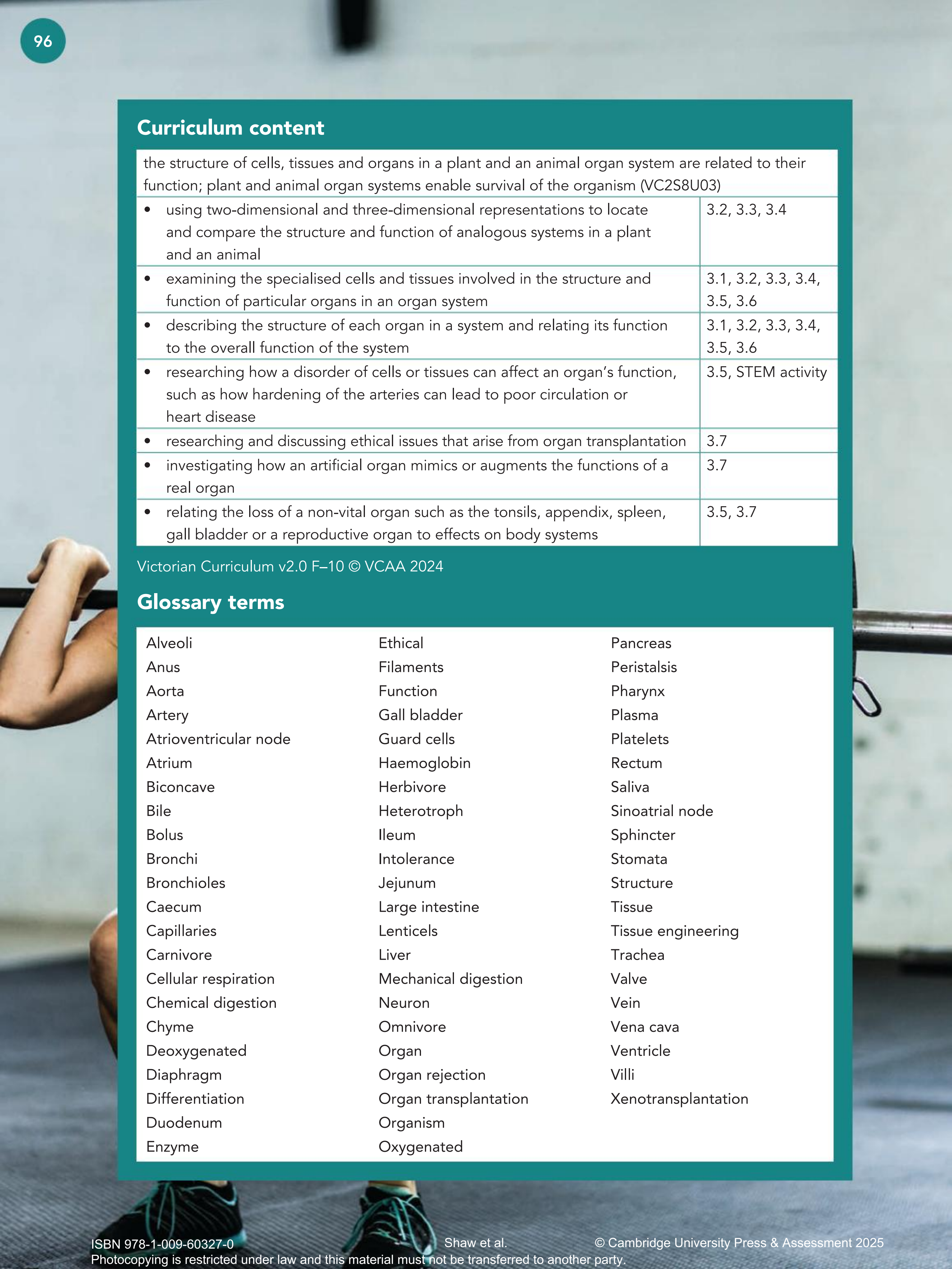

Curriculum content

the structure of cells, tissues and organs in a plant and an animal organ system are related to their function; plant and animal organ systems enable survival of the organism (VC2S8U03)	
• using two-dimensional and three-dimensional representations to locate and compare the structure and function of analogous systems in a plant and an animal	3.2, 3.3, 3.4
• examining the specialised cells and tissues involved in the structure and function of particular organs in an organ system	3.1, 3.2, 3.3, 3.4, 3.5, 3.6
• describing the structure of each organ in a system and relating its function to the overall function of the system	3.1, 3.2, 3.3, 3.4, 3.5, 3.6
• researching how a disorder of cells or tissues can affect an organ's function, such as how hardening of the arteries can lead to poor circulation or heart disease	3.5, STEM activity
• researching and discussing ethical issues that arise from organ transplantation	3.7
• investigating how an artificial organ mimics or augments the functions of a real organ	3.7
• relating the loss of a non-vital organ such as the tonsils, appendix, spleen, gall bladder or a reproductive organ to effects on body systems	3.5, 3.7

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Glossary terms

Alveoli
Anus
Aorta
Artery
Atrioventricular node
Atrium
Biconcave
Bile
Bolus
Bronchi
Bronchioles
Caecum
Capillaries
Carnivore
Cellular respiration
Chemical digestion
Chyme
Deoxygenated
Diaphragm
Differentiation
Duodenum
Enzyme
Ethical
Filaments
Function
Gall bladder
Guard cells
Haemoglobin
Herbivore
Heterotroph
Ileum
Intolerance
Jejunum
Large intestine
Lenticels
Liver
Mechanical digestion
Neuron
Omnivore
Organ
Organ rejection
Organ transplantation
Organism
Oxygenated
Pancreas
Peristalsis
Pharynx
Plasma
Platelets
Rectum
Saliva
Sinoatrial node
Sphincter
Stomata
Structure
Tissue
Tissue engineering
Trachea
Valve
Vein
Vena cava
Ventricle
Villi
Xenotransplantation

3.1 Cells to systems

Learning goals

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

1. Examine the specialised cells and tissues involved in the structure and function of particular organs in an organ system.
2. Compare 2D and 3D representations of organ systems to understand how organs are positioned within the body.

WORKSHEET
Cells to systems

Cells

A cell is the basic unit of life. Every living organism is made up of at least one cell. Unicellular organisms are made up of only one cell, which interacts directly with its environment. This means that the cell can absorb nutrients from the substance it is on or in and excrete waste directly into its surroundings. Humans are multicellular organisms and are composed of many specialised types of individual cells that carry out specific functions. These are known as specialised cells.

Specialised cells

Humans are animals, and our cells are eukaryotic; they contain membrane-bound organelles such as the nucleus, cell membrane, cytosol, mitochondria and many of the other organelles discussed in the previous chapter. Even though most of our cells contain the same basic components, the different types of specialised cells within our bodies all have certain features or **structures** that allow them to perform a specific **function**. A structure is any physical part of an object, and a function is the role or job of the object.

All the cell types in your body begin as unspecialised cells called stem cells. As the cells grow and develop, they **differentiate** (change into specialised cells), forming over 200 different types of cells that make up your body. When more cells are required to replace old or damaged ones, stem cells can replicate to produce more copies of each type of specific cell.

structure
a physical part of an object

function
the job that an object does

differentiation
the process by which stem cells become specialised

Making thinking visible 3.1

Creative hunt: Specialised cells

The image shows roughly 100 000 cells from a rhesus macaque monkey. Similar cells are clustered together, with every dot representing a single cell. The lines connecting the dots reflect how similar they are. Each colour represents cells from a different tissue. For example, brain cells are shown in grey, lung cells in pink and liver cells in green.

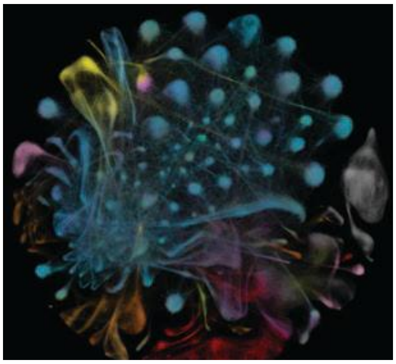

Figure 3.1 This representation of monkey cells won the Wellcome Photography Prize in 2019.

What is the **purpose** of the image?

What are the main **parts** of the image?

What do you think is particularly **creative** about the image?

Who do you think the image is **intended** for?

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

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Neurons

neuron
a nerve cell

haemoglobin
a protein in red blood cells that binds to oxygen

biconcave
concave on both sides

Nerve cells or **neurons** are specialised cells that allow all the parts of your body to work together, by sending signals to and from your brain to each part of your body through the nervous system. Neurons allow us to sense and respond to our environment via our senses. Neurons are long, thin cells that connect to each other by their highly branched ends. They have long axons, which are specialised to carry electrical signals over long distances at very fast speeds. The longest nerve cells in your body are found in your sciatic nerve, which stretches from the bottom of your spine to your big toe.

Figure 3.2 Neurons are shown on the left, and on the right is the main organ of the nervous system, the brain.

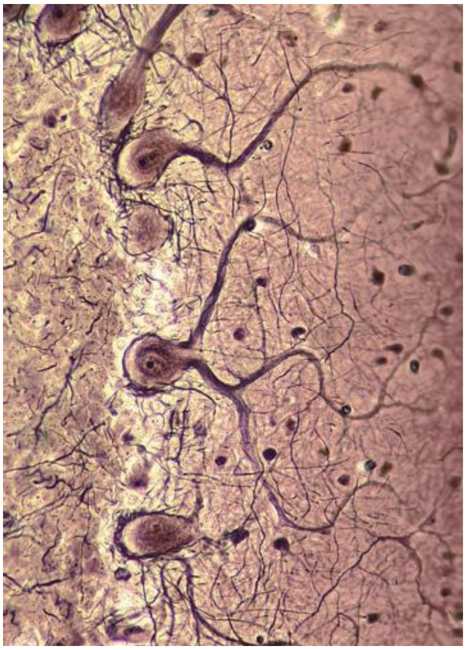


Figure 3.3 Neurons in the brain of a dog

Red blood cells

Red blood cells contain **haemoglobin**, which allows them to transport oxygen to all the cells in your body through the circulatory system. They have a **biconcave** shape that provides a large surface area for the attachment of oxygen-carrying haemoglobin molecules. It also makes the cells flexible, allowing them to squeeze through narrow blood vessels.

When red blood cells reach maturity, they do not have a nucleus, which allows extra room for haemoglobin to carry oxygen. Without a nucleus, they cannot undergo cell division, and so all red blood cells are produced in the bone marrow from stem cells. Red blood cells are replaced every 120 days.

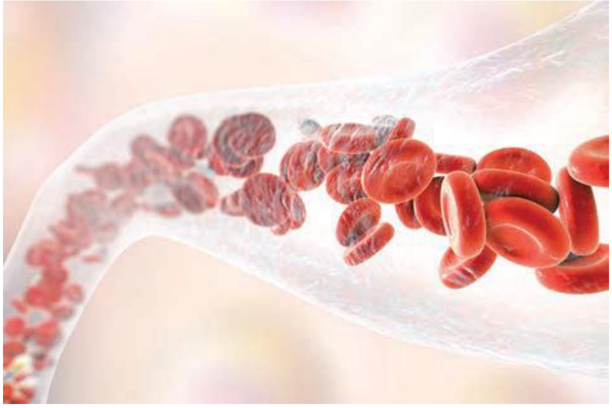


Figure 3.4 Representation of red blood cells travelling through a blood vessel. Note their biconcave shape.

Sperm cells

Sperm cells carry half the genetic information of a normal human body cell. Their purpose is to combine with an egg cell in a process known as fertilisation, which is the first step of reproduction. Sperm cells are mobile because they must be able to swim to the egg. That is why they have a specialised tail, called a flagellum, which beats in a corkscrew motion and allows the sperm cell to swim. Sperm cells have many mitochondria in their midpiece, to provide energy for fast movement. Their head also contains an acrosome, a sac of digestive enzymes that digest the membrane of the egg cell, allowing the sperm nucleus to enter.

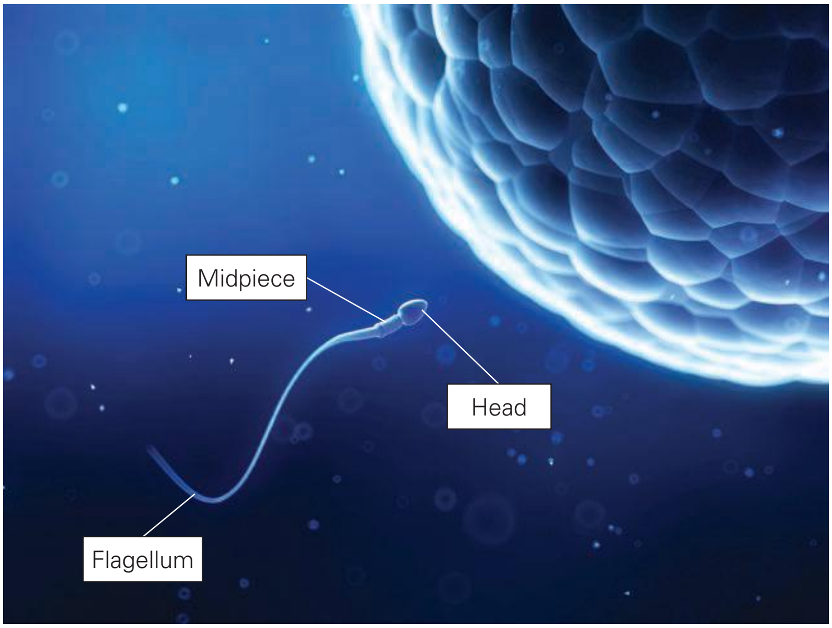


Figure 3.5 A sperm swimming towards an egg. Note its long flagellum.

Quick check 3.1

1. **Recall** the number of different types of cells in the human body.
2. **Recall** what unspecialised cells are called.
3. **Identify** one structural feature of each of the following cell types that helps with its function:
   a) neuron
   b) red blood cell
   c) sperm

Practical 3.1

Specialised cells

Be careful

Ensure that you carry the microscope appropriately. Carry it with one hand holding the arm and one hand under the base. Do not make big changes in magnification, so the glass slide does not get damaged.

Aim

To observe specialised cells under the microscope and estimate their size.

Materials

- light microscope
- prepared slides of blood
- prepared slides of blood vessels
- transparent ruler
- prepared slides of neurons

Method

Estimating the field of view

1. Place the transparent ruler on the stage of the microscope.
2. Starting on the lowest magnification, focus on the ruler.
3. Measure the diameter of the area you can see under the microscope (field of view) using the ruler.
4. Record this measurement (in mm) in the field of view (FOV) table.
5. Calculate the FOV diameter in micrometres (μm) by multiplying the FOV in millimetres by 1000.
6. Calculate the FOV for each of the higher magnifications by repeating steps 2–5.

Estimating the size of the object

7. Place your first prepared slide on the stage of the microscope.
8. Focus on the object using the lowest-power lens.
9. Estimate how many of the cells will fit in a straight line across the middle of the FOV.
10. Divide the total FOV diameter that you have already calculated by the estimated number of cells that will fit across the FOV.
11. Record your estimated diameter for the object in the results table.
12. Draw a scientific drawing of the cell you are observing.

RULES FOR DRAWING OBJECTS VIEWED UNDER A MICROSCOPE

Include a title for your image and the overall magnification used to view the specimen. Always use a pencil. Label your diagram, using a ruler for the lines.

13. Repeat steps 8–12 for each slide.

Results

Copy the following tables and use them to record your observations and measurements. Give your tables an appropriate title that describes what data it is displaying.

Magnification (ocular lens × objective lens)	FOV diameter (mm)	FOV diameter (μm) (mm × 1000)

Cell	Scientific drawing and magnification	Number of times cell would fit across the FOV	FOV diameter	Estimated diameter of object (FOV/number of times object fits across)
Blood				
Neuron				
Blood vessel				

continued →

Discussion: Analysis

1. Describe how the size and shape of each of the cells you observed benefits its function.

Discussion: Evaluation

1. Assess the accuracy of your estimated sizes.
2. Suggest a way of improving your size estimates.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Levels of organisation

In multicellular organisms, cells cannot gain nutrients and get rid of waste without the help of other cells. This is where tissues, organs and organ systems come into play. Cells are organised into tissues, tissues into organs and organs into organ systems. An example is shown in Figure 3.6.

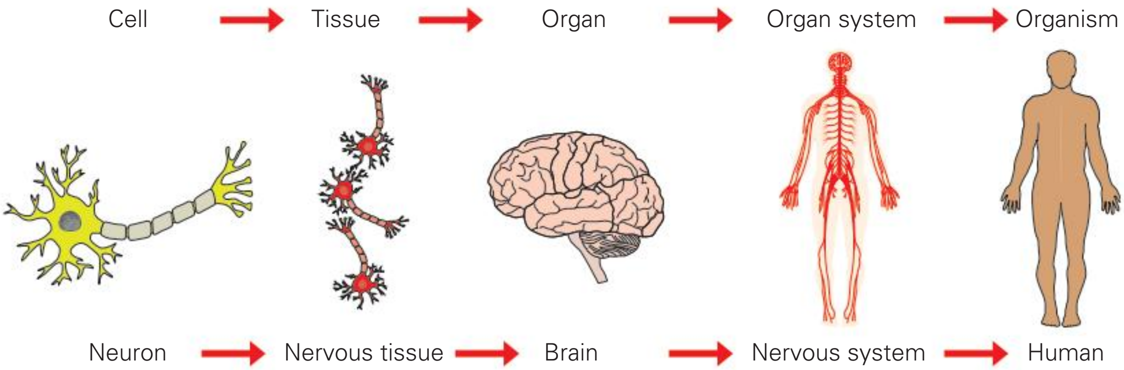


Figure 3.6 The nervous system is an example of cells being organised into an organ system.

Tissues

A group of cells of the same type that work together to perform a specific function is called a **tissue**. One of the most obvious tissues in animals is muscle tissue. These groups of cells contract and relax to generate movement by the animal. Muscle tissues require lots of energy, and so each cell has many mitochondria to carry out **cellular respiration** and provide that energy. Muscle cells also have a high blood supply to deliver oxygen and glucose for cellular respiration and to remove waste products such as carbon dioxide. Other types of tissue include lung tissue, liver tissue and connective tissues, such as tendons and ligaments. Even blood is considered a tissue.

tissue
a group of cells performing the same function

cellular respiration
a process that occurs inside mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

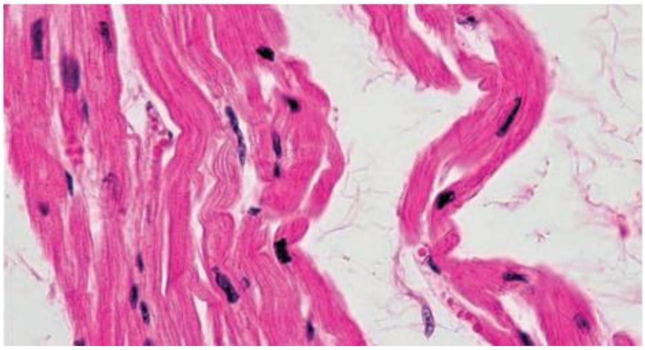


Figure 3.7 A high-magnification photograph of human cardiac (heart) muscle tissue, seen through a light microscope. Each of the long, thin muscle cells has a purple nucleus. Note that a stain has been added to the tissue to make it more visible.

Figure 3.8 Connective tissue in a tendon

Organs

organ
a group of tissues working together to perform a function

A group of different tissues working together to perform a specific function is called an **organ**. The brain is one of the most important organs in the body and is composed of different nerve tissues that comprise the grey and white matter. There are also many blood vessels that flow through the brain.

Figure 3.9 The human brain is a complex organ composed of neurons, blood vessels and other cells.

Did you know? 3.1

Human skin

The largest organ in the human body is our skin. On average, skin weighs around 2.7 kg and, if stretched out, would cover over 1.5 square metres. If you look closely at a small area of skin – say, the top of your hand – you will see tiny holes, called pores. What you can't see is that there are over six metres of blood vessels, thousands of nerve endings and hundreds of tiny glands secreting oil and sweat onto your skin. The skin cells themselves are replaced every 10–30 days, which means that, on average, we each go through around 900 complete skins in a lifetime.

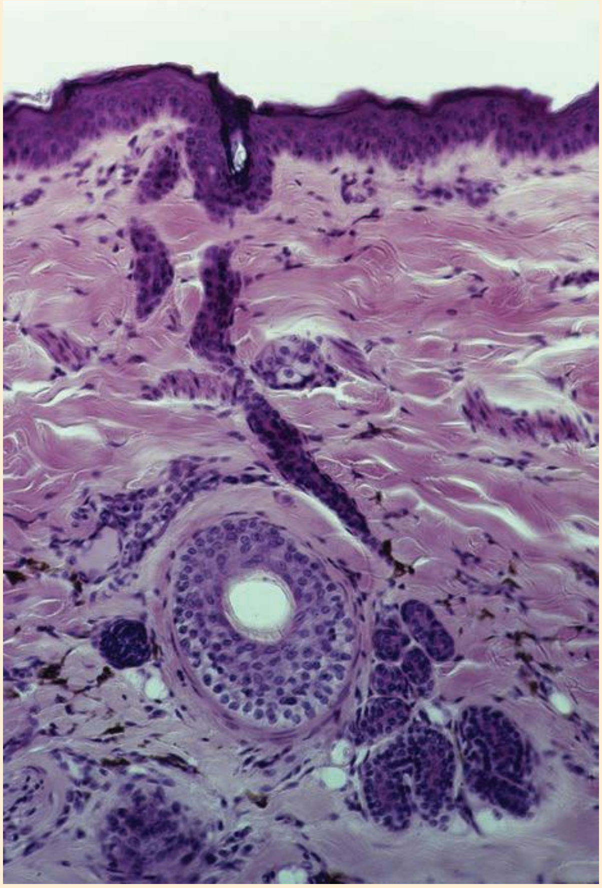


Figure 3.10 A sweat gland and duct on the head

ISBN 978-1-009-60327-0 Shaw et al.

Science as a human endeavour 3.1

Practice makes perfect

Haptic feedback gloves are gloves that provide sensory feedback to the wearer through vibrations or other means. They are being used in surgical training to provide a realistic and immersive experience for trainee surgeons. The gloves allow trainees to practise procedures in a simulated environment, where they can experience haptic feedback as they perform virtual reality surgeries.

This allows the trainees to get a more realistic sense of the physical aspects of surgery, such as the resistance and movement of tissues, or how the tissue of a baby would differ from an older person. This can help to build their surgical skills and improve their confidence before they perform procedures on real patients.

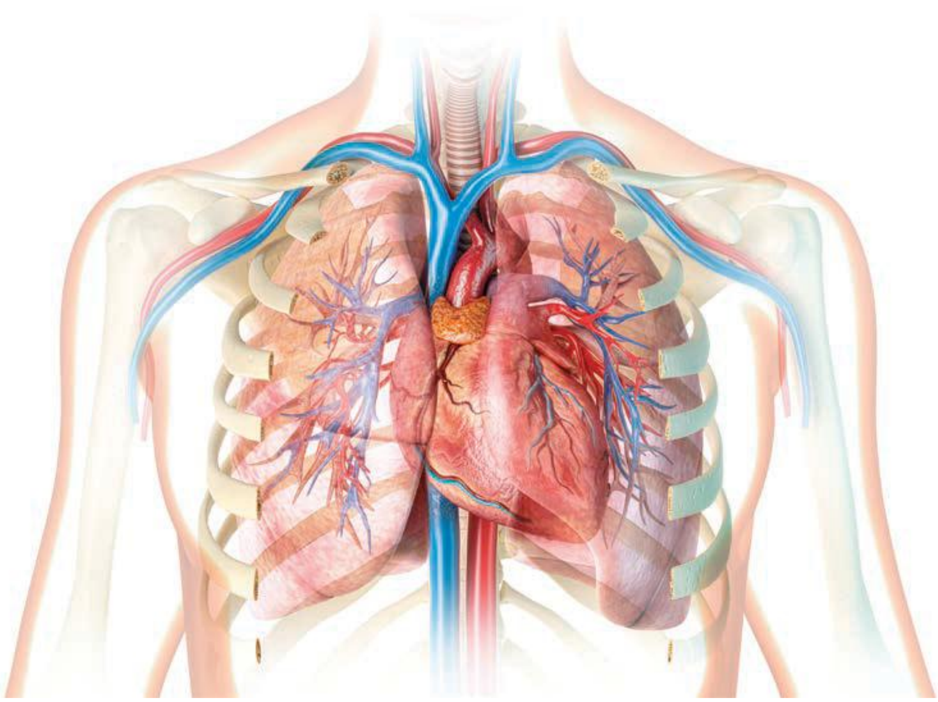
Figure 3.11 The HaptX Gloves DK2 system being used in 2019 with FundamentalVR's surgeon simulator software. This technology allows trainee surgeons to build their skills before performing a real operation.

VIDEO
Seeing a developing organism

Try this 3.1

Three-dimensional organ systems

Use the internet to find an online three-dimensional anatomy site such as ZygoteBody. You should compare the two-dimensional representations in this book with the three-dimensional representations of organ systems online to understand how organs are positioned within the body.



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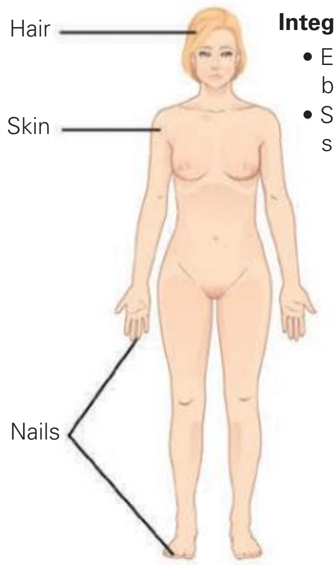
Organ systems

A group of different organs working together is called an organ system (or body system). Each organ system has a number of different structures that perform distinct processes or roles that contribute to the overall functioning of an organism. There are 11 organ systems in humans.

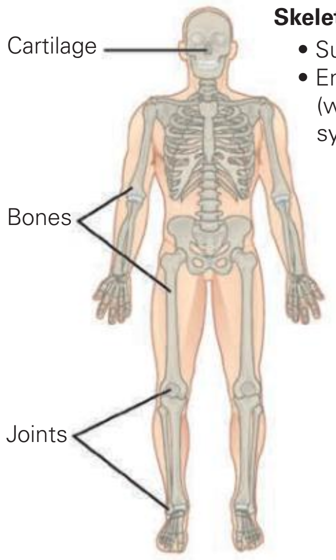
Integumentary system

- Encloses internal body structures
- Site of many sensory receptors



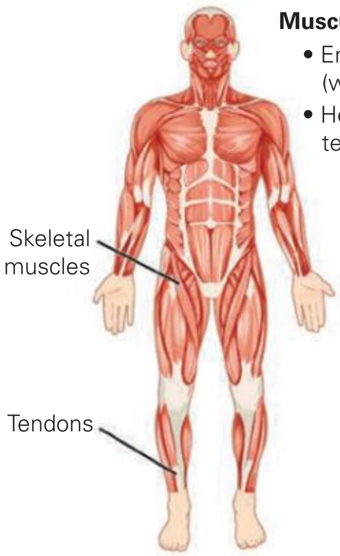
Skeletal system

- Supports the body
- Enables movement (with muscular system)



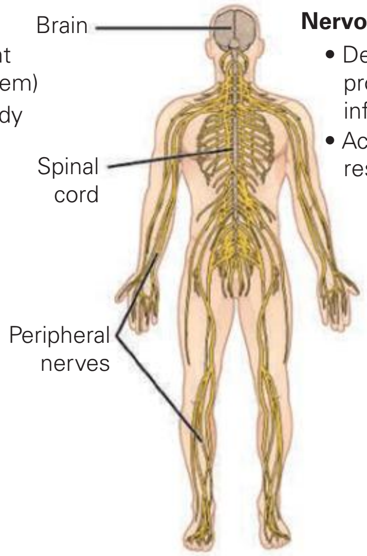
Muscular system

- Enables movement (with skeletal system)
- Helps maintain body temperature



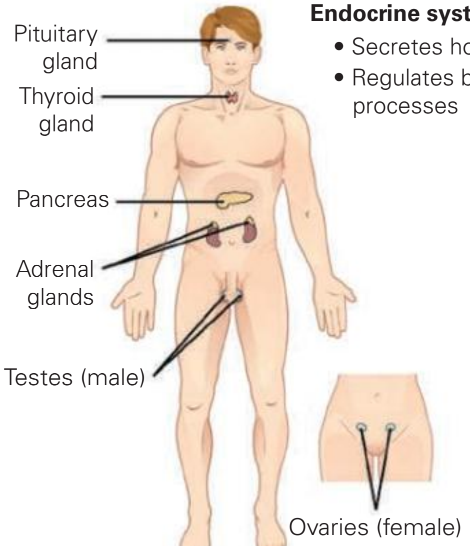
Nervous system

- Detects and processes sensory information
- Activates bodily responses



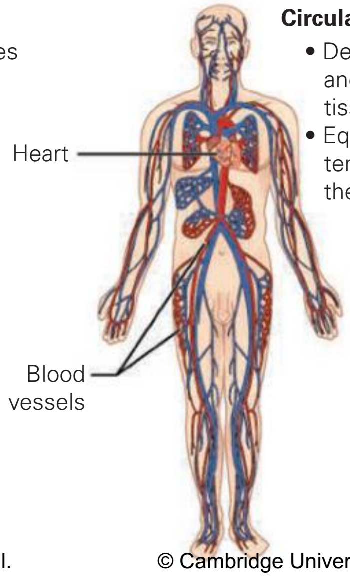
Endocrine system

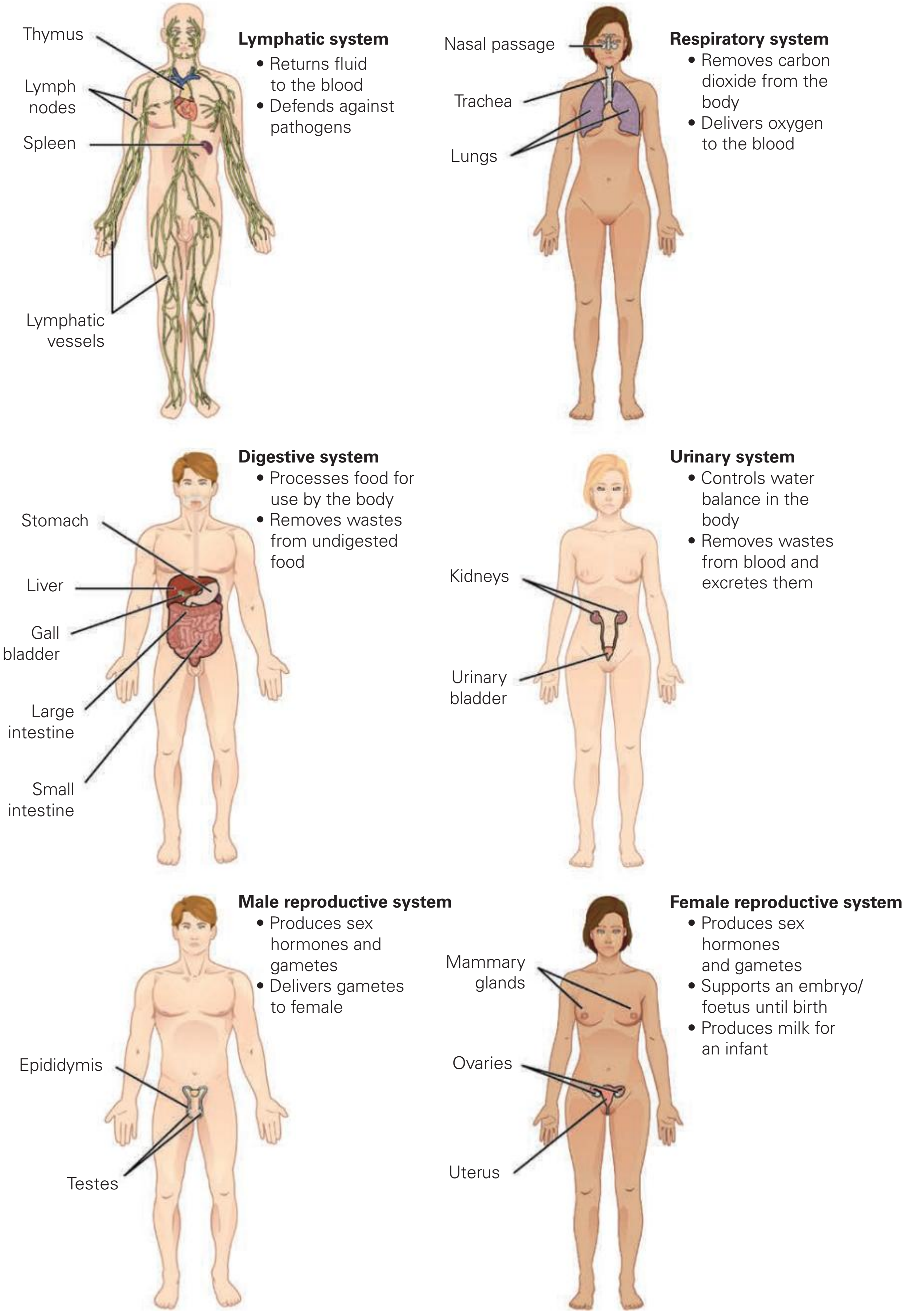
- Secretes hormones
- Regulates body processes



Circulatory system

- Delivers oxygen and nutrients to tissues
- Equalises temperature in the body





Lymphatic system
- Returns fluid to the blood
- Defends against pathogens

Respiratory system
- Removes carbon dioxide from the body
- Delivers oxygen to the 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 an embryo/foetus until birth
- Produces milk for an infant

Figure 3.12 The 11 human organ systems

Organisms

organism
a living creature, such as a plant or an animal

VIDEO
Seeing a developing organism

A group of organ systems working together supports a living being, called an **organism**. Each day, we eat food, breathe air and excrete waste products from our bodies. The many organ systems in our bodies work together in integrated ways to detect and respond to changes and complete the processes required to keep us alive.

Figure 3.13 A couple show an ultrasound image of their unborn baby. It is amazing to think that inside this tiny organism (within another organism!) all the body's essential organ systems are developing.

Quick check 3.2

1. **Sequence** the following structures into the correct level of organisation, from largest to smallest: cell, organ system, organism, organ, tissue.
2. **Propose** why unicellular organisms don't have organs.
3. **Distinguish** between a tissue and an organ.

Explore! 3.1

Plants are complex

Plants are eukaryotic organisms, just like us. This means their cells have complex membrane-bound organelles, such as the nucleus. We tend to think that because plants are usually sessile (stationary), they are less complicated than animals, but plants also have specialised cells that are organised into tissues, organs and organ systems.

Use an online interactive such as the *Seed Your Future Plant Interactive* to learn more about the roles of different parts of the plant. For each plant part, state which organ system in humans performs the same role.

Try this 3.2

Levels of organisation study mate

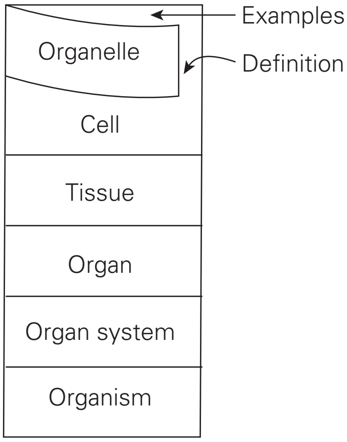
Step 1 Hold a piece of A4 paper in 'portrait' (upright) orientation.

Step 2 Fold it in half vertically – from left to right. You have formed a brochure with four sides or pages.

Step 3 Cut the front page only into six horizontal sections and label the front of these six flaps 'organelle, cell, tissue, organ, organ system, organism' from the top down.

Step 4 On the back of each flap, add the definition of each of the six levels of organisation.

Step 5 On the third page of the brochure, add some examples of each of the six levels of organisation.



When you look at the front of the brochure, you should see the names of the levels of organisation. As you open each flap, you should see the definition and examples.

Did you know? 3.2

Traditional knowledge of internal systems

Aboriginal and Torres Strait Islander Peoples have unique ways of communicating their understanding of the internal systems of organisms. Various Peoples often depict the internal features of animals through mediums like X-ray paintings, sculptures or head dresses.

Figure 3.14 Consider what internal systems are being shown in these pieces of art.

Section 3.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 3.1 questions

Remembering

1. **State** the function of red blood cells.
2. **State** one structure of a nerve cell that allows it to complete its function.
3. **Define** the term ‘tissue’.
4. **Identify** which of the following statements is correct.
   - A. A cell is composed of different types of tissue.
   - B. A tissue is composed of only one type of cell.
   - C. If you look at a tissue under the microscope, you will see many different organs.

Understanding

5. **Explain** how the sperm cell’s tail relates to its function.
6. **Explain** why multicellular organisms need multiple specialised cell types working together to function properly.

Applying

7. **Illustrate** some simple diagrams that model the difference between a cell, a tissue, an organ and an organ system.

Analysing

8. **Contrast** a sperm cell and a red blood cell.
9. **Categorise** the following terms as either cells, tissues, organs, organ systems or organisms: liver, neuron, sperm, dog, digestive, human, eucalyptus tree, brain, muscle, blood.

Evaluating

10. A new organism is discovered, and a study of its internal anatomy reveals that nutrients enter via a hole and are transported through a long tube into a storage area, before being excreted through a sphincter. **Justify** whether this is evidence of a tissue, an organ or an organ system.

3.2 The human respiratory system

WORKSHEET
Human respiratory system

Learning goal

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

1. Describe the structure of each organ in the respiratory system and relate its function to the overall function of the system.

Breathing versus respiration

You can probably hold your breath for about a minute, maybe two, but after that your body forces you to take a huge gulp of air. This is because the cells in our bodies need a constant supply of fresh oxygen to produce energy and function efficiently. Cellular respiration is the process that happens inside the mitochondria in our cells, which turns glucose and oxygen into useable energy called ATP. The process also produces the waste products carbon dioxide and water. Cellular respiration requires a number of complex chemical reactions to occur. The overall inputs and outputs of the process can be simplified in the following worded equation:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{ATP}$$

Breathing, the physical process of inhaling and exhaling, provides your body with oxygen to undertake cellular respiration. If you stop breathing, you are preventing oxygen entering your body and therefore depriving your cells of oxygen, meaning ATP cannot be made.

KEY IDEA

To summarise: breathing is a physical process, and cellular respiration is a chemical process.

Did you know? 3.3

Freedivers

While most people might be able to hold their breath under water for about 30 seconds, people who practise freediving can hold their breath for several minutes. The world record is more than 20 minutes! Freedivers do not use equipment like scuba gear. Instead, they have developed techniques such as hyperventilation, which allows them to reduce the concentration of carbon dioxide in their blood. Special breathing exercises aim to increase their lung capacity, and their bodies are adapted to dealing with prolonged periods of low oxygen. The current world record for freediving is held by Croatian, Budimir Šobat, who held his breath under water for 24 minutes and 11 seconds.

Figure 3.15 Freediving in the ocean

ISBN 978-1-009-60327-0 Shaw et al.

The respiratory system

The main function of the organs in the respiratory system is to get oxygen into your body cells and release the waste product carbon dioxide into the air. The respiratory system works very closely with the circulatory system, which together transport the oxygen you breathe in and remove carbon dioxide, which you breathe out.

Making thinking visible 3.2

Parts, purposes, complexities: Respiratory system

Examine Figure 3.16 closely.

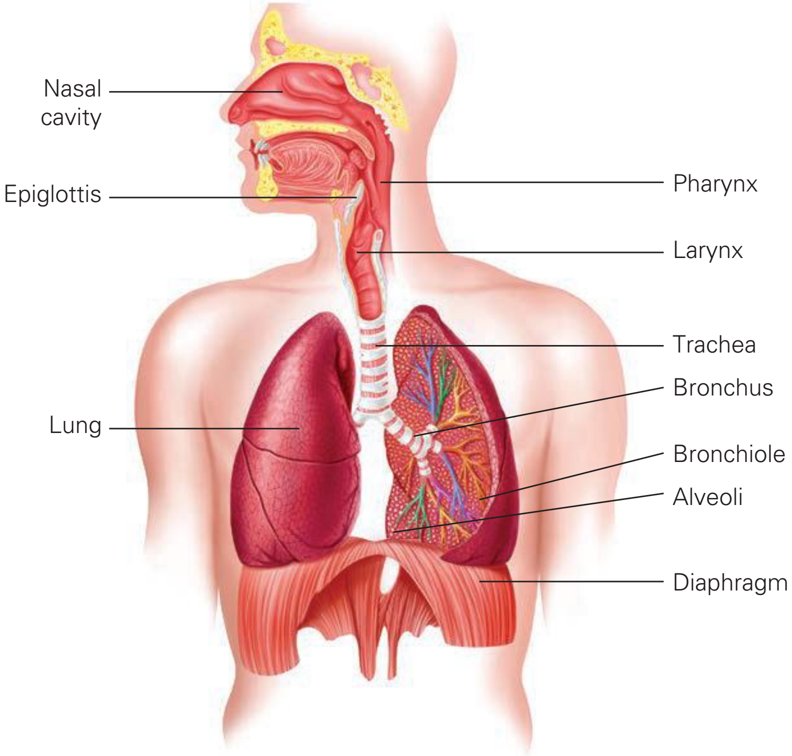


Figure 3.16 The structure of the human respiratory system

- What are the different **parts** of the respiratory system?
- What is the **purpose** of each of these parts?
- What is complicated about the diagram? Do you have any questions about these **complexities**?

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

Mouth and nose

The two main openings to your respiratory system are your mouth and your nose. When you inhale, air enters through your nostrils and travels through the nasal cavity before reaching the rest of the respiratory system. It is best to breathe through your nose, as the function of your nose is to warm up and moisten the air coming into your body, filter out any particles via the hairs in your nasal cavity and stimulate your sense of smell. If you close your mouth and exhale, the air will be directed out through your nose. This is because the nose and the mouth are connected in a region called the **pharynx**, which leads to the **trachea**, or windpipe.

pharynx
the throat region where the nasal cavity and oral cavity meet, leading into the trachea

trachea
the tube that carries air down to the lungs; also known as the windpipe

ISBN 978-1-009-60327-0 Shaw et al.

Trachea and bronchi

bronchi (sing. bronchus) the two branches of the airways that split off the trachea, one main left bronchus to the left lung and one main right bronchus to the right lung

bronchioles smaller branching tubes that branch off the two large bronchi and lead to the alveoli

The trachea is a wide tube with thick protective rings of cartilage that keep it open. If you place your hand on your throat, you can feel the rings. Warm, moist air from the nose and mouth enters the lungs by travelling down the trachea. The structure of your lungs is like an upside-down tree (Figure 3.18). The trunk of the tree is the trachea, and this large tube splits into two smaller tubes called primary **bronchi**, which are like branches and lead into the left and right lungs. The primary bronchi then branch into smaller and smaller bronchi, which then branch into even smaller tubes called **bronchioles**, which are like small twigs.

The cells of the trachea have hair-like structures on them called cilia (Figure 3.17). These cells play an important role in removing foreign particles and mucus from the respiratory system.

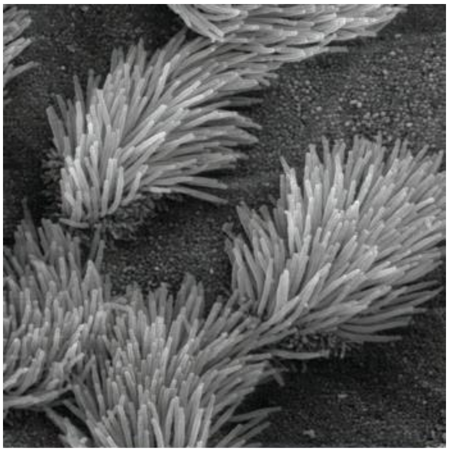


Figure 3.17 A scanning electron micrograph of ciliated cells in the trachea

Figure 3.18 This illustration of the lungs shows the blue central trachea dividing into the left and right primary bronchi. The red bronchi then eventually branch into bronchioles.

They move in a coordinated, beating motion, which moves mucus and particles upward towards the mouth and nose, where they can be removed. This helps to keep the trachea and lungs clear of potentially harmful substances.

Alveoli

VIDEO
Gas exchange in an alveolus

alveoli the tiny sacs at the end of bronchioles in the lungs; the site of gas exchange with the capillaries

capillaries the smallest blood vessels, one cell thick, and the site of gas exchange with cells

When the air gets to the end of the smallest bronchiole, it enters small sac-like structures called **alveoli**. The alveoli are only one cell thick and are surrounded by a net of very small blood vessels called **capillaries**. This is where gas exchange occurs: inhaled oxygen diffuses out of the alveoli and into the capillaries (into the bloodstream) for transport around the body. Carbon dioxide moves in the opposite direction, from the capillary into the alveoli. The carbon dioxide-rich air is exhaled out through your nose and mouth.

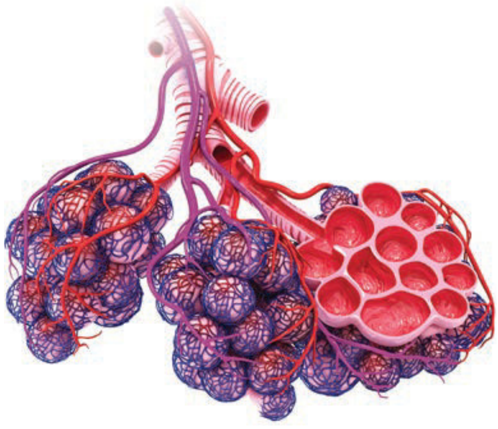


Figure 3.19 Gas exchange occurs between the alveoli and the capillaries. The oxygenated blood is returned to the heart, and the carbon dioxide-rich air is exhaled.

Quick check 3.3

1. **Define** the main function of the respiratory system.
2. **Describe** what happens to air as it passes through the nose.

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Big breath in!

When you breathe in (inhale), a large muscle at the base of your ribs, called the **diaphragm**, contracts and pulls down. At the same time, the intercostal muscles between your ribs contract, moving the ribs upwards and outwards. This increases the volume in your chest, decreasing the pressure in your lungs compared with the outside, which draws air in through your mouth and nose. As you breathe out (exhale), the diaphragm relaxes and air is passively released through your nose and mouth because the pressure has increased in the lungs.

diaphragm a dome-shaped muscle that separates the chest and abdominal cavities; it contracts to draw air into the lungs

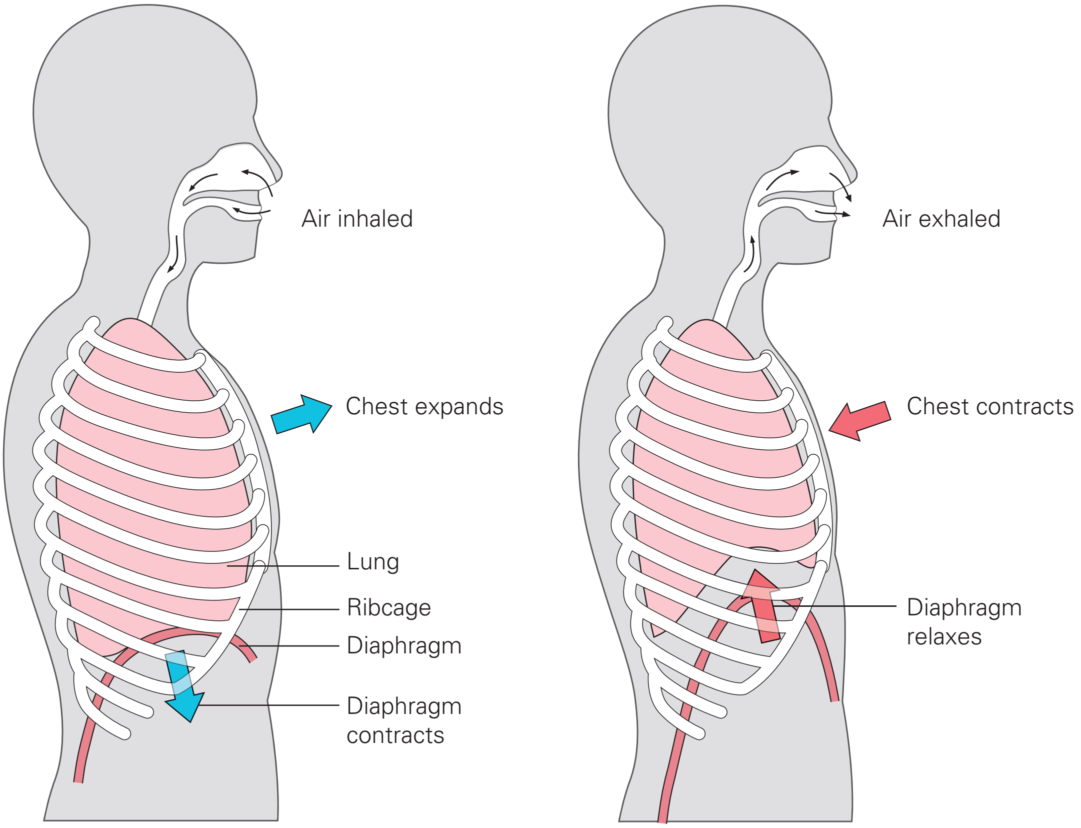

Figure 3.20 The movements of the chest during inhalation and exhalation

Try this 3.3

Pressure changes

This activity demonstrates how air from the atmosphere enters a space with lower pressure.

Materials: A glass bottle, a balloon, scissors, warm water (not boiling) and a jug or tall bowl of cold water.

Method:

1. Fill the bottle with warm water.
2. Allow the bottle to warm for a few minutes.
3. Pour out the water.
4. Stretch the neck of the balloon over the top of the bottle.
5. Place the bottle in a jug or bowl of cold water.
6. Observe what happens to the balloon after a few minutes.

Explanation: When the air inside the bottle is heated, it expands and some of it escapes. When the air cools down, it contracts, leaving some empty space with lower pressure. As a result, more air from the outside tries to enter and pushes the balloon into the bottle.

Explore! 3.2

Snoring

Snoring can be an annoying habit and can prevent people from getting a good night's rest. You snore because parts of your throat relax and vibrate as you breathe once you're asleep. However, snoring can also be a symptom of bigger medical problems. Do some research into why snoring occurs and what can be done to stop it. Your research should answer the following questions.

1. What are some risk factors for snoring (things that increase your likelihood of snoring)?
2. Which structures in the respiratory system are involved in snoring?
3. Snoring can be a warning sign of a medical condition called obstructive sleep apnoea. Describe this condition.
4. What treatments are available to reduce snoring?

Try this 3.4

Modelling the pressure changes in the lungs

Aim

To model how contraction of the diaphragm creates negative pressure inside the lungs

Materials

- plastic bottle, 500 mL or 1 L
- straw
- elastic bands × 2
- balloons × 2
- putty
- scissors
- sticky tape

Method

1. Tie a knot in one of the balloons and then cut off about a quarter of the other end.
2. Cut the bottle in half and only use the top half.
3. Put sticky tape around the cut edge of the bottle.
4. Stretch the cut balloon over the cut bottle opening and secure it in place with an elastic band and sticky tape.
5. Put a straw into the second balloon and use an elastic band to hold them together.
6. Place the straw with the balloon attached through the neck of the bottle and seal the hole with putty.
7. Pull down on the bottom balloon covering to mimic the diaphragm contracting and describe what you observe.

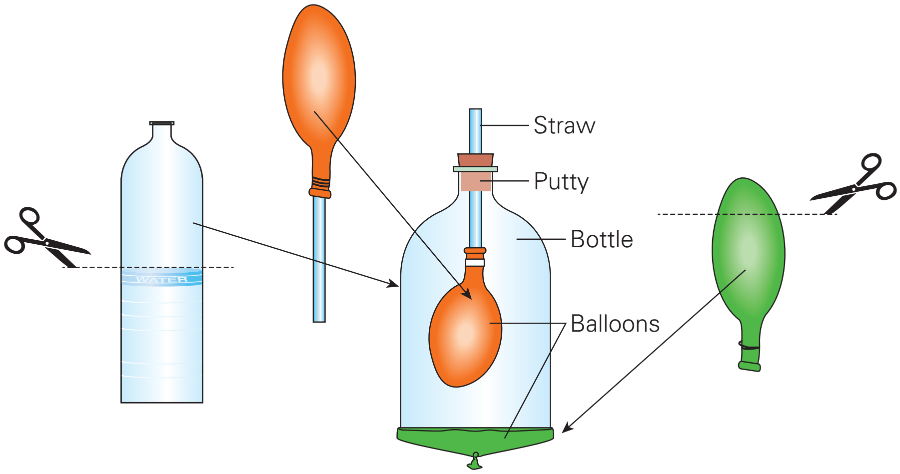

Figure 3.21 Experiment set-up. Breathing in: pressure in the lungs is lower than the atmosphere, so air flows in. Breathing out: pressure in the lungs is greater than the atmosphere, so air flows out.

Results

1. Draw your model of the lung in your book and label each of the parts that represent the following structures: lungs, ribs, diaphragm, trachea, mouth.

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Discussion: Analysis

1. What similarities can you draw between your model and the actual human respiratory system?
2. Describe the flow of air when you pull down on the balloon at the bottom of your model.
3. Explain what happens to the balloon lung when you push the balloon at the bottom of your model upwards.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Science as a human endeavour 3.2

Thunderstorm asthma

Asthma is a chronic lung condition that involves inflammation of the airways, tightening of the bronchioles and hypersecretion of mucus in response to certain triggers, such as exercise, smoke and pollen. People who suffer from mild asthma might feel slightly tight in the chest when they exercise or breathe in cold air, but some sufferers of severe asthma must take medications such as steroids every day to treat the inflammation and help prevent asthma attacks.

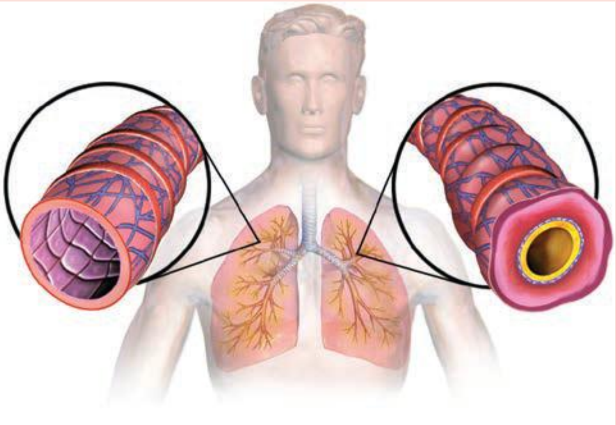

Figure 3.22 Asthma (right) causes a narrowing of the airways.

Thunderstorms can cause a phenomenon known as thunderstorm asthma, which can affect even those who do not have a history of asthma. The sudden change in weather conditions causes pollen grains to be drawn up into clouds as the storm forms. The moisture in the air causes the pollen grains to swell and then burst, generating tiny fragments of pollen that are pushed back down to the ground by wind. These small particles are then inhaled, leading to symptoms such as coughing, wheezing and shortness of breath.

The 2016 thunderstorm asthma event in Melbourne was one of the largest and most severe on record, with over 10 000 people affected, placing a significant strain on the healthcare system. The sudden surge in respiratory-related cases overwhelmed emergency departments and resulted in 10 fatalities.

Quick check 3.4

1. **Sequence** these terms in order so that they represent the direction of airflow during inhalation: alveoli, pharynx, nose/mouth, bronchus, trachea, bronchiole.
2. **Explain** how the diaphragm is involved in breathing in and out.

DOC
WORKSHEET
Asthma

Did you know? 3.4

Your lungs float!

Each of your lungs contains around 300 million alveoli, which you can imagine as tiny balloons. When 'inflated', the lungs are the only organ in the human body that can float on water.

Gas exchange in animals

In humans and other animals with lungs, it is the alveoli that are responsible for exchanging gases into and out of the blood. However, there are other members of the animal kingdom that have developed

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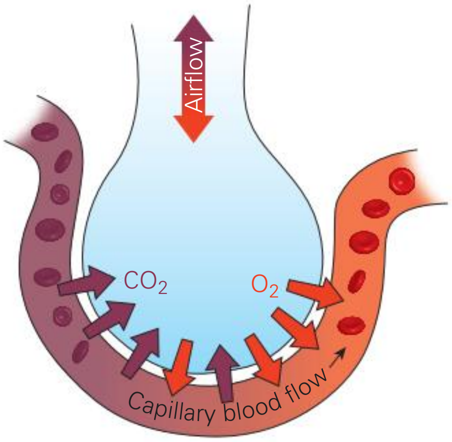

Figure 3.23 Gas exchange between the alveolus and the capillary. Note the direction of diffusion as oxygen enters the bloodstream and carbon dioxide leaves the bloodstream.

very different specialised structures for gas exchange, such as gills in fish, skin in frogs and tracheoles in insects. All these structures share common features to allow for efficient function. These features are:

- a very large surface area. This is usually achieved by a folded surface, which increases the amount of gas that can pass into and out of the animal's blood.
- a moist surface that gases dissolve into before they enter or leave the body. This makes the process of diffusion much easier for gases.
- a thin surface and small barrier between the inside and the outside of the body. This means that the gas has to travel a smaller distance.
- a transport system near these structures, such as blood vessels, to transport the gases to all parts of the body.

The 300 million alveoli in our lungs have all of these features, which makes them an extremely efficient gas exchange surface.

Practical 3.2

The products of breathing

Aim

To demonstrate the products found in exhaled air

Materials

- air pump
- straw
- conical flask
- glass Petri dish
- bromothymol blue
- water

Method

Bromothymol blue solution

1. Add 50 mL of water to a conical flask.
2. Add a few drops of bromothymol blue and record the colour in the 'Observations before' column of your results table.
3. Using a pump and a straw, blow air slowly through the solution for 30 seconds.
4. Record your observations in the 'Observations after' column.
5. Using your breath and the same straw, blow air slowly through the bromothymol blue solution for 30 seconds, being careful not to suck up any of the solution.
6. Record your results in the 'Observations after' column.

Petri dish

7. Using a pump, blow air directly over the Petri dish.
8. Record any changes in the results table.

Table showing observations of products in pumped versus exhaled air

Air source	Bromothymol blue solution		Petri dish	
	Observations before	Observations after	Observations before	Observations after
Pump				
Exhaled				

9. Using your breath, exhale directly over the Petri dish.
10. Record any changes in the results table.

continued ...

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Discussion: Analysis

When carbon dioxide is dissolved in water, it becomes acidic. Bromothymol blue turns from blue to green/yellow when it is exposed to acid.

1. Using the information above and the results you collected, explain your bromothymol blue 'before' and 'after' results.
2. Discuss your observations of the Petri dish portion of the practical and relate your findings to the products of respiration.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Explore! 3.3

Frog business

Billions of years ago, life began in the oceans, and gills were the first form of respiratory organ. As animals began to move onto land, a new gas exchange surface was needed. Evidence of this gradual change from aquatic life to terrestrial (land) life is present in amphibians today. In amphibians such as frogs, newts and salamanders, there are several ways in which gas can be exchanged. Unlike mammals and birds, amphibians are ectotherms, which means they depend on external sources of heat. As a result, their level of respiration can be lower than endothermic animals (those that produce their own body heat), and so their cells need less oxygen to function properly.

1. Tadpoles spend all their time in water. Find out how they get oxygen and explain how the features of gas exchange (thin, moist surface, etc.) relate to this process.
2. As tadpoles transition into adults, the process they use to gain oxygen changes. Explain how it changes.
3. Find out what 'cutaneous respiration' is and how it relates to a frog getting oxygen. Link this information to the features that gas exchange surfaces exhibit.
4. Research why frogs must undertake buccal pumping.

Figure 3.24 A frog keeping its nostrils above water to breathe

Figure 3.25 A frog with an extended buccal cavity

Try this 3.5

Modelling an animal respiratory system

Using whatever materials you can find (suggestions: plastic bags, string, bucket, rubber tubing), construct a model of an animal's respiratory system.

Quick check 3.5

1. **Recall** the site of gas exchange in the lungs.
2. **State** three other gas exchange structures found in the animal kingdom.
3. **Recall** the advantage of having a moist surface for gas exchange.

Go online to access the interactive section review and more!

Section 3.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 3.2 questions

Remembering

1. **Name** the gas that is absorbed into the blood by the respiratory system.
2. **Name** the gas that is removed from the blood by the respiratory system.
3. **State** the more biologically correct name for the 'windpipe'.

Understanding

4. **Describe** the features necessary for effective gas exchange.
5. **Explain** how the parts of the respiratory system are similar to a tree.
6. **Summarise** the functions of each of the following parts of the respiratory system:
   A. Alveolus
   B. Trachea
   C. Nose
   D. Bronchiole
7. **Summarise** the movement of the diaphragm during inhalation and exhalation.
8. **Describe** how the structure of the alveoli helps with gas exchange.

Applying

9. A person suffers a spinal cord injury at a level that paralyses their diaphragm. **Describe** the effect this would have on their ability to breathe.
10. **Construct** a flow chart showing the route taken by an oxygen molecule, starting from the air in your classroom and finishing in a body cell.

Analysing

11. **Contrast** the term 'breathing' with the term 'cellular respiration'.
12. The graph in Figure 3.26 shows a person's respiratory rate when resting and when exercising.
   a) **Identify** the person's respiratory rate at rest.
   b) **Identify** their respiratory rate at the maximum treadmill speed.
   c) **Infer** why their respiratory rate increased during exercise.

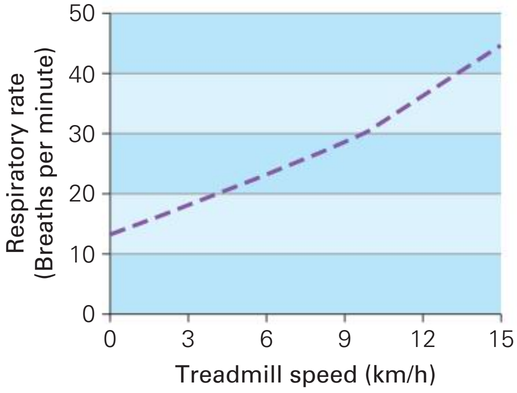

Figure 3.26 Respiratory rate versus treadmill speed

Evaluating

13. **Decide** why it is better to breathe through your nose than through your mouth.
14. Cystic fibrosis is a disease that causes over-production of mucus in the airways and can be life-threatening if the person catches a cold or the flu that results in a chest infection. **Propose** a reason why a build-up of mucus in the lungs can be harmful and why the person may experience shortness of breath.

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3.3 Other respiratory systems

Learning goal

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

1. Compare the structure and function of the analogous respiratory systems in plants and animals.

WORKSHEET
Plant respiration

VIDEO
Other respiratory systems

Gas exchange in plants

Gas exchange is important for all living organisms, including plants. Plants carry out both cellular respiration to make energy and photosynthesis to make their own food. Both of these processes require the exchange of oxygen and carbon dioxide between the inside and outside of the plant. This means plants must have organs that allow their internal structures to exchange gases with the environment. The main gas exchange organ in plants is the leaf.

Examine the worded equations for photosynthesis and cellular respiration below. Notice that photosynthesis requires carbon dioxide and produces oxygen, and the opposite happens in cellular respiration.

Photosynthesis:

$$\text{carbon dioxide} + \text{water} \rightarrow \text{glucose} + \text{oxygen}$$

Cellular respiration:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{ATP}$$

Each plant has many leaves, in the same way that your lungs have many alveoli. Leaves are usually flat, which increases the surface area not just for light absorption but also for gas exchange. Each leaf has tiny pores called **stomata** (singular: stoma). The stomata are mainly on the underside of the leaf, and they control the entry and exit of gases from the plant. **Guard cells** around the stomata enable them to open and close. Unfortunately, this means that water loss can also occur through stomata. When they are open, gas exchange can happen, but water is also lost to the environment.

stomata (sing. stoma)
tiny pores (holes) in leaves that allow entry/exit of gases such as oxygen and carbon dioxide

guard cells
cells on either side of a plant stoma that control gas exchange by opening and closing the stoma

The guard cells of stomata contain large vacuoles that, when filled with water, hold the stomatal pores open. The vacuoles fill with water when plants are in strong sunlight or high carbon dioxide concentration. However, when the plant begins to dry out in periods without rain, or in high temperatures or low humidity, the vacuoles inside the guard cells empty out and the cells become floppy or flaccid. This closes the stomata and reduces the amount of water vapour lost through the leaf. The stomata also close at night when the light levels are low. Plants need to allow gases to move in and out, but they also need to minimise the loss of water vapour through the stomata. It is a balancing act, and plants do an amazing job (especially those that live in the desert).

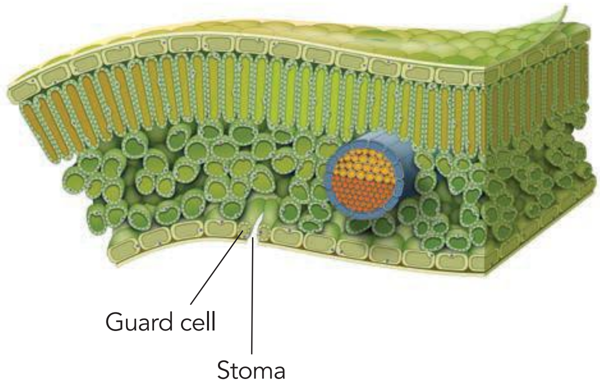

Figure 3.27 A cross-section of a leaf

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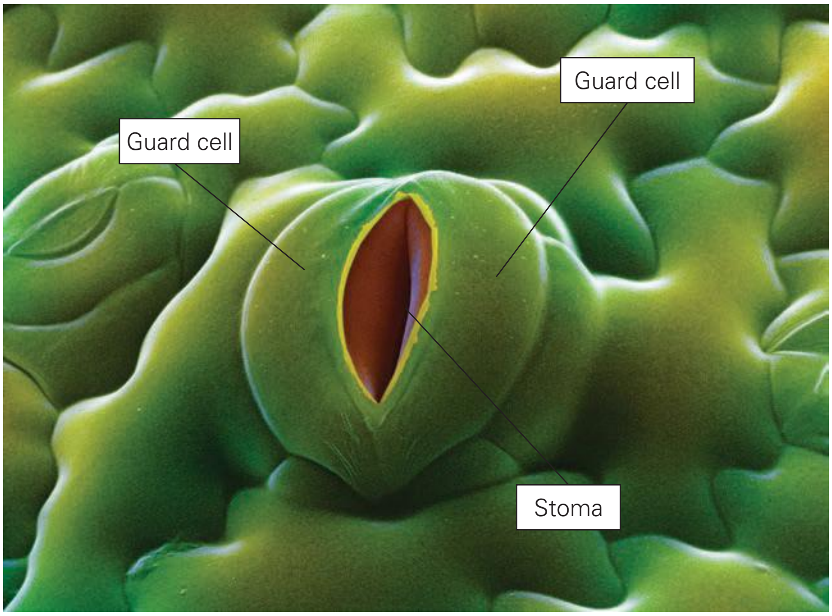

Figure 3.28 Swollen guard cells have forced open this stoma, allowing gases to enter and exit the leaf.

Try this 3.6

Modelling stomata with a balloon

1. Using a twist balloon, blow it up and fold it in half but do not tie a knot in the end.
2. Keeping the balloon folded, allow some air to escape slowly from the balloon.
3. Notice how the two sides of the balloon begin to come together.

This is like what happens in the stomata as they lose water. By closing the stomata, the plant can limit water evaporation and save water.

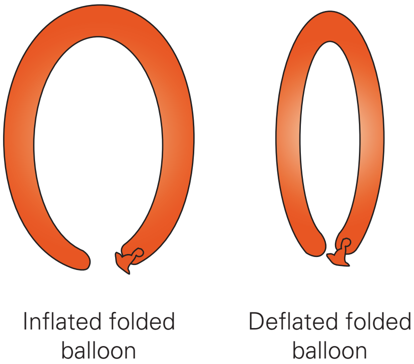

Figure 3.29 A twist balloon can be used to model stomata.

lenticels
small slits on trunks or branches of trees that allow gas exchange

Although the stomata on leaves are very effective at providing gas exchange for the leaves, other parts of the plant need to respire, as well. The thick woody parts of trees, such as the branches, stems and trunks, have structures called **lenticels**. You can often see these in the bark – they look like small dots or stripes (see Figure 3.30). Lenticels allow the thick woody parts of the plant to exchange gases with the air.

Figure 3.30 The small horizontal slits in this tree trunk are lenticels.

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Practical 3.3

Stomata lab

Be careful
Carry the microscope appropriately, with one hand holding the arm and one hand under the base. Do not make big changes in magnification, so that the glass slide is not damaged.

Aim

To observe plant stomata using a light microscope and estimate their size

Materials

- leaves
- light microscope
- transparent ruler
- sticky tape
- glass slide
- transparent nail polish

Method

Calculating FOV and estimating the size of the object

Refer to *Practical 3.1* for the methods of calculating the size of the field of view and estimating the size of the object.

Creating a stomata slide

1. Either pick three leaves from a walk around your school grounds or choose from leaves provided by your teacher.
2. Identify the top and bottom of the leaf.
3. Use the nail polish to paint a thin layer of varnish on a small section of the bottom side of the leaf.
4. Allow the polish to dry completely.
5. Place the sticky tape over the dry polish and pull it off.
6. Place the sticky tape with the polish impression onto a microscope slide and use the compound microscope to focus on the stomata impression.
7. Focus on the highest possible magnification and sketch an image of the stomata. Use the FOV calculations to estimate the diameter of the stomata.
8. Repeat for each leaf.

Results

Table showing magnification of field of view

Magnification (ocular lens × objective lens)	FOV diameter (mm)	FOV diameter (μm) (mm × 1000)

Table showing plant stomata size

Plant	Sketch, magnification and diameter estimate

Discussion: Analysis

1. State the estimated size of a stoma.
2. Explain why different plants are likely to have a different number of stomata.
3. Suggest a reason why some stomata are open while others are closed.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered, and include potential sources of error.

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Explore! 3.4

Trichomes

Plant hairs, also known as trichomes, can help to prevent water loss in plants. They break up the flow of air across the plant surface in windy regions, reducing water loss. When trichomes are dense, they reflect sunlight and in areas where plants obtain their water from fog, the trichomes allow water droplets to accumulate. Search the web to find images of three different plants displaying trichomes.

Figure 3.31 Scanning electron micrographs show a variety of trichomes on different leaves

Quick check 3.6

1. **Name** the structures in leaves that allow gas exchange.
2. **Recall** three environmental factors that could cause stomata to close.
3. **Explain** the process involved in closing the stomata.
4. **Identify** how plants conduct gas exchange through their trunks.

Respiratory systems in fish

Lungs are specialised to exchange gases in air and therefore cannot function under water. Conversely, gills have evolved to exchange gases that are dissolved in water and therefore cannot function on land. However, both these structures take in oxygen from the environment and excrete carbon dioxide as a waste product from the body.

It might seem strange to think of water containing gases such as oxygen and carbon dioxide, but it does. These gases are dissolved in the water, just like sugar can dissolve in water.

Most fish respire through their gills, which are on either side of their head, near the mouth. Fish open their mouths, gulp in water and then open their gill flaps to let the water out. This flow of water across the gills provides a constant supply of oxygen. The sections of gills look very similar to feathers and are called **filaments**. Filaments are like the alveoli in your lungs. They provide a large surface area to maximise the amount of gas that can be exchanged between the fish and the water around it. Each filament also contains individual capillaries that increase the blood's exposure to the water around the fish, and this increases the amount of oxygen that the fish can absorb.

filaments
red, fleshy part of the gills with thousands of fine branches that take oxygen from water into the blood

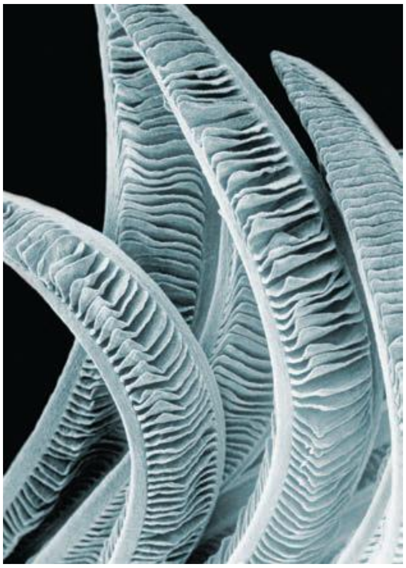

Figure 3.32 The highly folded surface inside of fish gills maximises the surface area available for gas exchange.

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Explore! 3.5

Counter-current flow

Fish also have another way of increasing the level of diffusion in their gills, known as *counter-current flow*. This process maximises the exchange of gases, because a guiding rule for diffusion is that the bigger the difference between the concentration of a gas in two areas, the faster that diffusion can occur.

1. Research what counter-current flow is and explain how it works.
2. Draw a picture to demonstrate counter-current flow in a fish gill.

Did you know? 3.5

Axolotls

Axolotls are neotenic, meaning they keep their juvenile characteristics when they become adults. Axolotls remain aquatic for their entire life, even though they develop fully functional lungs. Instead, they use their feathery gills on their heads to breathe underwater.

Figure 3.33 The gills of an axolotl stick out from the side of its head to maximise gas exchange with the surrounding water.

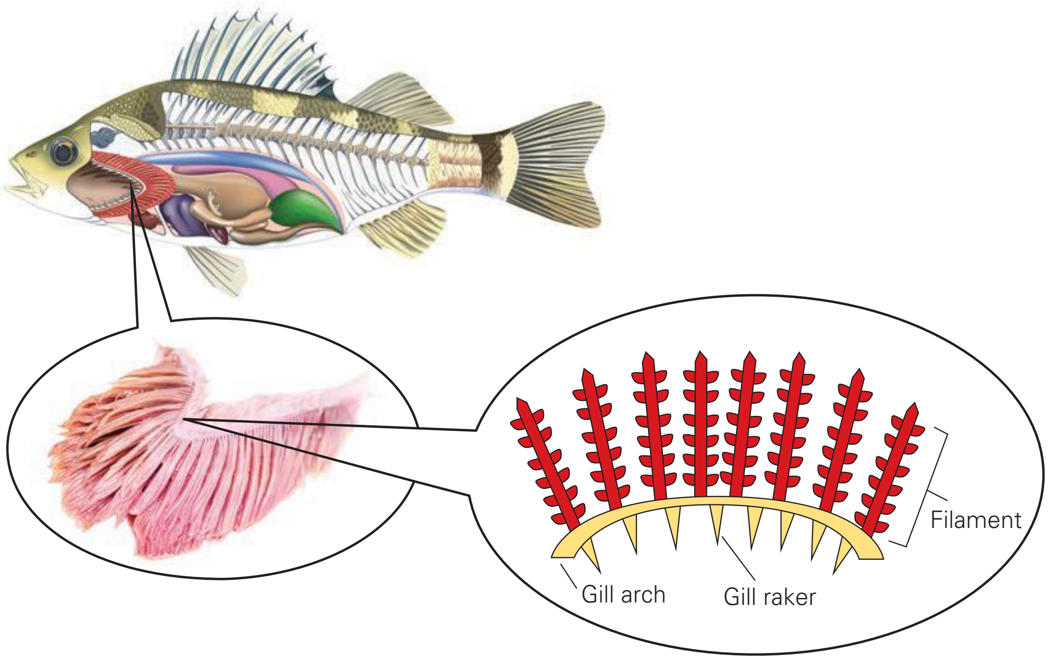

Figure 3.34 The complex structure of fish gills

Quick check 3.7

1. **State** the gases that fish need to exchange with their environment.
2. **Summarise** the features of gills that allow efficient gas exchange.
3. **Recall** three ways in which gills speed up the diffusion of gases into and out of a fish.

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Practical 3.4

Fish dissection

Be careful

Carry the microscope appropriately, with one hand holding the arm and one hand under the base. Do not make big changes in magnification, so the glass slide does not get damaged.

Aim

To observe a fish dissection and view gills under a microscope

Materials

- dissection microscope
- Petri dish
- half a fish per class
- dissecting scissors
- probe
- small knife
- disposable gloves

Method

Retrieving the gills

1. Your teacher will make incisions with dissecting scissors, as shown in Figure 3.35. This will expose the internal anatomy of the fish.
2. Your teacher will identify the structures shown in Figure 3.36.

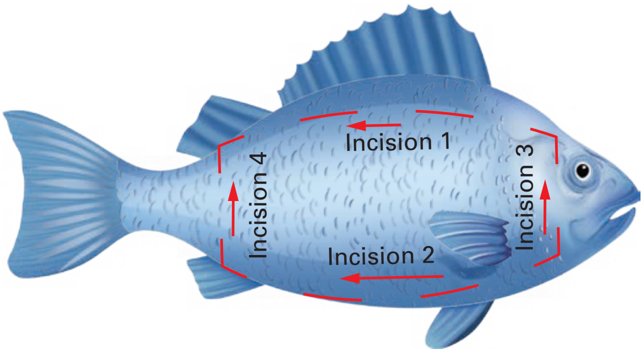

Figure 3.35 External incisions

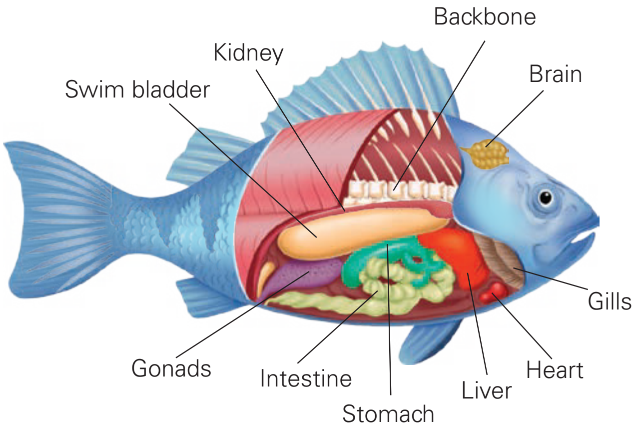

Figure 3.36 Internal organs of the fish

Organ	Feature
Heart	The heart of a slow-moving fish is small; the heart of a fast-moving fish is large.
Liver	A large organ located near the heart. It produces many digestive liquids and stores some vitamins and nutrients.
Gonads	Sex organs, male or female. Some species have both types of gonads in one fish.
Kidneys	Two kidneys, located near the spine, regulate water levels in the body.
Gills	The aquatic version of lungs. Each gill arch holds many hundreds of filaments, which are feather-like structures with a large surface area.

Table 3.1 Structural features of each organ

3. Your teacher will cut open the gill arch to expose the gills. You will be able to see that the gills are stacked on top of each other.
4. Your teacher will cut the gill arches and pass one to each group.

Observing the gills

5. Take one of the gill filaments that your teacher has cut from the fish and place it in a Petri dish. Observe the structure of the gill filaments – each filament has many plates, called *lamellae*.
6. Add a small amount of water to the Petri dish and observe how the gill filaments and lamellae separate when they are in water.

continued ...

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7. Use a dissecting microscope to focus on the structure and draw a sketch.
8. Notice that there is a yellow/red sticky substance on the gills. This is a protective mucus similar to the mucus in your lungs.

Discussion: Analysis

1. Name the organ involved in gas regulation in fish.
2. Explain what you observed when you added water to the gill arch.
3. Using your observations, suggest why fish cannot breathe out of water.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered, and include potential sources of error.

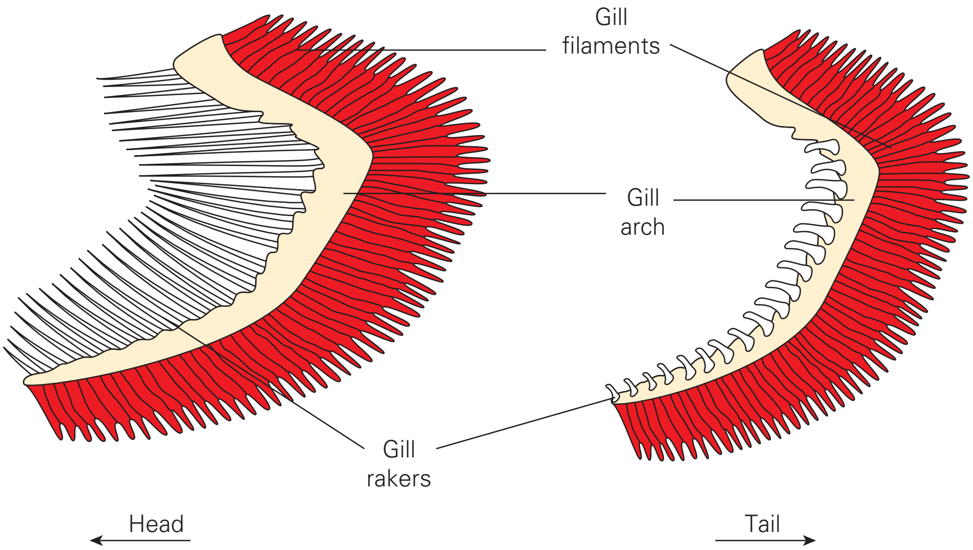

Figure 3.37 Observe the structures: *gill filaments* are the site of gas exchange; *gill rakers* are appendages along the front edge of the gill arch; *gill arches* support the gills.

Did you know? 3.6

Insect gas exchange

In insects, gas exchange occurs through a system of tubes called tracheae, which branch into smaller tubes called tracheoles, which eventually reach the individual cells. The tracheae open to the outside of the body through structures called spiracles, which are found on the sides of the insect's thorax and abdomen.

The spiracles can open and close to control the flow of air into and out of the tracheae. When the spiracles are open, air flows into the tracheae and can then diffuse into the individual cells, providing oxygen for respiration. At the same time, carbon dioxide produced by respiration diffuses out of the cells and into the tracheae, where it is expelled from the body through the spiracles.

Figure 3.38 Spiracles

Figure 3.39 A fly spiracle

Go online to access the interactive section review and more!

Section 3.3 review

Online quiz	Section questions	Teachers can assign tasks and track results

Section 3.3 questions

Remembering

1. **Define** the term 'gas exchange'.
2. **State** three gas exchange structures found in eukaryotic organisms.
3. **State** the location of stomata.

Understanding

4. **Explain** how stomata open and close.
5. **Explain** the function of lenticels on a tree trunk.
6. **Summarise** how surface area is maximised in gills.

Applying

7. **Explain** which part of the human respiratory system performs a similar job to stomata in plants.
8. There are lung diseases that cause alveoli to fill with fluid. **Explain** what symptoms a person is likely to experience if they have this condition.

Analysing

9. **Contrast** the structure of the lungs with the structure of a tree.
10. **Contrast** the structure of human lungs with the structure of frog lungs.

Evaluating

11. **Construct** a graph of the following data, showing the amount of dissolved oxygen (in mg/L) in fresh water and sea water at different temperatures. Use temperature as the independent variable (on the *x*-axis of the graph) and dissolved oxygen (mg/L) as the dependent variable (on the *y*-axis of the graph). Use different coloured lines for fresh water and sea water.

Water temperature (°C)	0	10	20	30	40	50
Dissolved oxygen in fresh water (mg/L)	14	11	9	8	7	6
Dissolved oxygen in sea water (mg/L)	12	9	7	6	5	5

12. Imagine a world where plants ceased to exist. **Discuss** the impact this would have on humans in terms of the gases that we each require and produce when breathing.

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3.4 The human circulatory system

Learning goal

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

1. Describe the structure of each organ in the circulatory system and relate its function to the overall function of the system.

WORKSHEET
Human circulatory system

The circulatory system (sometimes referred to as the cardiovascular system) is a transport system that moves oxygen, nutrients, hormones, immune cells, waste and heat throughout the body, in one continuous loop. It works closely with most of the other organ systems in the body and without it, none of the other organ systems would be able to function.

Heart

The heart is a powerful muscular pump. It has one job: to maintain pressure in your circulatory system, which moves the blood around your body.

It does this by contracting and relaxing about 60–90 times per minute. Your heart is located near the centre of your chest, and it is about the same size as when you form a fist with your hand. It is made up of four main sections: the right **atrium** and left atrium (top parts of the heart) and the right and left **ventricles** (bottom parts of the heart).

Unlike other muscles in your body, the heart is myogenic, meaning it contracts (beats) without having to receive instructions from the brain. The heart has its own conduction system, which includes the **sinoatrial node**, the heart's primary pacemaker located in the wall of the right atrium; and the **atrioventricular node**, located between the atria and the ventricles. The SA node sends an electrical signal to the atrioventricular node, which then sends it to the rest of the heart's conduction system. This causes the heart to contract.

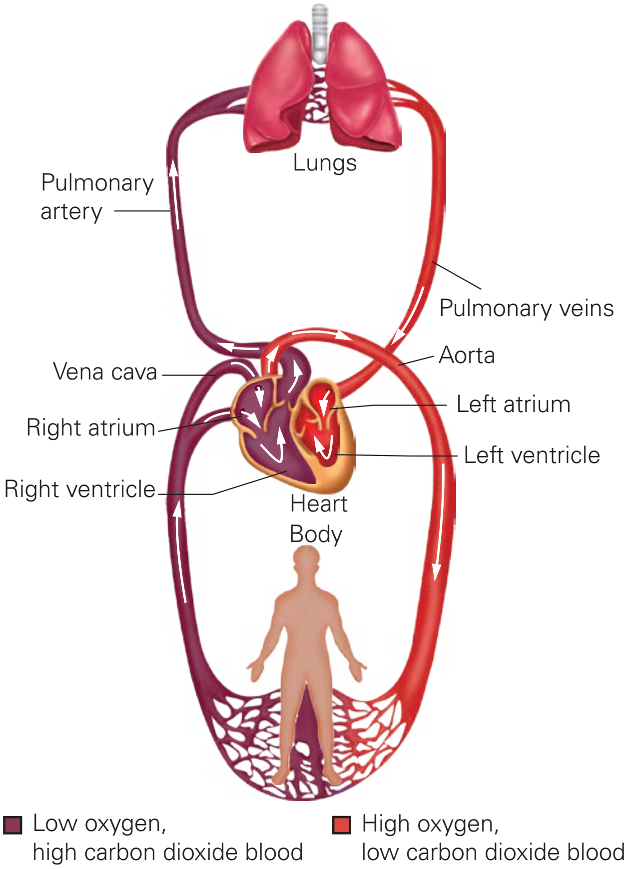

Figure 3.40 Blood flows in the following loop: right atrium → right ventricle → pulmonary artery → lungs → pulmonary vein → left atrium → left ventricle → aorta → body tissues → vena cava → right atrium … and the loop starts again.

The human heart is like a double pump: the left side sends blood out to the body, and the right side sends blood to the lungs. The path of a red blood cell through the circulatory system can be followed using Figure 3.40 and Figure 3.41.

atrium	one of the two upper chambers of the heart, the left atrium and right atrium
ventricle	one of the two lower chambers of the heart, the left and right ventricles
sinoatrial node	a natural pacemaker that controls the heartbeat and is located in the wall of the right atrium
atrioventricular node	a natural pacemaker that controls the heartbeat and is located in between the atria and the ventricles

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vena cava
the large vessel that returns deoxygenated blood from the body to the heart, emptying into the right atrium

deoxygenated
describes a substance that is low in oxygen

oxygenated
describes a substance that contains oxygen

aorta
the largest vessel leaving the heart, from the left ventricle, carrying oxygenated blood to the body

VIDEO
Contraction of heart chambers

Blood returning to the heart from the body enters the heart though the **vena cava** and fills the right atrium. This blood is said to be **deoxygenated** – that is, it has low levels of oxygen. This is because it is returning from the body, where red blood cells have given oxygen to body cells for cellular respiration. These red blood cells are carrying the carbon dioxide waste produced by body cells.

The blood then passes into the right ventricle and is prevented from travelling backwards by a valve between the atrium and the ventricle. Once in the ventricle, the blood is then pumped out of the heart and travels via the pulmonary artery to the lungs.

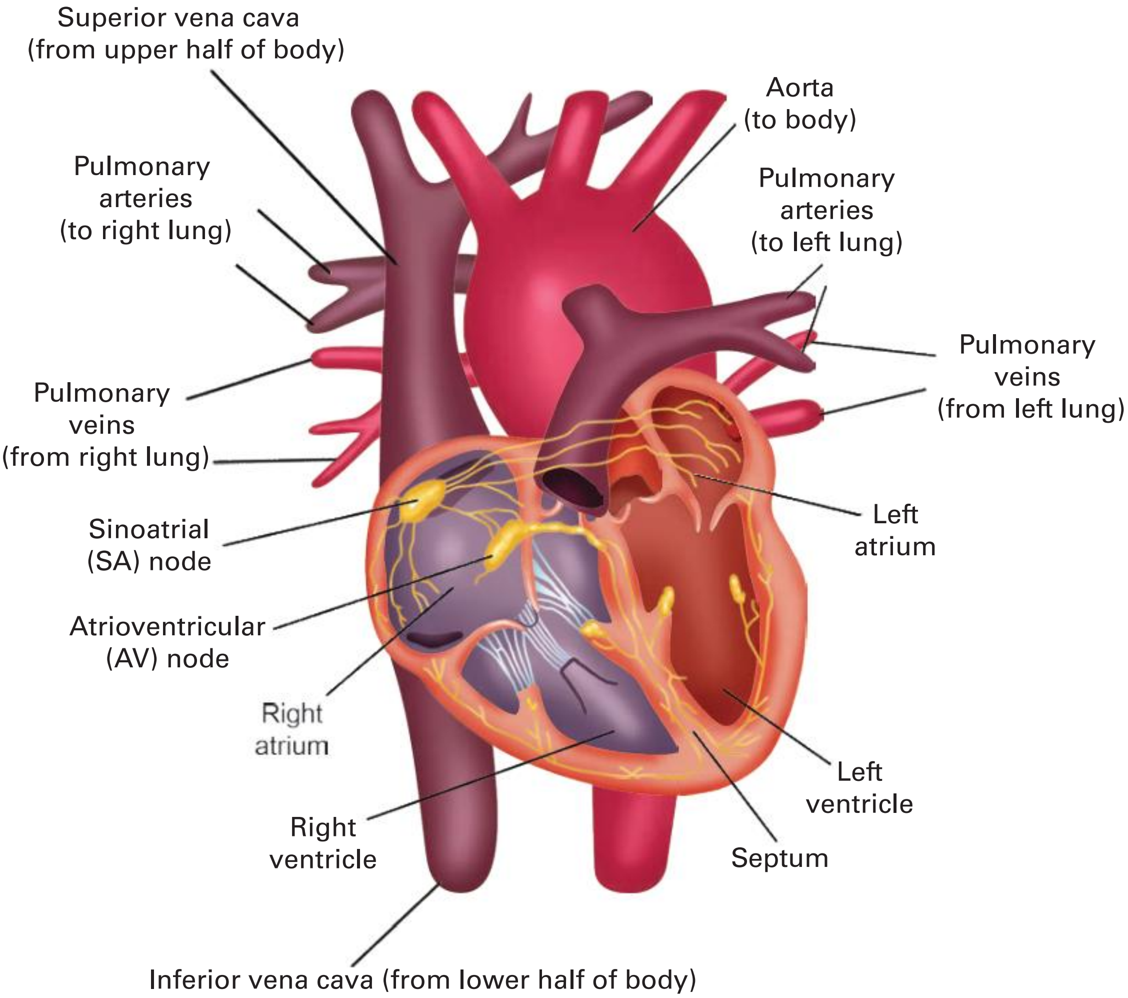

Figure 3.41 The human heart and its major vessels, chambers and valves. The heart is labelled as it sits in your chest, but it is drawn as if it were visible to someone facing you. Therefore, the left ventricle is located on the right-hand side of the diagram.

As the blood passes through the lungs, it releases the carbon dioxide it has stored within it and gains oxygen from the alveoli of the lungs.

The **oxygenated** blood then returns from the lungs through the pulmonary veins into the left atrium. From there, it passes into the left ventricle. The left ventricle pumps the blood out via the **aorta** to all the different parts of the body. This process delivers oxygen to the cells and picks up the carbon dioxide waste they produced.

Making thinking visible 3.3

Connect, extend, challenge: Bioprinting

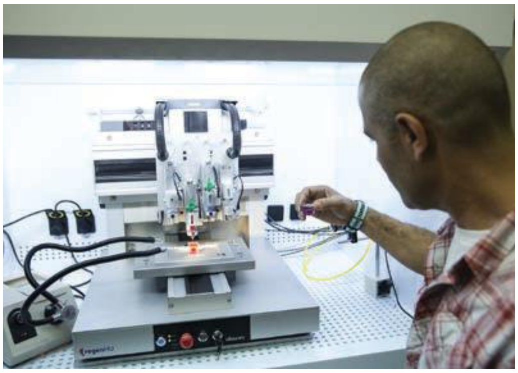

Figure 3.42 Three-dimensional printing of a human heart

Three-dimensional printing of organs, also known as bioprinting, is an emerging area of research where scientists create functional human organs using three-dimensional printing technology. The goal is to address the critical shortage of organs for transplantation and create tissue models for drug discovery and testing.

In bioprinting, a three-dimensional printer is used to layer living cells with a supportive material to create functional tissue. The cells can be taken from the patient, reducing the risk of rejection, or they can be sourced from a biobank. Once the tissue has been printed, it is incubated in a controlled environment that allows it to mature and develop into functional tissue.

While the technology is still in the early stages of development, significant progress has been made in bioprinting simple tissues, such as skin and cartilage. However, more complex organs, such as the heart, liver and lungs are much more challenging to bioprint, as they require intricate networks of blood vessels and other structures to support the cells.

Despite the challenges, researchers are optimistic about the potential of bioprinting to revolutionise the field of transplantation and provide a limitless supply of functional organs for patients. Bioprinting also has the potential to advance the field of drug discovery and testing, allowing researchers to test new drugs on functional human tissue before proceeding to clinical trials.

Consider what you have just read about bioprinting, then answer the following questions:

- How are the ideas and information about bioprinting connected to what you already know about organs?
- What new ideas extended your thinking or made you think differently?
- What questions do you have about bioprinting?

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

Try this 3.7

Testing your heart rate

Your heart rate responds to the oxygen requirements of your body. For each of the following test conditions, follow the procedure below and record your heart rate (in beats per minute) in the table. You will need a stopwatch.

Find your pulse by gently pressing two fingers over your radial artery (on the inner side of your wrist, slightly off-centre towards the thumb; see Figure 3.43). Count the number of beats you feel in 15 seconds, using the stopwatch, and then multiply the number by four to find your heart rate in beats per minute (bpm).

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Test your pulse under the following conditions, then copy and complete the table.

Test condition	Heart rate (bpm)
Lying down	
Sitting	
After jogging for three minutes	

Figure 3.43 Feeling for the radial pulse

Graph your data as a bar chart and answer the following questions.

1. During which test condition was your heart rate:
   a) at its highest?
   b) at its lowest?
2. For each answer you gave to Question 1, propose a reason why this was the case.

Did you know? 3.7

Red or blue?

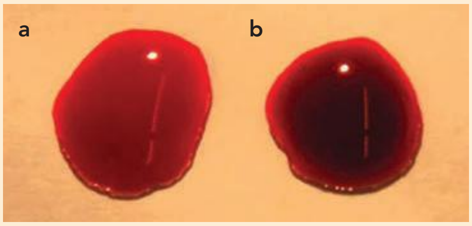

Figure 3.44 (a) Bright-red oxygenated blood and **(b)** darker deoxygenated blood

When you look at your wrist, you might be tempted to think that your veins are blue or green, depending on your skin tone. The light passing through our skin makes our veins look blue or green, but this is just an illusion! The appearance of blue or green veins is due to the interaction of light with the veins and the layers of skin above them. The colours you perceive are determined by the wavelength of light that reaches your eye. Different layers of skin cause the wavelengths to scatter in various ways. In individuals with darker skin tones, veins often appear green, rather than the blue seen in individuals with lighter skin tones. This is because green and blue light have shorter wavelengths compared to red light. Red light can penetrate human tissue better than blue light. As a result, our skin absorbs red wavelengths, while green and blue wavelengths are reflected and scattered back to us, contributing to the colour we observe in veins.

Blue veins are particularly noticeable on very pale skin and may have caused the expression 'blue blood' when talking about royalty in some European countries. In the eighteenth century, light-skinned nobility were untanned as they did no manual labour outside, and so their veins would have appeared very blue.

Your veins contain deoxygenated blood (lower levels of oxygen), which is still red, just a darker shade. Some diagrams use blue and red to distinguish deoxygenated blood from oxygenated blood. It is important to remember our blood is always red.

Quick check 3.8

1. **Name** the four chambers of the heart.
2. **Name** two structures in the heart's conduction system.
3. For each of the vessels listed below, **state** whether it carries oxygenated or deoxygenated blood.
   a) vena cava
   b) pulmonary artery
   c) pulmonary vein
   d) aorta

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Practical 3.5

Sheep heart dissection

Aim

To identify the path of blood flow through the heart and become familiar with the structures

Materials

- lamb heart, preferably with aorta and vena cava attached
- dissecting scissors
- disposable gloves
- two blue and two red pipe cleaners (or straws)
- wash bottle
- dissecting tray

Method

1. Place the heart on the dissecting tray and identify the front (anterior) and back (posterior).
2. Before cutting into the heart, identify:
    - the vena cava – Place a blue pipe cleaner into the vena cava (representing deoxygenated blood).
    - aorta – Place a red pipe cleaner into the aorta (representing oxygenated blood).
    - pulmonary artery – Place a blue pipe cleaner here (representing deoxygenated blood. Note that this connects to the same side as the vena cava).
    - pulmonary vein – Place a red pipe cleaner here (representing oxygenated blood. Note that this connects to the same side as the aorta).
    - right/left side (Remember, these will be opposite – your left and right).
3. Place your finger into the vena cava and then into the aorta. Notice the difference in strength and thickness of the walls of the blood vessels.

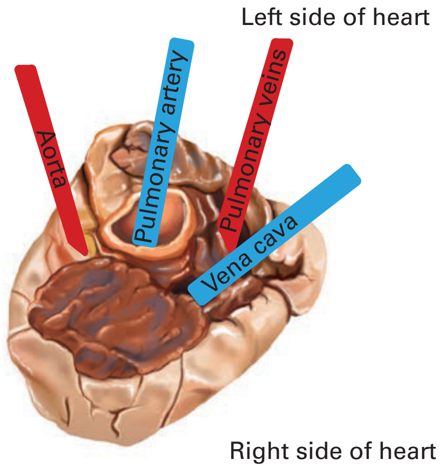

Figure 3.45 Diagram of where you will place the pipe cleaners in the lamb heart

Right atrium

4. To open the right side of the heart, place the dissecting scissors into the vena cava and cut down the wall of the heart, stopping about a quarter of the way down the heart.
5. Open the atrium chamber and locate the valve joining the right atrium to the right ventricle.
6. Using water from a wash bottle, fill the right ventricle through the valve.
7. Gently squeeze the heart and observe as the water moves up and tries to re-enter the atrium.

Right ventricle

8. Continue to cut down the same line you made earlier, to expose the right ventricle.
9. Locate the 'heart strings' within the ventricle.

Left side of the heart

10. Repeat the process above to expose the left side of the heart.
11. Compare the thickness of the walls of the heart on the left and right sides.

Discussion: Analysis

1. Identify which chambers of the heart receive the blood and which pump the blood.
2. Describe the action of the valves in the heart.
3. Compare the wall thickness of the right and left sides of the heart. Suggest a reason why they differ.
4. Describe how the vena cava and aorta felt on your finger.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Science as a human endeavour 3.3

Robot surgeons

Angioplasty is a medical procedure used to treat narrow or blocked arteries, especially those that supply blood to the heart. Coronary angioplasty aims to improve blood flow to the heart and reduce the symptoms of conditions such as angina (chest pain) or a heart attack.

During an angioplasty, a thin, flexible tube called a catheter is inserted into an artery, usually in the groin or arm, and guided to the site of the blockage. A small balloon at the tip of the catheter is then inflated to compress plaque (fatty deposits) against the walls of the artery and widen the opening. In some cases, a small device called a stent may also be inserted to help keep the artery open.

During the procedure, X-ray imaging is often used to guide the catheter to the site of the blockage and to monitor the progress of the procedure. X-ray imaging uses ionising radiation, which can be harmful if a person is exposed to high doses over time. The radiation exposure during angioplasty is relatively low, but it can add up over time for doctors and other medical personnel who perform many procedures. To minimise their exposure to radiation, medical staff usually wear protective clothing, such as lead aprons and thyroid collars, to shield their bodies from the radiation.

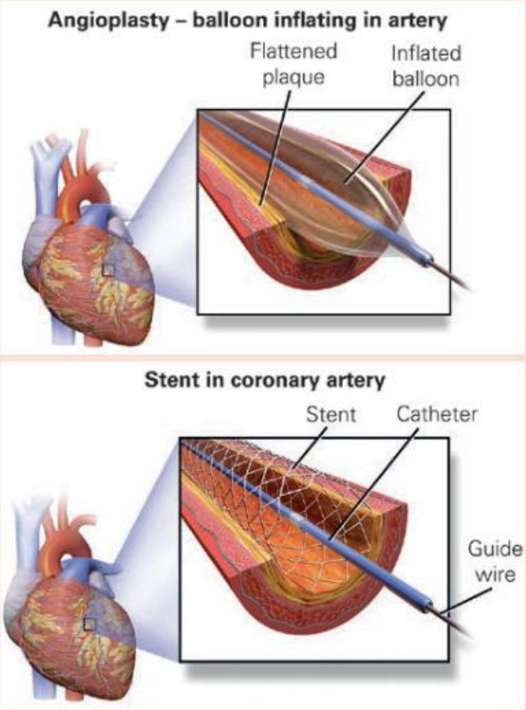

Figure 3.46 Angioplasty procedures

However, robots are now being used to perform coronary angioplasties. Medical staff can work from a control station shielded against radiation and use joysticks to remotely control the devices needed for the procedure, such as guidewires, balloons and stents. In addition to reducing exposure to radiation, staff do not need to wear heavy lead protective gear during the procedure.

Robot angioplasties have improved the navigation and accuracy of balloon and stent placement due to the millimetre precision of the robotic controls.

Vessels of the circulatory system

There are three main types of blood vessels in the body: arteries, veins and capillaries.

Arteries

artery
a thick, muscular elastic vessel that carries blood away from the heart

Arteries take blood away from the heart. They carry oxygenated blood to all the cells of the body, with one exception: the pulmonary artery, which carries deoxygenated blood to the lungs. The blood in arteries is pumped out of the heart with a lot of force, and this means that the artery walls must be thick, elastic, muscular and strong to withstand the pressure being placed upon them.

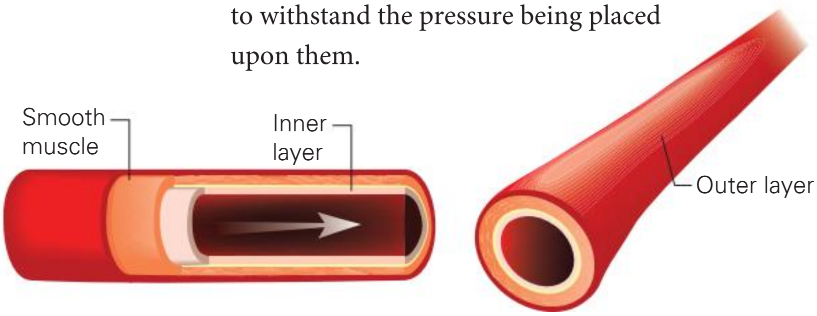

Figure 3.47 The structure of an artery

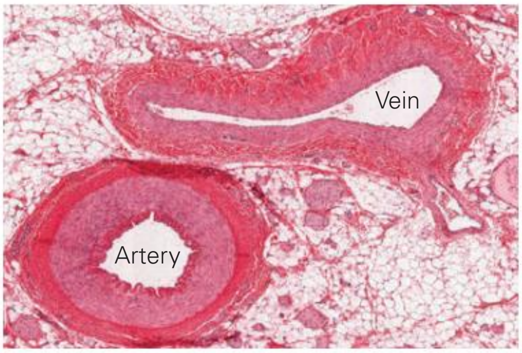

Figure 3.48 An artery and a vein in a cross-section of tissue viewed under a microscope. Note that the wall of the artery is thicker than that of the vein.

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Capillaries

As the blood travels away from the heart in the arteries, it enters smaller and smaller blood vessels, eventually reaching the capillaries. Just like the alveoli in the lungs, all other tissues in the body are surrounded by a network of tiny capillaries that allow nutrients and gases to be delivered to cells while removing waste. The walls of capillaries are extremely thin, only one cell thick, to allow nutrients and gases to pass into the tissues.

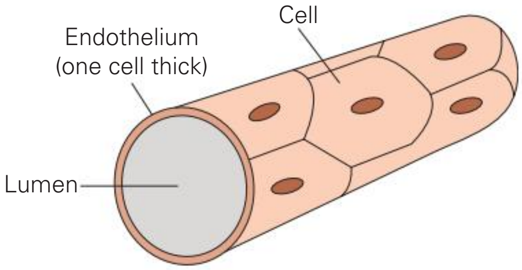

Figure 3.49 The structure of a capillary

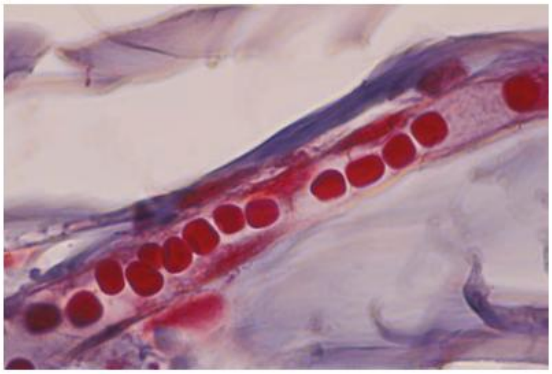

Figure 3.50 A capillary is only slightly wider in diameter than a red blood cell.

Veins

After delivering oxygen to cells, the deoxygenated blood must return to the heart in order to be sent to the lungs. As blood travels away from the body tissues and back towards the heart, it moves from the capillaries into the **veins**. At this point in the cycle, the blood is under much less pressure and so the vein walls do not need to be as thick and muscular as artery walls. Blood returns to the heart with the help of muscle contractions. However, the veins need to prevent blood from flowing backwards, and so they have special **valves** that prevent this from happening.

vein
a thin-walled vessel with valves that carries blood back to the heart

valve
a structure that prevents the backward flow of blood

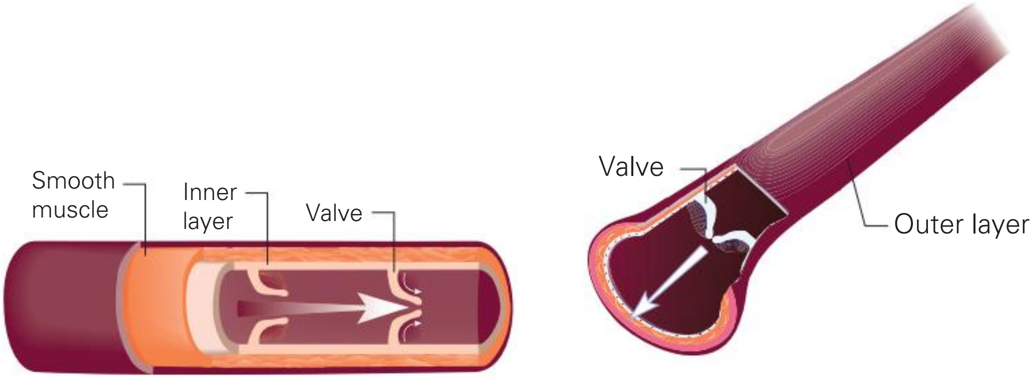

Figure 3.51 The structure of a vein

Quick check 3.9

1. **State** the vessel type that matches each feature listed below.
   - a) thick, muscular walls
   - b) diameter one cell wide
   - c) valves to prevent backflow of blood
   - d) carry oxygenated blood (except for the pulmonary vessel)
2. **Explain** why arteries carry blood at high pressure.
3. **Explain** why capillaries need to be one cell thick.

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Did you know? 3.8

Bruises

Bruises occur when an impact breaks the capillaries under the skin. As the trapped haemoglobin in the red blood cells breaks down, it changes colour, leading to the colour changes you see in bruises over a couple of weeks.

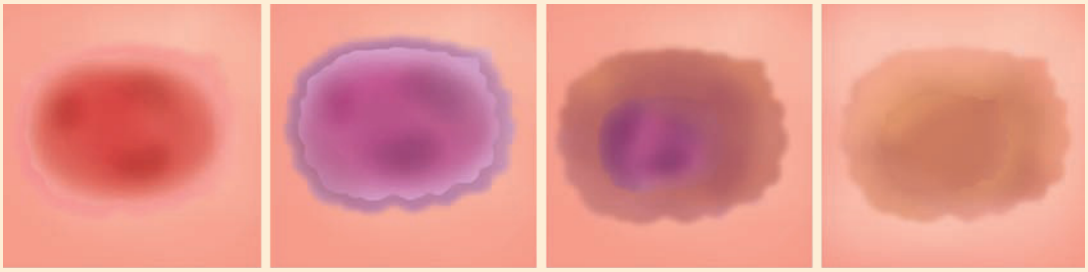

Figure 3.52 From left to right, a stage 1 bruise is red; a stage 2 bruise is purple. At stage 3 it becomes blue, and at stage 4 it becomes more yellow.

Blood

The human circulatory system is structured around a pumping heart and connected vessels, but the third part is the tissue that is actually circulated: blood.

You have around five litres of blood circulating around your body all the time. This blood contains dissolved nutrients, gases and several types of cells.

plasma the yellow liquid component that makes up 55% of blood; it carries water, dissolved gases, hormones and other proteins

Most of your blood is made up of a liquid called **plasma** (see Figure 3.53). Plasma is yellowish in colour, made up mainly of water and contains all the dissolved nutrients and hormones that are travelling to the tissues around your body.

Figure 3.53 Blood plasma

The second-largest component of blood is the red blood cells. These cells contain a molecule called haemoglobin, which gives blood its red colour. Haemoglobin molecules contain iron and can bind with oxygen molecules. Red blood cells are unusual, as they do not have a nucleus. This gives them more space for haemoglobin, which allows them to carry more oxygen molecules. The biconcave shape provides a greater surface area for gas exchange and allows the cells to be extremely flexible so that they can fit through small capillaries easily.

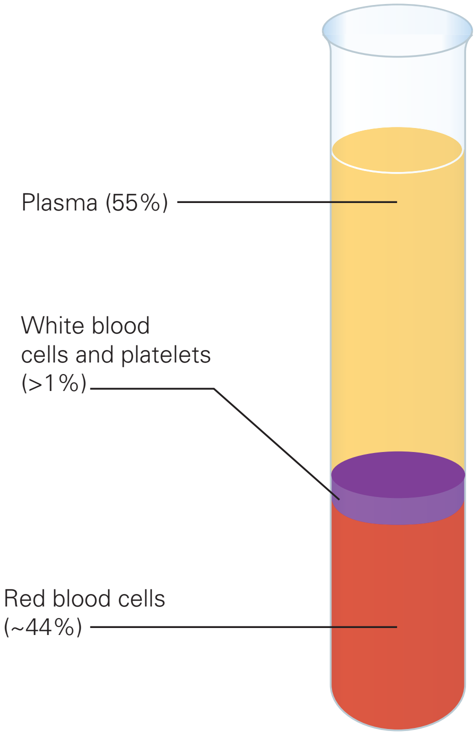

Figure 3.54 The components of blood, separated into layers using a centrifuge

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Explore! 3.6

Circulatory system technologies

There are several surgical procedures and devices that can assist people who have malfunctioning hearts, such as when a hardening of the arteries leads to poor circulation or heart disease. Choose one or more of the following to research and answer the questions below.

- automatic external defibrillators
- implanted pacemakers
- mitral valve replacements

1. How does this device or technique work?
2. What problems of the heart does it assist with?

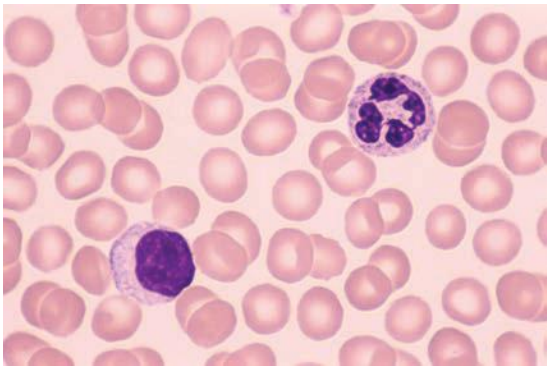

Figure 3.55 An image of a human blood sample. A white blood cell is easily identified due to its size and presence of a nucleus (the nucleus appears dark purple due to a stain being added to the sample). The red blood cells do not have a nucleus and are smaller in size. Their biconcave shape is indicated by the thinner, transparent centre.

White blood cells make up about one per cent of the overall volume of blood. This varies depending on whether you are sick, because white blood cells are part of the immune system. White blood cells are generally much bigger than red blood cells. They help the body fight infection by foreign organisms, by engulfing these organisms and breaking them down or by producing special molecules known as antibodies to destroy the invaders.

Another component of your blood is **platelets**. These tiny cell fragments help blood to clot and help scabs form. Platelets are much smaller than red blood cells. If platelets encounter any punctures along the blood vessels, they become activated and change shape. They then bind to a thread-like protein called fibrin and form a plug. This allows them to seal the puncture (Figure 3.58). If your body has too few platelets, then you won't be able to stop bleeding if you have an injury. On the other hand, if you have too many platelets, clots can form inside the blood vessels and stop the blood from flowing properly. These internal clots can lead to heart attacks or strokes.

platelets tiny cell fragments that assist with blood clotting

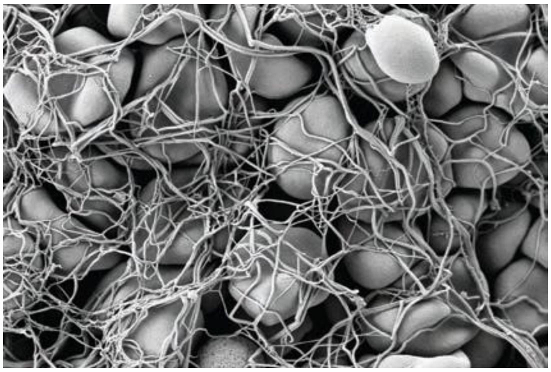

Figure 3.56 Red blood cells trapped in fibrin threads

Figure 3.57 Platelets help a scab to form over a wound

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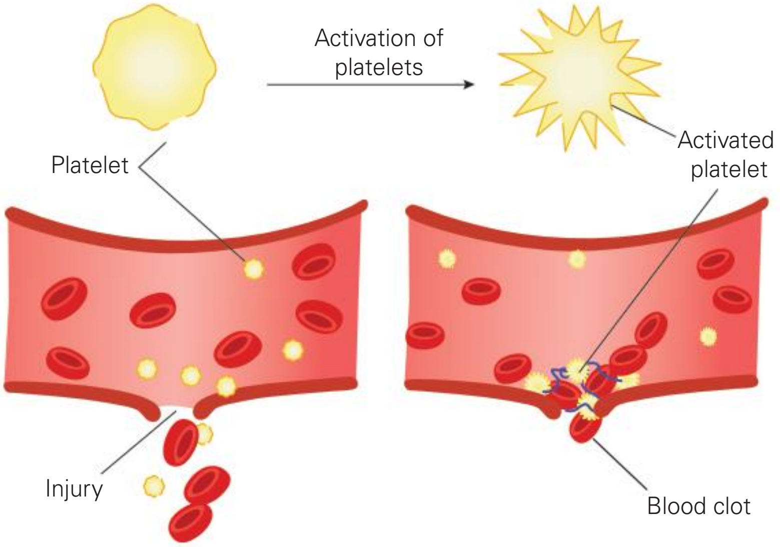

Figure 3.58 Platelets in the blood, sealing a hole in a blood vessel

Did you know? 3.9

Changing blood composition

The composition of your blood can change depending on many environmental factors. At higher altitudes there is less air, and so there is less available oxygen. People who live at higher altitudes have more red blood cells to cope with this. If you were to go and live on the top of a mountain, after about a week your blood would have adjusted too.

Quick check 3.10

1. On average, **recall** how much blood is in your body.
2. **Name** three components found in the blood and state their approximate percentage composition in the blood.
3. **Recall** what is contained in the plasma.

Explore 3.7

Circulation in plants

Like humans, plants need to move substances from one part to another. The xylem and phloem are specialised vessels in the plant that do this. They are similar to our blood vessels in their role but have some key differences. The xylem is responsible for transporting water and minerals from roots to leaves. So, like our arteries and veins, it only moves substances in one direction throughout the organism. The phloem, however, transports food from the leaves to all other parts of the plant and facilitates the flow of liquid in two directions. Use an online interactive tool, such as the *SAPS Transport of Water and Sugar in Plants* animation, to explore the plant vascular system.

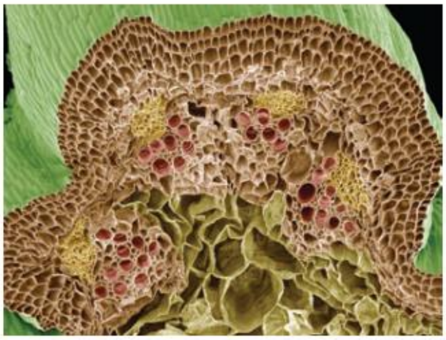

Figure 3.59 A scanning electron micrograph of a plant stem showing xylem vessels in pink and phloem vessels in yellow

Go online to access the interactive section review and more!

Section 3.4 review

Online quiz	Section questions	Teachers can assign tasks and track results

Section 3.4 questions

Remembering

1. **State** the function of the heart.
2. **Recall** how many times a healthy human heart beats per minute.
3. **State** the components of blood.
4. **Name** the smallest type of blood vessel.

Understanding

5. **Explain** how heart muscle is different from a muscle in your arm.
6. **Explain** the function of a platelet.
7. **Explain** how the structure of a capillary allows it to exchange nutrients and gases with cells.

Applying

8. **Identify** the point in your circulatory system where your blood pressure would be highest.
9. **Identify** the point in your circulatory system where your blood pressure would be lowest.
10. The image in Figure 3.60 is an ECG readout of a person's heartbeat. The ECG machine captures the electrical signals of the heart. The section between the arrows represents one full cardiac cycle (heartbeat + refilling stage). If the person's heart rate is 120 beats per minute, **calculate** how much time this full cycle takes.

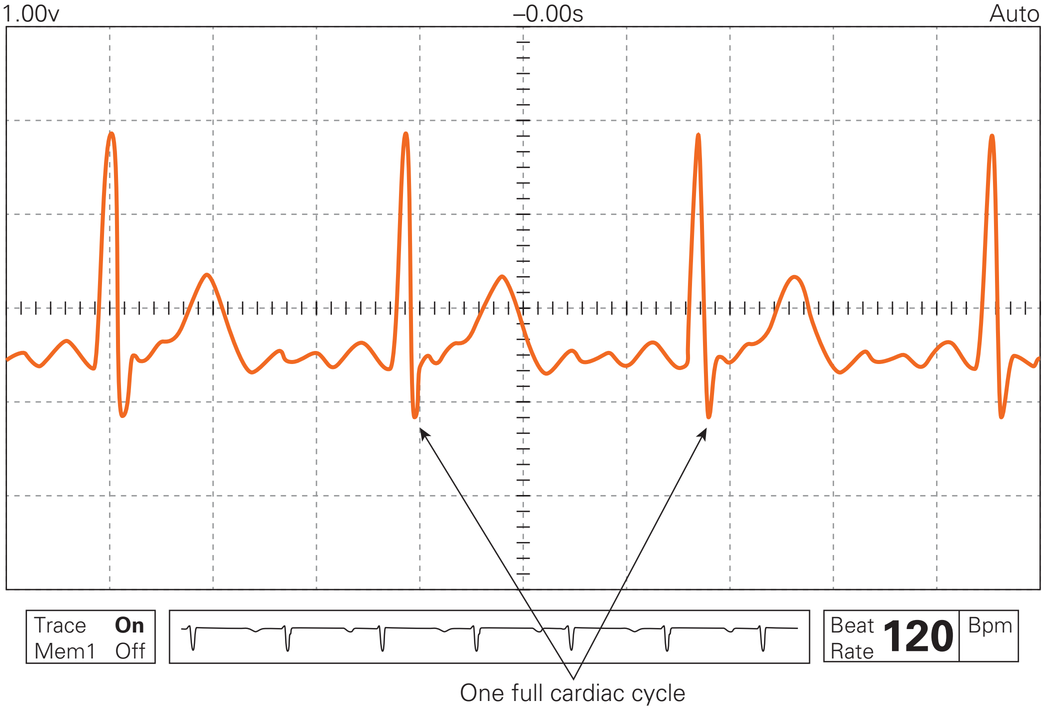

Figure 3.60 ECG printout of a person's heartbeat

Analysing

11. A baby is diagnosed with 'patent foramen ovale', a condition distinguished by a hole in the wall of the heart, between the left and right atria. **Infer** what effect this hole would have on the blood that is being pumped out the aorta.

Evaluating

12. **Construct** a flow chart showing the path of an oxygen molecule, from when it diffuses from an alveolus into a capillary, until it reaches a muscle cell in your leg.
13. **Propose** a problem that would be faced by someone who has too few platelets in their blood.

Available online in the Interactive Textbook:
Section 3.5 The human digestive system
Section 3.6 Other digestive systems

3.5 The human digestive system

WORKSHEET
Human digestive system

Learning goal

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

1. Describe the structure of each organ in the digestive system and relate its function to the overall function of the system.

The nutrients we need

heterotroph
any organism that obtains its nutrients by consuming other organisms

Humans are **heterotrophs**, which means we cannot produce our own food as plants can. We need to obtain nutrients from the environment around us by eating other organisms. The types of nutrients that humans need can be grouped into four main categories:

- carbohydrates – the main source of energy in the human diet. Bread, pasta, rice and oats are all great sources of carbohydrates. The simplest carbohydrate is glucose.
- proteins – the building blocks of life and the main structural component of most of the living parts of your body. Proteins are needed for growth and repair. Meat, cheese, eggs, seeds, nuts and legumes are great sources of protein.
- lipids – also called fats and oils. Fats transport some vitamins around our bodies, are a good energy source and help protect the delicate organs inside our bodies from shock or impact.
- vitamins and minerals – essential for the efficient functioning of our body. There are many vitamins and minerals that we can't make ourselves, so we must consume them in the food we eat.

Did you know? 3.10

Where does vitamin C come from?

Vitamin C helps the body to absorb more iron, which is required for oxygen-carrying haemoglobin in the blood. It also aids in the production of collagen, which helps heal cuts in your skin.

Figure 3.61 All citrus fruits have a high level of vitamin C.

You would get most of your vitamin C from red, yellow and orange fruits and vegetables. One of the richest natural sources of vitamin C is gubinge (also known as Kakadu plum), a fruit native to northern Australia. Gubinge has the highest recorded levels of vitamin C in any fruit, far exceeding oranges. Aboriginal Peoples use it as both a food source and medicine for its powerful nutritional and healing properties.

Quick check 3.11

1. **Recall** the simplest carbohydrate.
2. **Recall** another name for lipids.
3. **Name** some sources of protein.

Parts of the human digestive system

The role of the digestive system is to acquire all the nutrients the body needs. Food is broken down into its smallest components by chemical and mechanical digestion, and the nutrients are absorbed into your bloodstream and transported to the cells that need them.

Mechanical digestion involves physical changes – that is, physically breaking food into smaller components but not changing the chemical structure of the food. Examples include breaking food apart with your teeth and tongue when you chew, and the churning of your stomach.

Chemical digestion involves chemical changes that occur when enzymes break the food down into its most basic chemical components.

The human digestive system is a long, continuous tube from your mouth to your anus. Let us take a closer look at the structure and function of this vital organ system.

mechanical digestion
a series of mechanical processes that break food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

chemical digestion
a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

bolus
a lump of partially digested food

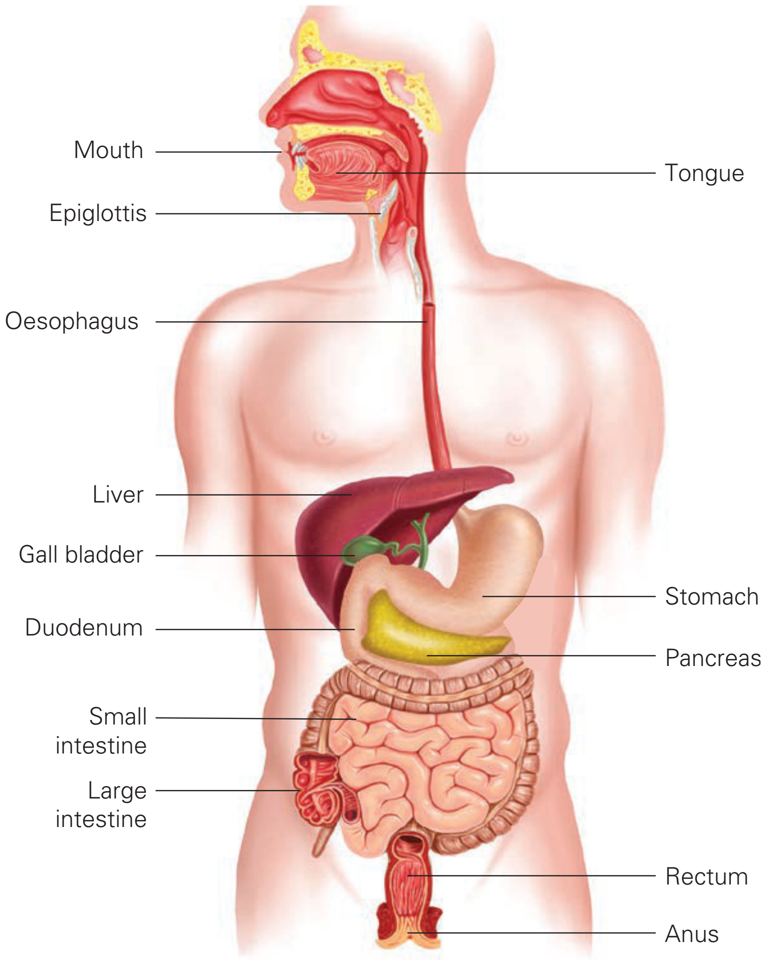

Figure 3.62 The human digestive system

Mouth and tongue

The mouth has many specialised structures that start the digestive process. First, your teeth cut, tear and grind the food, breaking it into smaller pieces. This increases the surface area of the food, which helps with chemical digestion later. The tongue moves the chewed food around the mouth and coats it in saliva. It forms a lump of partially broken-down food, called a **bolus**.

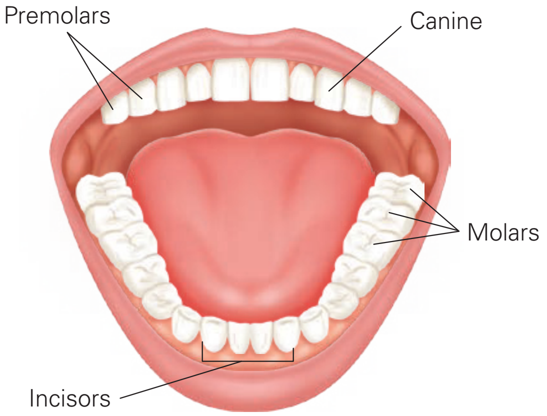

Figure 3.63 Adults have different kinds of teeth: incisors for cutting, canines for tearing and molars for grinding

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Did you know? 3.11

Taste buds

The average person's tongue is around 8.5 cm long and has 2000–4000 taste buds on it. A quarter of the population has 4000 taste buds and therefore a superior sense of taste. Your taste for certain foods can change throughout your life, because as you age you lose some taste buds and your sense of smell decreases, meaning that you become less sensitive to food. As a teenager, your sense of smell and taste are much stronger than an adult's.

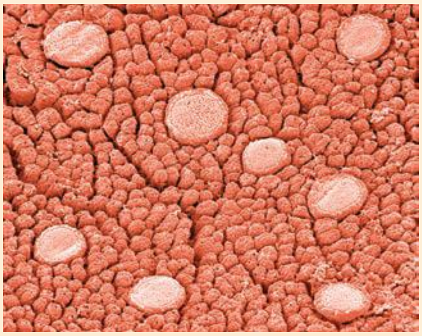

Figure 3.64 The surface of the tongue is covered with a mucous membrane and is also covered with tiny bumps called papillae. The papillae contain taste buds, which are responsible for detecting different tastes, such as sweet, sour, salty, bitter and umami.

saliva
liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

enzyme
a protein that can speed up chemical reactions in living organisms

peristalsis
a wave-like contraction of the muscles of the digestive tract that pushes the food along

Saliva lubricates the food to make its movement through your body smoother. It also has a role in chemical digestion because it contains special proteins, called **enzymes**, that begin to break down the food at a molecular level.

The main enzyme found in your saliva is called *amylase*, and it begins to break down carbohydrates, such as starch, into a simple sugar called maltose in your mouth. Many more enzymes are found along the digestive tract, and each is designed to break down a particular food type. Foods high in starch include bread, potatoes and pasta.

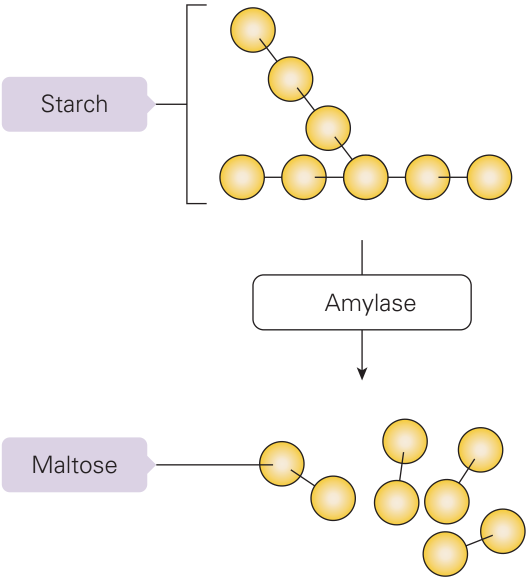

Figure 3.65 Amylase breaks the bonds in starch to form smaller maltose molecules.

Try this 3.8

Thanks, enzymes!

Place a small piece of bread or a dry savoury cracker on your tongue and leave it to sit there for a while. As the amylase in your saliva begins to break down the carbohydrates, you should be able to taste the sweeter maltose subunits.

Oesophagus

The oesophagus is a muscular tube that connects the throat to the stomach. When you swallow food, a wave-like contraction of the muscles in your oesophagus pushes the food down towards your stomach. This movement is known as **peristalsis**, and it continues all the way along your digestive tract to constantly keep the food moving along (see Figure 3.66). Peristalsis is so effective that you could eat upside down and the food would still be pushed against gravity, up your oesophagus!

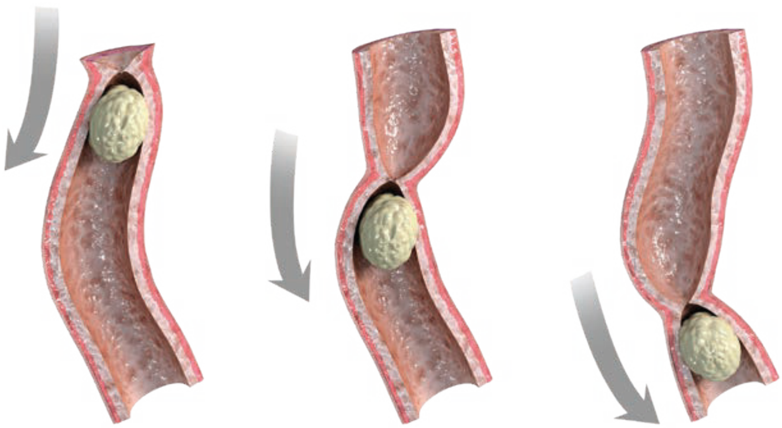

Figure 3.66 Peristalsis moves the bolus of food down the oesophagus.

VIDEO
Peristalsis

Try this 3.9

Modelling peristalsis

Find an old nylon stocking and cut off the toe end of the leg. Place a tennis ball at the toe end and gently squeeze behind the tennis ball, to move it along the length of the stocking. This is how the muscles of the oesophagus push a bolus of food along.

Quick check 3.12

1. **Describe** the function of saliva.
2. **Name** the enzyme found in saliva.
3. **Recall** the number of taste buds that an average person has.
4. **State** if chewing food is an example of mechanical or chemical digestion.
5. **Define** ‘peristalsis’.

Stomach

At the bottom of your oesophagus is a **sphincter** that opens to allow food to enter your stomach. The stomach contains many types of enzymes, along with very strong hydrochloric acid – together, these are known as the gastric juices. The sphincter at the opening of the stomach is very important, as it prevents these enzymes and acid from entering the oesophagus and irritating the tube. This irritation causes a burning sensation in the chest that is commonly known as ‘heartburn’.

sphincter
a muscle that surrounds an opening in the body and can tighten to close it, e.g. at the bottom of the oesophagus, leading into the stomach

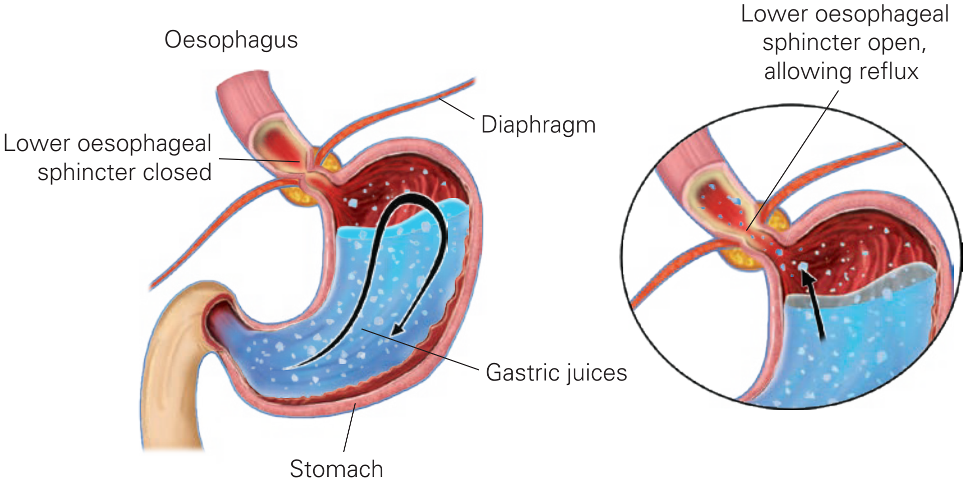

Figure 3.67 When the oesophageal sphincter fails to close, gastric juices can irritate the bottom of the oesophagus.

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Try this 3.10

How do antacids work?

Antacid tablets are taken during episodes of heartburn to try to neutralise some of the acid in the stomach. Let's observe how they work.

You will need the following: pH data logger and probe, 1 M hydrochloric acid, antacid tablets (such as Rennie®), 200 mL beaker, 3 mL pipette, mortar and pestle, distilled water.

Step 1 Crush one antacid tablet using the mortar and pestle. Place it in the beaker with 50 mL of distilled water and mix well.

Step 2 Measure the pH using the probe.

Step 3 After a minute, add around 1 mL of 1 M hydrochloric acid and monitor the change in pH. Stir the beaker regularly.

Food stays in your stomach for two to six hours, depending on the size, amount and type of food. During this time, the stomach contracts and churns the food (mechanical digestion), helping to further break up the large particles, while mixing the bolus with the gastric juices (chemical digestion). The acid in your stomach also performs some important functions: it kills many of the harmful bacteria that might be found on the food you eat and provides an optimum pH for digestive enzymes to work. The stomach wall is lined with a mucosal membrane, which produces mucus to protect the stomach tissue from the strong acid. Without this mucus, the acid is strong enough to digest the stomach itself!

The main enzyme in your gastric juices is called *pepsin*, and its role is to begin the digestion of protein. Each enzyme has a specific shape that fits only one type of molecule, and therefore each food type has a special enzyme dedicated to breaking it down in the body. For example, pepsin can only break down protein.

The stomach absorbs some substances into the bloodstream, such as water, medicines and alcohol. The digested bolus is now a liquid called **chyme**, and it leaves the stomach by passing through the pyloric sphincter, at the base of the stomach, into the small intestine.

chyme
a partially digested mass of food after it leaves the stomach

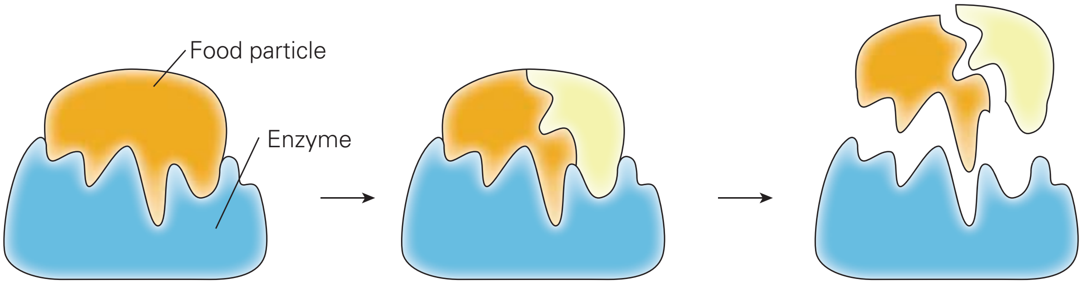

Figure 3.68 Each enzyme fits a specific type of molecule, like a key fitting a lock. An enzyme attaches itself to a food particle and speeds up the chemical reaction that breaks down the food particle, and then it releases the broken-down food particle.

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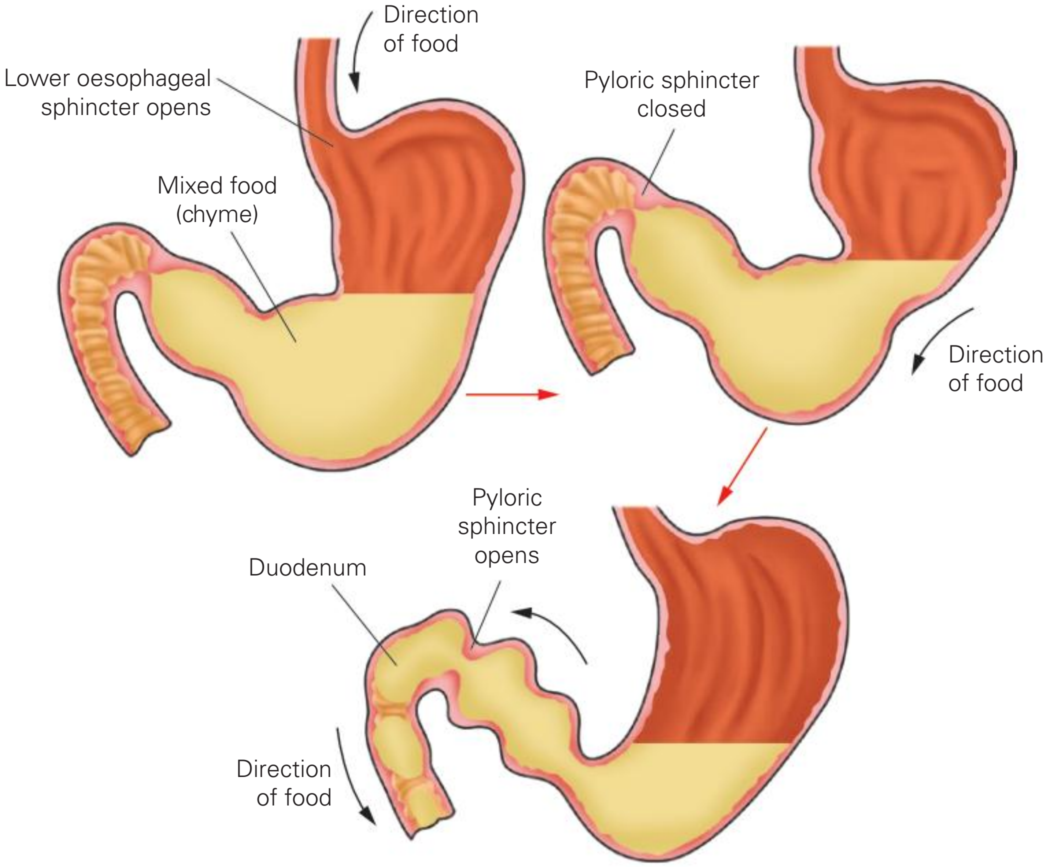

Figure 3.69 The pyloric sphincter controls the flow of chyme out of the stomach and into a region of the small intestine called the duodenum.

Quick check 3.13

1. **State** two sites of mechanical digestion.
2. **Define** ‘chyme’.
3. **Name** the enzyme that catalyses the digestion of protein.
4. **Explain** why the stomach wall is lined with mucus.

Practical 3.6

Investigating enzymes

Introduction

Gelatine is a protein that helps foods like jelly set. An enzyme found in pineapple called bromelain chemically digests gelatine, which is why when fresh pineapple is added to jelly, it will not set. Part of the canning process involves exposing the canned goods to high heat to kill any microorganisms in the food so it can have a longer shelf life.

Aim

To determine what conditions are needed for an enzyme to digest protein

Materials

- packet of jelly crystals
- boiling water to make up jelly
- large beaker to make up jelly
- 100 mL beakers × 4
- fresh pineapple
- boiled pineapple
- tinned pineapple

continued …

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Method

1. Label beakers 1–4.
2. Add a few pieces of fresh pineapple to beaker 1.
3. Make up the jelly according to the instructions on the packet.
4. Pour jelly into the beaker up to the 80 mL mark.
5. Repeat steps 2–4 with boiled pineapple in beaker 2 and tinned pineapple in beaker 3. Beaker 4 should contain only jelly.
6. Place beakers in the fridge to set overnight.
7. Copy the results table in your science book and record your observations.

Results

Table showing observations of gelatine reacting

Beaker	Observations
1	
2	
3	
4	

Discussion: Analysis

1. State in which beaker the jelly did not set and explain why.
2. Explain what happened to bromelain in the boiled and tinned pineapple.

Discussion: Evaluation

1. Describe the purpose of beaker 4.
2. Suggest one way this experiment could be improved to increase the reliability of the results.

Conclusion

1. Draw a conclusion from this experiment about the conditions that are needed for an enzyme to digest protein, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that _____________.

Small intestine, liver, gall bladder and pancreas

The small intestine is only called ‘small’ because it is narrower in diameter than the large intestine. It is actually very long, measuring, on average, nearly six metres. Because it is so long, the small intestine is divided into three main parts: **duodenum**, **jejunum** and **ileum**.

The duodenum is the first part of the small intestine. Many digestive enzymes are secreted into it, which help to continue digestion of the chyme. Peristalsis also occurs in the small intestine, and it propels the chyme forwards and continues all the way along the digestive tract.

The **liver** produces **bile**, which helps to mechanically break down fats or lipids. The bile is stored in the **gall bladder** and is excreted into the duodenum if you eat a fatty meal. Bile acts like a detergent – it emulsifies or breaks big globs of fats and oils into smaller ones that can be easily moved and broken down further. Bile has the second job of neutralising the acids from the stomach and preventing damage to the intestines. The **pancreas** secretes pancreatic juices, which also help to neutralise the acids from the stomach and contain more enzymes to keep chemically digesting the different food types.

Most of the nutrient absorption takes place in the middle section of the small intestine, the jejunum. This section is lined with millions of finger-like structures, called **villi**. These structures have a large surface area and a large blood supply, which increase the efficiency of nutrient absorption into the bloodstream.

duodenum
the first section of the small intestine where many enzymes are secreted

jejunum
the second section of the small intestine, where food breakdown and nutrient absorption occur

ileum
the third section of the small intestine, where further food breakdown and nutrient absorption occur

liver
a large organ that has many functions, including the production of bile

bile
a substance that helps break down fats; it is produced in the liver and stored in the gall bladder

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The end section of the small intestine is the ileum. The main function of this portion of the intestine is to finish off any absorption of nutrients and to compact the remaining digested food and pass it through into the large intestine.

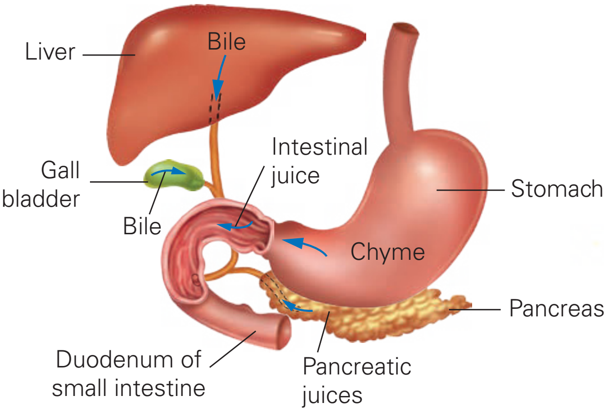

Figure 3.70 The liver, gall bladder and pancreas all contribute to the digestion of food and are connected to the duodenum.

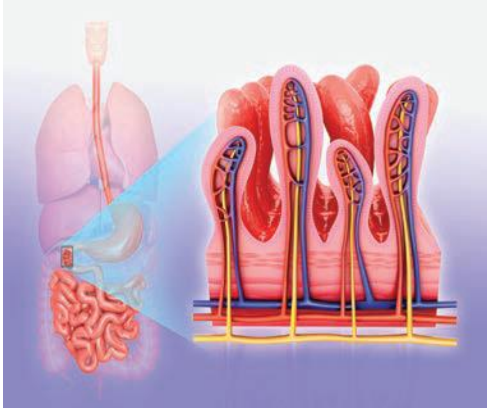

Figure 3.71 Finger-like villi in the intestines are specialised for absorption of nutrients.

Large intestine

The **large intestine** is one to two metres long and has five parts: caecum, appendix, colon, rectum and anus. Its main function is to absorb water from the material left over from digestion. The large intestine also has large numbers of helpful bacteria that can produce vitamin K and vitamin B for your body to use. In humans, the **caecum** is a pouch at the start of the large intestine, where it joins the small intestine. The caecum helps digest and absorb nutrients, especially plant materials, with the assistance of bacteria. The appendix has long been considered a useless organ that is a remnant of evolution, but there is ongoing debate about what its actual role is. As waste enters the large intestine and passes through the colon, water leaves the waste and is absorbed back into the bloodstream, resulting in a solid mass called faeces remaining in the colon. Faeces are stored in the **rectum**, and when the rectum is full, it sends a signal to your brain to tell you to go to the toilet. The faeces then pass out through a sphincter called the **anus**.

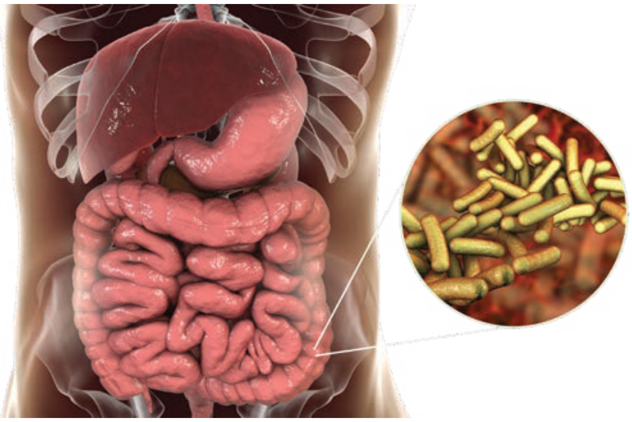

Figure 3.72 Most bacteria in your body are in the intestine. It is thought that the appendix could be a safe haven for good bacteria that can repopulate the gut after sickness and diarrhoea.

Figure 3.73 The five sections of the large intestine

gall bladder
a small organ near the liver that stores bile and secretes it into the duodenum

pancreas
an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

villi
finger-like structures in the digestive system that have a high surface area and rich blood supply for absorption of nutrients

large intestine
the organ that is connected to the small intestine at one end and ends with the anus at the other

caecum
a pouch that forms the first part of the large intestine

rectum
the second-last section of the large intestine; stores faeces

anus
the opening at the end of the digestive tract, through which solid waste leaves the body

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Explore! 3.8

A lot of you is not you!

The average person's body has around the same number of human cells as bacterial cells.

Until recently, it was thought that the number of bacteria in our bodies outnumbered our own cells 10:1. However, new research suggests that the average person is more likely to have a 1:1 ratio of bacteria and human cells. In any human body there are approximately 30 trillion human cells, but our microbiome is an estimated 39 trillion microbial cells that live on and in us. Despite only making up 1–3% of our body mass, they play an important role in our health and wellbeing.

Three quarters of the types of microbes in you can be traced back to your birth. The bacteria in the vaginal microbiome plays a key role in establishing the gut microbiome in newborns, and babies born via caesarean section are at increased risk of certain health problems later in life such as asthma, allergies and obesity.

Research the role that your microbiome plays in the following:

- digestion
- immune response
- metabolism
- mental health.

Figure 3.74 Faecal microbiota transplantation (FMT) is a medical procedure that involves the transfer of gut bacteria from a healthy donor's faeces to the gut of a person with a digestive or immune system disorder.

Quick check 3.14

1. **State** the three sections of the small intestine.
2. The liver produces bile, which is stored in the gall bladder. **Recall** the type of food that bile helps to mechanically digest.
3. **Explain** how villi improve the absorption of nutrients.
4. **Organise** the following sections of the large intestine in the correct order: rectum, colon, anus, caecum.

Did you know? 3.12

Is your stomach rumbling?

Ever heard those gurgling stomach noises when you are hungry? Well, they are the sounds of hyperactive peristalsis in the intestines and are named *borborygmi*. When the muscles in your stomach and small intestine are pushing everything along, all the food packed inside muffles the sound. But if it's been a while since you've eaten, most of that food is gone (hence why you equate it with being hungry!) and all those gurgling gases are easier to hear.

Did you know? 3.13

Gallstones

In some people, bile can harden into a pebble-like mass called a gallstone. Most people with gallstones don't even know they have them. However, when a gallstone blocks the bile duct, it can cause pain. The most common treatment for gallstones that cause painful symptoms is a cholecystectomy: surgery to remove the gallbladder. Humans can live a healthy life without a gallbladder; bile is secreted by the liver straight into the small intestine instead of being stored in the gallbladder first.

Digestion gone wrong

Food poisoning

Your body can detect hazardous substances in the food you eat. Sometimes food can be contaminated with toxins or microorganisms that could do harm to your body. If your body senses the presence of these harmful substances, it signals to your digestive system to empty quickly. This causes the stomach to contract violently, causing vomiting, and it also causes the intestines to contract, causing diarrhoea. Even though getting sick is never fun, it is your body's way of protecting you by removing the harmful substances.

Digestive disorders

Many people cannot eat certain foods because of **intolerance** or allergy. An intolerance is when a food cannot be properly broken down by the body and results in an adverse reaction.

intolerance an inability to eat a food without experiencing adverse effects

One of the most common intolerances in humans is lactose intolerance. Lactose-intolerant people are unable to digest the sugar in milk and dairy products, called lactose. Normally, when somebody eats food containing lactose, the enzyme *lactase* is released in the small intestine to break down the sugar into more simple sugars. People who are lactose intolerant do not have lactase, and this means that the sugars do not get digested and absorbed. Instead, the bacteria in the intestines break down these sugars, leading to bloating, lots of gas and diarrhoea.

Because humans are mammals, we all drink milk as infants. This means that the enzyme lactase, which breaks down lactose, is found in everybody when we are young. As we grow older and start to eat solid foods, some of us may lose the lactase enzyme. Anyone can become lactose intolerant at any stage in their life, although there are certain groups of people who are more likely to become lactose intolerant. Some examples:

- People who already have problems with their digestive system caused by disorders such as coeliac disease or Crohn's disease are more likely to develop lactose intolerance.
- Certain antibiotics can trigger temporary lactose intolerance by interfering with the intestine's ability to produce the lactase enzyme.
- As people get older, their bodies can stop producing lactase.
- If you go for a long period of time without eating dairy, your body may stop producing lactase.

Figure 3.75 All mammals produce milk, but not all adult humans can digest it.

Explore! 3.9

Coeliac disease

Coeliac disease is a condition where a person's immune system damages the lining of the small intestine when they eat gluten.

Gluten is a protein in wheat, rye and barley-based products such as bread, pasta, pastry, cakes and biscuits. Bread has been a stable part of the human diet for thousands of years, and so many people view gluten intolerance and coeliac disease as new phenomena, but humans have been affected by these conditions throughout history. However, it was not until about 100 years ago that doctors began to diagnose and treat coeliac disease.

In coeliac disease, the immune response to gluten causes inflammation that damages the villi, making them blunted or flattened. This leads to a decrease in the surface area available for absorption of nutrients, which can result in malabsorption and malnutrition.

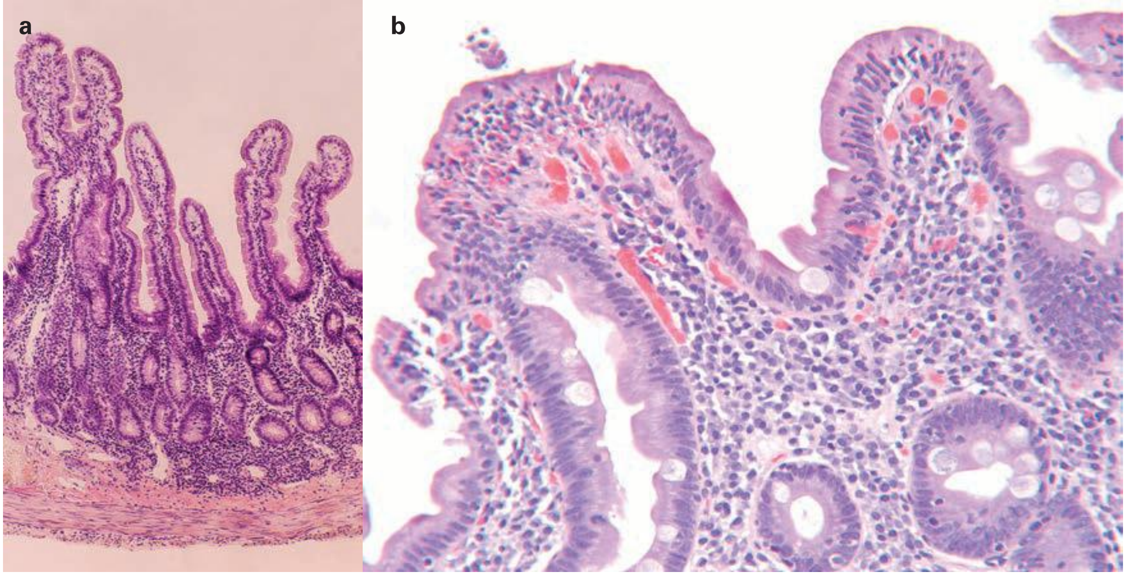

Figure 3.76 **(a)** Villi in the small intestine of a healthy person compared with **(b)** blunted villi in a person with coeliac disease.

1. Find out how many people suffer from coeliac disease and how many people have gluten intolerance. You may like to find out the statistics for the world or investigate different countries.
2. Outline the symptoms of coeliac disease.
3. Research and then summarise what it is about gluten that makes people sick. Include an explanation of how the body of a person living with coeliac disease responds to gluten.

Science as a human endeavour 3.4

Seeing you from the inside

Capsule endoscopy is a medical procedure that involves swallowing a small camera-equipped capsule that captures images of the digestive system. The capsule travels through the digestive tract and transmits real-time images to a recording device worn by the patient. This procedure allows doctors to visually examine the interior of the small intestine, which is otherwise difficult to access using traditional endoscopic techniques.

Capsule endoscopy is used to diagnose and monitor conditions such as Crohn's disease, ulcerative colitis, bleeding in the small intestine and unexplained abdominal pain. It is a non-invasive, painless and well-tolerated procedure for most patients and provides a valuable tool for the diagnosis and treatment of a range of gastrointestinal conditions.

Figure 3.77 Camera capsules used to examine the oesophagus (left), small intestine (middle) and large intestine (right).

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Section 3.5 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 3.5 questions

Remembering

1. **State** the food group that glucose belongs to.
2. **Recall** the route that food takes after it leaves the stomach. List the three sections of the small intestine and the five sections of the large intestine it passes through.
3. **State** the function of the tongue in digestion.
4. **Name** the type of acid that is found in the human stomach.

Understanding

5. **Describe** the role of the stomach in food digestion.
6. **Explain** how the structure of villi assists in the absorption of nutrients.
7. **Explain** how food is transported along the digestive tract.

Applying

8. A friend who is coming to your house for dinner is living with coeliac disease and lactose intolerance. **Describe** a meal you could cook that would be suitable for this friend.

Analysing

9. **Contrast** the duodenum and the jejunum.
10. **Classify** the processes listed in the table as mechanical or chemical digestion.

Process	Mechanical or chemical?
Stomach churning and contracting	
Chewing food	
Bile released from gall bladder into duodenum to break down fats	
Lactase breaking down lactose	

Evaluating

11. Certain nutritional deficiencies in the body can be linked to damaged digestive organs. **Predict** what deficiencies could be linked to a damaged large intestine.
12. **Propose** what might happen if the gall bladder was removed from the digestive tract.
13. Crohn's disease is a bowel condition that causes flare-ups of inflammation in the ileum, which leads to impaired nutrient absorption. It also causes inflammation of the large intestine. **Propose** what effect this might have on the faeces.

3.6 Other digestive systems

WORKSHEET
Comparing skeletal structure and diet

Learning goal

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

1. Compare the structure and function of analogous digestive systems in animals.

Have you ever had food poisoning after eating undercooked or old food? Food can make you sick when it contains too many bacteria for your body to deal with. But why does that happen to you while some scavenger animals can eat rotten meat and not get sick?

How is it that some animals eat only leaves and still manage to get all the protein, fats and iron they need to be healthy?

The answers to both these questions can be found in their specialised digestive systems.

Carnivores

The human digestive system is designed to process and break down both animal and plant products. However, unlike other animals, we cook our food, which reduces the number of harmful bacteria entering our digestive system.

carnivore
a consumer (heterotroph) that feeds on animal matter

herbivore
a consumer (heterotroph) that feeds on plant matter

omnivore
a consumer (heterotroph) that eats a variety of plant and animal matter

Carnivore and scavenger species, such as vultures, have traits that have evolved that allow them to eat food containing large amounts of bacteria without getting sick.

Digestive system length

Carnivores have a shorter digestive system compared to a **herbivore** or an **omnivore**. Animal cells do not have a cell wall like plants, which makes them easier to digest (cell walls contain cellulose, which is hard to digest). This means the food passes through the animal's digestive system quickly, and harmful bacteria have less chance to grow and cause illness.

Figure 3.78 A black vulture eating a dead wood stork

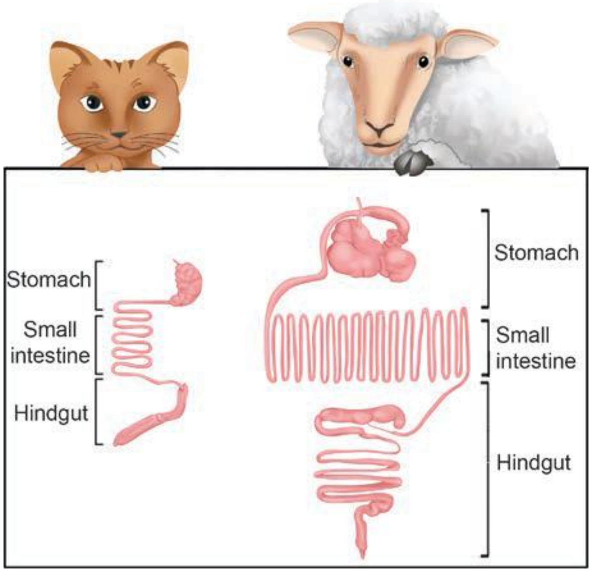

Figure 3.79 Cat (carnivore) and sheep (herbivore) digestive systems

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Stomach acid

The stomach acid in humans is around 1.0 to 3.5 on the pH scale. This is strongly acidic, allowing our bodies to kill many harmful microorganisms, but not all of them. In comparison, a vulture's digestive acid is 0–1 on the pH scale, which is strong enough to dissolve certain metals and so is more than a match for any bacteria.

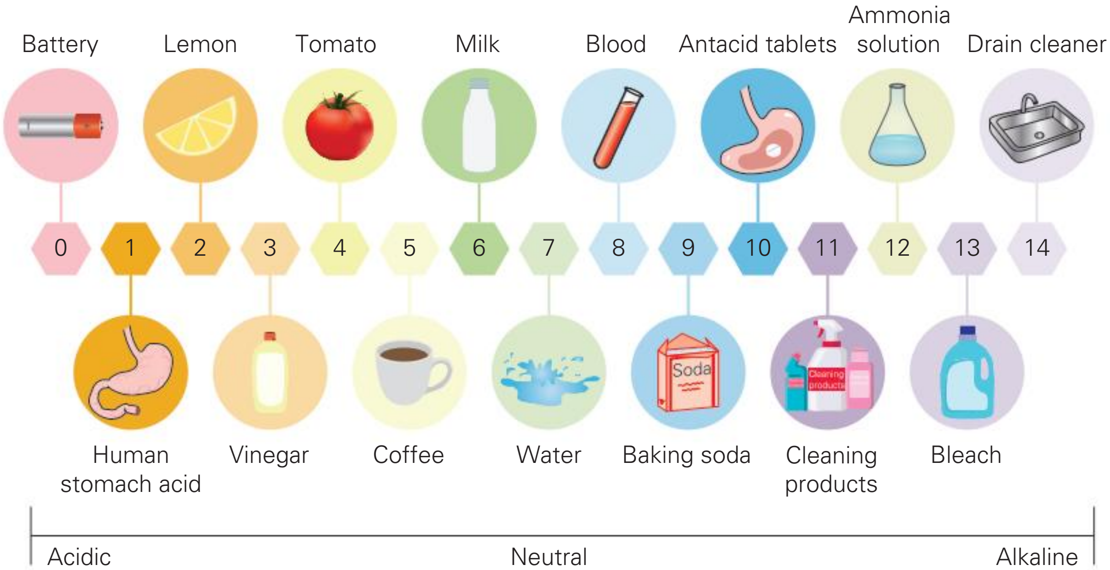

Figure 3.80 The pH scale shows the pH of common substances.

Did you know? 3.14

Pandas

Giant pandas are technically classified as carnivores due to the presence of carnivorous characteristics, such as sharp teeth, a gastrointestinal tract typical of carnivores and strong jaw muscles. They also do not have the genes for plant-digesting enzymes. Despite this, their diet is mainly bamboo, which makes up over 99% of their daily intake.

This means that pandas must consume large quantities of bamboo to extract sufficient nutrients from it. They spend most of their day eating and can consume up to 20 kg of bamboo every day. This is a challenge for their digestive system, as bamboo fibres are difficult to break down, leading to a slow and inefficient digestion process.

Figure 3.81 Despite eating bamboo, giant pandas have digestive systems that are better suited to eating meat.

It is still unclear what caused them to stop eating meat, but some scientists think it was due to an abundance of bamboo and a lack of available protein sources in their native habitat of central China. Other researchers have suggested that they stopped eating meat at the same time that their gene for the savoury umami taste receptor became inactive.

Quick check 3.15

1. **Contrast** the pH of a vulture's stomach acid with a human's.
2. **State** who has a shorter digestive tract: carnivores or herbivores.

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Explore! 3.10

VIDEO Carnivorous plants

Carnivorous plants

Not all plants rely on sunlight and water for their food. Some add meat to their diet to give them a nutrient boost. Most carnivorous plants live in swamps and marshes, where the soil doesn't have many nutrients, especially nitrogen, and so they rely on breaking down insects to absorb nutrients.

Find out about each of the following carnivorous plants and summarise how they catch their prey, the structures they have that allow them to catch their prey, and how they digest their prey.

1. Venus flytrap
2. Sundew
3. Pitcher plant

Figure 3.82 A Venus fly trap and an unsuspecting fly

Figure 3.83 A sundew wrapping around an insect

Figure 3.84 A pitcher plant and its possible prey

Herbivores

Eucalyptus leaves are toxic for humans. If you tried to eat some you could find yourself struggling to breathe, losing your balance and feeling dizzy. Leaves are also made of cellulose, which is not easy for humans (or carnivores) to digest and obtain nutrients from. So, it may seem surprising that eucalyptus leaves are the koala's primary source of nutrition.

Koalas are herbivores with adaptations that allow them to obtain the nutrients that they need from eucalyptus leaves. They have a long digestive tract and a very large caecum, around 200 cm long and 10 cm wide, where the cellulose in the cell walls can be digested. In herbivores, the caecum contains millions of helpful bacteria that are specialised to break down certain plant materials (such as eucalyptus leaves).

Figure 3.85 Grasses and roots make up most of a wombat's diet, but wombats will also feed on the young leaves of eucalyptus trees when available. Their long and slow-moving digestive tract allows them to extract the maximum amount of nutrients from the fibrous matter.

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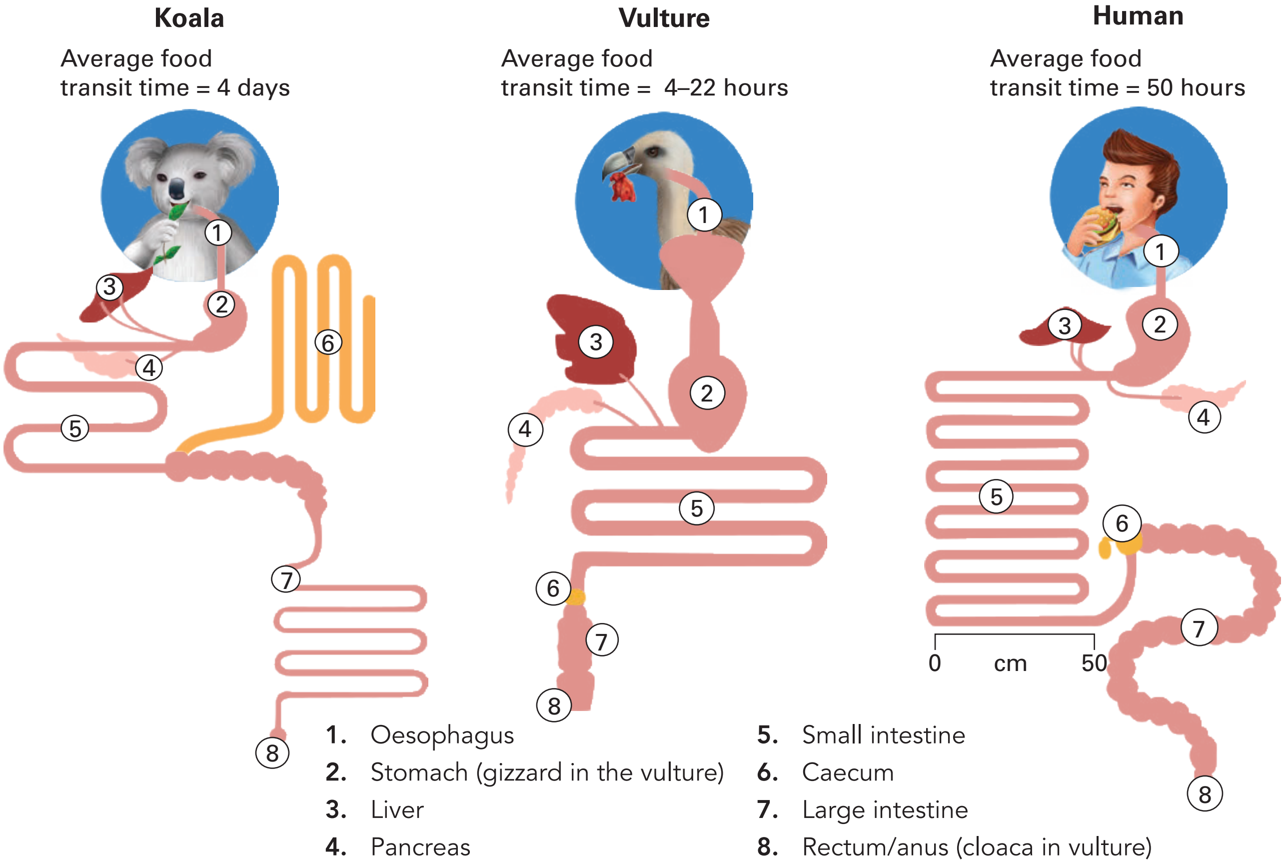

Figure 3.86 Digestive systems and food transit times for koalas, vultures and humans

Koalas get most of their water from the leaves they eat, so they rarely need to climb down from the tree they are living in to find water.

Eucalyptus leaves are very low in nutrients and so, even with a large caecum, koalas need to eat for five hours a day to get enough food to sustain them. They spend most of the rest of their day sleeping, to conserve energy and to allow their bodies to digest their food.

In total, it can take around four whole days for a leaf to pass through a koala's digestive system. This maximises the amount of nutrients and water that is absorbed from the food.

Did you know? 3.15

Koala faeces

Baby koalas are not born with the gut bacteria they need to digest eucalyptus leaves. They need to eat their mother's faeces (called pap) to start their own colony of bacteria in their caecum.

Figure 3.87 A mother and baby koala

Ruminants

Cows are herbivores, just like koalas, so they need to eat for most of the day to gain as much nutrition from their food as possible. Cows are in a special category of herbivores called *ruminants*. Ruminants, including antelope, sheep, buffalo and goats, digest their food in a unique way. Figure 3.88 shows the path of food through a ruminant.

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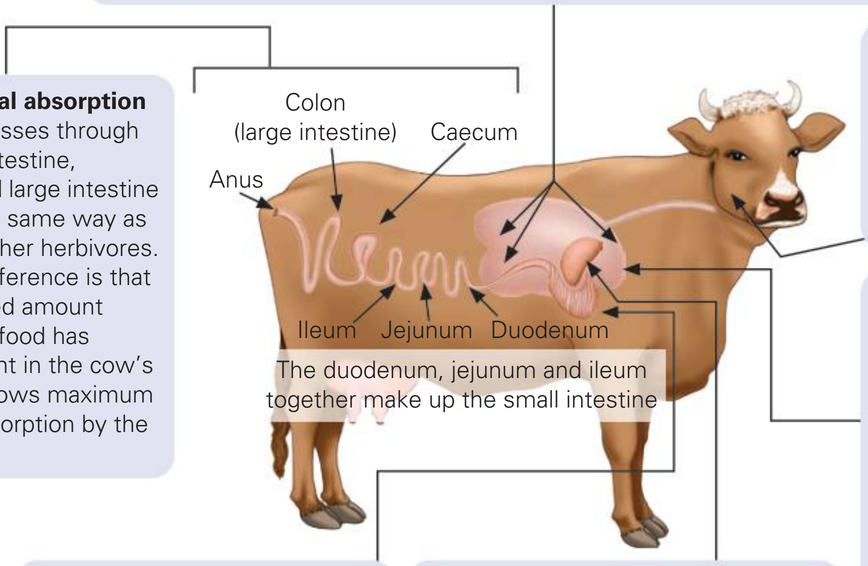
2 Stomach round 1
The grass passes into the largest part of the four-part stomach, called the rumen (this is where the term ‘ruminant’ comes from). The rumen, like the caecum, contains bacteria that digest cell walls.



1 First chewing
Cows graze on plants using their incisor teeth to snip leaves and then grind and chew their food using their molar teeth briefly before swallowing it for the first time.

6 Intestinal absorption
The food passes through the small intestine, caecum and large intestine in much the same way as it does in other herbivores. The only difference is that the extended amount of time the food has already spent in the cow’s stomach allows maximum nutrient absorption by the intestines.

3 Second, third and fourth chewing
Food from the rumen is regurgitated back up into the mouth, with the help of the second chamber of the stomach, called the reticulum. This process assists the bacteria in breaking the grass down ready to be digested. The regurgitated food is called ‘cud’. Cows ‘chew the cud’ for around 6–8 hours during times of the day when they are not grazing.

5 Stomach round 4
Finally, the food passes into the abomasum, or ‘proper stomach’, where enzymes and digestive juices start to properly digest and absorb the nutrients.

4 Stomach rounds 2 and 3
When the cud is sufficiently broken down, it passes into the third chamber of the stomach, called the omasum, where most of the excess water and saliva are absorbed.

Figure 3.88 The passage of food through a cow’s stomach

WIDGET
The mammalian digestive system

Quick check 3.16

1. **Summarise** the role of the caecum in herbivores.
2. **Distinguish** between the length of a carnivore and a herbivore digestive tract.
3. **Describe** the way a ruminant digests plant matter.

Try this 3.11

Digestive flow charts

Construct three flow charts on a poster showing the digestive tracts of a carnivore, a herbivore and a ruminant. Annotate the structures of the digestive tract, showing their specialised functions so that the key differences between these organisms are obvious.

Go online to access the interactive section review and more!

Section 3.6 review

Online quiz	Section questions	Teachers can assign tasks and track results

Section 3.6 questions

Remembering

1. **Recall** the parts of a herbivore’s digestive system.
2. **State** the number of chambers there are in the stomach of a cow.
3. **Name** the substance that plant cells contain, which is difficult for humans to digest and gain nutrients from.

4. **Identify** the words to correctly fill in the gaps: Acids have a ___________ pH and bases have a ___________ pH.
5. **Identify** the product in the stomach that kills bacteria.
6. **Identify** two ways in which a vulture's digestive system is different from a human's digestive system.

Understanding

7. **Explain** how a carnivore can eat meat containing harmful bacteria without becoming sick, while humans cannot.
8. **Describe** how baby koalas gain their gut bacteria.

Applying

9. **Explain** why food moves through the digestive system of a koala more slowly than in humans.
10. **Explain** how vultures are able to decrease the spread of infectious diseases in the areas they inhabit.

Analysing

11. Copy and complete the table to **contrast** the digestive system of a koala with that of a human.

Human	Koala

12. Use the images in Figure 3.89 to answer the following questions.

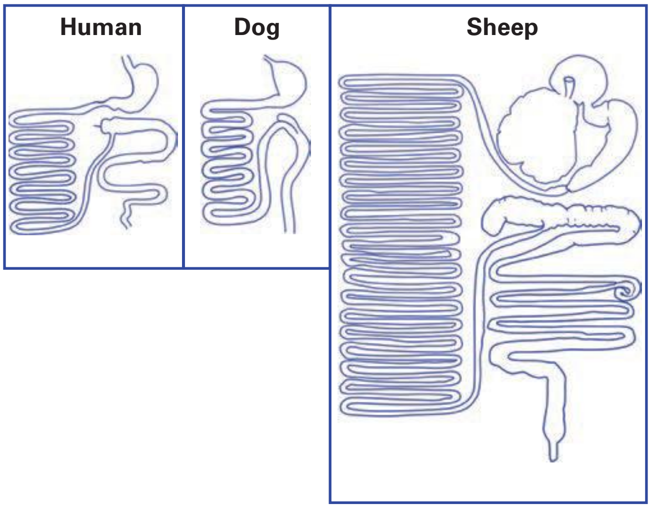


Figure 3.89 Digestive systems of a human, a dog and a sheep

a) **Contrast** the digestive system of a dog and a sheep.
b) **Identify** which two of the animals in Figure 3.89 probably have a similar diet.

Evaluating

13. Carnivorous plants tend to prey on small insects or amphibians. **Propose** why attracting larger mammals rather than insects might be a problem for carnivorous plants.

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3.7 Organ disorders

WORKSHEET
Organ replacement and repair

Learning goals

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

1. Describe how a disorder in cells or tissues can affect how an organ functions.
2. Describe how an artificial organ mimics or augments the function or functions of a real organ.

Each of the organ systems in your body relies on the specialised function of many different organs working together to keep you healthy. But when cells or tissues within an organ become diseased or dysfunctional, it can impact the overall functioning of the organ.

The treatment of an organ that is not functioning properly depends on the specific type of dysfunction and the underlying cause. Common treatments for less severe dysfunction may include medication or lifestyle changes. However, this is sometimes not enough, and the organ may need to be completely replaced.

Explore! 3.11

Medical imaging

Technological advancements in microscopy and medical imaging have significantly contributed to a better understanding of cells and organs. Medical imaging now allows doctors and researchers to non-invasively visualise the inside of the human body. Techniques like MRI (magnetic resonance imaging) and CT (computed tomography) produce detailed images of organs and tissues, while technologies like PET (positron emission tomography) and SPECT (single photon emission computed tomography) can reveal functional information about cellular processes.

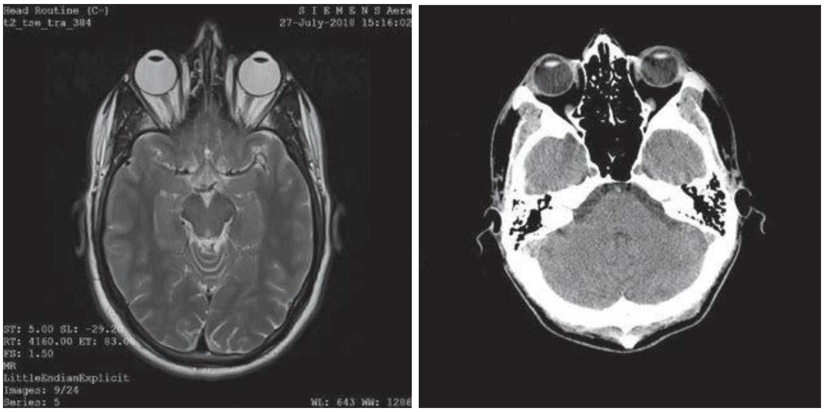

Figure 3.90 MRI scan (left) and CT scan (right) of a head

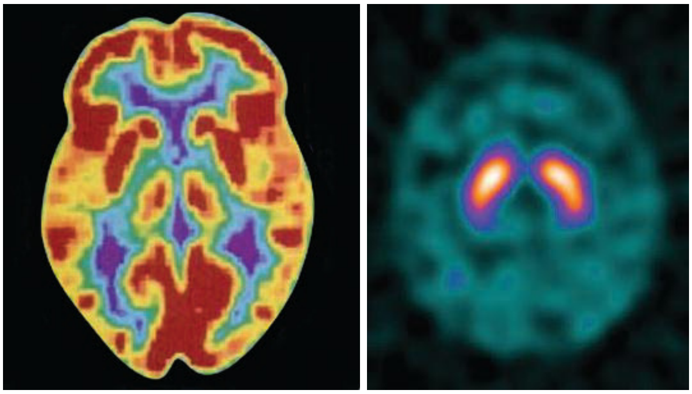

Figure 3.91 PET scan (left) and SPECT scan (right) of a head

Organ transplants

Damaged organs can sometimes be given the chance to repair through certain medications, diet and lifestyle changes. However, if an organ becomes so damaged that it can no longer work at all, the only option may be to completely replace it. This is done through a medical procedure known as **organ transplantation**, in which a healthy organ from one body is used to replace the damaged organ in another.

organ transplantation the process of removing a donor organ and then surgically implanting it into a recipient, to improve their organ function or replace a diseased organ

organ rejection when an organ transplant recipient's immune system recognises the organ as foreign and attacks it

One organ that is commonly transplanted is the kidney. The kidney is located near your lower back. It filters waste products out of your blood and produces urine. Diseases and environmental factors that can damage your kidneys include medications, alcohol and diabetes. We have two kidneys in our body, but we can manage with only one. Therefore, some people volunteer to donate one of their healthy kidneys to a friend or family member who needs a replacement one.

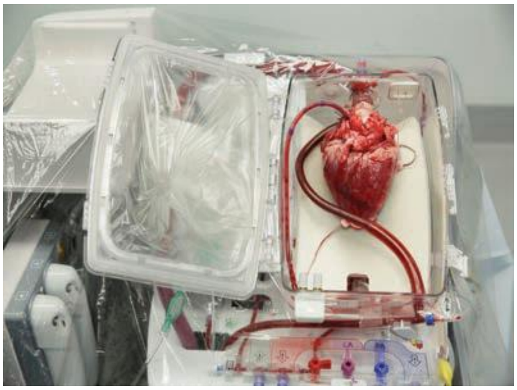

Figure 3.92 A heart being transported ready for transplantation

For an organ transplant to be successful, the donor (person giving the organ) and the recipient (person receiving the organ) must have similar matching markers on their cells. If these markers are not matched, the body will recognise the new organ as foreign and attack the organ using the immune system. This is known as **organ rejection**. Unfortunately, the chances of two people being a match is extremely low, even within families. This means that there is a high demand for organs but a very low supply available.

VIDEO Organ transplants

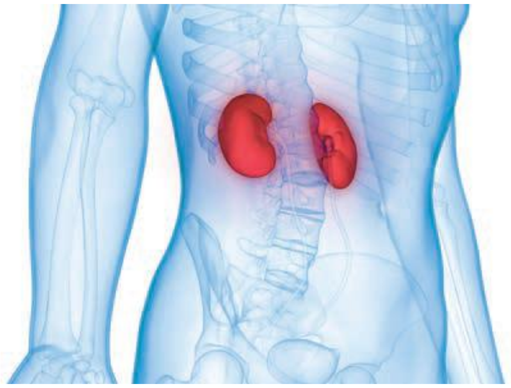

Figure 3.93 Most of us have two healthy kidneys. If they are damaged through disease, one option is a kidney transplant.

Organ donation is sometimes possible when a person dies and has previously indicated that they would like to donate their organs. This donation can save multiple lives, as organs such as the heart, lungs, kidneys, liver, large intestine, pancreas and some tissues, such as skin and corneas from the eye, can all be donated. In 2023, 1396 Australian lives were transformed by 513 deceased and 253 living organ donors and their families.

Not many deaths occur in a way that allows organ donation. In Australia, organ donation typically occurs when a person dies in a hospital setting. This is because the organs need to be removed as soon as possible after death to ensure their viability for transplantation.

Sometimes the families of registered organ donors refuse to give consent. This is why it is very important that people discuss their wishes with their families and consider registering their intentions on the Organ Donor Register.

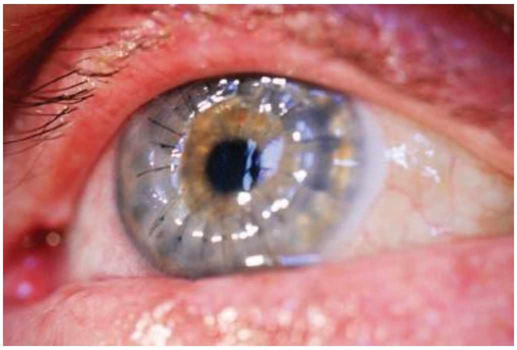

Figure 3.94 A corneal transplant, two weeks after surgery. The sutures are 0.003 81 cm thick.

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Quick check 3.17

1. If an organ is damaged, **recall** the first treatment options before a transplant is considered.
2. **Name** some of the organs and tissues that can be donated in Australia.
3. **Describe** what would happen if a transplanted organ came from a donor who was not a good match for the recipient.

Explore! 3.12

Downsizing dialysis

Dialysis is a medical treatment used to remove waste products and excess fluid from the blood of people with kidney failure. The treatment involves patients travelling to a clinic, where they are connected to a large 100 kg machine that filters the blood outside of the body and returns it to the patient. Usually, each treatment lasts about four hours and is done three times per week. This leads to some significant environmental impacts, particularly with regard to water waste as each four-hour session uses 120–180 litres of water.

Many companies are developing alternatives to clinic-based dialysis. Research the benefits of the following new innovations:

- KidneyX
- NextKidney
- automated wearable artificial kidney (AWAK) device
- artificial kidney.

Figure 3.95 An artificial kidney could replace the need for large dialysis machines.

Did you know? 3.16

Vestigial organs

Have you had your tonsils removed? If you have, like many others, it may have been because you had tonsilitis. What about your appendix? Many people have their appendix removed due to having appendicitis. Tonsils and the appendix are examples of vestigial organs and were once thought to have no use in the human body but are leftovers from our ancestors. The appendix was much larger in our ancestors and played an important role in digesting tough foods like tree bark. Due to our change in diet, we no longer need an appendix and can survive just fine without one. However, recent research shows that the appendix and tonsils may not be useless after all. Both organs have been found to play a role in the immune system. While there are no immediate consequences of having your tonsils or appendix removed, scientists are researching the long-term effects on a population level, which may include increased risk of certain diseases.

Figure 3.96 Tonsils are found at the back of the throat.

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Organ replacement

Because of the high demand but low supply of organs available for transplantation, scientists are developing new ways to overcome this problem. One method is **xenotransplantation**. This is the process of transplanting organs from a different species than the recipient.

xenotransplantation transplanting organs from one species into another

Doctors have been transplanting porcine (pig) heart valves into humans since 1965, as pig organs are a similar size and shape to human organs. However, there are two main biological challenges that scientists face with any pig–human transplant procedure:

- The biological markers on pigs' cells and organs do not match those in humans, and so the human recipient's body can reject the organ.
- There are viruses in pigs' genetic material that could infect and harm humans who receive a pig organ.

In 2024, a woman in the United States became the third person to receive a kidney from a genetically modified pig. The kidneys were sourced from pigs that had 69 genetic modifications which blocked pig DNA from triggering the human immune system and added genes to improve pig–human compatibility.

Although much progress is being made in the field of xenotransplantation research, this procedure remains experimental and is currently only available for patients that are too ill to receive a human organ.

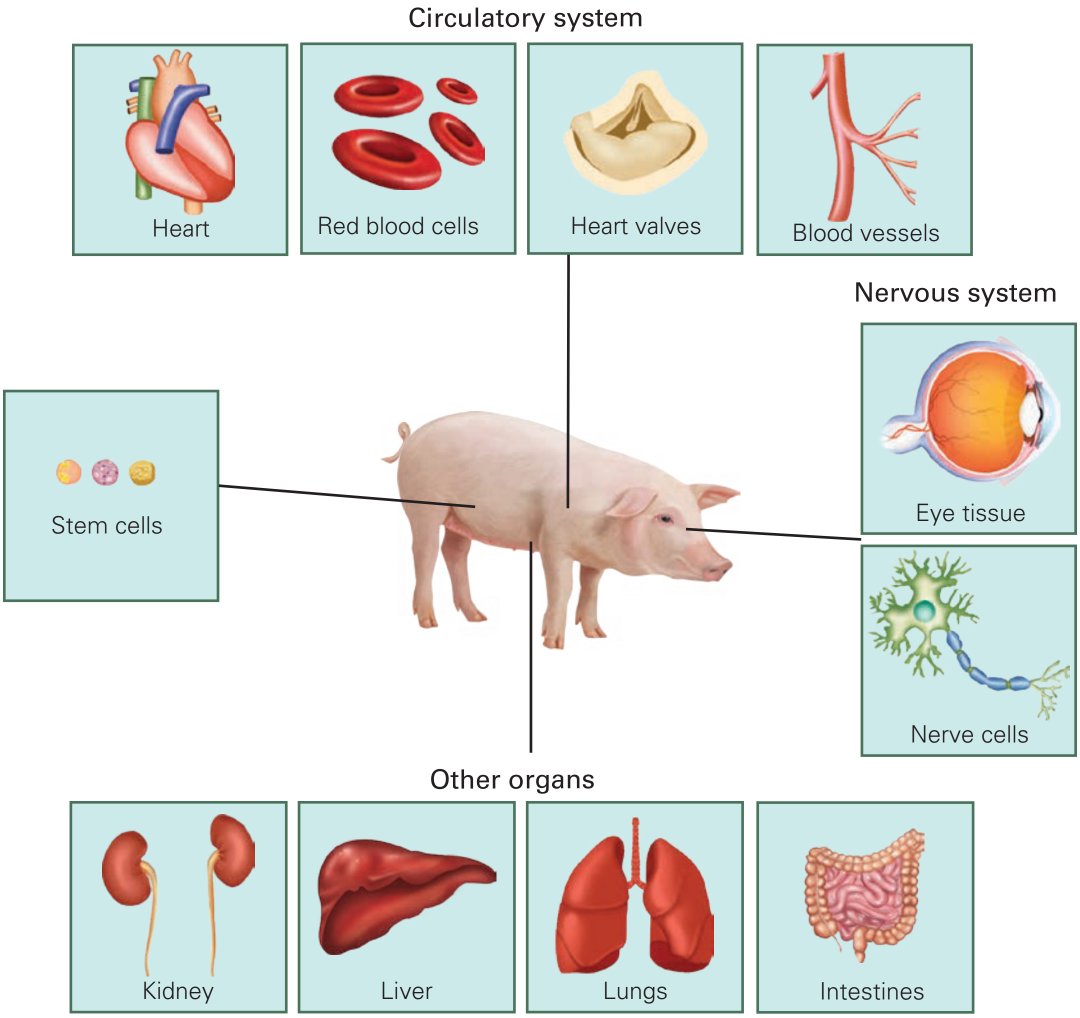

Figure 3.97 Some of the possible transplanted tissues and organs we could get from pigs

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Explore! 3.13

Ethical organs

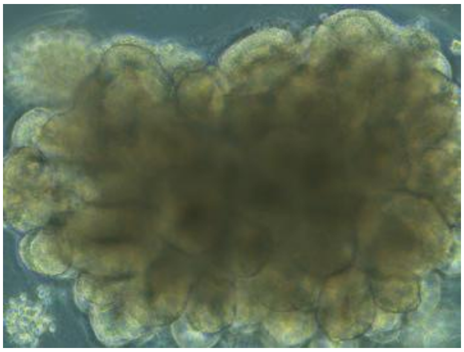

Figure 3.98 Developing human cerebral organoid, made from human brain cells. The organisation, structure and nervous signalling are similar to brain tissue. Organoids are used to study diseases of the nervous system.

Organoids are tiny clusters of cells that organise themselves into miniature and rudimentary versions of our organs. They present biomedical researchers with an opportunity to study organ development and experiment with drug technologies. Organoids develop from stem cells that have been grown in tiny 'wells' and made to differentiate into specialised cells, such as neurons. These neurons then make connections and begin to behave in a similar way to how they do in a patient's actual brain.

The development of organoids has had a significant impact on using live animals in laboratory research. Many people object to the use of live animals in research, and the use of organoids has the potential to reduce the number of animals used.

Complete some research and discuss how the use of organoids has impacted the ethical, environmental, social (impacting society) and economic (impacting the economy) issues associated with using live animals in laboratory research.

Organ regeneration

The liver is the largest internal organ in your body and the only human organ that can not only repair itself but can regrow dead or damaged areas. It is located just below your ribs, on the right side of your body. The liver is involved in many important processes, such as producing enzymes for digestion, storing vitamins and removing toxins from your blood. If the liver is exposed to too many toxins over a long period of time, it can become damaged and not perform its job properly.

Alcohol is a toxin that the liver filters out of the blood. People who regularly drink too much alcohol can permanently damage their liver. Fatty liver is the earliest stage of liver damage caused by excessive alcohol consumption, occurring when the liver begins to accumulate excess fat.

If the person continues to drink, they can develop alcoholic hepatitis, a condition in which the liver becomes inflamed and damaged, and then fibrosis, where the liver becomes scarred. Cirrhosis is the final stage of liver damage from alcohol consumption, where healthy liver tissue is replaced with fibrous tissue. Cirrhosis can lead to several serious health problems, including liver failure. If caught early enough, a change in lifestyle habits can reverse or limit the damage done to the liver. In severe cases, however, liver transplantation surgery may be necessary.

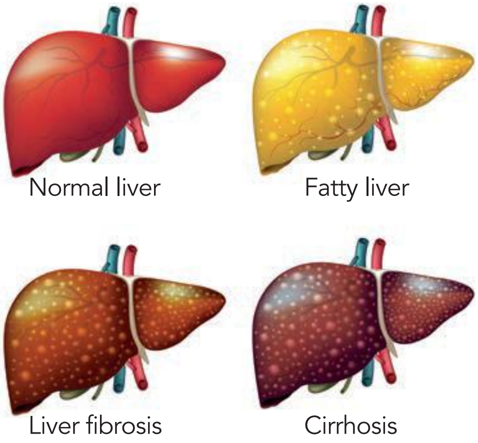

Figure 3.99 The stages of liver disease

tissue engineering the combined use of cells and engineering to improve or replace biological tissues

As you learned earlier in this section, organ transplants come with many risks, and matching donors are hard to find. That is why scientists are working on the ability to regenerate or grow organs from living healthy tissues. This process is called **tissue engineering** and it is a fast-growing area of research. This means that healthy living organ donors can donate part of their liver and

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their liver can grow back to nearly the same size over time. Because of the regenerative properties of the liver, scientists can grow whole new organs from as little as a quarter of an original liver.

If scientists could grow and regenerate organs using the patient's own tissue, then the body would not reject the transplanted organ.

Artificial organs

Advances in technologies have enabled the repair and replacement of organs using synthetic materials. An artificial organ can mimic or enhance the function of a real organ in several different ways.

Regardless of their design, artificial organs are constructed using materials that are compatible with the human body. Some artificial organs are also equipped with sensors and other devices that can monitor and adjust their function in real time.

Purpose	Description
Replacement	Some artificial organs are designed to replace a damaged or failing organ.  **Figure 3.100** An artificial heart can be implanted in a patient with heart failure to help pump blood.
Supplementation	Artificial organs can supplement the function of a real organ.  **Figure 3.101** Dialysis machines and artificial kidneys can be used to filter the blood and remove waste products in patients with kidney failure.
Enhancement	Artificial organs can enhance the function of a real organ.  **Figure 3.102** A cochlear implant can be surgically implanted in the ear to enhance hearing in individuals with hearing loss.
Control	Artificial organs can control the function of a real organ.  **Figure 3.103** A pacemaker can be used to control the heartbeat and regulate the electrical activity of the heart.

Table 3.2 Different purposes of artificial organs

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Try this 3.12

The benefits of artificial organs

Research the benefits of using artificial organs and create a persuasive text that influences a specified audience regarding their use. You may want to think about their cost effectiveness, their medical outcomes and the impact on organ donor waiting times.

Quick check 3.18

1. **Contrast** organ replacement and organ regeneration.
2. **Define** 'xenotransplantation'.
3. **Summarise** two potential problems with xenotransplantation.
4. **Name** two toxins filtered out by the liver.
5. **Recall** the size of liver that the organ can regrow from.

Investigation 3.1

Investigating the impact of salt on liver function

Be careful

Safety glasses and gloves must be worn.

The liver breaks down hydrogen peroxide, a toxic substance that is produced as a by-product of various metabolic processes in the body. Hydrogen peroxide can cause damage to cells, so it must be quickly broken down into non-toxic products. The liver does this by using the enzyme catalase, which converts hydrogen peroxide into water and oxygen. Some research has suggested that a high-salt diet may lead to high risk of liver damage and fibrosis.

Aim

During this experiment you will add hydrogen peroxide to blended cow liver. If the hydrogen peroxide is broken down, then oxygen bubbles will be produced. The aim is to test the effect of different concentrations of salt solution on liver function.

Materials

- large test tubes × 5
- liver solution (100 g of cow liver blended with 100 mL water)
- 10 mL measuring cylinder
- 0%, 10%, 20%, 30%, 40% salt solutions
- 3% hydrogen peroxide solution
- test-tube rack
- disposable gloves
- marker
- stopwatch

Method

1. Write a rationale about the role of the liver and factors that can affect liver function.
2. Write a specific and relevant research question for your investigation.
3. Identify the following variables in your experiment: independent, dependent and three controlled variables.
4. Construct a hypothesis for your experiment: predict what effect the different concentrations of salt solution will have on the number of oxygen bubbles being created.
5. Write a risk assessment for your investigation.

continued ...

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6. Place the test tubes in a rack and label them 0%, 10%, 20%, 30%, 40%.
7. Add 3 mL of liver solution and 3 mL of the first salt solution and allow them to combine for three minutes.
8. Mark the level of the solution with a marker.
9. Add 2 mL of hydrogen peroxide to the test tube and time until the bubbles stop being produced.
10. When the bubbles stop being produced, record the time in the results table.
11. Repeat steps 8–10 after combining liver solution and a different salt solution in each of the remaining tubes.

Results

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

Discussion: Analysis

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

Discussion: Evaluation

1. Identify any limitations in your investigation.
2. Using your results, suggest a range of salt percentage that you would test in a follow-up investigation.
3. Explain the reason that a test tube containing no salt was included in the experiment.

Conclusion

1. Draw a conclusion from this experiment about the effect of salt concentration on liver function, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that _____________. Therefore, the hypothesis is/is not supported by these findings.

Ethics of organ transplants

When we discuss organ transplants, we must think about the **ethical** implications of taking an organ from one person and using it in another. 'Ethics' is the term we use to discuss what is right and wrong in society. As there are many different beliefs, cultures and people around the world, ethics can vary from country to country or from person to person. When something is considered right, we say it is ethical, and if it is considered wrong, we say it is unethical.

ethical relating to ethics, the field of considering what is right and wrong

Our laws are linked to the ethical beliefs of a nation and can change over time as people's perception of ethics evolves. However, just because something is considered unethical does not necessarily mean that it is illegal.

Figure 3.104 Judges make decisions based on law, but ethics may also be a consideration in the decision-making process.

Some donated organs, such as kidneys and partial livers, come from living donors. This creates an ethical dilemma for the doctor who is performing the surgery. Should they risk the life of a healthy person to save or improve the life of a patient? Some questions they must consider are:

- Does the living donor know and understand all the risks?
- What if something goes wrong during surgery and puts the donor's life at risk?
- What if the transplant is rejected by the patient and the organ goes to waste?
- What happens if the donor is left with long-term pain, infection or impaired health after the surgery?

The donor may be under a lot of pressure from friends or family, which can make them feel forced into donating.

At any one time, there are around 1600 people on the Australian organ transplant waiting list. There are many rules in place to ensure that organs are allocated to patients in a fair process that is not affected by race, religion, gender, disability, social status or age, unless an adult organ is too large for a child, or a child's organ is too small for an adult, for example.

There is a very limited number of organs available at any one time, and so the wait for an organ could be anywhere from six months to more than four years. As a result of this, several factors are used to decide who gets an organ, such as:

- how long the person has been waiting for a transplant
- how well the organ matches the patient
- how urgent the transplant is for the patient's health
- whether the organ can be brought to the person in time.

Try this 3.13

The pros and cons of organ donation

Create a table showing the possible advantages and disadvantages (risks) for both an organ donor and a recipient.

Explore! 3.14

Opt in or opt out?

In some countries, such as Wales and Spain, all adults are automatically registered as organ donors. These adults can 'opt out' of the registration if they do not wish to be an organ donor. Many do not opt out. Spain consequently has one of the shortest waiting times for organ transplants in the world.

Research the current percentage of Australians who are registered organ donors and our average waiting list times and compare these with Spain's.

Answer the following questions and justify your opinion with evidence.

1. Do you think Australia would benefit from an 'opt out' organ donation system?
2. What are some of the advantages and disadvantages of an 'opt out' system?
3. Discuss the ethical issues that arise from organ transplantation.

Go online to access the interactive section review and more!

Section 3.7 review

Online quiz	Section questions	Teachers can assign tasks and track results

Section 3.7 questions

Remembering

1. **State** the function of the kidneys.
2. **Name** two factors that can damage the kidneys.
3. **Recall** two main challenges that scientists face with xenotransplantation.
4. **Name** the largest internal organ in a human.
5. **Define** 'organ donor'.

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6. **Define** 'organ transplant'.
7. **Identify** one organ that can regenerate.
8. **Identify** how Australian rules keep organ donation fair.

Understanding

9. **Explain** why transplanted organs may be rejected.
10. **Summarise** how too much salt can be harmful to a person.

Applying

11. **Explain** why it is necessary to investigate alternatives to organ transplantation.
12. Imagine that a person required a kidney transplant and you have matching markers to this person, enabling you to be a donor. **Discuss** some of the ethical issues you would consider when deciding whether or not to donate.

Analysing

13. **Distinguish** between ethics and laws.
14. Patients who are waiting for a kidney transplant might undergo daily or weekly dialysis treatment. Dialysis involves attending a hospital and being connected to a machine that filters your blood and then returns it to your circulation. The graph in Figure 3.105 shows percentage survival rates for patients on dialysis versus patients who have received a kidney transplant. Use the graph to answer the following questions.
    - a) **Identify** the difference in survival rates at the one-year mark for dialysis patients versus transplant recipients.
    - b) **Identify** the difference in survival rates at the five-year mark for dialysis patients versus transplant recipients.
    - c) Using your knowledge of organ transplantation, **reflect** on the difference in survival rates for these two patient populations. What advantages does transplantation offer?

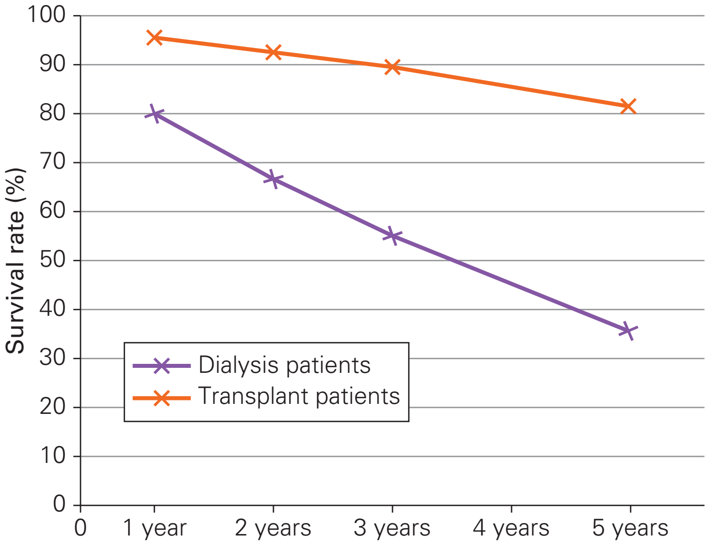

Figure 3.105 Survival rate of patients on dialysis versus patients who have received a kidney transplant

Evaluating

15. **Justify** why liver regeneration would be more beneficial than a liver transplant.

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Chapter review

Chapter checklist

Success criteria		Linked questions
3.1	I can describe how a specialised cell's structure is related to its function.	5, 8
3.1	I can use two-dimensional and three-dimensional representations of organ systems to understand how organs are positioned within the body.	6
3.2	I can describe the structure of each organ in the respiratory system and relate its function to the overall function of the system.	6, 22, 15
3.3	I can compare the structure and function of the analogous gas exchange systems in plants and animals.	1, 12, 26
3.4	I can describe the structure of each organ in the circulatory system and relate its function to the overall function of the system.	2, 7, 20, 21, 24
3.5	I can describe the structure of each organ in the digestive system and relate its function to the overall function of the system.	3, 6, 11, 22, 24
3.6	I can compare the structure and function of analogous digestive systems in animals.	14, 17
3.7	I can describe how a disorder in cells or tissues can affect how an organ functions.	8, 18
3.7	I can describe how an artificial organ mimics or augments the function or functions of a real organ.	9

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Define** 'lenticels' and where they might be found.
2. **Name** the blood vessel:
   a) that carries blood away from the heart to the lungs to become oxygenated.
   b) that carries oxygen-rich blood out of the heart.
   c) that returns blood to the heart from the body.
3. **State** the key roles of the small intestine and the large intestine in humans.
4. **Define** 'xenotransplantation'.
5. **Recall** the name of the process by which cells become specialised.
6. **Identify** the correct word for each of the numbers in Figure 3.106: mouth, liver, larynx, alveoli, diaphragm, tongue, anus, stomach, nasal cavity, trachea, rectum, lung, pancreas, gall bladder, epiglottis, duodenum, large intestine, oesophagus, pharynx, small intestine, bronchus, bronchiole.

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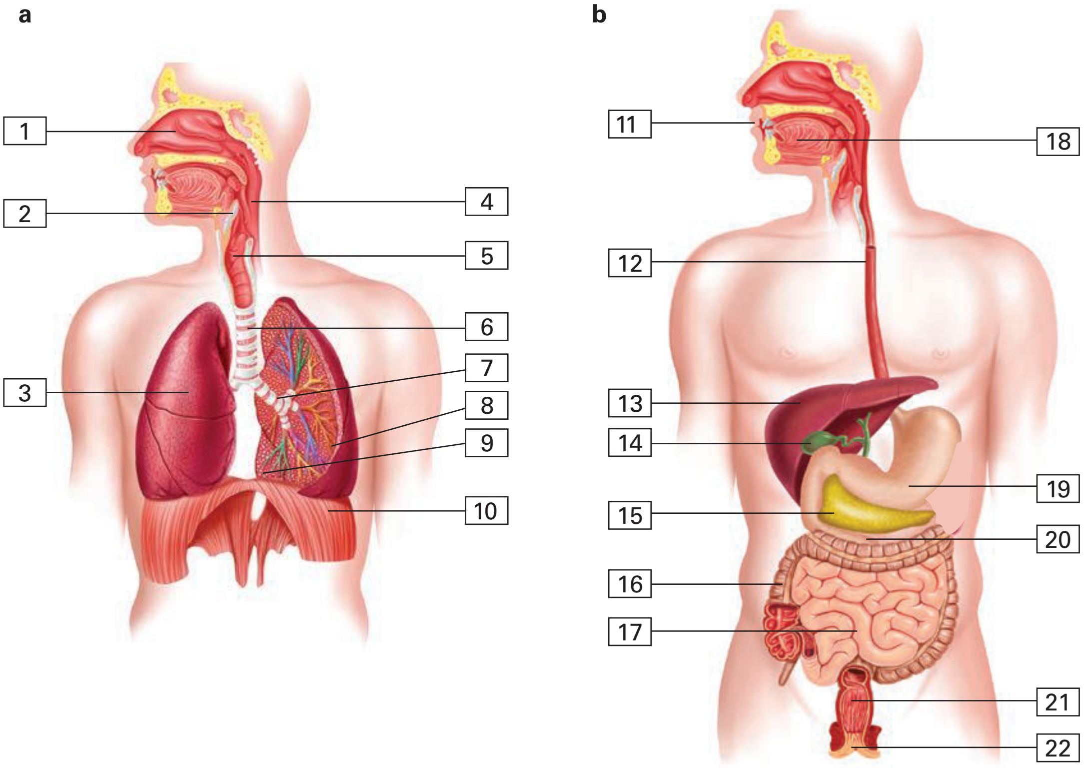

Figure 3.106 Human respiratory **(a)** and digestive **(b)** systems

Understanding

7. **Describe** the different components of blood.
8. **Describe** why a disorder in cells or tissues can affect how an organ functions.
9. **Describe** some of the benefits of using artificial organs.
10. **Explain** the role of enzymes in the digestive system, using examples.
11. **Explain** the function of the liver.
12. **Summarise** three essential features of gills if they are to efficiently exchange gases and act as lungs for fish.

Applying

13. **Explain** what is meant by a 'living donor'.
14. **Explain** why it could be harmful to treat a koala with antibiotics for an infection.
15. **Construct** a flow chart or a story that depicts the path taken by a single molecule of oxygen, from when it enters the nose to when it enters a cell and diffuses to the mitochondria to be consumed in cellular respiration. Then show how a molecule of carbon dioxide is produced and follow its story until it is exhaled. Make sure you include all relevant parts of the respiratory and circulatory systems.

Analysing

16. **Sequence** these terms in order of increasing size/complexity: organ, organism, tissue, cell, organ system.
17. **Contrast** the digestive systems of a carnivore and a herbivore.
18. Examine this statement: 'Lactose intolerance should be referred to as lactase deficiency'. **Consider** why this is the case.
19. **Distinguish** between mechanical digestion and chemical digestion.
20. **Contrast** the contents of the blood as it leaves your heart to when it returns to the heart.

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21. Copy and complete the table to **distinguish** between an artery, a capillary and a vein in terms of both their structure and function.

	Structure	Function
Artery		
Capillary		
Vein		

22. Complete the table to **compare** the structure and function of villi and alveoli.

	Villi	Both	Alveoli
Structure			
Function			

23. Forced vital capacity (FVC) is a measure of how much air a person can blow out in one exhalation. The graph in Figure 3.107 shows the normal values for males (in orange) and females (in purple) according to their age. Use the graph to answer the following questions.

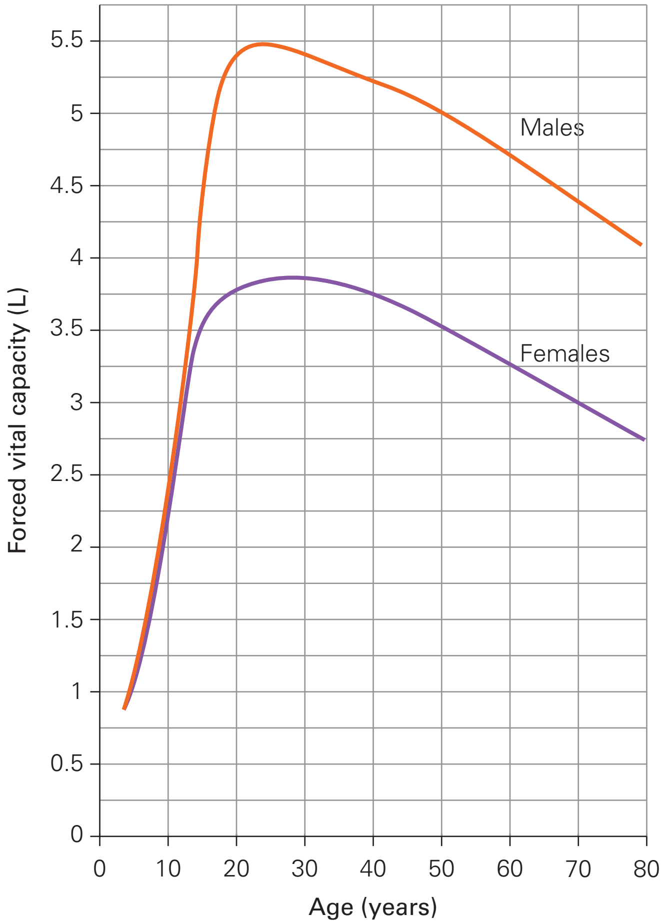

Figure 3.107 Forced vital capacity versus age for males and females

a) **Identify** the average FVC for a male and a female at age 30.
b) **Identify** the age range when a person's lung capacity increases the most.
c) **Propose** a reason why males tend to have a larger FVC than females.

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Evaluating

24. Other than helping enzymes to break down food, **propose** another function of stomach acid.
25. **Propose** two reasons why most frogs need to remain near water.
26. **Construct** a Venn diagram to compare the gas exchange structures of fish, frogs and humans.
27. A child is diagnosed with a rare and potentially fatal condition, but a bone marrow transplant from a matching donor will likely save their life. Neither of the parents is a match, but they are told by the doctors that a sibling is likely to be a suitable match. The parents decide to have another child, with the intention that when the baby is born, he or she can provide a bone marrow donation to their sibling. Research what is involved in bone marrow transplantation and discuss the ethical dilemma these parents face. **Discuss** the pros and cons of the parents' decision and defend your personal opinion on whether they should or should not have the second sibling.

Data questions

Biathlon is a winter sport whereby an athlete competes by completing three legs of cross-country skiing and two legs of shooting at a target, followed by a final sprint. In each phase of the race, the biathlon athlete's heart rate will change as the athlete uses energy to ski and then calms themselves for a shooting phase. The heart rate of a biathlon competitor is plotted over the various phases of the race in Figure 3.108. The relationship between maximum heart rate (HR_{max}) and age of the athlete is shown in Figure 3.109.

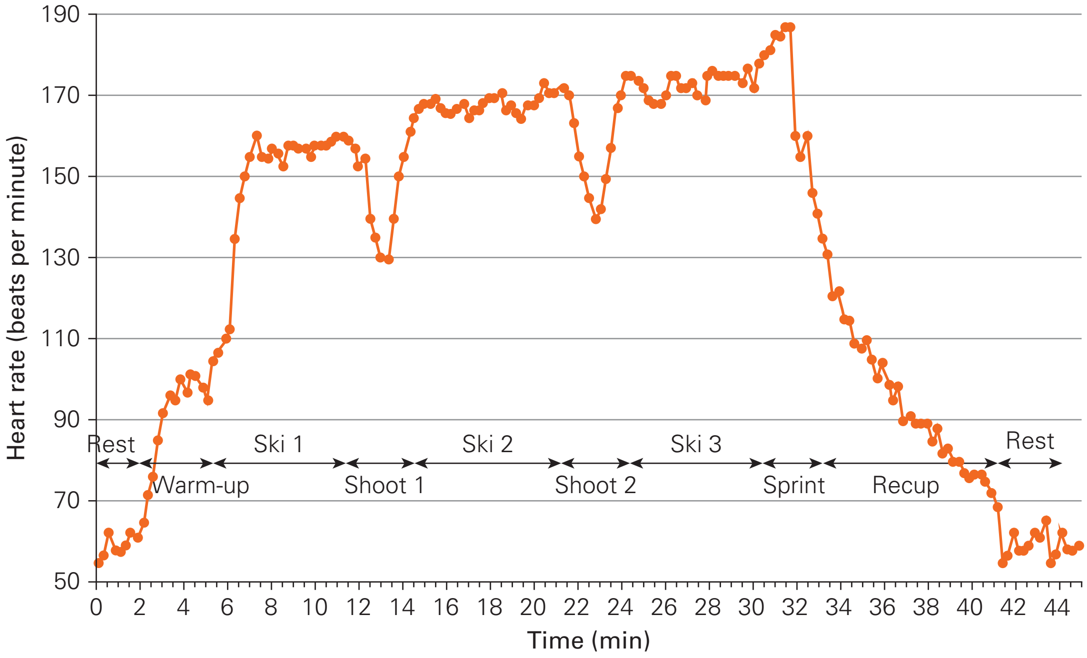

Figure 3.108 Heart rate of an athlete during a biathlon race, including warm-up, three ski phases, two shootings, a final sprint and a recuperation phase

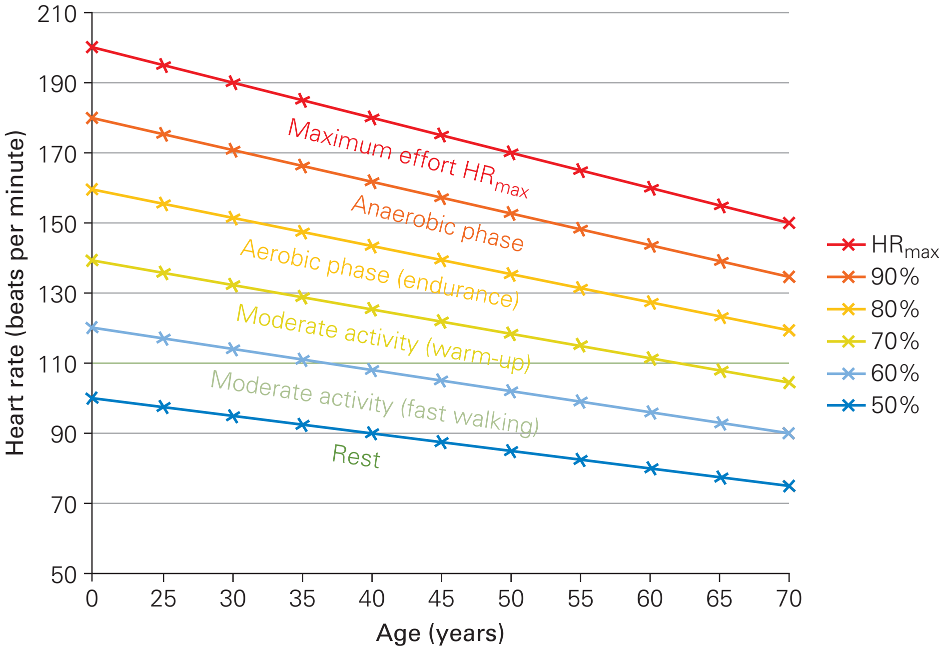

Figure 3.109 Activity intensity linked to the average human heart rate as a function of age (following the commonly accepted relation $HR_{max} = 220 - age$).

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Applying

1. With knowledge that the heart rate is higher during the ski periods and lower for the shooting periods, **identify** the time range for each of the three ski periods and the two shooting periods.
2. **Identify** when the athlete's heart is beating at its lowest rate.
3. **Calculate** the duration of the athlete's recuperation phase, when the heart rate goes from its highest, back to the resting pace.
4. Using the graph in Figure 3.109, **identify** the potential age of the athlete, knowing their HR_{max} is 190 and that $HR_{max} = 220 - \text{age}$.

Analysing

5. **Identify** the relationship between the heart rate and successive ski periods.
6. **Contrast** the heart rate between 24 and 30 minutes (third ski phase) and between 30 and 32 minutes (final sprint).

Evaluating

7. Another athlete in the race was 40 years old and had a heart rate of 150 beats per minute during the second shooting phase. **Deduce** the activity intensity for this athlete during this phase.
8. **Infer** whether or not the heart rate of the athlete during the ski phase would be identical on a longer race with five ski periods and four shootings.
9. **Predict** the maximum heart rate of a 70-year-old athlete running a marathon if the athlete was using the maximum effort.

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STEM activity: Clearing a blocked artery

Background information

The heart is responsible for pumping oxygen and nutrients around your body and to every cell. It continues to pump for your entire lifetime and you can't live without it. Unfortunately, many people around the world experience heart conditions that are life threatening. An example is coronary artery disease (CAD), a major cause of death in Australia. Many heart conditions can be treated with medication, and some require surgery. Other conditions, such as dilated cardiomyopathy, CAD and heart-related birth defects, can only be treated with a heart transplant. A donor heart can be used from a person who has died and has consented to being an organ donor. However, sadly, the number of people on waiting lists for heart transplants is far greater than the number of donor hearts available, and many people die while they are waiting for a transplant.

Like all our organs, the heart requires oxygen and nutrients. These are supplied to the heart in blood that comes via the coronary arteries. When a person has CAD, substances including cholesterol, calcium and fat deposit on the walls of their coronary arteries. These deposits make the coronary arteries narrower, reducing the blood supply to the heart and therefore reducing the supply of oxygen to the heart muscle.

Two ways of using surgery to overcome this problem of blocked coronary arteries are shown in Figures 3.110 and 3.111.

It is important to note that neither of these methods actually cleans the plaque away. This is because blood vessels are fragile, and removing the plaque would cause it to dislodge, which is dangerous because it might then completely block a narrower blood vessel, causing a heart attack.

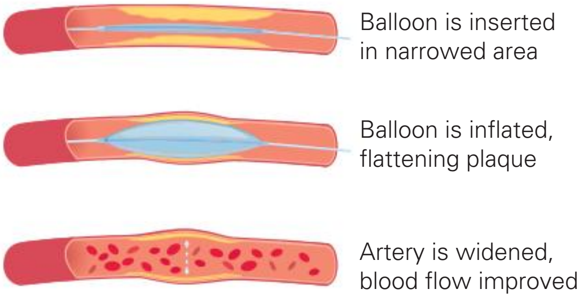

Figure 3.110 In angioplasty, a small 'balloon' is inflated inside the artery, which pushes the plaque aside and widens the vessel.

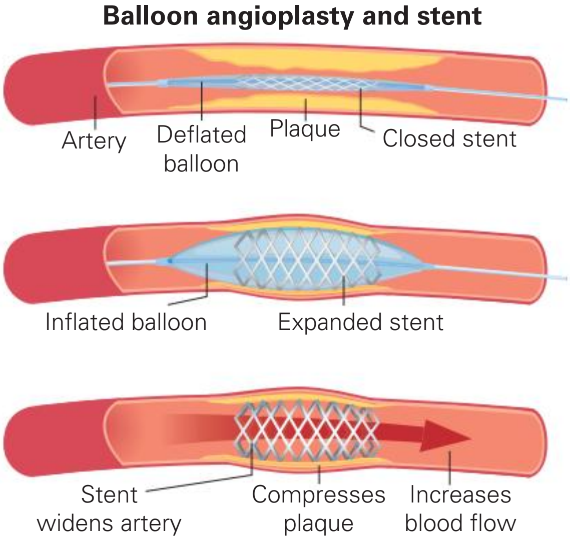

Figure 3.111 Many people also have a stent inserted inside the artery after the artery has been widened by angioplasty. A stent is a small tube made of plastic or metal that is inserted into the artery to prevent it narrowing again.

DESIGN BRIEF

Design a device and a procedure to clear blocked arteries while trapping the dislodged plaque.

Activity instructions

In groups of three or four, you will design a device along with the procedure to unblock an artery. As part of the design brief, your device and procedure will also need to trap any of the plaque that is cleared out.

You can only insert any devices from the top end of the 'artery' tube (see Figure 3.112).

Suggested materials

- model of a blocked artery, created using a tube or a toilet roll tube and play dough
- paper clips
- string
- popsicle sticks
- cloth
- glue
- tape
- cardboard
- paper

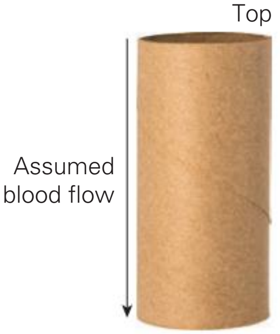

Figure 3.112 A model of an artery

Research and feasibility

1. Together as a group, discuss your understanding of the problem. Discuss the materials you have available and any constraints you may have in your design.
2. As a group, research methods of filtration and reflect on their suitability for trapping dislodged plaque.

Method of filtration	How it works	Usability of filtration method for trapping plaque
e.g. Mesh/sieve	The mesh stops things that are larger than the hole from passing through.	Mesh would stop plaque of a certain size; the mesh size and material would need to be thought of.

Design and sustainability

3. Research materials used in surgery, and as a group, think about the sustainability of these materials. Use this information when considering your design.
4. As individuals, sketch your own solution/s to the design brief and then share as a group. Annotate each group member's sketches and together sketch your preferred model, making note of annotations for your design.

Create

5. As a group, build the model agreed upon by the group and then test for effectiveness. You may wish to create a table such as the one below.

	Prototype 1	Prototype 2
Time taken for removing plaque		
Difficulty of procedure		
Percentage estimate of dislodged plaque caught in trap		

6. Modify your model and test again. You can test as many prototypes as you have time for.

Evaluate and modify

7. For each model that you created, discuss how effectively the model performed. Consider how long the procedure was and how difficult it was to carry out. Evaluate how effective the 'trap' was at catching the dislodged pieces – how much of the plaque did it catch?
8. Imagine you had to do this procedure on a real patient. Discuss the limitations of your model of a blocked artery and how your device and procedure might need to be modified to better reflect real life.

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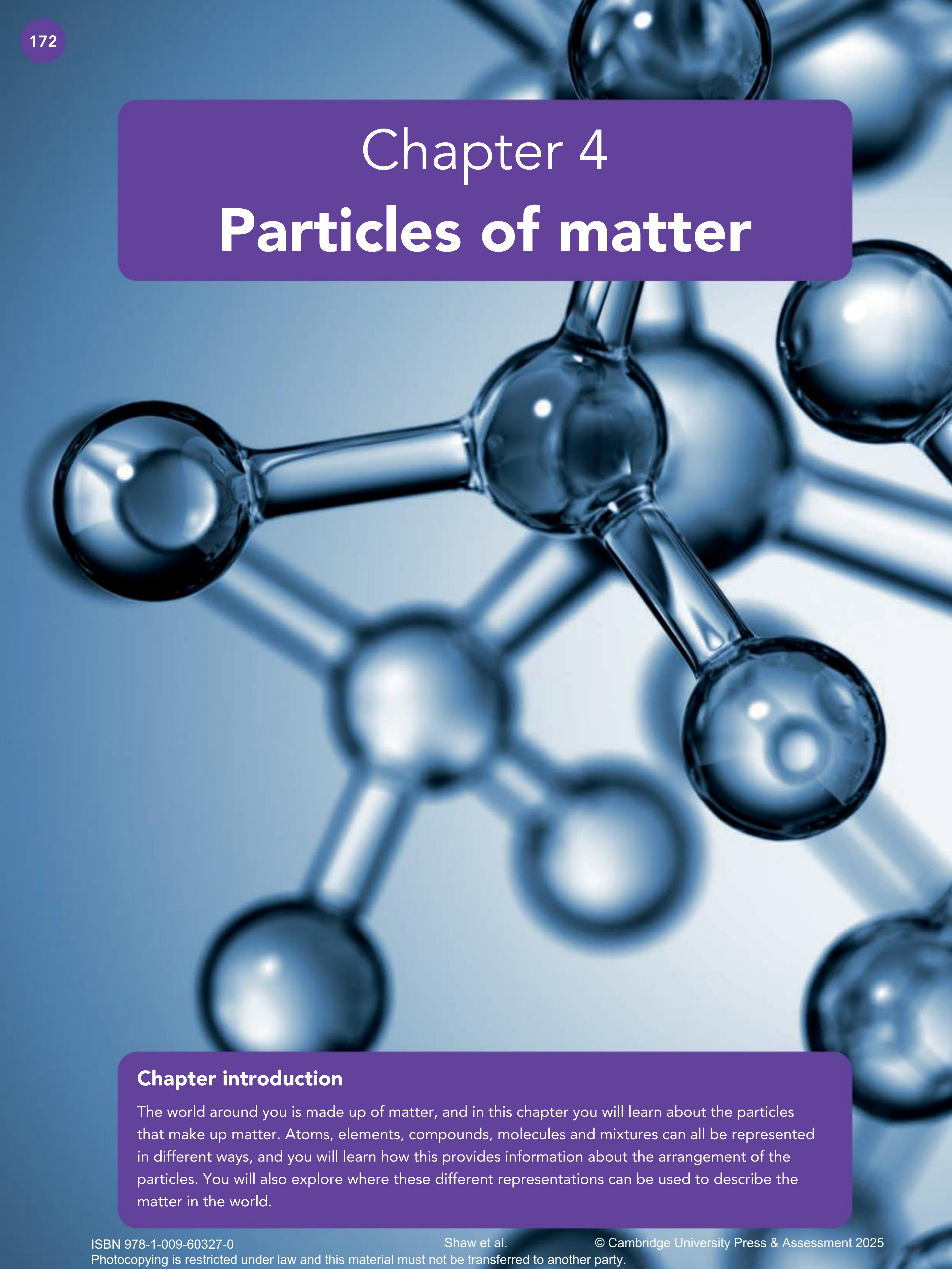
Chapter 4

Particles of matter



Chapter introduction

The world around you is made up of matter, and in this chapter you will learn about the particles that make up matter. Atoms, elements, compounds, molecules and mixtures can all be represented in different ways, and you will learn how this provides information about the arrangement of the particles. You will also explore where these different representations can be used to describe the matter in the world.

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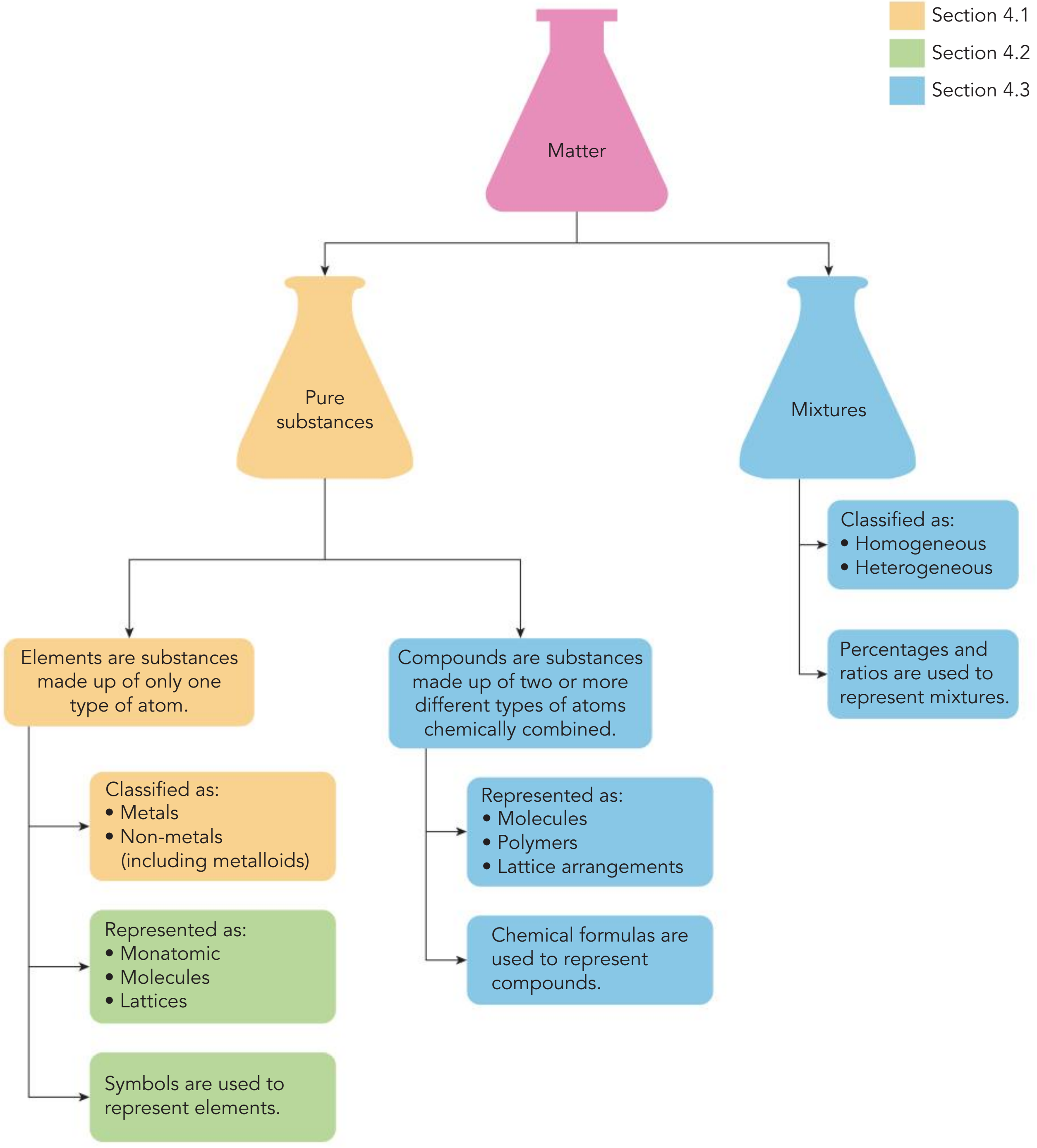
Concept map



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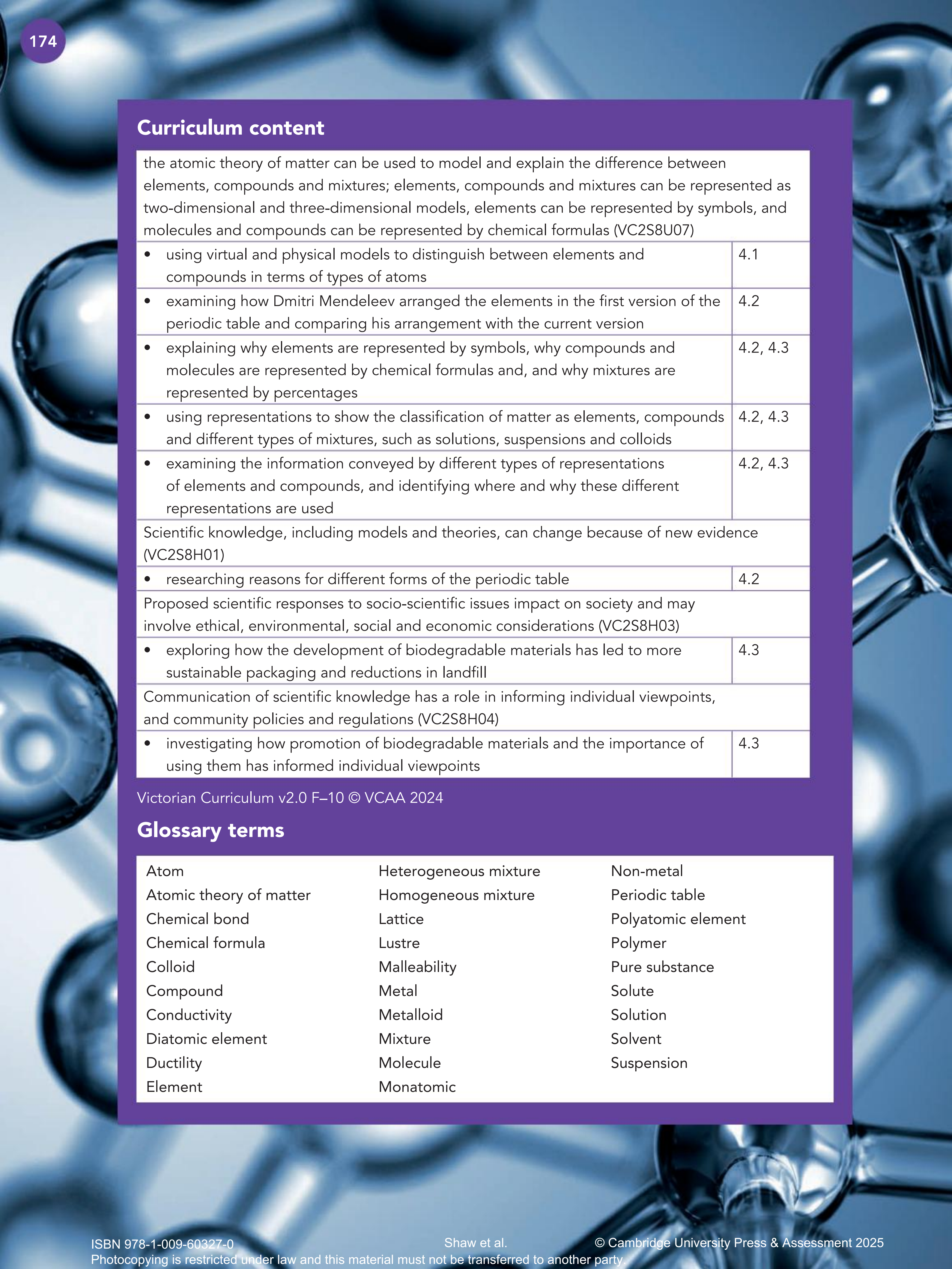

Curriculum content

the atomic theory of matter can be used to model and explain the difference between elements, compounds and mixtures; elements, compounds and mixtures can be represented as two-dimensional and three-dimensional models, elements can be represented by symbols, and molecules and compounds can be represented by chemical formulas (VC2S8U07)	
• using virtual and physical models to distinguish between elements and compounds in terms of types of atoms	4.1
• examining how Dmitri Mendeleev arranged the elements in the first version of the periodic table and comparing his arrangement with the current version	4.2
• explaining why elements are represented by symbols, why compounds and molecules are represented by chemical formulas and, and why mixtures are represented by percentages	4.2, 4.3
• using representations to show the classification of matter as elements, compounds and different types of mixtures, such as solutions, suspensions and colloids	4.2, 4.3
• examining the information conveyed by different types of representations of elements and compounds, and identifying where and why these different representations are used	4.2, 4.3
Scientific knowledge, including models and theories, can change because of new evidence (VC2S8H01)	
• researching reasons for different forms of the periodic table	4.2
Proposed scientific responses to socio-scientific issues impact on society and may involve ethical, environmental, social and economic considerations (VC2S8H03)	
• exploring how the development of biodegradable materials has led to more sustainable packaging and reductions in landfill	4.3
Communication of scientific knowledge has a role in informing individual viewpoints, and community policies and regulations (VC2S8H04)	
• investigating how promotion of biodegradable materials and the importance of using them has informed individual viewpoints	4.3

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Glossary terms

Atom
Atomic theory of matter
Chemical bond
Chemical formula
Colloid
Compound
Conductivity
Diatomic element
Ductility
Element
Heterogeneous mixture
Homogeneous mixture
Lattice
Lustre
Malleability
Metal
Metalloid
Mixture
Molecule
Monatomic
Non-metal
Periodic table
Polyatomic element
Polymer
Pure substance
Solute
Solution
Solvent
Suspension

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4.1 Atoms and elements

Learning goals

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

1. Define an element, an atom, a molecule, a compound, a pure substance and a mixture.
2. Distinguish between metals and non-metals, as well as metalloid elements.
3. Identify and create two-dimensional and three-dimensional representations of elements, molecules, compounds and mixtures.

Atoms

In Year 7, you learned about matter and that it makes up everything in the world around you. Matter comes in three main states: solid, liquid and gas. In this chapter we are going to zoom in on what matter is actually made up of at the smallest level. If you were to cut a piece of paper in half and then in half again, you would end up with a smaller piece of paper. But what if you kept cutting it in half until all that was left was a particle that couldn't be cut in half again? This particle would be called an **atom**. The word 'atom' comes from the Greek word *atomos*, which means 'indivisible' or 'un-cuttable'. Atoms are so incredibly small that across the width of one single strand of hair there are likely close to 1 million atoms! This idea that all matter is made up of particles called atoms is known as the **atomic theory of matter**.

atom
the smallest particle that makes up all matter

atomic theory of matter
all matter consists of indivisible particles called atoms

pure substance
a material that is made up of just one type of particle

element
a chemical substance made up of only one type of atom

molecule
two or more atoms chemically bonded by strong covalent bonds

Try this 4.1

Cutting paper

Cut a strip of paper that measures 28 cm x 1 cm. Now cut it in half, and you will have two 14 cm lengths of paper. This is cut one. Repeat this as many times as you can, counting your cuts as you go.

How many cuts were you able to make? Name one item that is the same size as the paper with one cut, three cuts and five cuts. How do you think you could keep cutting the paper smaller and smaller? Imagine this: it would take 31 cuts to get a piece of paper the size of an atom!

You may like to visit the University of Utah's *Cell size and scale* online interactive to gain an understanding of the size of an atom.

Pure substances and mixtures

A chemical substance can be a pure substance or a mixture.

A **pure substance** is made up of only one type of particle or atom. There are two types of pure substances: elements and compounds.

An **element** is a chemical substance made up of only one type of atom. These can be single atoms or atoms that are bonded together, called **molecules**, but they are all the same type of atom. For example, gold is an element and is made up of many single gold atoms. In contrast, the atoms of the element hydrogen like to bind together to form molecules, each with two hydrogen atoms joined by a covalent bond.

You will notice the term 'bond' mentioned many times throughout this topic. Atoms may exist alone, but they can also join to other atoms. In this case, the strong force of attraction used to join atoms is called a **chemical bond**. There are several different types of chemical bonds: covalent bonds (a bond usually between two non-metal atoms), metallic bonds (bonds between metal atoms) and ionic bonds (a bond usually between a metal and a non-metal atom).

chemical bond a strong force of attraction between two atoms

compound a chemical substance made up of two or more different types of atoms

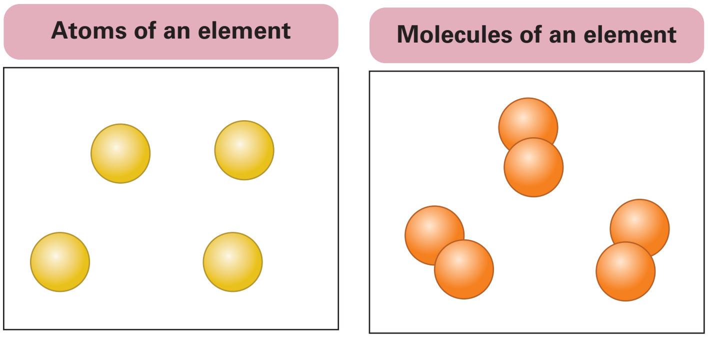

Figure 4.1 In an element, all the atoms are the same.

Explore! 4.1

The evolution of the element

The element has taken on a few different definitions prior to the one that scientists use today. The earliest report is from the fifth century BC when the Greek philosopher Empedocles proposed that there were four 'roots' or 'elements' in the world: earth, water, air and fire.

Use the internet to find information on the different definitions of the term 'element' from the following philosophers and scientists.

- Democritus
- Paracelsus
- Robert Boyle
- John Dalton

Figure 4.2 Empedocles proposed four elements: earth, water, air and fire.

A **compound** is a chemical substance made up of two or more different types of atoms bonded together. For example, water is a compound, as it is made up of two hydrogen atoms bonded to one oxygen atom. We also call water a covalent molecular compound as the bonds holding the atoms in the molecule together are covalent bonds.

You may have noticed that all compounds are molecules – they all have two or more atoms bonded together. But not all molecules are compounds!

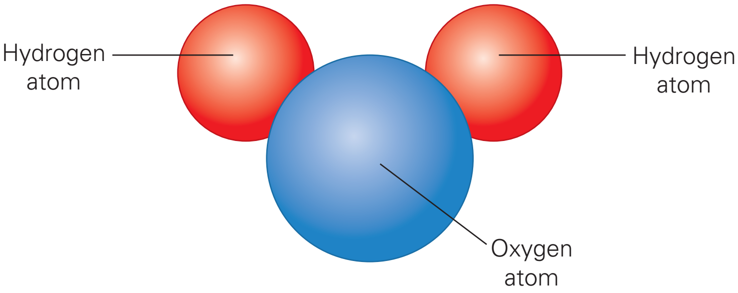

Figure 4.3 A water molecule is a compound because it has two different types of atoms: one oxygen atom covalently bound together with two hydrogen atoms. Water is also a pure substance, as it is made up of only one type of molecule, the one shown here.

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A **mixture** is not a pure substance as it is made up of two or more different chemical substances (compounds or elements) that are not bonded together. For example, air is a mixture of several different elements and compounds. You will look at compounds and mixtures in more detail in Section 4.3.

mixture
a substance made up of two or more different pure substances (compounds or elements) that are not chemically bonded together

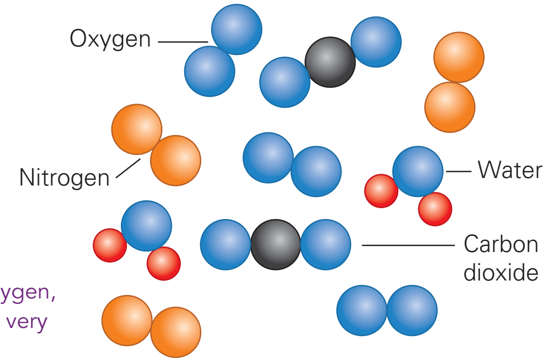


Figure 4.4 Air is a mixture of nitrogen, oxygen, argon, carbon dioxide, water vapour and very small amounts of other gases.

Making thinking visible 4.1

See, think, wonder: The water molecule

1. What do you see? Describe exactly what you see. Can you identify the parts?
2. What do you think about when you look at the image? Can you suggest roles for each of the parts? Why might the parts be organised in this way? Would changing the shape change the water molecules properties?
3. What does it make you wonder? Are there other questions you have about water molecules? Or about molecules in general?

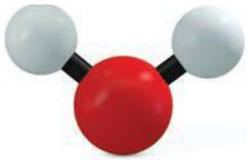


Figure 4.5 A model of a water (H_2O) molecule

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

Putting it all together

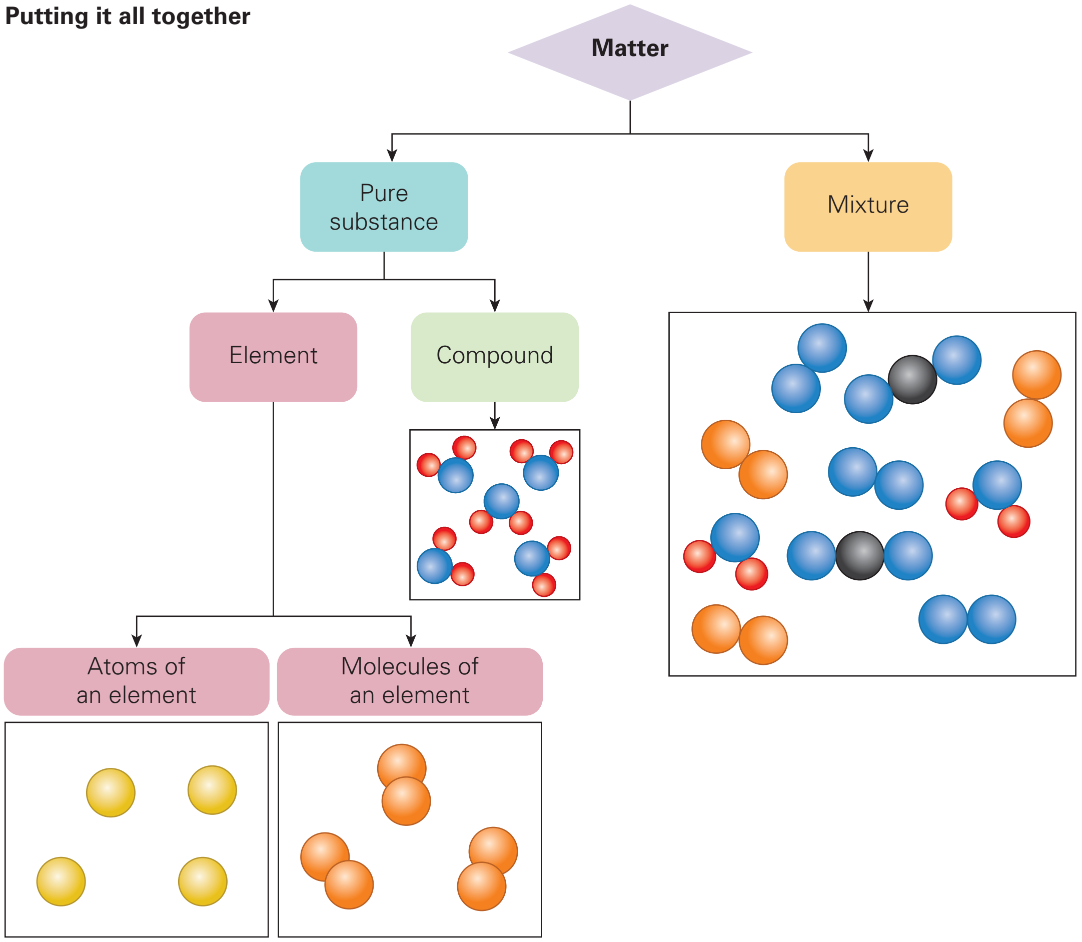


Figure 4.6 Putting it all together: matter is made up of pure substances (elements and compounds) and mixtures.

Try this 4.2

Model-making

Scientists love models and modelling. This is because it allows them to represent an idea or theory that perhaps cannot be experienced directly. Teachers love you to use models and modelling too. This is because it allows you to determine where your misconceptions lie and gives them an opportunity to help you. Using nuts, bolts and washers, make models to represent a:

- single atom of an element
- compound
- mixture of two compounds
- mixture of elements and compounds.

Take photos of each model you make and explain:

- why the atoms are arranged as they are
- why the atoms are the items they are
- if bonds are involved.

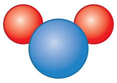
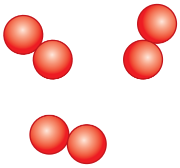
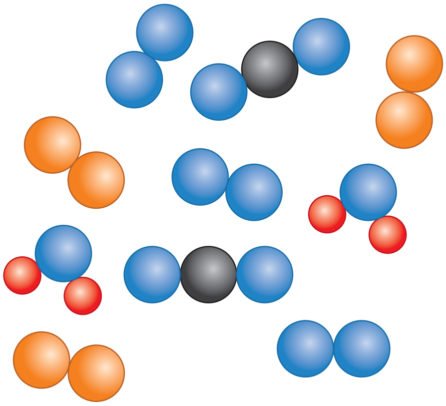
You may like to turn your photos and information into a PowerPoint presentation or a poster using Canva.

Quick check 4.1

1. **Match** the following terms with their correct definitions.

Molecule	The smallest particle that makes up all matter
Compound	Chemical substance made up of only one type of atom
Chemical bond	Chemical substance made from two or more different types of atoms
Element	Two or more atoms chemically bonded together by covalent bonds
Atom	Strong force of attraction that holds atoms together

2. In the following table, **match** each term and example with the correct diagram (A–E).

Term	Example	Diagram
Mixture of elements	Oxygen and helium	A 
Pure compound	Water	B 
Element	Hydrogen	C 

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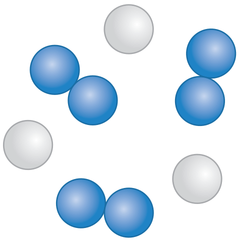
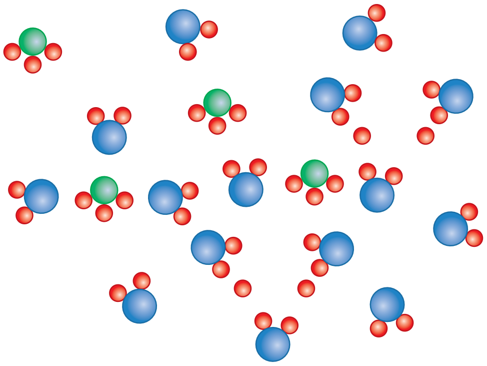
Term	Example	Diagram
Mixture of compounds	Salt and water	D 
Mixture of elements and compounds	Air	E 

WIDGET
Elements, compounds and mixtures

Science as a human endeavour 4.1

Electron microscopes

Electron microscopes allow scientists to visualise matter smaller than the microscale, which is the limit of most light microscopes that you might use in your school classroom.

The three main types of electron microscope are the scanning tunnelling microscope (STM), scanning electron microscope (SEM) and the transmission electron microscope (TEM). A SEM has been used in recent years to see the SARS-CoV-2 virus, the virus responsible for the COVID-19 disease.

In 2021, scientists in the United States published their image of an atom with the highest resolution ever seen! They used a special technique in electron microscopy called electron ptychography.

Scientists all over the world are continuing to improve the resolution of their images – the more they see, the more information they have to help design more powerful and efficient phones and computers, and longer-lasting batteries.

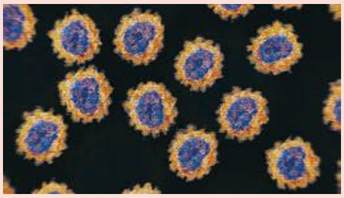


Figure 4.7 Scanning electron microscopic (SEM) image of SARS-CoV-2

Figure 4.8 This transmission electron microscope in the US can observe atoms.

Elements

We know that elements are an example of a pure substance that is made up of just one type of atom or one type of molecule. Elements are the purest substances we can find or extract from matter, and they make up everything we know of. The first elements were identified thousands of years ago with the discovery of the metals gold, tin, copper and iron. After these elements, scientists and philosophers discovered and hypothesised other elements that could be found in the earth, rocks, air and water. In more modern times, elements have been made by shooting atoms at each other at very high speeds in particle accelerators to attempt to 'merge' them. This is how the newest element, oganesson (Og), was discovered in 2002.

Grouping elements

Metals and non-metals

In chemistry, as in all other areas of science, we like to group similar things together or classify them – for example, as pure substances or mixtures. One of the first steps in classifying elements is to determine whether the substance is a **metal** or a **non-metal**. To do this, scientists look at the physical and chemical properties that the elements have in common (see Table 4.1). You can see that all metals share the same properties. Similarly, non-metals also share the same properties.

metal
a chemical substance that is shiny (lustrous), can conduct electricity and heat, is malleable and ductile, and is usually silvery/grey

non-metal
a chemical substance that is dull, cannot usually conduct electricity and is brittle

metalloid
a non-metallic substance that has some of both properties of both metals and non-metals

Metalloids

However, some of the elements have properties that could be considered like metals, but also like non-metals. One example is silicon (see Figure 4.9). Silicon can conduct heat and electricity a little, but it cannot be bent (malleable) or made into wire (ductile). It is lustrous (shiny) when polished, but is brittle and can shatter like glass. When an element has properties of both metals and non-metals, it is called a **metalloid**. However, it should be noted that all metalloids are officially considered non-metals, as they are not metals! There are six elements that are typically considered metalloids: boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb) and tellurium (Te).

Figure 4.9 Three examples of metalloids. **(a)** Silicon is shiny and brittle and can conduct electricity but not as well as a metal. **(b)** Antimony is shiny like a metal but brittle like a non-metal. **(c)** Boron conducts electricity but is brittle.

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Property	Metals	Non-metals
State at room temperature	Solid (exception: mercury)	Solid, gas or liquid
Colour	Silver/grey (exceptions: gold, copper)	A range of colours, as well as colourless
Lustre	Shiny when polished	Usually dull
Conductivity	Conducts electricity and heat	Cannot usually conduct electricity or heat
Malleability	Can be bent or flattened	Cannot be bent or flattened; often brittle
Ductility	Can be made into a wire	Cannot be made into a wire
Melting point	Usually high temperature (exception: mercury)	Usually low temperature

Table 4.1 The general properties of the metal and non-metal elements

lustre
the ability of a substance to become shiny when polished

conductivity
the ability of a substance to conduct or carry electricity or heat

malleability
the ability of a substance to be bent or flattened into a range of shapes

ductility
the ability of a substance to be drawn into a wire

Did you know? 4.1

Conductors and semiconductors

As shown in Table 4.1, metals are good conductors of heat and electricity. However, some non-metals are good conductors too. Carbon (a non-metal) in the form of graphite is both a good heat and electrical conductor, and surprisingly, carbon in the form of diamond is the best-known thermal conductor, with a conductivity five times higher than copper!

Figure 4.10 Graphite is a form of carbon, a non-metal that is a good conductor of heat and electricity.

Metalloids have an intermediate level of heat conductivity when compared to metals and non-metals, and if they can conduct electricity, this usually can only occur at higher temperatures. Metalloids that are good electrical conductors at high temperatures are called semiconductors. Silicon is an example of a semiconductor.

After oxygen, silicon is the second most abundant element in Earth's crust but is rarely found naturally in its pure form. Instead, it can be extracted from silica sand, a combination of silicon and oxygen.

Practical 4.1

Investigating the properties of metals and non-metals

Aim

To investigate the properties of metals and non-metals

Hypothesis

Write a prediction about the properties you are expecting the metals to have, and the properties you are expecting the non-metals to have. Begin with, 'It is hypothesised that…'.

Materials

- samples of metals in a tub
- samples of non-metals in a tub
- fine sandpaper

continued …

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Method

1. Begin by drawing up the results table in your workbook. Fill in the definitions of the properties in the first blank column.
2. Start with the selection of metals you have been provided with. Record the colours of the different metals in the results table.
3. Use the fine sandpaper to rub each substance and determine its lustre – is it shiny or dull? Record your observations in your table.
4. Try to bend each of the substances – is it malleable or not? Record your observations in your table.
5. Make a prediction about the ductility of the metals. Record your observations in your table.
6. Finally record the state of each metal as it appears in your classroom.
7. Repeat with the selection of non-metals you have been provided with.

Results

Table showing the properties of metals and non-metals

Property	Definition	Metals observations	Non-metals observations
Colour			
Lustre			
Malleability			
Ductility			
State at room temperature			

Discussion: Analysis

1. Did you notice any patterns or trends with your results? Did the metals all share the same properties? Did the non-metals all share the same properties? Were there any exceptions?
2. Imagine you discover a new element. What other tests would you perform in order to determine if you had discovered a metal or a non-metal?

Conclusion

1. Draw a conclusion from this experiment about the properties of metals and non-metals, by copying and completing this statement in your science book.

   From this activity it can be claimed that ____________. This is supported by the observations that ____________. Therefore, the hypothesis *is/is not* supported by these findings.

WORKSHEET
Elements, compounds and mixtures

Quick check 4.2

1. **Define** the following key terms: element, metal, non-metal, metalloid, malleability, lustre, conductivity, ductility. Provide examples where possible.
2. **Demonstrate** your knowledge of metals and non-metals by rewriting the following properties in the correct columns.

Metals	Non-metals
Solid, liquid or gas	Usually dull
Usually in the solid state	Lustrous surface
Usually unable to conduct electricity or heat	Can conduct electricity and heat
Ductile	Unable to be made into a wire
Low melting temperature	Malleable
High melting temperature	Unable to bend

Section 4.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

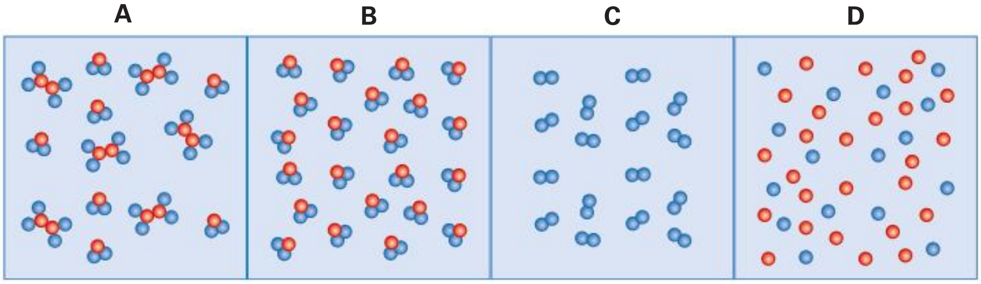
Section 4.1 questions

Remembering

1. **Define** the terms 'pure substance' and 'mixture', providing examples of each.
2. **Recall** three properties of metals and three properties of non-metals.
3. **State** what holds two or more atoms together in a molecule.
4. **Identify** the missing word in this sentence: A molecule consists of two or more ______________ bonded together.

Understanding

5. Look at diagrams A to D below. **Identify** which diagram is:
   a) an element
   b) a compound
   c) a mixture of elements
   d) a mixture of compounds



Applying

6. **Summarise** three of the tests you can do to find out whether a substance is a metal or a non-metal.
7. Here are the answers to some questions: properties, atom, compound, conduct electricity. **Write** two possible questions for each answer, taking care to demonstrate your understanding.

Analysing

8. **Distinguish** between:
   a) an atom and a molecule
   b) an atom and an element
   c) an element and a compound
   d) a molecule and a compound

Evaluating

9. Consider what elements are and what compounds are. **Discuss** why there are many more compounds than there are elements.
10. **Justify** why the metalloids are considered a separate group from the metals and non-metals. Use an example to illustrate your point.

4.2 Organising elements

WORKSHEET
Properties of elements

Learning goals

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

1. Describe how Mendeleev organised elements in his first periodic table, and how this compares to today's version.
2. Identify and name elements according to their symbols.
3. Describe different elemental structures, including monatomic, diatomic, molecules and lattices.

Representing elements as symbols

For all scientists, from all language backgrounds, to understand the language of chemistry, elements are represented by universally understood symbols. These symbols should be clear and unique to each element so that there is no confusion when communicating about elements.

Elements are assigned a 'symbol' made of either a capital letter or two letters where the first letter is capitalised and the second letter is lower case. Usually, the letter used for the symbol is the first letter of the element's name. For example, H is the symbol for hydrogen. Sometimes, the symbol is two letters. For example, helium has the symbol He. This is to ensure it is a unique symbol and can't be muddled up with H for hydrogen. But what about magnesium? Its symbol is Mg, not Ma. Well, there is another element with a similar name, manganese, so to use 'Ma' for either element would cause confusion. Therefore, both elements use the first and third letters of their names for their symbol – magnesium is Mg and manganese is Mn.

Sometimes the letters from the element's Latin or Greek name are used. For example, the symbol for copper is Cu, which comes from the Latin word for copper, *cuprium*. Another example is mercury, which has the symbol Hg, taken from its Latin name, *hydragyrum*, which means 'shining water'. Some elements are also named after famous people or places, like einsteinium and francium. Table 4.2 shows the symbols for the first 20 elements of the periodic table (this is a special chart you will learn about next). Can you identify any symbols that aren't based on the element name?

Element	Symbol	Metal/non-metal	Melting point (°C)	Year of discovery
Hydrogen	H	Non-metal	–259	1766
Helium	He	Non-metal	–272	1895
Lithium	Li	Metal	180	1817
Beryllium	Be	Metal	1278	1798
Boron	B	Metalloid	2300	1808
Carbon	C	Non-metal	3500	Ancient
Nitrogen	N	Non-metal	–210	1772
Oxygen	O	Non-metal	–219	1774
Fluorine	F	Non-metal	–220	1886
Neon	Ne	Non-metal	–249	1898
Sodium	Na	Metal	98	1807
Magnesium	Mg	Metal	650	1755
Aluminium	Al	Metal	660	1825
Silicon	Si	Metalloid	1410	1824
Phosphorus	P	Non-metal	44	1669

Table 4.2 The first 20 elements, their symbols and some of their properties

Element	Symbol	Metal/non-metal	Melting point (°C)	Year of discovery
Sulfur	S	Non-metal	119	Ancient
Chlorine	Cl	Non-metal	–101	1774
Argon	Ar	Non-metal	–189	1894
Potassium	K	Metal	64	1807
Calcium	Ca	Metal	850	1808

Table 4.2 *(continued)*

Quick check 4.3

1. **Explain** why not all the elements use the first letter of their name as their symbol.
2. **Recall** the reason for using symbols for elements instead of the elements' full names.
3. Refer to Table 4.2 with the 20 elements listed.
    a) **Name** the elements with the following symbols: K, S, Mg, Be, B.
    b) **Identify** the element with the lowest melting point.
    c) **Identify** the most recently discovered element.
4. **Connect** each element name below to its correct symbol.
   Names: hydrogen, carbon, oxygen, nitrogen, helium, sulfur, magnesium, aluminium
   Symbols: Mg, O, Al, S, N, H, C, He

WORKSHEET
Elements in our world

Periodic table

An organised list of all the known elements and their symbols is called the **periodic table** (see Figure 4.11). It shows the elements in order from lightest to heaviest according to their atomic number (with some exceptions) and even clearly shows which elements are metals, which are non-metals and which are metalloids.

periodic table
an organised list of all the known elements and their symbols

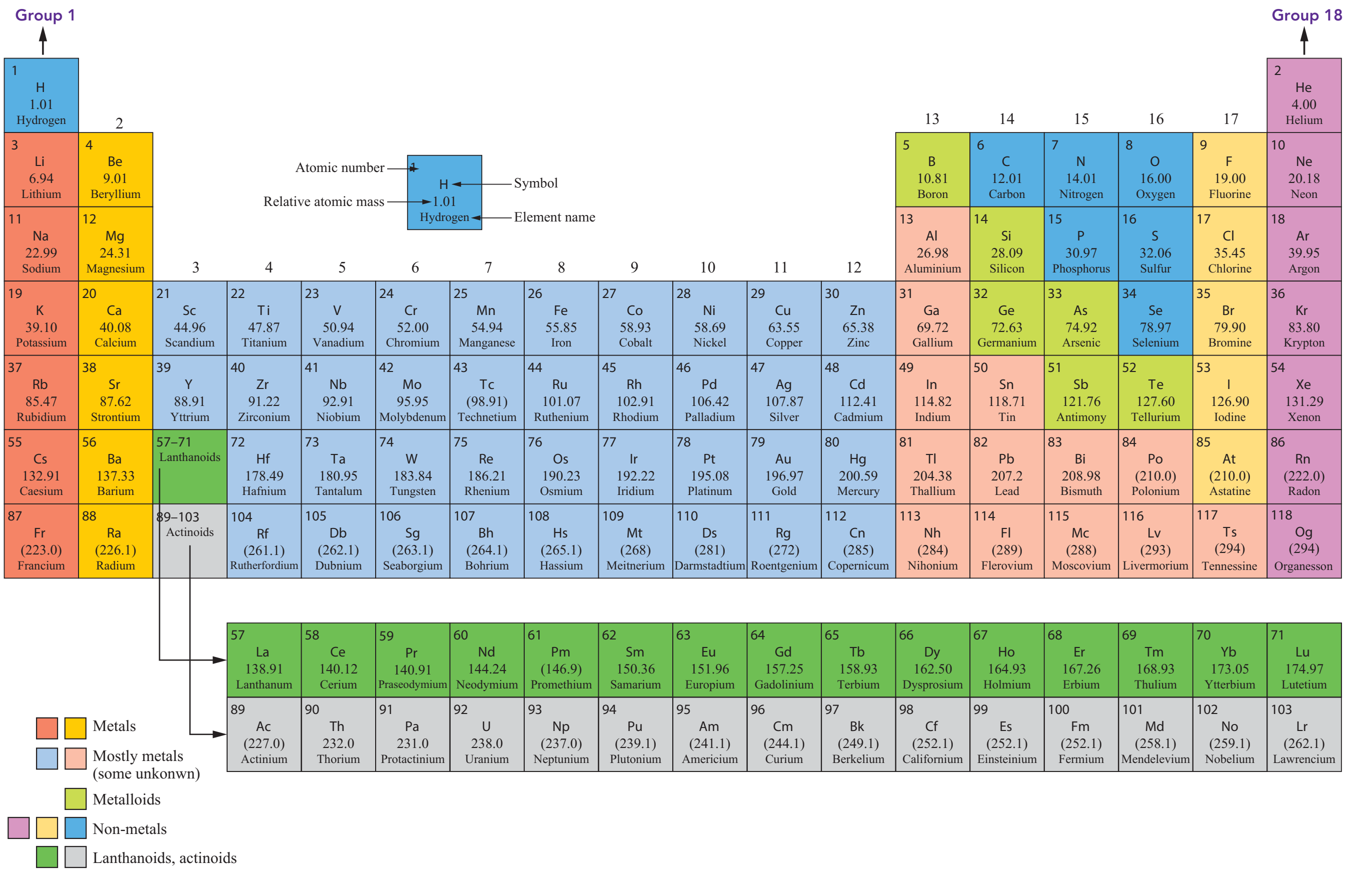


Figure 4.11 This periodic table includes all 118 known elements. See Appendix for a larger version of the periodic table.

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The modern periodic table displays not only elemental data, but also many trends, including metallic character and chemical reactivity. This form of the periodic table, with its characteristic shape, wasn't created overnight – there were many iterations with ideas from many great scientists and philosophers.

Try this 4.3

Identifying metals, non-metals and metalloids

Look at the periodic table in Figure 4.11. Use the legend to identify all six metalloids. What colour are they in the periodic table?

Next, identify some of the metals you know. Where are they in relation to the metalloids? What about the non-metals – where are they positioned in the periodic table?

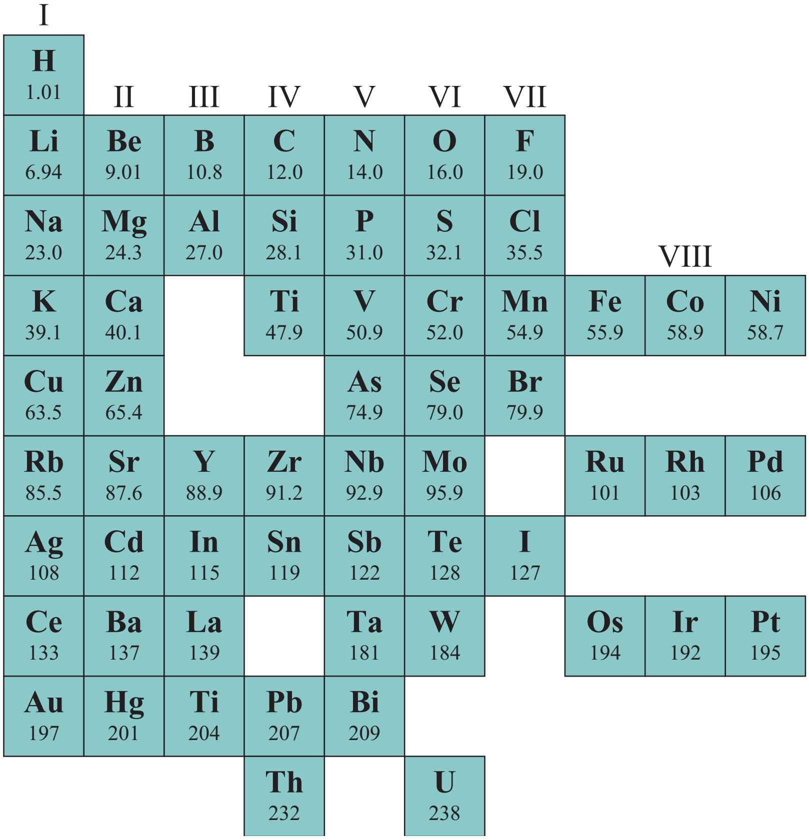
Explore! 4.2

Mendeleev's periodic table

Dmitri Mendeleev was a Russian scientist who is often called the 'father of the periodic table' after he proposed the novel 'periodic system' in 1869.

Use the internet to research the following questions:

1. Why did Mendeleev arrange the known elements in the vertical groups shown in Figure 4.12, with some blank spaces?
2. How is the organisation of elements in Mendeleev's periodic table similar to the modern periodic table used today? How is it different?
3. Research the following scientists who all contributed to the development of the periodic table prior to Mendeleev: John Dalton, Johann Wolfgang Döbereiner, Alexandre-Émile Béguyer de Chancourtois and John Newlands.



I	II	III	IV	V	VI	VII	VIII		
H 1.01									
Li 6.94	Be 9.01	B 10.8	C 12.0	N 14.0	O 16.0	F 19.0			
Na 23.0	Mg 24.3	Al 27.0	Si 28.1	P 31.0	S 32.1	Cl 35.5			
K 39.1	Ca 40.1		Ti 47.9	V 50.9	Cr 52.0	Mn 54.9	Fe 55.9	Co 58.9	Ni 58.7
Cu 63.5	Zn 65.4			As 74.9	Se 79.0	Br 79.9			
Rb 85.5	Sr 87.6	Y 88.9	Zr 91.2	Nb 92.9	Mo 95.9		Ru 101	Rh 103	Pd 106
Ag 108	Cd 112	In 115	Sn 119	Sb 122	Te 128	I 127			
Ce 133	Ba 137	La 139		Ta 181	W 184		Os 194	Ir 192	Pt 195
Au 197	Hg 201	Ti 204	Pb 207	Bi 209					
			Th 232		U 238				

Figure 4.12 Mendeleev's first periodic table was proposed in 1869.

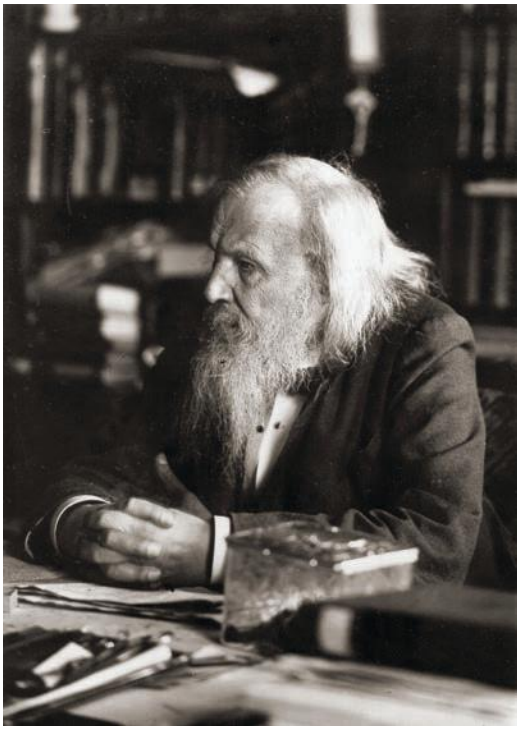


Figure 4.13 Dmitri Mendeleev is considered the father of the modern periodic table.

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Did you know? 4.2

Mendeleev loved card games!

Dmitri Mendeleev was known to have been a keen card player. It is said that he wrote the name of each element and their weight on separate playing cards and then sorted them as though he was about to play solitaire. It makes sense that he used cards as a way to organise the elements as this is what he understood and was familiar with. You may notice that you have a way you most like to work too.

Quick check 4.4

1. **Describe** what the periodic table is.
2. The symbols in the periodic table that start with C or S are listed below. **State** the full element name for each symbol.

C	Cd	Si	Sb
Cl	Cs	S	Sm
Ca	Ce	Sc	
Cr	Cm	Se	
Co	Cf	Sr	
Cu		Sn	

WORKSHEET
Naming elements

ISBN 978-1-009-60327-0

Practical 4.2

Flame tests

Be careful
Ensure appropriate personal protective equipment is worn.

Aim

To investigate the colour that a flame will turn when an element is heated and use this information to determine the metal element in three unknown samples.

Materials

- heatproof mat
- Bunsen burner
- flame test wires × 10
- 5 mol L^{-1} hydrochloric acid in five test tubes, labelled with the test solutions below
- known test solutions in test tubes:
  - barium (barium chloride)
  - copper (copper(II) chloride)
  - sodium (sodium chloride)
  - calcium (calcium chloride)
  - strontium (strontium chloride)
  - unknown samples × 3

Method

1. Check if your flame wires are clean by holding the metal loop in the hottest part of the blue Bunsen burner flame. If it is not clean, a coloured flame will appear, so clean it by dipping it into the hydrochloric acid provided and then holding the loop in the Bunsen burner flame again.
2. Dip the clean flame test loop into one of the known test solutions, then hold the metal loop in the hottest part of the Bunsen burner flame. Record the colour of the flame in your results table.
3. Clean the flame test wire, then test another known test solution. Keep going until you have recorded the colour for all the known solutions.
4. Flame-test the four unknown solutions and record their flame colours in a second results table.
5. Work out which metals are in each of the unknown samples and record them in your table.

Figure 4.14 This substance burning in the flame of a Bunsen burner produces an orange flame

Results

Table showing the flame colours of known substances

	Barium	Calcium	Copper	Strontium	Sodium
Flame colour					

Table showing the flame colour of each unknown substance, and the metal indicated by the colour

	Sample 1	Sample 2	Sample 3
Flame colour			
Metal			

Discussion: Analysis

1. Suggest why a blue flame, not a yellow flame, on the Bunsen burner is necessary.
2. List the elements that produced the most easily identified colours. Were there any colours that were tricky to identify?
3. Based on your observations, would this method be useful to determine the identity of metals that are in a *mixture*? Why or why not?
4. Give at least two reasons why the flame test may not always provide the right answer.

Discussion: Evaluation

1. Describe some sources of error for this experiment and the improvements you would make if you were to repeat this task.

A closer look at the structure of elements

While elements are made up of only one single type of atom, those atoms can arrange themselves in different ways. Section 4.1 mentioned how the atoms of an element can exist as single atoms (**monatomic**) or chemically bonded as molecules. But they can even form larger three-dimentional structures called **lattices**.

Monatomic elements

Monatomic means ‘single atom’. A monatomic element is made up of single atoms that are not chemically combined. The only elements that take this form are known as the noble gases and include helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Can you see where these elements all sit in the periodic table? (Refer back to Figure 4.11.)

Molecules

Some elements chemically bond to form **diatomic elements**. These molecules have two atoms of the same type bonded together. Common examples of diatomic elements include hydrogen gas (H_2) and oxygen gas (O_2). You can use a mnemonic to help you remember the elements that exist as diatomic molecules, such as this commonly used one: **H**ave (hydrogen) **N**o (nitrogen) **F**ear (fluorine) **O**f (oxygen) **I**ce (iodine) **C**old (chlorine) **B**erries (bromine).

Other elements exist in **polyatomic** form. Sulfur exists as S_8 and phosphorus exists as P_4. Oxygen can also exist as ozone (O_3).

Some examples of different molecular elements are shown in Figure 4.15. As you look at the diagram, it is important to notice not only the range of molecules but also how to write the chemical formula for elements that are molecules. For example, look at the oxygen molecule. It has two oxygen atoms, so we write O_2, where O is the elemental symbol for oxygen, and the subscript 2 shows how many atoms are joined by bonds in the molecule. O_3 is therefore three atoms of oxygen chemically bonded together.

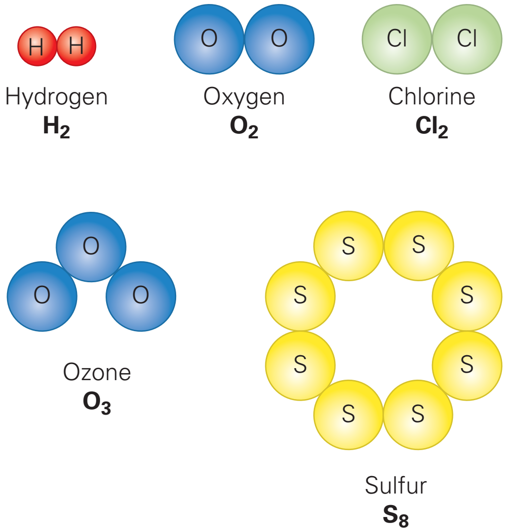

Figure 4.15 Some elemental molecules: hydrogen, oxygen, chlorine, ozone and sulfur. You may notice that these elements are all non-metals.

Lattices

All metals in their solid state (and some non-metals, such as carbon and silicon) are organised in what we call a lattice formation. A lattice is a three-dimensional shape that allows the atoms to pack together very tightly and form strong bonds. The bonds are strong because the atoms bond to each other in multiple directions, and so it is hard to separate them completely.

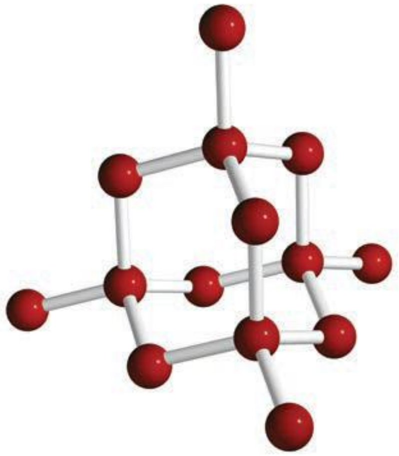

Figure 4.16 A lattice structure: every atom is attached tightly to other atoms in multiple directions.

monatomic
an element that exists as single atoms, all of one type

lattice
a three-dimensional shape of atoms that pack together very tightly and form bonds that are extremely strong because the atoms bond to each other in multiple directions

diatomic element
an element that exists as a molecule consisting of two atoms of the same type

polyatomic element
an element that exists as a molecule containing more than two atoms of the same type

Quick check 4.5

1. **Describe** the three ways in which elements can be structured.
2. **Draw** a simple diagram to show the arrangement of atoms in each of the three ways described in Question 1.

VIDEO Forms of carbon

Explore! 4.3

Forms of carbon

Carbon is an element that occurs in many different forms. Each form consists solely of carbon atoms, but the way the atoms are organised differs. This affects the properties of the different forms.

1. Investigate one of the hardest substances in the world: diamond. Find out its uses and its properties.
2. Investigate the substance that is in the middle of your pencil: graphite. Find out its uses and its properties.
3. Investigate the coolest-sounding molecules: buckyballs. Find out their uses and their properties.
4. Compare the structure of the lattices of diamond, graphite and buckyballs. Do this by describing what each looks like and include a sketch.

Science as a human endeavour 4.2

Figure 4.17 Aboriginal and Torres Strait Islander Peoples use the cultural knowledge of the properties of materials found on Country.

Aboriginal and Torres Strait Islander Peoples' material culture

Material culture is a term used in the scientific community to refer to the physical aspects of the objects that surround people, that is, the relationships between people and their things.

Aboriginal and Torres Strait Islander Peoples have passed down ancestral knowledge about the properties and uses of different elements and the materials that contain them for millions of years. Their knowledge of the interconnectedness of all living things (connection to Country) allows a deep and sophisticated knowledge of the use of the properties of plant and animal life for food, clothing and medicine, as well as tools, such as grinding stones, coolamons and fish traps.

Thus, a vast material culture has existed in many Aboriginal and Torres Strait Islander cultural groups over many generations.

Making thinking visible 4.2

Generate-sort-connect-elaborate: Elements

1. Generate a list of terms that come to mind when you think about Sections 4.1: *Atoms and elements* and 4.2: *Organising elements*.
2. Sort your terms according to how central or tangential they are. Place central ideas near the centre and more tangential ideas towards the outside of the page.
3. Connect your terms by drawing lines between the terms that have something in common. Explain and write in a short sentence how the terms are connected.
4. Elaborate on any of the terms you have written so far by adding new terms that expand, extend or add to your initial terms.

You may like to continue generating, connecting and elaborating new terms and ideas as you move through the next section.

The *Generate-sort-connect-elaborate* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Section 4.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 4.2 questions

Remembering

1. **State** the chemical symbol for the following elements.
   - a) carbon
   - b) oxygen
   - c) hydrogen
   - d) silicon
   - e) sodium
   - f) copper
   - g) chlorine
   - h) potassium
2. **Identify** the names of these elements.
   - a) Ag
   - b) Au
   - c) Sn
   - d) Si
   - e) Hg
   - f) Li
   - g) Zn
   - h) Pb
3. **Name** all the elements in the periodic table that have symbols beginning with A.

Understanding

4. **Select** the appropriate word from the list to complete the sentences below:
   compound, symbol, properties, sulfur, pure, letters, carbon dioxide, periodic table, atoms
   - a) ____________ cannot be separated or broken down any further chemically.
   - b) An element's name can be written as a ____________, which consists of one or two ____________.
   - c) Elements are organised in the ____________.
   - d) When two or more different elements are chemically combined, the end result is a ____________.
   - e) ____________ is an example of an element and ____________ is an example of a compound.
   - f) Elements and compounds are called ____________ substances because they have specific chemical and physical ____________.
5. Using the periodic table as a reference, **identify** each of the following as either an element (E) or a compound (C).
   - a) silver
   - b) water
   - c) chalk
   - d) plastic
   - e) tin
   - f) silicon dioxide
   - g) chromium
   - h) arsenic
   - i) carbon dioxide
   - j) sodium chloride (table salt)

Applying

6. **Classify** the following elements as monatomic, molecular or lattice: helium, diamond, hydrogen, aluminium, oxygen, argon, chlorine, copper, neon

Analysing

7. **Distinguish** between a monatomic element and a molecular element.
8. **Distinguish** between a molecular element and a lattice. Include examples in your answer.

Evaluating

9. We use symbols to describe elements. **Propose** the reasons why we do this.

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4.3 Compounds and mixtures

Learning goals

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

1. Name a chemical compound using naming conventions and formulas.
2. Distinguish homogeneous and heterogeneous mixtures.
3. Explain why mixtures are represented by percentages or ratios and not chemical formulas.

Compounds

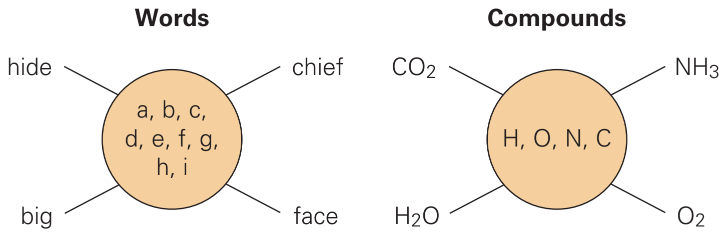

Figure 4.18 Elements are like the letters of the alphabet – letters can form thousands of words, and elements can form millions of compounds.

As we learned in Section 4.1, when two or more different types of atoms chemically bond together, a chemical compound is formed. For example, water is a compound – it is made up of two hydrogen atoms covalently bonded to one oxygen atom, so it has two different types of atoms. Just as the 26 letters of the alphabet can form thousands of words, elements can form millions of compounds. And, just like there are rules we need to follow when we form words from letters, there are rules we need to follow when making compounds from elements.

Grouping compounds

Compounds can be *covalent* or *ionic* – these terms describe the types of bonds that hold the compound together.

Covalent compounds consist of units called molecules (e.g. water) while ionic compounds consist of units called ions (e.g. sodium chloride). The properties of a compound are affected by the elements that are in the compound, the types of bonds between atoms and how they are arranged. For example, the properties of carbon vary depending on the arrangement of the carbon atoms. You learned about some of the different forms of carbon in Explore! 4.3: graphite, diamond and buckyballs. Hydrogen has the following properties: it is colourless, odourless, non-toxic and highly combustible. However, the properties of the compounds formed from carbon and hydrogen combined are very different from the two elements on their own. Figure 4.19 shows examples of the uses and properties of compounds made of only carbon and hydrogen.

Figure 4.19 Substances that contain only carbon and hydrogen include **(a)** butane (in lighter fluid), **(b)** polymers (plastic waste) and **(c)** octane (a component of petrol).

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A closer look at the structure of compounds

The atoms in compounds can be arranged in three different ways: as a discrete and small molecule, a **polymer** or a lattice. These are summarised in Table 4.3.

polymer
a long molecule made of a chain of atoms in a pattern that repeats

Arrangement	Description	Examples
Small molecule	Groups of atoms held together by covalent bonds. A particular compound always has the same elements in the same ratio and these molecules are generally called 'discrete' due to being distinctly separate from one another, unlike in polymers and lattices.	Carbon dioxide (CO_2) Water (H_2O)
Polymer	A long molecule made of a chain of atoms in a pattern that repeats	Plastics Natural fibres (e.g. cotton) Proteins
Lattice	A three-dimensional continuous network of atoms in a fixed arrangement, held together by chemical bonds. However, most compounds that exist as lattices are ionic, so the lattices are made up of positive and negative ions rather than atoms.	Sodium chloride (NaCl) Silicon dioxide (SiO_2)

Table 4.3 The atoms in a compound can be arranged into a small molecule, a polymer or a lattice.

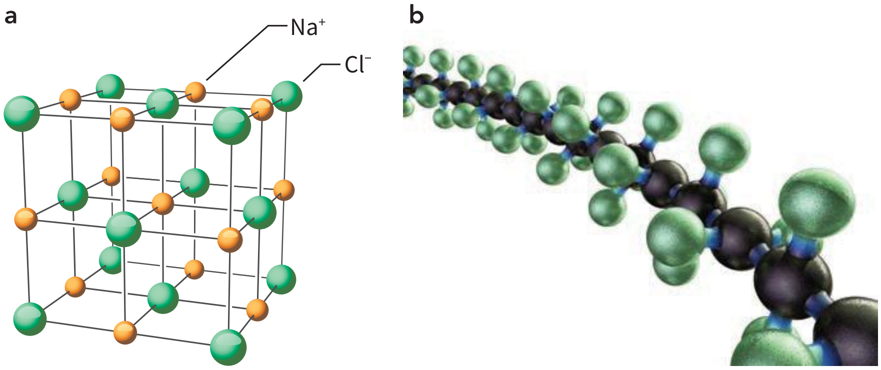

Figure 4.20 **(a)** Sodium chloride (NaCl) in lattice arrangement and **(b)** Teflon polymer arrangement

Putting it all together

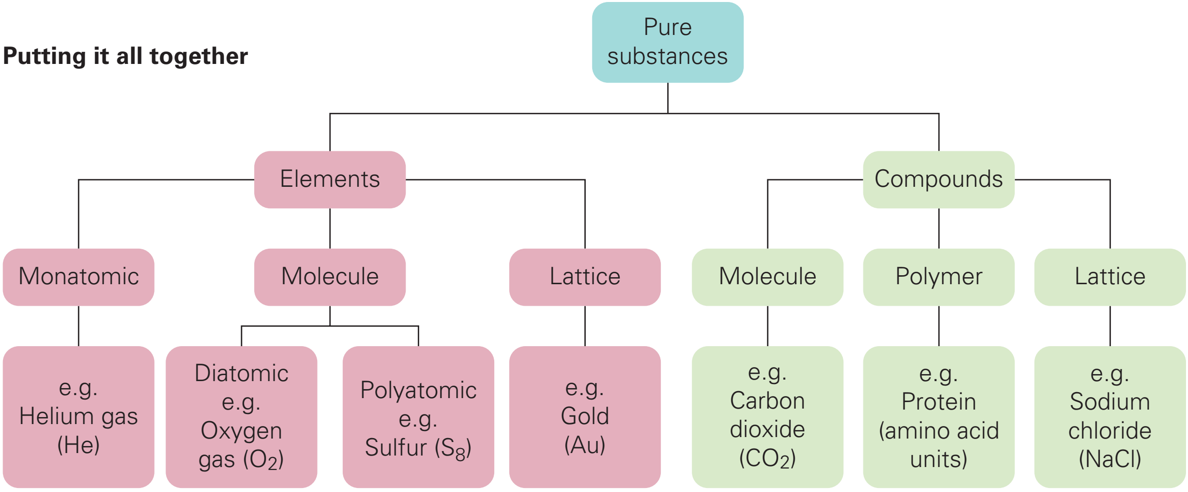

Figure 4.21 Putting it all together: the different arrangements of atoms in elements and in compounds

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VIDEO
Polymers and bioplastics

Science as a human endeavour 4.3

Bioplastics

For over 100 years, humans have been developing polymer plastic products for use in a plethora of circumstances, including food packaging, electronics and other consumer products. However, when these materials are disposed of in landfill, they take thousands to millions of years to degrade! This issue sparked the Victorian Government to ban the supply of lightweight plastic shopping bags in 2019, and in 2023 the ban was expanded to include plastic drinking straws, plates, cutlery, drink stirrers and some plastics from personal care products, such as cotton buds.

Figure 4.22 Cotton buds with plastics stems are banned from supply as of 2023, to promote the production of biodegradable alternatives.

This is all part of the CSIRO's Circular Economy Roadmap for Australia. Unlike a traditional linear economy, where we take things from the environment, make them into something and then dispose of them, a circular economy aims to stop waste from being produced in the first place and keep our resources and materials in circulation for longer through repair, reuse and recycling. For example, single-use plastics can be replaced with much more environmentally friendly biodegradable or biobased products, which degrade when placed in soil or landfill. Biodegradable products can be broken down in the soil to produce biomass, carbon dioxide and water, while biobased materials are sourced from biomass, which naturally decays when placed in the earth.

By placing bans on non-degradable plastic products, the Victorian Government is making an informed decision to promote biodegradable and environmentally friendly alternatives, and reduce landfill.

Did you know? 4.3

Polymer banknotes

In 1988, Australian scientists at CSIRO developed the first polymer banknotes, and they were introduced to the general population. These polymer-based Australian banknotes start out as plastic pellets, which are melted and blown into a bubble three storeys high! The walls of the bubble are pressed together and cooled to form laminated polymer films. Since the introduction of polymer banknotes in Australia, they are now used in over 30 countries in the world, including our neighbours, New Zealand and Indonesia.

Figure 4.23 Australian, Indonesian and New Zealand polymer banknotes

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Quick check 4.6

1. **Compare** and **contrast** the terms 'compound' and 'molecule'.
2. **Explain** why the properties of elements and the compounds made up of those elements are different.
3. **Name** two examples of compounds that have a molecular structure, two that have a polymer structure and two that have a lattice structure.

Representing compounds as formulas

A **chemical formula** is a shorthand way of representing the elements that are in a compound. The formula tells you which elements are present in the compound and how many atoms of each element are present in one molecule or one basic unit of that particular compound.

chemical formula a symbol for a compound that shows which elements, and how many atoms of each element, are present in one molecule or one basic unit of that compound

For example:

- Carbon dioxide, found in the air, has the chemical formula CO_2. This means that one covalent molecule of the compound carbon dioxide has two elements in it: carbon (C) and oxygen (O). There is one carbon atom and two oxygen atoms covalently bound to each other.
- Sodium sulfate, found in common detergents, is an ionic compound and has the chemical formula Na_2SO_4. This means that one basic unit of the compound has three elements in it: sodium (Na), sulfur (S) and oxygen (O). Each basic unit of sodium sulfate contains two atoms of sodium, one atom of sulfur and four atoms of oxygen.

What if the formula has brackets in it? Consider the compound aluminium carbonate. Its formula is $Al_2(CO_3)_3$. The brackets tell us that there is more than one CO_3 unit. In this case, there are three units of CO_3. So, from the formula, we can see that there are three elements in each basic unit of this compound: aluminium (Al), carbon (C) and oxygen (O). Each unit of aluminium carbonate is made of two atoms of aluminium, three atoms of carbon and nine atoms of oxygen.

Figure 4.24 Sodium sulfate is a compound used in common household detergents.

Try this 4.4

Ethanoic acid

Consider the compound ethanoic acid, CH_3COOH, more commonly known as vinegar. First, identify the elements in one basic unit of the compound and then how many atoms there are of each of the elements.

Naming compounds

When naming a compound, there are some general rules to follow depending on whether the compound contains a metal and a non-metal or only non-metals. Note that there are some exceptions to these rules, but the exceptions will be learned in future school years.

Metal and non-metal compounds

1. If there is a metal in the compound, it gets named first. For example, $CaCl_2$ is calcium chloride. Calcium is the metal, so it is named first.
2. If the non-metal present is a single element, it will usually be named with a suffix, -ide. Again, consider $CaCl_2$. As the non-metal present is only chlorine, it will be named second as chlor*ide*.

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3. When the non-metal component of a metal and non-metal compound contains more than one element, it usually takes a special name ending in -ate. Some common examples include: nitrate (NO_3), carbonate (CO_3), sulfate (SO_4) and phosphate (PO_4). For example, $CaCO_3$ would be named calcium carbonate.

Non-metal-only compounds

1. When a compound contains only non-metals, such as oxygen (O) and chlorine (Cl), the start of the second element word changes based on how many atoms there are in the compound. For example, CO_2 contains one carbon atom and two oxygen atoms, and so the second word starts with the prefix di- and the compound is called carbon dioxide. Another example would be the compound CO, which would be named carbon monoxide, as the second element starts with the prefix mono-. Table 4.4 summarises the prefixes used, depending on how many atoms of the second element there are in the compound.
2. In some cases, there is more than one atom of the first non-metal element present, and in these cases the prefix is also used for the first element. For example, H_2O would be named dihydrogen monoxide, although you will be more familiar with its common name of water!
3. If the prefix ends in an ‘a’ and the start of the element name starts with a vowel, the ‘a’ can be dropped from the name. For example, N_2O_4 would be dinitrogen tetroxide (rather than tetraoxide).

Number of atoms of second element	Prefix (start) of second element word	Example
1	Mono-	Monochloride
2	Di-	Dichloride
3	Tri-	Trichloride
4	Tetra-	Tetrachloride
5	Penta-	Pentachloride

Table 4.4 Prefix used at the start of the second element when naming compounds containing only non-metals

Quick check 4.7

1. Complete the following table to **identify** the elements and number of atoms present in each compound.

Compound	Scientific name	Formula	List of elements	Number of atoms of each element
Natural gas	Methane	CH_4	Carbon Hydrogen	C 1 H 4
Petrol	Octane	C_8H_{18}		
Alcohol	Ethanol	C_2H_6O		
Aspirin	Acetylsalicylic acid	$C_9H_8O_4$		
Eggshells	Calcium carbonate	$CaCO_3$		
Alum	Aluminium sulfate	$Al_2(SO_4)_3$		

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2. **State** the formula for each of the following compounds:
   a) hydrochloric acid – contains one atom of hydrogen and one atom of chlorine
   b) glucose – a sugar, contains six carbon atoms, 12 hydrogen atoms and six oxygen atoms
   c) rust – contains two atoms of iron and three atoms of oxygen.
3. **Determine** the names of the following compounds:
   a) one carbon atom and four chlorine atoms
   b) two hydrogen atoms and one oxygen atom
   c) one magnesium atom and one oxygen atom

Practical 4.3

Making a compound

Be careful
Do not look directly at the reaction. The reaction is very bright and can damage your eyes. Wear safety glasses.

VIDEO
Practical 4.3
Making a compound

Aim

To make a compound from two elements and to practise using elemental symbols and naming compounds

Materials

- strip of magnesium ribbon (approximately 5 cm)
- fine sandpaper
- crucible with lid
- pipeclay triangle
- safety glasses
- tongs
- Bunsen burner and matches
- heatproof mat

Method

1. Examine the strip of magnesium and record its properties. If it isn't shiny and clean, gently use the sandpaper to remove any imperfections from the surface.
2. Coil the ribbon up and place it in the crucible with the lid. Place the crucible on the pipeclay triangle, as shown in Figure 4.25.
3. Put on your safety glasses. Heat the crucible with a blue flame and, every so often, monitor the reaction using the tongs to carefully lift the edge of the crucible lid. Ensure you do not look directly at the reaction.
4. When the reaction has finished, the magnesium ribbon will no longer be recognisable. Turn off the Bunsen burner and let the crucible cool down.
5. Record what you see in the crucible.

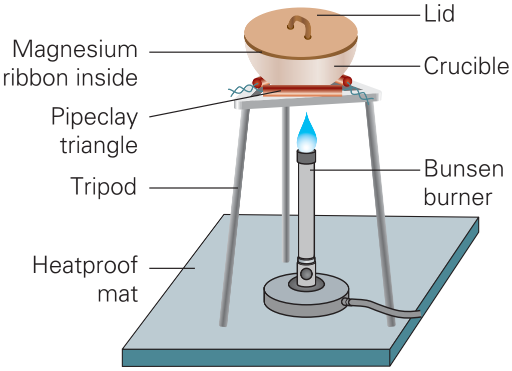

Figure 4.25 Experimental set-up

Results

Record your observations.

Discussion: Analysis

1. Magnesium is an element. What is its elemental symbol?
2. When magnesium is heated, it reacts with something. What is the other element, and what is its elemental symbol?
3. Describe what you saw in the crucible after heating and decide whether it is an element or a compound. Explain your answer.
4. Work out the chemical formula for this compound and the name of the substance formed in the crucible.

Practical 4.4

Breaking down a compound

Be careful

Safety glasses must be worn at all times.

Wash hands thoroughly at the end of the experiment.

Aim

To investigate the breakdown of copper carbonate

Materials

- copper carbonate ($CuCO_3$)
- limewater
- straw
- large test tubes × 3
- Bunsen burner
- matches
- heatproof mat
- wooden tongs
- paper towel
- retort stand and clamp
- delivery tube and stopper
- spatula

Method

1. Half-fill a test tube with limewater. Using the straw, blow into the limewater so it bubbles. Record your observations when CO_2 from your breath is bubbled through limewater.
2. Use the diagram in Figure 4.26 as a guide to the steps that follow.

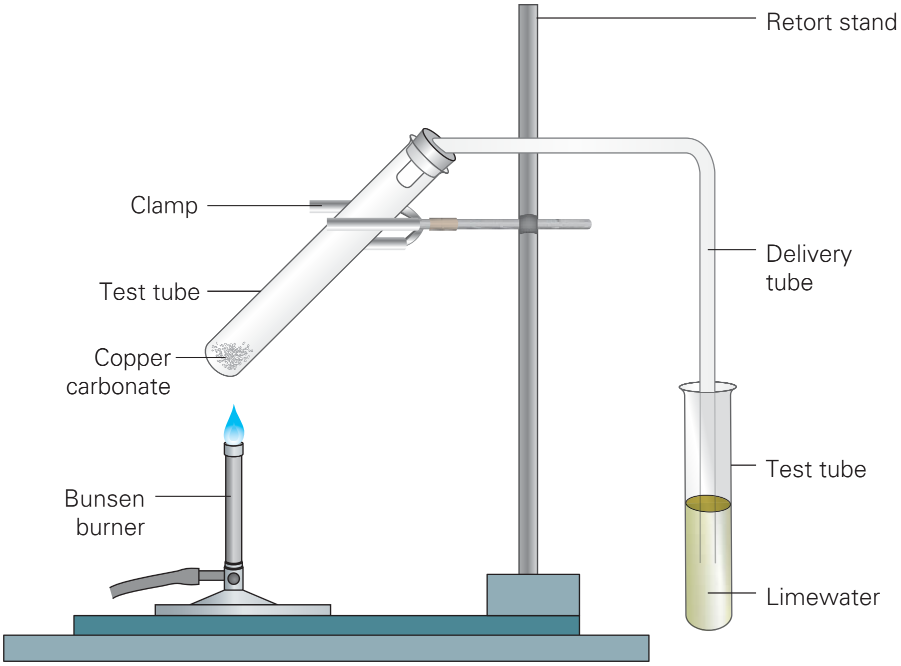

Figure 4.26 Experimental set-up

3. Place a small amount of the copper carbonate in a large test tube and fit it with the gas delivery tube and stopper. Clamp the test tube to a retort stand.
4. Record the appearance of the copper carbonate.
5. Half-fill another test tube with limewater and place the gas delivery tube in it.
6. Using a small blue flame on the Bunsen burner, gently heat the copper carbonate.
7. Observe and record the changes in the copper carbonate and the limewater.
8. Remove the limewater solution before turning off the Bunsen burner.
9. Allow to cool.

Results

Record your observations of the limewater after bubbling, the copper carbonate before heating, and the substance and the limewater after heating.

continued …

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Discussion: Analysis

1. What caused the change in the limewater when you blew into it? What is the chemical formula of this substance?
2. Describe the copper carbonate before and after heating. Mention the changes you observed in the limewater. List the chemical formulas for copper carbonate before and after heating.
3. What is the evidence that copper carbonate is a compound and not an element?
4. Why is it important to remove the delivery tube from the limewater as soon as heating is stopped?
5. Why do some gas bubbles pass through limewater when heating is first started?

Discussion: Evaluation

1. Identify any limitations in the practical.
2. Suggest some improvements for this experiment.

Mixtures

Recall that a compound or a molecule is not a mixture as the atoms are joined with chemical bonds. A mixture is the name given to a material or substance made up of two or more types of pure substances that are not chemically joined. This means that the components of a mixture can be separated. Some examples of mixtures that you may be familiar with are soft drinks (a mixture of sugar, water, carbon dioxide, flavouring and colouring), a cup of tea (a mixture of tea leaves and water), tap water (a mixture of water, oxygen, carbon dioxide and dissolved ionic compounds) and spaghetti bolognaise (a mixture of tomatoes, beef, garlic and herbs).

Figure 4.27 This salad is an example of a mixture – the components are not chemically combined, and so they can be separated.

Mixtures have different properties from those of compounds, as there is no chemical bond between the parts of a mixture. Table 4.5 summarises the differences between compounds and mixtures.

In Year 7, you learned that mixtures can be broadly classified into two categories: **homogeneous mixtures** and **heterogeneous mixtures**.

homogeneous mixture describes a mixture of two or more substances that are evenly distributed and do not separate out easily

heterogeneous mixture describes a mixture that can be separated into its parts, and the parts retain their original properties; the mixture is not blended evenly

	Compound	Mixture
Components	Contains two or more elements	Contains two or more elements or compounds
Bonding between atoms	Elements are chemically bonded together	Elements/compounds are not chemically bonded together
Properties	The compound has properties that are different from the properties of the elements it contains	Each substance in the mixture keeps its own properties
Separation	Most compounds can be separated into their elements using chemical decomposition reactions	Each substance can be separated out of the mixture by a physical process
Ratio of different atoms	Elements occur in strict ratios to each other	Substances in the mixture can occur in any ratio
Classification	A compound is always homogeneous	A mixture can be homogeneous or heterogeneous
Examples	Water, baking soda, salt	Muddy water, sugar solution, milk, blood

Table 4.5 The differences between a compound and a mixture

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Homogeneous mixture

Homogeneous mixtures are those where you cannot tell that two or more substances have been mixed together, as they don't separate out when left to stand. The components of the mixture are all evenly distributed, so the entire mixture has the same properties. A type of homogeneous mixture where a **solute** is dissolved in a **solvent** is called a **solution**.

Examples: air, water, chocolate pudding, soft drink.

Figure 4.28 Apple juice is an example of a homogeneous mixture where the components stay evenly distributed.

Heterogeneous mixture

Heterogeneous mixtures are not blended together evenly and are not the same consistency throughout. So, if you took samples from different parts of the mixture, the samples would contain different amounts of the substances making up the mixture. Heterogeneous mixtures that have components not evenly distributed include **colloids**, and **suspensions**.

Examples: fresh orange juice, choc-chip cookies, mayonnaise.

Figure 4.29 Blood is an example of a heterogeneous mixture as it contains solid and liquid components that can be separated by centrifuging.

solute
a substance that dissolves in a solvent to form a solution

solvent
a liquid substance that dissolves a solute to form a solution

solution
a liquid mixture in which the solute is dissolved and uniformly distributed within the solvent

colloid
a mixture in which particles of one chemical substance will not dissolve but remain distributed throughout another chemical substance

suspension
a mixture in which one chemical substance will eventually settle out of the solvent

WORKSHEET
Compounds and mixtures

Putting it all together

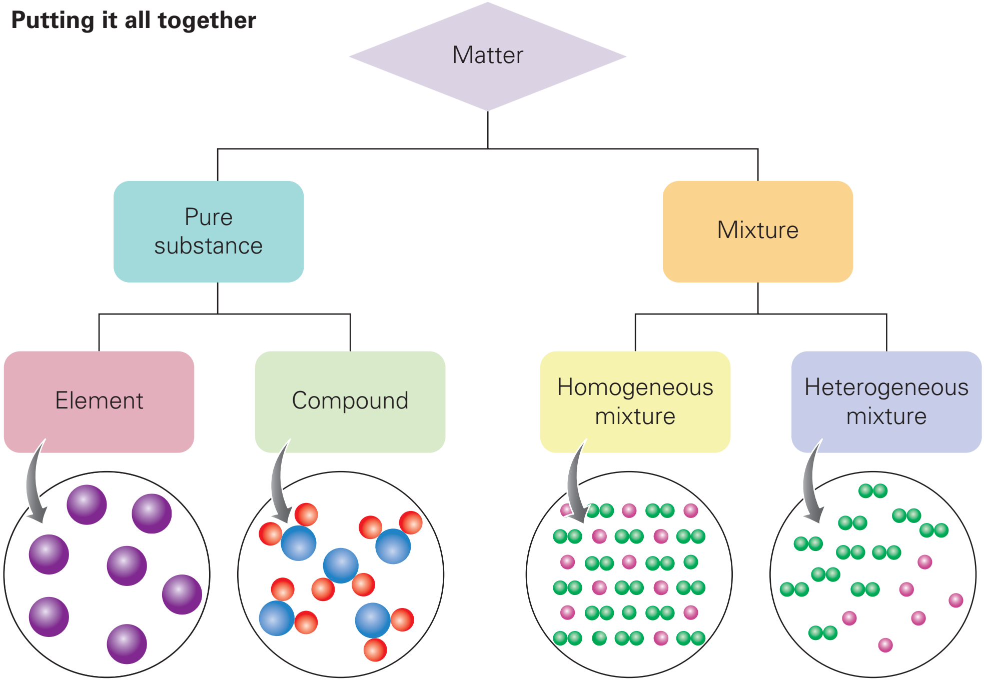

Figure 4.30 Putting it all together: Matter consists of pure substances and mixtures. In this chapter, you have learned about both of these groups.

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Representing mixtures as percentages or ratios

You know how to write symbols for elements and formulas for molecules and compounds, but what about mixtures? Mixtures do not have a chemical formula as the elements are not chemically combined. Instead, they are represented by a percentage composition or a ratio of each pure substance. The pure substances in a mixture retain their original symbols or chemical formulas.

Let's look an example of how this works. The simplest unit of the compound sodium chloride is made up of one Na atom and one Cl atom. Thus, its chemical formula is NaCl. Similarly, the molecular compound water is made up of two H atoms and one O atom in its simplest chemical formula. Thus, its chemical formula is H_2O. Now, a brine solution (NaCl dissolved in H_2O) could be described as having 25% NaCl by mass or even one part NaCl to three parts H_2O (or 1:3, NaCl:H_2O). Remember, mixtures are not represented by elemental symbols being combined, such as with compounds. This would suggest that the elements are chemically bonded, but in mixtures they are not.

Figure 4.31 Adding table salt (NaCl) to water (H_2O) creates a mixture. The two compounds might interact, but they do not chemically combine.

Practical 4.5

Sulfur and iron: Element, mixture and compound

Be careful
To be conducted in a fume hood or well-ventilated area. Wear safety glasses, gloves and lab coats.

Aim

To investigate the properties of two elements, iron and sulfur, as elements, a mixture and a compound

Hypothesis

Write a hypothesis about the relationship between the properties of elements, mixtures and compounds. Begin with, 'It is hypothesised that…'.

Materials

- iron filings
- sulfur powder
- Pyrex test tube
- mineral wool
- watch glass × 4
- retort stand, boss head clamp and retort clamp
- 100 mL beaker with water × 4
- magnet and cling wrap
- Bunsen burner, heatproof mat and matches
- spatula
- PPE

Method

1. Begin by drawing up the results table in your workbook and carrying out a risk assessment.
2. Place 1 teaspoon of sulfur in a watch glass (elemental sulfur) and 1 teaspoon of iron filings in another (elemental iron).
3. Place 1 teaspoon of iron filings and 1 teaspoon of sulfur into the same watch glass and gently mix (iron and sulfur mixture).
4. Describe the colour of the elemental iron, the elemental sulfur and the iron and sulfur mixture. Record your observations in your results table.

continued …

5. Using a magnet wrapped in cling film, move the magnet over the iron filings, then the sulfur and then the iron and sulfur mixture. The cling film may need to be removed between each observation and anything magnetic returned to its watch glass before the cling film is reapplied. Record your observations in your results table.
6. Using the waft test you learned in Year 7, record any observations of smell in your results table.
7. Tip the iron filings in the watch glass into a beaker of water. Record your observations in your results table. Repeat with the sulfur and then with the iron and sulfur mixture.

Steps 8–11 will need to be carried out by your teacher.

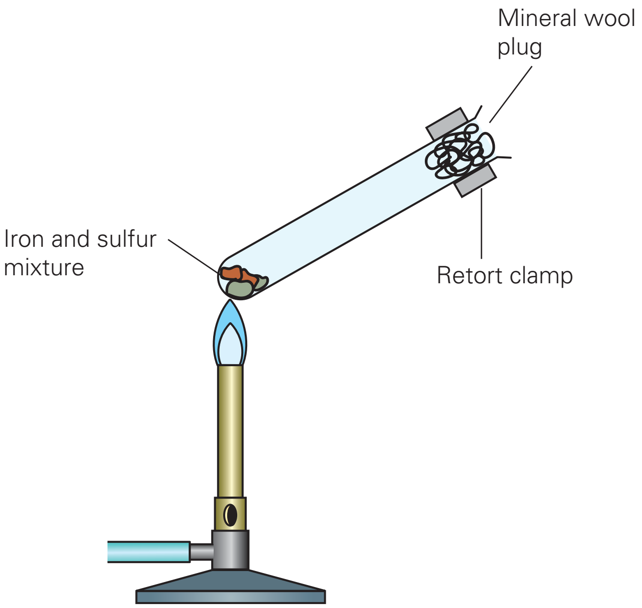

Figure 4.32 Experimental set-up

8. *Use a spatula to place two scoops of sulfur and two scoops of iron filings into the Pyrex test tube. Use the mineral wool to plug the end of the test tube.*
9. *Set up the retort stand, boss head clamp and retort clamp in the fume hood, with a heatproof mat and Bunsen burner.*
10. *When ready, place the Pyrex test tube in the retort clamp as shown in Figure 4.32.*
11. *Using the blue heating flame, heat the mixture until it turns red. Leave it to cool.*
12. Repeat steps 4–7 using the compound made by your teacher. Record all observations in your results table.

Results

Table showing the properties of sulfur and iron as elements, in a mixture and as a compound

Property	Elemental iron	Elemental sulfur	Iron and sulfur mixture	Iron sulfide compound
Colour				
Magnetic				
Odour/smell				
Soluble in water				

Discussion: Analysis

1. Define the terms ‘element’, ‘mixture’ and ‘compound’.
2. What are the chemical symbols for sulfur, iron and iron sulfide?
3. How did the properties of the elemental iron and the elemental sulfur compare to the properties of the iron and sulfur mixture?
4. Explain how you knew the mixture of iron and sulfur was a mixture and not a compound. Use your understanding of bonding, properties and separation.

Conclusion

1. Draw a conclusion from this experiment about the properties of elements, mixtures and compounds, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that ____________. Therefore, the hypothesis *is/is not* supported by these findings.

Section 4.3 review

Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 4.3 questions

Remembering

1. Read each of the following statements and **identify** whether it applies to compounds or mixtures.
   a) The substances in it are not chemically bonded.
   b) The substances in it are chemically bonded.
   c) Each substance keeps its own properties.
   d) Its properties are not the same as the properties of the elements that make it up.
   e) The substances can be separated by chemical means only.
   f) The substances can be separated by physical methods.
2. **State** the chemical formula for the following compounds:
   a) marble, which contains one calcium atom, one carbon atom and three oxygen atoms
   b) propane, which contains three carbon atoms and eight hydrogen atoms
   c) sucrose, which contains 12 carbon atoms, 22 hydrogen atoms and 11 oxygen atoms

Understanding

3. **Identify** the names of the following compounds:
   a) sand, which contains one silicon atom and two oxygen atoms
   b) Epsom salts, which contain one magnesium atom, one sulfur atom and four oxygen atoms
   c) one phosphorus atom and three chlorine atoms

Applying

4. **Describe** the following key terms, related to the arrangement of atoms in compounds: molecule, polymer, lattice.

Analysing

5. **Compare** the properties of a heterogeneous mixture to those of a homogeneous mixture.

Evaluating

6. A tiny sample of quartz contains 1 000 000 atoms of silicon and 2 000 000 atoms of oxygen. **Determine** what the formula would be, based on this information.
7. Substances A, B and C were tested and were found to have the following chemical compositions: (A) 70% oxygen, 30% carbon; (B) 60% hydrogen, 40% carbon; (C) 60% oxygen, 40% carbon. **Deduce** if any two of these substances are the same compound. Give reasons for your answer.
8. a) **Determine** the correct answers to complete the following table.

Name	Formula	Number of different elements in the compound	Number of atoms in each molecule
Water	H_2O	2	3
	CO		
Sulfuric acid	H_2SO_4		
Nitrogen monoxide	NO		
Dinitrogen monoxide			
Methanol	CH_4O		

   b) **Describe** the difference between nitrogen monoxide and dinitrogen monoxide.
   c) **Explain** which is bigger: a molecule of sulfuric acid or a molecule of carbon monoxide.
   d) **Describe** the ways in which dinitrogen monoxide and water are similar.

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Chapter review

Chapter checklist

Success criteria		Linked questions
4.1	I can define the following key terms: atom, molecule, element, pure substance, compound, mixture.	1, 3, 5, 14
4.1	I can distinguish between metals, non-metals and metalloids.	9
4.1	I can identify and create two-dimensional and three-dimensional representations of elements, molecules, compounds and mixtures.	6, 8
4.2	I can describe how Mendeleev organised elements in his first periodic table and compare it to today's version.	4, 11
4.2	I can identify and name elements according to their symbols.	2, 14, 15
4.2	I can describe elemental structures, including monatomic, diatomic, molecular and lattice structures.	6, 10
4.3	I can name a chemical compound using naming conventions and formulas.	12, 13, 15
4.3	I can distinguish between homogeneous and heterogeneous mixtures.	3, 7
4.3	I can explain why mixtures are represented by percentages or ratios and not chemical formulas.	15

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Identify** the difference between a compound and an element.
2. **Identify** the correct symbol for each element name.
   Symbols: O, C, He, Br, Au, Zn, H, S, Na, Mg
   Names: sodium, hydrogen, oxygen, helium, magnesium, carbon, bromine, sulfur, zinc, gold

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Understanding

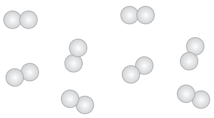
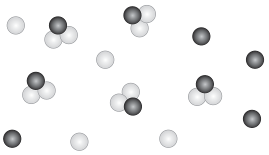
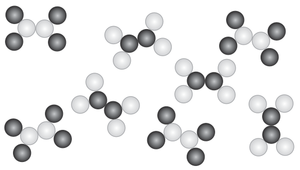
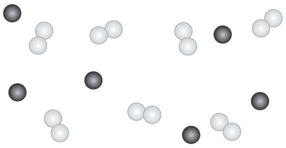
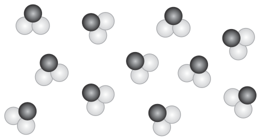
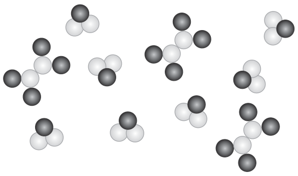
3. **Identify** the correct word to complete the blanks in the following sentences.
   a) Elements are pure substances containing only one kind of ____________.
   b) All known elements are listed and classified in the ____________.
   c) In compounds, the atoms are ____________ combined using bonds.
   d) The properties of a compound are usually ____________ to the properties of the elements it contains.
   e) Mixtures contain two or more ____________ or ____________ that are not chemically combined.
   f) Mixtures can be uniform (called ____________).
   g) Mixtures can also be non-uniform (called ____________).
   h) The properties of a mixture are ____________ to the properties of its components.
   i) A ____________ is an example of a homogeneous mixture.
   j) A fizzy drink that is 5% sugar is an example of a ____________, not a compound.

Applying

4. **Explain**, using examples, how the properties of an element relate to its use.
5. **Explain** why carbon dioxide does not appear in the periodic table.
6. **Summarise** the arrangement of atoms in an element, a compound and a mixture.

Analysing

7. **Distinguish** between a homogeneous mixture, a heterogeneous mixture and a chemical compound.
8. **Classify** each of the following substances as an element, a compound, a mixture of elements, a mixture of compounds or a mixture of elements and compounds. Some of the substances are named, and some are provided as diagrams.

a)	Chicken soup	b)	Bismuth (Bi)
c)	Dry ice (CO_2)	d)	Concrete
e)		f)	
g)		h)	
i)		j)	

9. **Compare** the properties of metals and non-metals.
10. Sodium chloride (NaCl) has a lattice arrangement of atoms, whereas oxygen gas (O_2) is a diatomic molecule. **Describe** the difference between these structures.

Evaluating

11. **Describe** how Mendeleev's first periodic table provided a scaffold for the development of the modern periodic table used today.
12. Methane (natural gas), hexane (solvent in glue for shoes) and octane (petrol) are substances that contain only carbon and hydrogen. **Deduce** why they are all so different.
13. **Determine** the correct answers to complete the following table.

Name of compound	Formula	Number of elements in the compound	Name of the elements in the compound	Number of atoms in the compound
Magnesium oxide	MgO	2	Magnesium, oxygen	2
	FeS			
Potassium oxide	K_2O			
	$FeSO_4$			
Benzene	C_6H_6			
	Al_2O_3			
	SO_3			

14. We can use the letters of the alphabet to make up words, sentences, paragraphs and more. Using this analogy, what would best represent compounds, mixtures and elements – letters, words or paragraphs? **Justify** your answers.
15. **Propose** why elements and compounds can be represented by chemical formulas, but mixtures are represented by percentages or ratios.

Data questions

Refer to the melting points and boiling points for various elements shown in Table 4.6 and Figure 4.33.

Element	Classification	Melting point (°C)	Boiling point (°C)
Carbon	Non-metal	3550	4827
Nitrogen	Non-metal	–210	–196
Oxygen	Non-metal	–219	–183
Helium	Noble gas	–272	–269
Neon	Noble gas	–249	–246
Fluorine	Halogen	–220	–188
Chlorine	Halogen	–102	–34
Bromine	Halogen	–7	59
Iodine	Halogen	114	184
Magnesium	Metal	650	1091
Iron	Metal	1538	2861
Nickel	Metal	1455	2913
Copper	Metal	1085	2560
Silver	Metal	962	2162
Platinum	Metal	1768	3825
Gold	Metal	1064	2836
Mercury	Metal	–39	357

Table 4.6 Classification, and melting and boiling point of various elements

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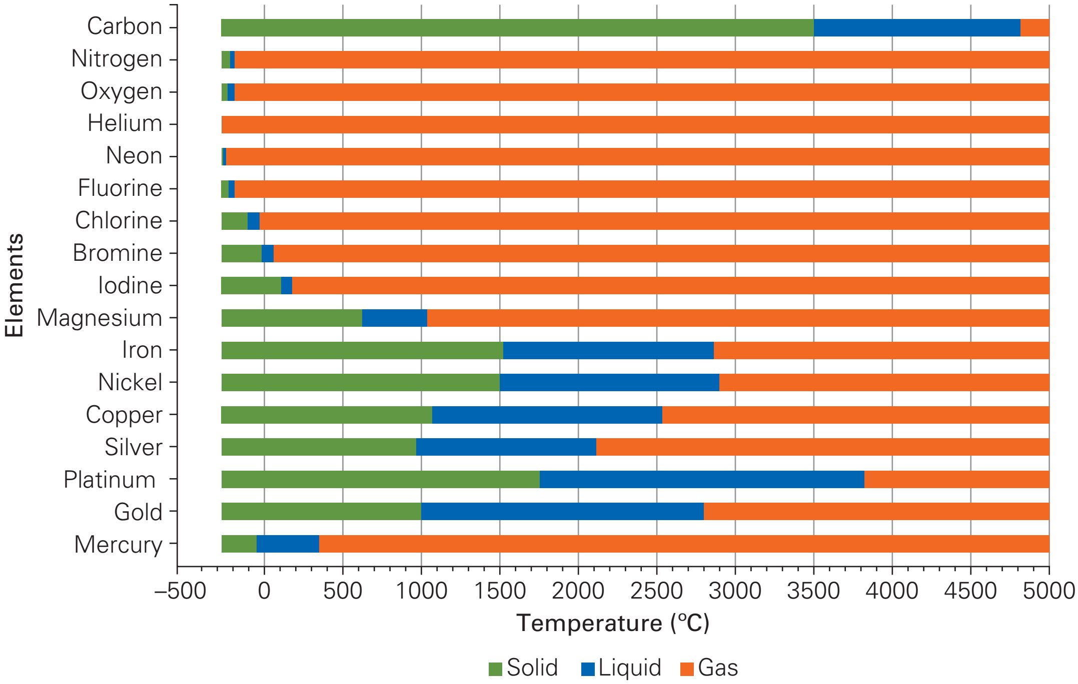

Figure 4.33 States of various elements at different temperatures

Applying

1. **Calculate** the difference in temperature between the melting and boiling point of elemental mercury.
2. **Identify** the element with the lowest melting point.
3. **Name** the elements in Table 4.6 that are classified as halogens.

Analysing

4. **Contrast** the general melting point of the noble gases and the metals in Table 4.6.
5. **Identify** the element where the data does not match that of similarly classified elements.
6. **Categorise** the halogen elements as either 'gas at 25°C' or 'not gas at 25°C'.

Evaluating

7. **Compare** the temperature range for which each metal is present in the liquid state.
8. Given the data in Table 4.6, **deduce** whether the noble gases can exist in the liquid state.
9. Argon is another noble gas element. **Predict** whether the boiling point of elemental argon is closer to 3000°C, 100°C or –150°C.

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STEM activity: Prosthesis design

Background information

Your skeleton protects your organs and gives your body shape and structure. Your skeleton is necessary for you to move, make blood cells, store calcium and more. You would look very different without it. For various reasons, not everyone has all the bones that complete their skeleton. Biomedical engineers can help in this area. They apply engineering principles and problem-solving strategies to medicine for healthcare purposes. In this case, a biomedical engineer would study the strength and durability of bones so that they can replicate them to make prostheses (artificial devices that replace body parts). Of course, there are criteria and constraints that a biomedical engineer needs to think about when designing, for example, a prosthetic leg. Consider what would be some important features of a good prosthetic leg.

Biomedical engineers design new ways to create prosthetic legs that have all the characteristics you have thought of, but most importantly, biomedical engineers must carefully select the right materials for the project. Whenever something is made by engineers, they must consider both the chemical and physical properties of the materials they use – their choices are key to biomedical technologies.

Figure 4.34 An artificial lower leg

DESIGN BRIEF

Construct a lower-leg prosthesis that can assist in movement.

Activity instructions

In teams, you will become a biomedical engineer and investigate the technology of prosthetics. First, list the characteristics and features that are important for a prosthetic leg, then design your prototype using various ordinary materials that you have selected on the basis of their physical properties, before creating a lower-leg prosthetic prototype. Your team will then demonstrate your prosthetic's strength, analyse your prototype and make suggestions for design improvements.

Suggested materials

- ruler or tape measure
- scissors
- prosthetic structural materials from home, e.g. cardboard tubes, sponges, pants, shoes, rope
- roll of duct tape

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Research and feasibility

1. Conduct research to find out what types of materials are used to manufacture prostheses, the physical properties of the materials and design considerations of the prosthesis.
2. Consider important design factors for the prosthesis, including aesthetics, cost and customisation of the prosthesis. Use a table to rank important considerations of the prosthesis. You can also add other design considerations.

Design consideration	Why this is important?	Rank of importance
Aesthetics (how it looks)		
Cost of materials		
Customisation of the prosthesis		
Useability (how easy it is to use)		

Design

Figure 4.35 An artificial limb restores functionality and independence.

3. Design a lower leg prosthesis and label all the design features. Consider the types of materials you have available, how they will be used in construction and the durability of these materials compared to the materials used in manufacturing. Also, ensure your design is practical and considers how the prosthesis would be attached to the limb and how it allows ankle movement.

Create

4. Construct the lower leg prosthesis you have designed using the materials available.

Evaluate and modify

5. Create a reflection chart containing positives, negatives and interesting observations, and evaluate your constructed lower-leg prosthesis prototype. Make sure you reflect on the strength, durability, useability and comfort of the prototype.

Positives	Negatives	Interesting
e.g. Ankle movement is realistic and the ankle has a 60° range.	e.g. Cardboard tubing used was not strong and broke when tested.	e.g. The foam used around the tubing was a strong support for the tubing.

6. Explain the improvements and modifications you would make to the prototype in a presentation to the class.

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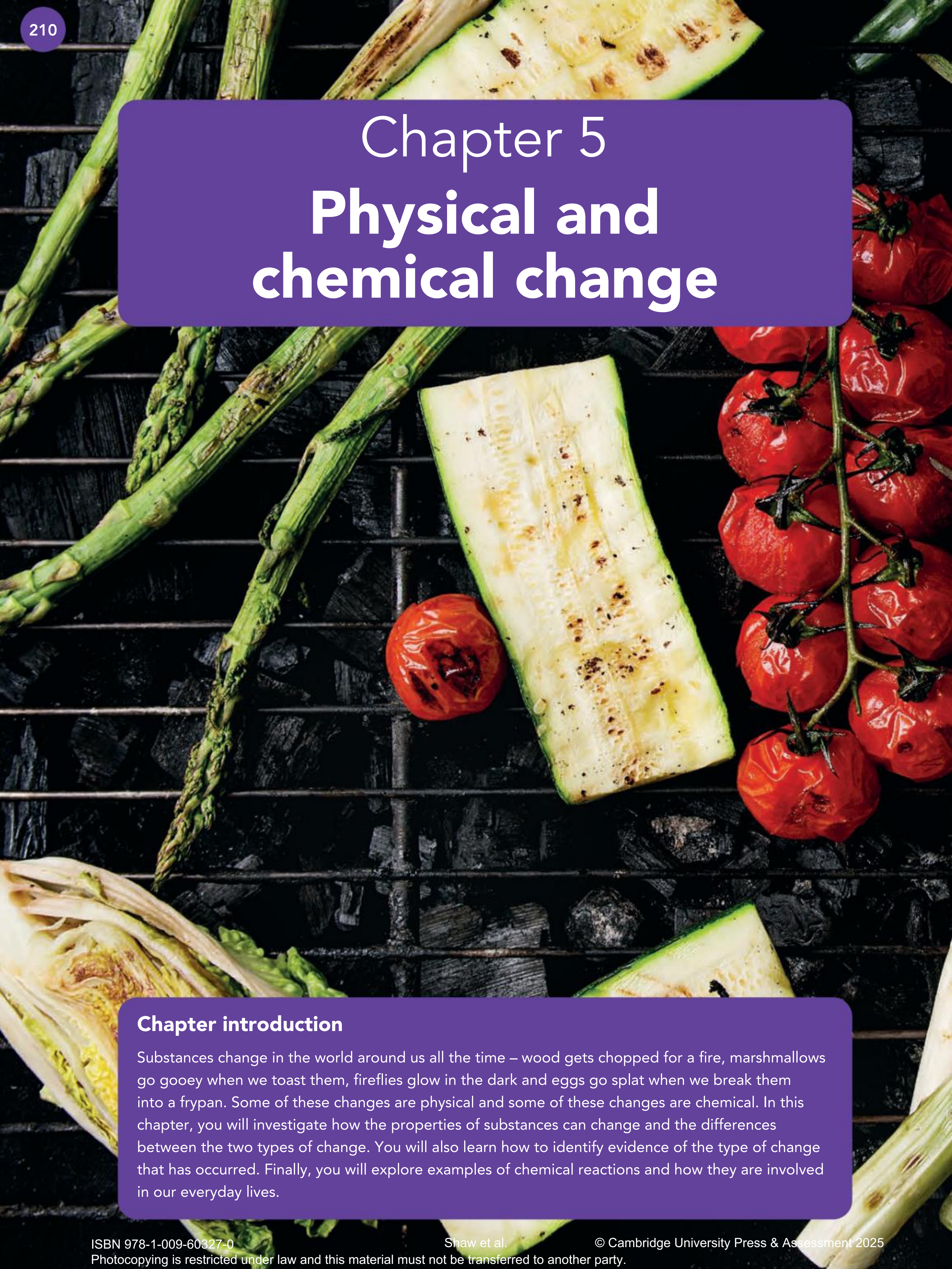


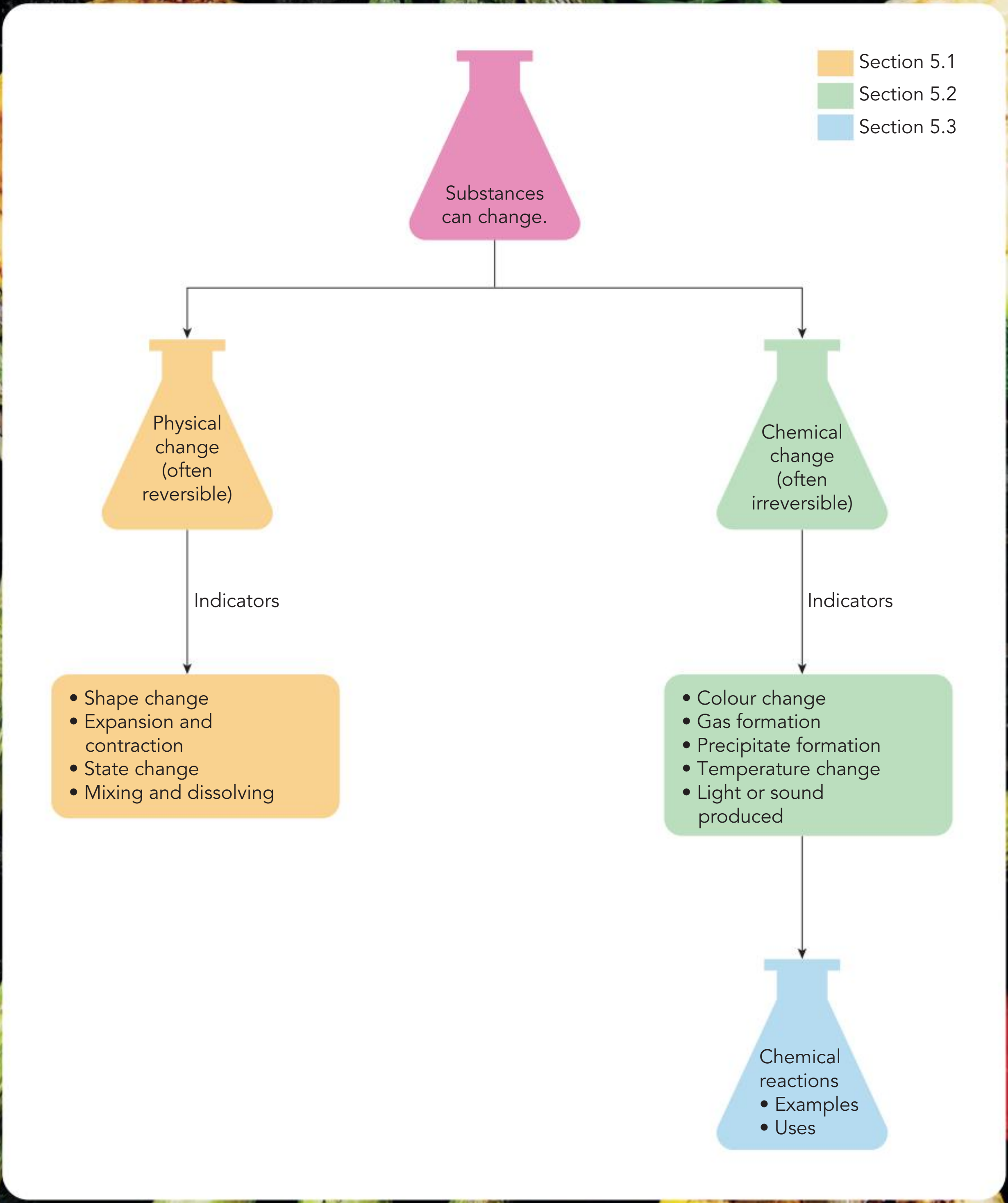
Chapter 5

Physical and chemical change

Chapter introduction

Substances change in the world around us all the time – wood gets chopped for a fire, marshmallows go gooey when we toast them, fireflies glow in the dark and eggs go splat when we break them into a frypan. Some of these changes are physical and some of these changes are chemical. In this chapter, you will investigate how the properties of substances can change and the differences between the two types of change. You will also learn how to identify evidence of the type of change that has occurred. Finally, you will explore examples of chemical reactions and how they are involved in our everyday lives.

Concept map



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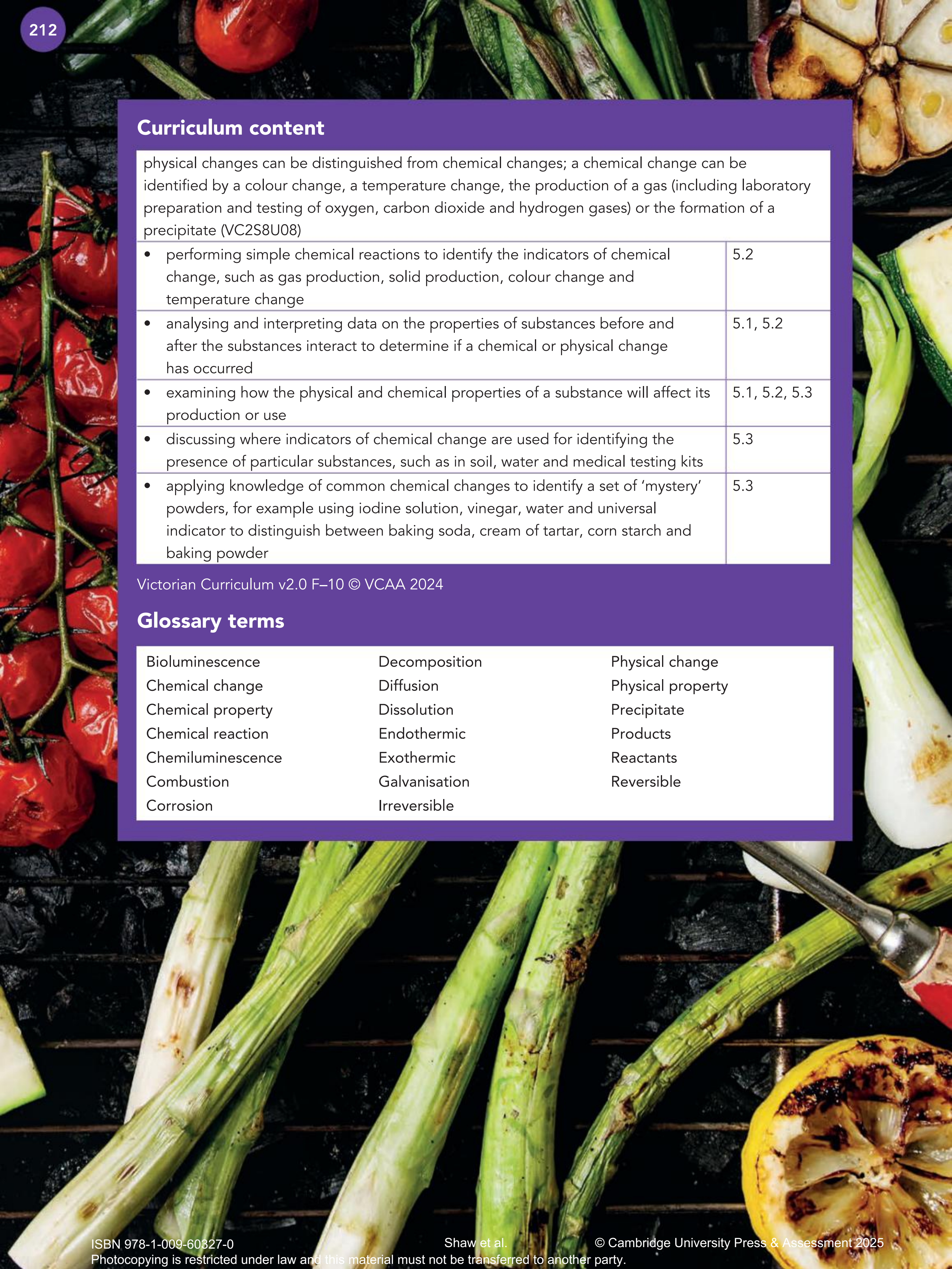

Curriculum content

physical changes can be distinguished from chemical changes; a chemical change can be identified by a colour change, a temperature change, the production of a gas (including laboratory preparation and testing of oxygen, carbon dioxide and hydrogen gases) or the formation of a precipitate (VC2S8U08)	
• performing simple chemical reactions to identify the indicators of chemical change, such as gas production, solid production, colour change and temperature change	5.2
• analysing and interpreting data on the properties of substances before and after the substances interact to determine if a chemical or physical change has occurred	5.1, 5.2
• examining how the physical and chemical properties of a substance will affect its production or use	5.1, 5.2, 5.3
• discussing where indicators of chemical change are used for identifying the presence of particular substances, such as in soil, water and medical testing kits	5.3
• applying knowledge of common chemical changes to identify a set of 'mystery' powders, for example using iodine solution, vinegar, water and universal indicator to distinguish between baking soda, cream of tartar, corn starch and baking powder	5.3

Glossary terms

Bioluminescence
Chemical change
Chemical property
Chemical reaction
Chemiluminescence
Combustion
Corrosion
Decomposition
Diffusion
Dissolution
Endothermic
Exothermic
Galvanisation
Irreversible
Physical change
Physical property
Precipitate
Products
Reactants
Reversible

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5.1 Physical change

Learning goals

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

1. Define physical change and give examples.
2. Identify the indicators of physical change.

VIDEO
Physical change

When scientists talk about matter, they refer to two types of properties: **physical properties** and **chemical properties**. It is the physical and chemical properties that help us identify what substances would be best suited for a particular use. For example, you wouldn't want to wear a t-shirt made of a material that can break (physical property) or reacts with sunlight and catches on fire (chemical property)!

See Table 5.1 for a reminder of what was covered in Year 7.

	Property	
	Physical	**Chemical**
Definition	A characteristic of a substance that can be observed and/or measured without changing it chemically.	A characteristic of a substance that can only be observed and measured by performing a chemical reaction or chemical change.
Examples	Colour, size, solubility, hardness, boiling point, shape, density, conductivity	Flammability, toxicity, corrosiveness, acidity, biodegradability

Table 5.1 The two types of property investigated when we look at matter

However, matter doesn't always stay the same; it can change. There are two types of change we will now explore: physical and chemical.

Physical change

During a **physical change**, the characteristics of a substance, or its physical properties, change in some way, but no new chemical substance is formed. Examples of physical properties that may change are texture, shape, size, colour, odour, volume, mass and density. As the chemical nature of the substance is not changed, physical changes are usually considered to be **reversible**.

physical property a characteristic of a substance that can be observed and/or measured without changing it chemically

chemical property a characteristic of a substance that can only be observed and measured by performing a chemical reaction or chemical change

physical change when the physical properties of a substance change in some way, but no new chemical substance is formed; it is mostly reversible

reversible capable of going in both directions

Indicators of physical change

Indicators or evidence of a physical change can be any one or more of the following:

- a change in shape
- a change in state
- a non-permanent colour change.
- expansion or contraction (change in size)
- mixing or dissolving

Figure 5.1 Evidence that a physical change has occurred: **(a)** change in shape, **(b)** expansion or contraction, **(c)** change in state

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Changing shape

When an object changes shape, it is generally a physical change. For example, when an elastic band is stretched, the physical properties of the elastic band change but its chemical structure does not; no new chemical substance has formed and it is reversible. Think about a soft drink can being crushed. Ask yourself, have its physical properties changed? Has its chemical structure changed? Has anything new been made? Is it reversible? So, is it a physical change?

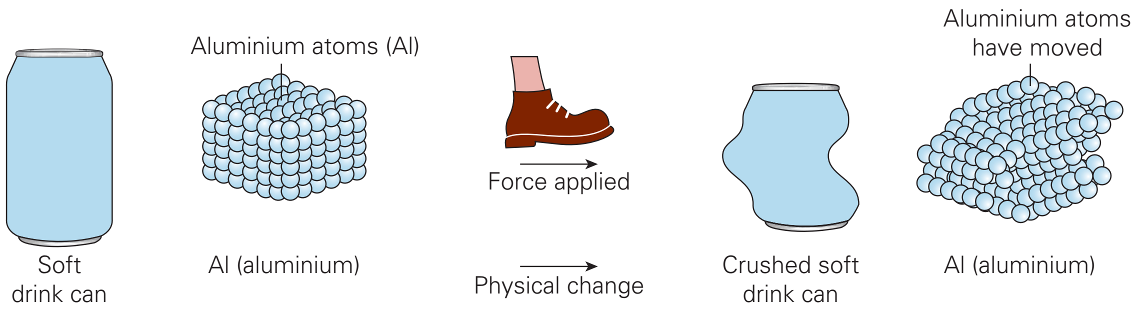

Figure 5.2 When an aluminium can is crushed, the characteristics of the can (its physical properties) have changed, but nothing new is formed. Therefore, it is a physical change.

Figure 5.3 An example of a physical change is when glass breaks: its physical characteristics change, but it is still glass.

Quick check 5.1

1. **Define** the term 'physical change'.
2. **Name** four pieces of evidence to look for when determining whether a physical change has occurred.
3. **Explain** how changing shape is an example of physical change.

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Expansion and contraction

Substances can expand or contract when exposed to changing temperatures. As the particles in a solid, liquid or gas are exposed to a higher temperature, they absorb some of the energy and convert it to kinetic energy. The particles move more rapidly, which causes them to move apart. This is called expansion. Expansion is an example of physical change as the properties of the substance have changed (volume increases and density decreases), but no new chemical substance has formed, and it is reversible. Hot air balloons and thermometers are two examples of where we can see evidence of the physical change, expansion.

The reverse of expansion is contraction, and this is also evidence of a physical change occurring. As the substance cools down, the particles lose energy, they move less rapidly, and the distance between the particles gets smaller (volume decreases and density increases).

Figure 5.4 When the air inside a hot air balloon is heated, the atoms in the heated air gain energy, move faster and move away from one another, taking up more space. This is an example of a physical change occurring and it results in the air being less dense on the inside of the balloon, so the balloon rises.

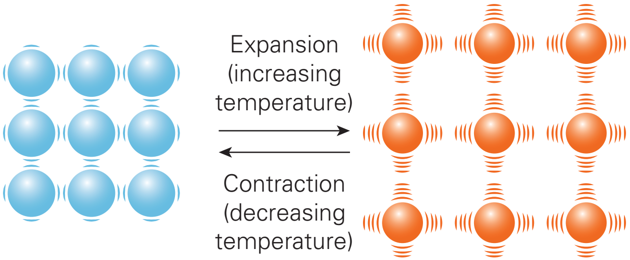

Figure 5.5 The physical changes experienced by atoms during expansion and contraction

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Practical 5.1

Making a model thermometer

VIDEO
Practical 5.1
Making a
model
thermometer

Aim

To demonstrate expansion and contraction by making a model thermometer

Materials

- 250 mL conical flask
- glass tube (or plastic straw)
- red food colouring
- 250 mL beaker
- rubber stopper
- ice or chilled water
- glass thermometer
- ice cream container
- kettle or hotplate
- permanent marker
- water

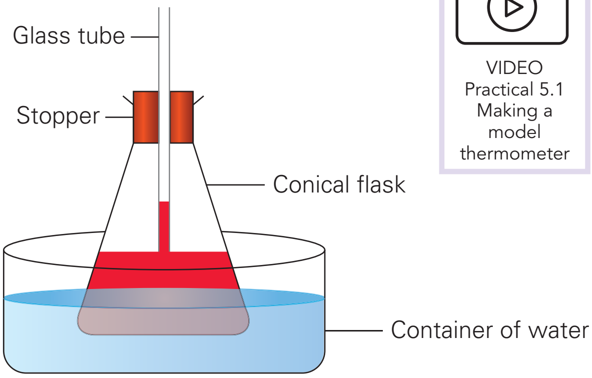

Figure 5.6 Experimental set-up

Method

1. Half-fill the conical flask with water.
2. Add a drop or two of food colouring.
3. Place the glass tube in the flask, but do not let it touch the bottom. Place the rubber stopper in the top of the flask with the tube in the middle. The stopper will hold the tube in place and prevent it from touching the bottom of the flask.
4. On the side of the flask, use a permanent marker to mark the height of the liquid inside the tube (your thermometer) at room temperature. Record the temperature of the room using the glass thermometer.
5. Place the flask into an ice cream container with chilled or iced water and allow it to cool. Record the temperature inside the ice cream container using your glass thermometer and mark the side of the flask to document where the liquid level is up to in your tube.
6. Now heat up some water using a kettle or hotplate and pour into the ice cream container, being careful not to overfill the container. Let the flask sit there for several minutes. If the liquid level has not changed, you may need to pick up the flask, gently swirl and place back into the water. Record the new temperature using the glass thermometer and mark the side of the flask to document where the liquid level is up to in your tube.
7. Make a scale on your model thermometer, using the temperatures you have recorded and the marks you have made on the flask.
8. Now test your model thermometer by using it to predict the temperature of different environments, such as a sunny spot in the school or when you change the ratio of hot and cold water in the ice cream container. Check your predictions with the glass thermometer.

Results

Record your observations and tabulate your results: the temperature of each environment and the height of the fluid in the tube.

Discussion: Analysis

1. Compare your model thermometer results with the actual glass thermometer results. How close are they?
2. Explain your results. Why did the fluid move up/down the tube? Use your knowledge of the atomic theory of matter and physical change to aid in your explanation.
3. Imagine you repeated your experiment but with a narrower tube. How would you expect the measurements to be different for a narrower tube? Explain whether this new thermometer would be likely to be more or less accurate than your first thermometer.

Discussion: Evaluation

1. Outline possible errors in this experiment and explain how each could have affected your results.
2. Suggest improvements for this experiment if you were to carry it out again.

continued …

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Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Changing state

If the temperature change is large enough, atoms can move beyond expansion and contraction and change into another state! You learned about these states in Year 7, and they are solids, liquids and gases. If the heat energy is sufficient, particles in a solid can gain enough kinetic energy to move them far enough apart to form a liquid or even a gaseous state. In contrast, if heat energy is removed, gaseous particles can move closer together to form a liquid or a solid. The different changes of state are summarised in Figure 5.7.

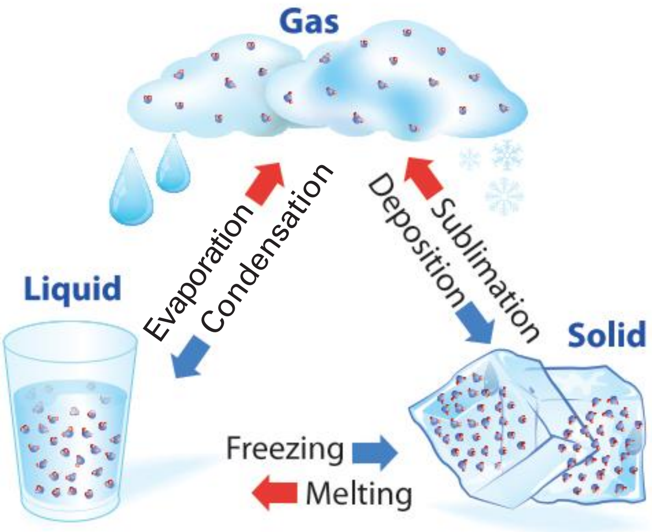

Figure 5.7 When some substances gain or lose heat energy, they undergo a physical change: no new substance is produced. The substance changes its physical properties but is still the same substance.

Figure 5.8 A snowman melting is an example of physical change. Can you explain why?

Figure 5.9 Condensation is an example of a physical change, as no new substance has formed; it is reversible and it is only the physical properties of the water that have altered, not its chemical make-up.

Did you know? 5.1

Physical changes formed Hanging Rock

Mount Diogenes at Woodend in Victoria, better known as Hanging Rock, is located near the traditional boundaries of the Woi Wurrung (Wurundjeri), the Djaara and the Taungurung Peoples. It is a beautiful example of physical changes occurring over a long period of time. The area formed over six million years ago, created by the eruption of thick lava through a narrow vent in the bedrock below. This resulted in steep-sided volcanic structures, where there has been subsequent weathering, erosion, heating and cooling. These are examples of physical change. The geology of Hanging Rock is of national significance, and it is the best example of this type of geological formation in Victoria.

Figure 5.10 Solidification of volcanic lava and physical erosion over millions of years have formed Hanging Rock in Woodend.

Quick check 5.2

1. **Explain** how expansion and contraction are examples of physical change.
2. **Explain** how changing state is an example of physical change.

Mixing and dissolving

dissolution the process where individual molecules of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

diffusion the movement of particles from an area of high concentration to an area of low concentration

Dissolution is a physical change that can occur when you mix substances together, for example, mixing sugar in water. Sugar is the solute that dissolves in the water, which we call a solvent, and this forms a sugary solution. The solute does not evenly distribute itself in the solvent immediately. The particles, in this case sugar, spread out in the water, moving from an area of high concentration of sugar to an area of low concentration of sugar. They keep spreading out until there is an even distribution of sugar throughout the water. This process is called **diffusion**. When the sugar is evenly spread out in the water, there are still the particles of sugar and the particles of water, but they are now mixed with each other. The physical characteristics of the sugar have changed from a crystalline, solid structure to one where all the sugar molecules can move around freely in the water. No new chemical substance has been formed, and the process is reversible if you evaporate the water. This is why mixing and dissolving are considered evidence of physical change.

DOC
WORKSHEET
Dissolving substances

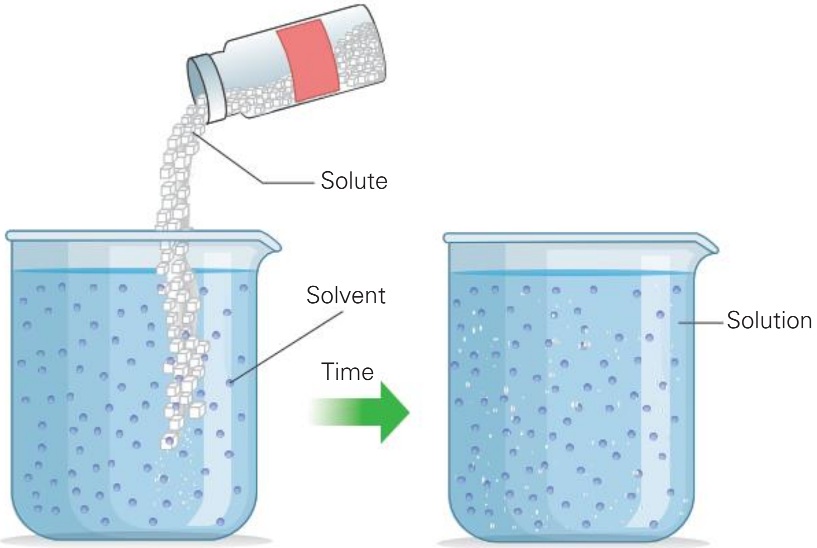

Figure 5.11 Molecules of water (blue) move randomly in a beaker. Add sugar (white) and the new, dissolved molecules will eventually become distributed uniformly throughout the water. This is diffusion.

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Making thinking visible 5.1

See, think, wonder: Diffusion

1. Observe a tea bag being added to some hot water. What a handy use for a physical change!
2. What do you think is happening to the particles to cause the change in appearance? How long does the change take to complete?
3. Thinking like a scientist, what questions do you have about the physical change taking place?

Figure 5.12 A tea bag in hot water demonstrates diffusion.

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

Quick check 5.3

1. **Explain** how mixing and dissolving are examples of physical change.
2. **Identify** which of the following are physical changes.
   a) slicing bread
   b) flicking a light switch
   c) breaking an egg
   d) mowing grass
   e) setting off fireworks
   f) breaking glass
   g) freezing water
   h) cutting hair
   i) making a fire
   j) drying clothes
   k) burning toast
   l) melting chocolate
   m) colouring hair
   n) yoghurt going past its use-by date
   o) popping popcorn
   p) squeezing an orange

Try this 5.1

Modelling physical changes

Scientists love to make models! It helps them visualise a concept or idea that can't otherwise be seen. In the classroom, models are also a great way for figuring out if you understand what you have been learning, and your teacher can help with any misunderstandings.

Using software or materials of your choice, create a physical model, stop-motion video or animation to help your classmates visualise one of the following physical changes:

- changing shape
- changing state
- dissolving and diffusion

Present your visual model to the class to aid their understanding of the physical change.

Section 5.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 5.1 questions

Remembering

1. **Identify** which of the following are examples of physical properties.
   a) blue colour
   b) odour
   c) density
   d) sweet taste
   e) flammable
   f) reacts with air
   g) reacts with water
   h) boiling point
   i) hardness
   j) dissolves in water
   k) lustre
   l) volume

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2. **Identify** which of the following are physical changes.
   - a) cutting an apple
   - b) milk going past its use-by date
   - c) digesting food
   - d) ice melting
   - e) cooking pikelets
   - f) wood rotting
   - g) reacting with vinegar
   - h) inflating a bike tyre
   - i) grass growing
   - j) silver tarnishing
   - k) mopping up water
   - l) Milo® dissolving in milk
3. **Define** the following terms: reversible, expansion, contraction, melting, freezing, evaporation, condensation, dissolving, diffusion.

Understanding

4. **State** if each of the following statements is true or false. Then, rewrite the false statements so that they are true.
   - a) During a physical change, the chemical make-up of the substance also changes.
   - b) Melting is a physical change.
   - c) As particles warm up, expansion can occur, so this is a physical change.
   - d) Physical changes are never reversible.
   - e) When heat is lost from a substance, the particles can move closer together, and a gas can change to a liquid.
   - f) Cutting up a cake changes the shape and size of the cake, so this is a physical change.
   - g) Burning wood in a fire forms charcoal and ash, so this is a physical change.
   - h) When a solute dissolves in a solvent, nothing new is formed, so this is a physical change.
5. **Identify** five physical changes that happen in your home.
6. **State** the name of the process whereby a strong-smelling deodorant is sprayed in one corner of the room but eventually everyone in the room can smell it.

Applying

7. **Summarise** the following physical changes, using your knowledge of how particles behave.
   - a) why the tyres on your family car seem more deflated on a cold day
   - b) how the liquid in a glass thermometer works
   - c) why, on extremely hot days, there are concerns about train tracks not working well

Analysing

8. **Consider** how you could reverse the following physical changes.
   - a) salt dissolving in water
   - b) inflating a balloon
   - c) ice melting
   - d) glass breaking
9. Thinking back to the examples you have looked at in this section, **determine** relationships between the physical properties of two substances and their use.

Evaluating

10. **Justify** why each of the following is an example of a physical change.
    - a) blow-drying your dog's coat after giving him a bath
    - b) making cordial from a concentrate and water
    - c) your camping airbed getting tight and ready to pop after lying in the sun
    - d) crushing cereal boxes before putting them out for recycling

5.2 Chemical change

Learning goals

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

1. Define chemical change and give examples.
2. Identify the indicators of chemical change.

Chemical change

You may recall from Year 7 that substances have chemical properties as well as physical properties. Chemical properties can be defined as the behaviour of a substance when it reacts with another substance, or its ability to undergo a chemical change. For example, is it flammable and can it catch on fire? Does it become toxic? Does it react quickly or slowly? Can it cause corrosion? Often, to work out the chemical properties of a substance, we look for a chemical change.

During a **chemical change**, a new chemical substance is formed. This new chemical substance could be a solid, a liquid or a gas, and will have different chemical properties to the substance it was made from. That is, the new substance may explode in the presence of a flame, or be very acidic, or have the ability to biodegrade. Chemical changes are generally considered to be **irreversible**. 'Irreversible' means that the substances formed during a chemical change cannot easily be converted back to the substances that formed them. To reverse a chemical change requires another chemical change to take place.

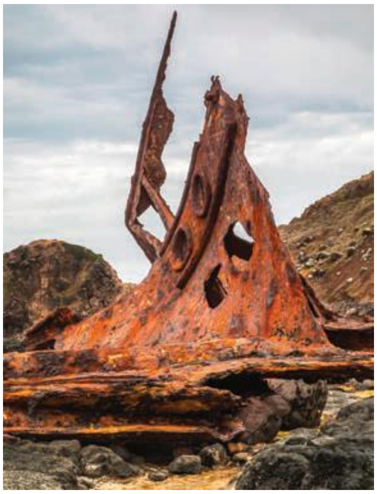

Figure 5.13 This brown-coloured rust on the shipwreck of the SS *Speke* at Kitty Miller Bay, Phillip Island, is an example of a chemical change. Could the rusting be reversed easily?

chemical change where one or more substances undergo a chemical reaction and a new substance, or substances, is formed; chemical properties change; it is mostly irreversible

irreversible incapable of going in the opposite direction

precipitate the solid that forms when two solutions are mixed and undergo a chemical change

Indicators of chemical change

The following list describes some examples of indicators that a chemical change has occurred:

- a permanent colour change
- a gas being given off; effervescence (as an odour or bubbles)
- a solid (called a **precipitate**) forming in a solution
- a change in temperature (increase or decrease)
- energy in the form of light or sound being produced (e.g. an explosion).

A campfire burning away is an example of chemical change; light, heat and gas are produced, and the burning wood permanently changes colour. Aboriginal and Torres Strait Islander Peoples have been using fire to cook meat and bush bread for thousands of years. Cooking is also a chemical reaction that provides evidence of chemical change. Think about how the properties of your favourite meal changes pre- and post-cooking. Is there evidence of chemical change?

Figure 5.14 A Aboriginal person prepares bush bread, a food made from finely ground native seeds and cooked over hot coals on Country near Broome, WA. Aboriginal Peoples were the world's first bakers, farming, harvesting, and processing grains tens of thousands of years before other civilisations. This sophisticated knowledge of native plants and sustainable land management has been passed down through generations, ensuring food security and cultural continuity for millennia.

VIDEO Evidence of chemical reactions

Quick check 5.4

1. On a chemical level, **explain** what has happened when a chemical change has occurred.
2. **List** the five pieces of evidence to look for when determining whether a chemical change has occurred.
3. **Describe** the evidence that a chemical change has occurred in each of these situations.
    - a) leaves turning red in the autumn
    - b) sherbet fizzing in your mouth
    - c) bread baking in the oven

Figure 5.15 Bananas ripening and changing colour are evidence that a chemical change has occurred.

A permanent colour change is evidence that a chemical reaction has occurred, as the new chemical substance formed has a different colour to the substances that made it. Cooking is an example in which colour changes frequently occur. Consider what happens to a marshmallow when it is held over a fire or when a piece of bread is put in the toaster. Can the cooking of the crispy brown marshmallow or toasted bread be easily reversed?

The ripening of fruit and vegetables is another example of a chemical change where a colour change occurs. For example, when a banana reaches the green stage of its development, it starts to produce ethene gas. The ethene then interacts with enzymes in the banana to start the ripening process, which involves chemical reactions. The evidence of this chemical change is the banana changing from green to yellow to brown.

Rusting is also an example of colour change. This occurs when objects containing iron react with the oxygen in the air. This produces iron oxide, which has a brown colour. We will look at rusting in more detail in *Section 5.3*.

Science as a human endeavour 5.1

Detecting cancer using colour change

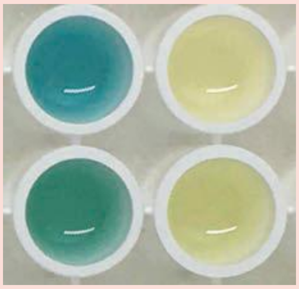

Figure 5.16 Mouse urine becomes blue in the presence of colon cancer, indicating a chemical change has occurred.

As you can imagine, detecting cancer in its early stages is very important for the survival of the patient and their quality of life. Unfortunately, cancer screening requires visits to hospitals and is expensive, so scientists around the world are working on developing cheaper and quicker testing procedures. In a study published in 2019, researchers shared their excitement when they developed a tool that changes the colour of mouse urine when colon cancer is present. They found that the tumours in mice produce a certain enzyme, and when a special molecule called a 'nanosensor' is injected into the mouse, the nanosensor breaks down this enzyme. The remnants of the sensor can be detected in the mouse urine as it reacts with a reagent, making a bright blue colour. Professor Molly Stevens, one of the scientists involved in the project, said, 'By taking advantage of a chemical reaction that produces a colour change, this test can be administered without the need for expensive and hard-to-use lab instruments'. How cool is science!

Gas is formed

In some chemical reactions, the new chemical substance formed is in a gaseous state. These gases can be useful, particularly in cooking when we want a cake to rise. When the gases are formed, they make air bubbles in the mixture, and this inflates the cake batter.

Figure 5.17 Hot, fluffy bread is a delicious result of chemical change.

VIDEO
Airbags

WORKSHEET
Chemical reactions in bread

Another example is when bread is made using microorganisms called yeast. The yeast uses the starch and sugars in the flour to produce alcohol and carbon dioxide gas. The alcohol escapes during cooking, but the carbon dioxide expands inside the dough, creating bubbles of gas and making the bread rise.

Rotting fruits also often produce gas, and again, this is evidence that a chemical change is occurring. For example, vegetable scraps in the compost bin are broken down by microorganisms in a process called **decomposition**, and this produces carbon dioxide gas.

decomposition
a reaction in which one substance breaks up into smaller ones

Practical 5.2: Teacher demonstration

Elephant's toothpaste

Be careful
Ensure you wear appropriate personal protective equipment, including gloves, during this experiment.

Aim

To observe the evidence that shows the decomposition (or breaking down) of hydrogen peroxide is a chemical reaction

hydrogen peroxide → water + oxygen

Materials

- 300 mL conical flask
- 125 mL of 6% hydrogen peroxide
- 17 g packet of dried yeast
- warm water
- dishwashing detergent
- pipette
- 250 mL beaker
- food colouring
- funnel
- large plastic tray

Figure 5.18 Experimental set-up

VIDEO
Practical 5.2
Elephant's toothpaste

Method

1. Measure 125 mL of hydrogen peroxide and pour it into the flask using a funnel.
2. Add a large squirt of detergent to the flask and swirl to mix.
3. Add 3 drops of food colouring.
4. In the beaker, mix about 80 mL of warm water and the dry yeast, and stir to combine.
5. Pour the yeast into the flask with the peroxide. Stand back and observe what happens. Record your observations.

Results

1. Take photos of each stage of the method and record the chemical reaction using a phone or video camera.
2. Once the reaction is complete, touch the foam (while wearing gloves) and the edge of the flask, and record your observations of the temperature.

continued …

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Discussion: Analysis

1. What evidence was there that a chemical change had occurred?
2. How do you think the foam was formed? Why do you think it is called 'elephant's toothpaste'?
3. How was the heat made?
4. Write a word equation for the decomposition of hydrogen peroxide.
5. Investigate yeast and find out why it is included as an ingredient in this reaction.

Practical 5.3

Which gas is which?

Be careful

Ensure you wear appropriate personal protective equipment, including gloves, during this experiment.

Aim

To investigate how to test for oxygen, carbon dioxide and hydrogen gas

Materials

- wooden splints × 6
- matches
- test tubes × 4
- test-tube rack
- stoppers or rubber bungs that fit the test tubes × 2
- stopper/bung with delivery tube attached
- limewater (calcium hydroxide)
- marble chips (small)
- dilute hydrochloric acid (2.0 mol L^{-1})
- 3% hydrogen peroxide
- 1 teaspoon baker's yeast
- granulated zinc
- spatula

Method

Read though the entire method and carry out a risk assessment.

Carbon dioxide test

1. Place approximately 1 teaspoon of marble chips (calcium carbonate) and 3 cm of hydrochloric acid in a test tube.
2. Place a stopper with a delivery tube connected into the reaction test tube as soon as the reaction has started, and place the other end of the tube into a test tube containing limewater. The gas produced is bubbled through the limewater. If carbon dioxide is present, then it will mix with the limewater, and the solution will turn cloudy or milky.

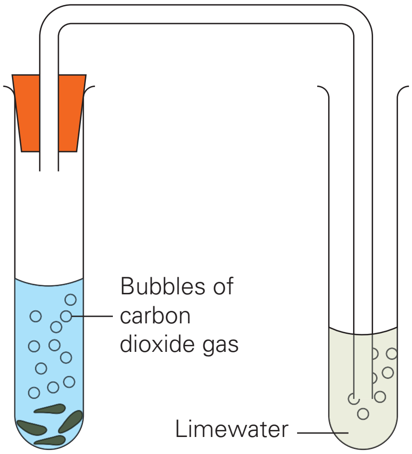

Figure 5.19 Experimental set-up

Oxygen gas test

1. Place approximately 4 cm of hydrogen peroxide into a test tube.
2. Add 1 teaspoon of yeast into the test tube.
3. Stopper the reaction test tube in order to contain the gas being produced.
4. Light a match and hold it under a wooden splint until the splint starts to glow.
5. Hold a glowing splint at the open end of the test tube after the stopper is removed. If the test tube contains oxygen, the glowing splint will relight.

Hydrogen gas test

1. Place 3 cm of hydrochloric acid in a test tube with a spatula of granulated zinc.
2. Stopper the reaction test tube in order to contain the gas being produced.
3. Light a match and hold it under a wooden splint until the splint starts to burn.
4. Hold a burning splint at the open end of a test tube after the stopper has been removed. If hydrogen is present, a squeaky pop will be heard.

continued …

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Results

Complete the table below.

Table showing three chemical reactions and your observations of testing for the presence of different gases

Reaction	Observations
Marble chips and hydrochloric acid	
Hydrogen peroxide and yeast	
Hydrochloric acid and zinc	

Discussion: Analysis

1. List the indicators that a chemical change has occurred.
2. Describe the evidence that indicated a gas was being produced.
3. List any other indicators of chemical change in any of the reactions besides a gas being produced.
4. Using a sentence for each gas, summarise the indicators that the gas produced in a chemical reaction is:
    - hydrogen
    - carbon dioxide
    - oxygen.

Precipitate is formed

When two solutions are mixed together and undergo a chemical reaction, a solid, or precipitate, may form. The precipitate is unable to dissolve in water and so, when it forms, it makes the solution look cloudy before it settles on the bottom. Precipitates can form in many colours.

Figure 5.20 A blue solution is added to a colourless solution to form a blue precipitate.

Quick check 5.5

1. **Name** three examples where a colour change indicates that a chemical change has occurred.
2. **List** two examples where a gas being formed provides evidence of chemical change. In each case, explain the chemical reaction.
3. **Define** the term 'precipitate'.

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Change in temperature

We know a chemical reaction can produce a new chemical substance. Interestingly, however, every chemical reaction will always cause a change in temperature. Either energy is released as heat and the temperature goes up, or heat energy is absorbed from the surroundings and the temperature goes down. For example, when you start a campfire and the fire burns, you will feel heat radiating from the fire. In this case, heat is released as part of the chemical change, and the surrounding temperature increases.

Figure 5.21 When natural gas burns, a lot of heat energy is released, and we use this heat to cook our food.

exothermic a release of heat energy in a chemical reaction characterised by an increase in surrounding temperature

endothermic an absorption of heat energy in a chemical reaction characterised by a decrease in surrounding temperature

The chemical reaction that is occurring is:

carbon + oxygen → carbon dioxide + heat

But the opposite can also happen; heat energy can be absorbed, and the temperature decreases. Chemical ice packs are a common example of this. If you injure yourself, you may be offered an ice pack. You pop a bubble inside the pack and the pack starts to feel cold. The chemical reaction is absorbing heat from the surrounding environment.

WORKSHEET Graphing endothermic and exothermic reactions

VIDEO Exothermic and endothermic chemical reactions

In chemistry, we have special names for these sorts of reactions:

- reactions that release energy to the surroundings, like the burning of wood on a campfire, are described as **exothermic** reactions.

Figure 5.22 The word 'exothermic' means external heat.

- reactions that take in energy from the surroundings, like the reaction in an ice pack, are described as **endothermic** reactions.

Figure 5.23 The word 'endothermic' means internal heat.

Quick check 5.6

1. **List** some examples of where a change in temperature provides evidence of chemical change.
2. During a chemical reaction between hydrochloric acid and sodium hydroxide, the temperature went up by 5°C. **Infer** whether the reaction is endothermic or exothermic.
3. During a chemical reaction, the temperature of the solution decreases. **Infer** whether this reaction is endothermic or exothermic.

Explore! 5.1

Fireworks

Figure 5.24 Fireworks in Melbourne

Every year, people around the world welcome in the new year using fireworks. They are exciting, colourful, loud and beautiful. One of the main ingredients in fireworks is a black explosive powder discovered more than a thousand years ago by Chinese alchemists. The black powder is a combination of different substances – find out what they are and what elements make them up. It is this black powder that launches the fireworks into the air and ignites the chemicals inside that produce the colours we see. Investigate what each of the elements that produce these different colours inside the firework are. You may also like to refer to your findings in Practical 4.2 of Chapter 4.

The dramatic sounds of a firework display are just as exciting as the colours we see. Research online to determine in which part of the process the noise is produced. Try and find out how the whistle effect is produced.

Light or sound produced

Light and sound can also be evidence that a chemical change has taken place. We can use fire as an example again – it releases light energy, and you may even hear a crackling sound. Consider fireworks: they release light and sound. Could they be an example of a chemical change? What other examples can you think of where light or sound are emitted as evidence of a chemical change?

bioluminescence a chemical reaction that produces light in living things

chemiluminescence a chemical reaction that produces light

Did you know? 5.2

Victoria's glow worms

You may have seen the glow worms in Melba Gully in the Otways. In the abdomens of glow worms a chemical reaction occurs, allowing them to produce light! This process is called **bioluminescence** and is shared by many other organisms, mostly sea-dwelling or marine organisms. (Note that bioluminescence is a type of **chemiluminescence**).

When oxygen combines with the chemical luciferin, and a bioluminescent enzyme is also present, light is produced and the glow worm's light organ glows. When oxygen is not available, the light goes out. Amazingly, the glow worm can control the beginning and end of the chemical reaction, and thus start and stop the production of light. Unlike a light globe, which gets hot when it produces light, a glow worm's light is cold light, and so very little energy is lost as heat. This is very lucky for the glow worm because it would not survive getting as hot as a light globe!

Figure 5.25 The abdomen of a glow worm produces light through a chemical reaction known as bioluminescence.

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Quick check 5.7

1. **List** some examples of where light or sound being produced provides evidence of chemical change.

Figure 5.26 Glowsticks produce light through chemiluminescence.

Practical 5.4

Chemical change

Aim

To conduct a series of activities/experiments in order to explore chemical change and be able to identify the evidence of change

Be careful

Hydrogen gas is flammable. Personal protective equipment is to be worn.

All waste is to be collected and disposed of appropriately.

Materials

- Bunsen burner
- matches
- wooden skewer
- 1 mol L^{-1} strontium chloride solution
- 1 mol L^{-1} and 0.1 mol L^{-1} copper(II) sulfate solutions
- 0.1 mol L^{-1} sodium hydroxide solution
- test tubes and test-tube rack
- 2 cm strip of magnesium ribbon
- 2 mol L^{-1} hydrochloric acid
- thermometer
- 200 mL glass beaker
- lemon juice
- baking soda
- Pasteur pipette

VIDEO
Practical 5.4
Chemical
change

Method

Copy the results table into your science book.

Activity 1

1. Light the Bunsen burner.
2. Take a wooden skewer and break it in half.
3. Dip the broken-off end of the skewer into the strontium chloride solution.
4. Place the wet end of the skewer into the flame.
5. Record your observations for Activity 1 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.
6. Repeat steps 1–5 with the 1 mol L^{-1} copper(II) sulfate solution.

continued ...

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Activity 2

1. Place 10 mL of sodium hydroxide into a test tube in a rack.
2. Gently stand a thermometer in the same test tube.
3. Add the 0.1 mol L^{-1} copper(II) sulfate solution, drop by drop – no more than 10 drops – into the sodium hydroxide.
4. Record your observations for Activity 2 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Activity 3

1. Place approximately 5 mL of dilute hydrochloric acid into a test tube in a rack.
2. Gently stand a thermometer in the same test tube.
3. Add a 2 cm strip of magnesium ribbon to the test tube.
4. Record your observations for Activity 3 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Activity 4

1. Place approximately 8 mL of dilute hydrochloric acid into a test tube in a rack.
2. Gently stand a thermometer in the same test tube.
3. Add a 1 cm strip of magnesium ribbon to the test tube.
4. Record your observations for Activity 4 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Activity 5

1. Put approximately 40 mL of lemon juice in a 200 mL glass beaker.
2. Gently stand a thermometer in the beaker.
3. Add 1 heaped teaspoon of baking soda to the lemon juice.
4. Record your observations for Activity 5 in your results table and tick which of the pieces of evidence show that a chemical change has occurred.

Results

Table showing the evidence of chemical change seen in different activities

Activity	Change in colour	Change in temperature (°C)	Gas produced	Light produced	Precipitate produced	Other observations
1						
2						
3						
4						
5						

Discussion: Analysis

1. Define 'chemical change'.
2. Outline the evidence that a chemical change has occurred and provide an example from your activities.
3. Compare the temperature difference obtained in Activity 3 and Activity 4. Is there a relationship between the proportions of reactants and the temperature change?
4. Were there any pieces of evidence that were not demonstrated during these activities? Write an activity that would allow you to demonstrate this piece of evidence of chemical change. You may need to do some online research first.

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Did you know? 5.3

Digestion is all about change

Thousands of physical and chemical changes take place during the digestion of your food … yes, thousands!

Part of the body	Type of change	Details
Mouth	Physical	Food is chewed by teeth to break it down into smaller pieces so that enzymes have a greater surface area to work on.
	Chemical	An enzyme in saliva (called amylase) starts to break down complex carbohydrates into simpler forms that your body can absorb.
Oesophagus	Physical	As the oesophagus moves food from the mouth to the stomach, the muscles contract, pushing the food along, in a process called peristalsis.
Stomach	Physical	The stomach muscles contract and churn the food to break it into smaller pieces so that enzymes have a greater surface area to work on.
	Chemical	Enzymes start to break down proteins. Hydrochloric acid provides the optimum conditions for this to occur.
Small intestine	Physical	As the small intestine moves food along towards the large intestine, the muscle contractions mix the food to help break it down further. Bile emulsifies fats into smaller droplets so that enzymes have a greater surface area to work on.
	Chemical	Enzymes break down proteins and fats even further so they can be absorbed into your bloodstream through the walls of the intestine.

Table 5.2 Some of the many physical and chemical changes that occur in the digestive system

Figure 5.27 The digestive system uses physical changes and chemical changes to break down your food for absorption.

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Section 5.2 review

Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 5.2 questions

Remembering

1. **Name** three examples of chemical change occurring in your home.
2. **Recall** one example of an endothermic reaction and one example of an exothermic reaction.

Understanding

3. For each of the following situations, **summarise** the indicators of chemical change you would observe.
   a) Bread is baking in an oven.
   b) Glow sticks emit light when you break them.
   c) Sandwiches go mouldy.
   d) Baking soda and vinegar are mixed.
4. **Explain** the process of rusting and why it is an example of chemical change.

WIDGET Physical versus chemical change

WORKSHEET Physical versus chemical change

Applying

5. A stoppered test tube of yellow liquid is left on the windowsill of a science lab over the weekend. When the students come back to class, they observe that there is condensation on the inside of the tube, the liquid has gone green, and the stopper has popped out. **Explain** whether these observations indicate physical or chemical changes and give a reason for your answer.
6. During photosynthesis, plants use the sun's energy to make their own food. **Explain** why this is an example of an endothermic reaction.
7. **Identify** the types of changes occurring in the following situations. (There may be more than one type.)
   a) Pastry is defrosted and then used to make a pie.
   b) To make honeycomb, sugar is mixed with water and honey, heated, and then bicarbonate of soda is added.
   c) A candle burns and wax drips down the side.

Analysing

8. **Distinguish** between bioluminescence and chemiluminescence.
9. **Classify** each of the following as a physical or chemical change.
   a) vegetable scraps breaking down in the compost bin
   b) separating sand from gravel
   c) cutting fingernails
   d) drilling a screw into wood
   e) chipping tree branches
   f) a stock cube dissolving in hot water
   g) fruit on the ground going mouldy
   h) crushing a can
   i) trees growing new leaves in spring
   j) breakfast cereal going soggy
   k) rain making the ground muddy
   l) dropping and breaking a plate
   m) baking a quiche

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Evaluating

10. **Suggest** how you would determine the type of gas produced during a chemical reaction.
11. For each of the following situations, **deduce** whether a physical change, a chemical change, or both, has occurred. Give reasons for your answers.
    - a) biting, chewing and swallowing noodles
    - b) ice cubes melting in your iced-chocolate drink
    - c) petrol burning in a car
    - d) bread dough being kneaded, then rising
    - e) a steel spoon left out after being washed and little red spots forming on it

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5.3 Chemical reactions

Learning goals

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

1. Define and identify reactants and products in a chemical reaction.
2. Summarise examples of chemical reactions in everyday life.

In this section you will further explore chemical change by looking at examples of chemical reactions. Some may be new to you and some may be familiar as they produce substances we use in our everyday lives.

Introducing chemical reactions

If there is evidence of a chemical change occurring, then this means that a **chemical reaction** has occurred. As we look at examples of chemical reactions, keep in mind that the chemical properties of a substance can only be determined by carrying out a chemical reaction.

In a chemical reaction, the chemical substances that react are called **reactants**, and the substances that are produced are called **products**. A chemical reaction can be represented in different ways, such as a word equation or a symbol equation (also called a chemical equation).

Whatever way a chemical reaction is being represented, the reactants are on the left of the chemical equation, the products formed are on the right, and an arrow is placed in between showing the direction of the reaction.

chemical reaction
a process or chemical change that transforms one set of substances (the reactants) into another set of substances (the products)

reactants
the chemical substances that are present at the beginning of a chemical reaction

products
the chemical substances that are present at the end of a chemical reaction

reactant AB + reactant C ⟶ product A + product BC

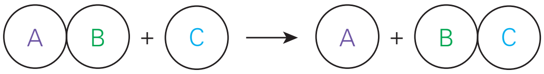

Figure 5.28 Rearranging atoms in a chemical reaction

From Figure 5.28 you can see that during chemical reactions, the atoms in the starting substances, the reactants, are rearranged to make the new substances, the products. For this to happen, chemical bonds holding the atoms together in the reactants must be broken and new bonds must form in different arrangements to make the products.

An example of a chemical reaction is when light hits photographic film. The film is coated with tiny crystals of the compound silver chloride. When the film is exposed to light, a chemical reaction occurs, and this darkens the film to produce an image. This change in colour is evidence that a chemical change has occurred.

Figure 5.29 Photographic film works because of chemical reactions.

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This reaction can be represented by a word equation and by a chemical equation.

Word equation:

$$\underbrace{\text{silver chloride}}_{\text{reactant}} \rightarrow \underbrace{\text{silver + chlorine}}_{\text{products}}$$

Chemical equation:

$$\underbrace{2AgCl}_{\text{reactant}} \rightarrow \underbrace{2Ag + Cl_2}_{\text{products}}$$

The reactants, or in this case reactant, are on the left of the reaction arrow – silver chloride. Note that the formula for silver chloride is $AgCl$, one atom of silver joined to one atom of chlorine.

The products are on the right of the reaction arrow – silver and chlorine. For this reaction to occur, the bonds between the atoms in $AgCl$ must have been broken and then new bonds have formed to make the products like Cl_2. Note that chlorine has the formula Cl_2 as it exists as a molecule (in this case two atoms), never as an atom on its own. When a small number is placed after an element symbol, it is called a subscript. A subscript multiplies the number of that particular atom by the number indicated.

You may have noticed that in front of the $AgCl$ is the number 2, and there is also a number 2 in front of the Ag. These numbers in the front of an elements symbol are called coefficients, and they are part of the process of balancing equations, which you will learn more about in years 9 and 10. To put it simply, atoms cannot be created or destroyed; they just move around during chemical reactions. We call this the Law of Conservation of Mass. This means the number of silver atoms in the reactants must be the same as the number of silver atoms in the products, and the number of chlorine atoms in the reactants must be the same as in the products. These extra numbers you see in the equation are there to balance the numbers of atoms on each side of the equation.

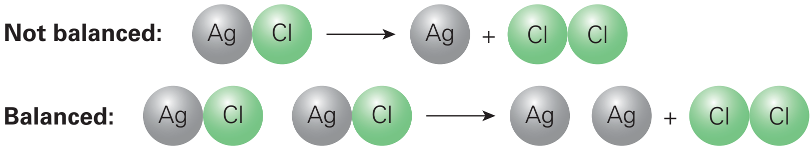

Figure 5.30 Keeping it simple: balancing equations is like working out whether you need one or two cups of flour to make bread. The top equation is not balanced because the number of chlorine atoms is not the same on both sides of the reaction. Remember the rule: matter cannot be created nor destroyed.

Quick check 5.8

1. a) **Recall** if chemical reactions involve physical change or chemical change.
   b) **Recall** examples of what evidence there would be if a chemical reaction occurred.
2. **Define** the terms 'reactants' and 'products'.
3. **Name** and give examples of two different ways in which we can represent chemical equations.
4. Matter is neither created nor destroyed; it is just rearranged through chemical and physical changes. **Name** the law being referred to here.

Examples of chemical reactions

Combustion

Chemical reactions that involve the burning or exploding of a chemical substance in the presence of oxygen are called **combustion** reactions. This type of reaction is also categorised as exothermic. The exothermic heat released can often be harnessed and transformed into different types of energy, including electrical energy.

combustion
a reaction that involves the burning or exploding of a chemical substance in the presence of oxygen

For example, methane, also called natural gas, can be used for gas cooking or heating water in a household. Methane reacts with oxygen to produce carbon dioxide, water, light and heat.

Word equation:

$$\underbrace{\text{methane} + \text{oxygen}}_{\text{reactant}} \rightarrow \underbrace{\text{carbon dioxide} + \text{water}}_{\text{products}}$$

Chemical equation:

$$\underbrace{CH_4 + 2O_2}_{\text{reactant}} \rightarrow \underbrace{CO_2 + 2H_2O}_{\text{products}}$$

Another example is octane, the fuel used to power modern cars. It reacts with oxygen to produce carbon dioxide, water, light and heat.

Word equation:

$$\underbrace{\text{octane} + \text{oxygen}}_{\text{reactant}} \rightarrow \underbrace{\text{carbon dioxide} + \text{water}}_{\text{products}}$$

Chemical equation:

$$\underbrace{2C_8H_{18} + 25O_2}_{\text{reactant}} \rightarrow \underbrace{16CO_2 + 18H_2O}_{\text{products}}$$

Figure 5.31 Octane is a component of petrol.

Try this 5.2

Creating a visual model of a combustion reaction

For this task you will need to:

- draw and colour in two circles labelled 'C' for carbon, eight circles labelled 'H' for hydrogen and eight circles labelled 'O' for oxygen
- cut out these circles such that they represent individual atoms
- organise the atoms such that they illustrate the combustion of methane:
  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- check whether the same number of atoms are present on each side of the chemical reaction. Why or why not?

Did you know? 5.4

Candle combustion

Candles are a great source of light and can last for hours with a controlled flame. A common misconception is that when a candlewick is ignited, it is only the wick that burns. In fact, the wax surrounding the wick burns in a combustion reaction when it comes into contact with oxygen in the air. This is why the wax eventually disappears from the candle: it has become carbon dioxide and water vapour! This steady burn and relatively controlled flammability have allowed candles to be a perfect candidate for lighting purposes for thousands of years.

Figure 5.32 The wick provides a surface on which the wax can undergo a combustion reaction.

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Practical 5.5: Teacher demonstration

Sugar snake

Be careful

Wear appropriate personal protective eqiupment, including safety glasses. Only conduct this experiment in a well-ventilated area.

Aim

To investigate a combustion reaction

Materials

- fume hood or well-ventilated area (outdoors recommended)
- teaspoons
- aluminium pie tin
- sand
- mixing bowl
- lighter fluid (or isopropyl alcohol)
- matches
- powdered sugar
- baking soda

Method

1. In a bowl, combine four teaspoons of powdered sugar with one teaspoon of baking soda.
2. In the fume hood, fill the pie tin with sand and create a small mound in the centre. Then use your hand to make an indent in the middle of the mound.
3. Pour lighter fluid on the mound and in the indentation. Make sure the sand is well soaked.
4. Spoon the sugar and baking soda mixture into the centre of the mound.
5. Carefully light the sand near the sugar mixture.

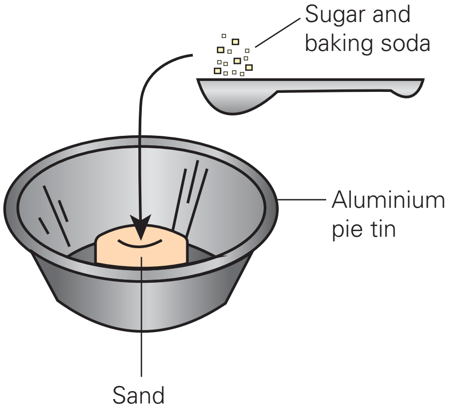

Figure 5.33 Experimental set-up

Results

Take photos of each stage of the method and record the chemical reaction using a phone or video camera.

Discussion: Analysis

1. Define the terms 'chemical change' and 'combustion'.
2. What evidence do you see that a chemical change has occurred?
3. Which ingredient or reactant do you think is undergoing combustion? What gas is being made or produced?
4. Can you explain why the snake goes black? Why does it keep growing?
5. Explain the purpose of the sand.
6. Why is it recommended that this experiment is done wearing safety glasses, in a well-ventilated area or fume hood?

Quick check 5.9

1. **Explain** how you would identify that a chemical reaction was a combustion reaction.
2. **Write** the word equation for a combustion reaction involving methane. Label the reactants and the products.
3. **State** what is useful about the combustion of methane and octane.
4. **State** one chemical property of methane based on the combustion reaction.

Detecting substances

Chemical reactions, and the indicators that a chemical change has occurred, are particularly useful when trying to determine if a substance is present in a sample. For example, testing for contaminants in water, testing for prohibited substances in blood, testing for toxins in soil or testing for chemicals at a crime scene.

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Example: Detecting nitrates in water

Figure 5.34 Chemical reactions can indicate the presence of particular substances, for example, the presence of nitrate in a water sample as indicated by the permanent colour change.

Nitrates, NO_3^-, are naturally occurring compounds composed of nitrogen and oxygen. However, high levels of nitrates in drinking water can cause serious health problems. So how do the nitrates get into water? Nitrates are very soluble in water and typically get into our water supplies through surface runoff or leakage from wastewater, landfills, fertilised soil or septic systems. The EPA recommends strict monitoring of drinking water for the presence of nitrates. There are different methods of testing for nitrates, but whichever method is used, the water sample is treated with reagents, and if nitrate is present, a chemical reaction occurs. The indicator that there has been a chemical change is a permanent colour change. The strength of the colour indicates the amount of nitrate in the sample.

Explore! 5.2

The detection and detoxification of substances in the environment

Many agricultural industries use chemicals which can be harmful to people and also to the environment. It is important that we monitor and regularly assess the build-up of chemicals in the environment so we can keep an eye on the impact we are having. Chemical sensors are a powerful tool for environmental monitoring as they can detect and measure the smallest concentrations of dangerous substances. Some chemical sensors work by using chemical reactions which produce a signal that can be measured, such as a change in colour.

Researchers in Thailand have developed a method to not only detect dangerous environmental chemicals, but also detoxify them in one step! The process involves two chemical reactions which convert the harmful substances into the same molecules that cause the glowing in fireflies, luciferin. These reactions involve enzymes.

Use the internet to find out what an enzyme is and what role it has in a chemical reaction.

Making thinking visible 5.2

Connect, extend, challenge: The detection of doping in sport

The fairness of professional sport is of utmost importance for the integrity of many sporting codes and competitions worldwide. In Australia, the Australian Government founded the Australian Sports Anti-Doping Authority (ASADA) in 2006, to protect Australia's sporting integrity and eliminate doping. Doping is the act of giving a person, or animal, drugs that will make them perform better or worse in a competition.

ASADA uses a variety of chemical tests on athletes to detect the use of recreational or performance-enhancing drugs. These tests work by using chemical reactions to identify specific chemicals, such as enzymes and proteins, or to prepare a sample for further testing.

This type of testing is becoming more and more commonplace at professional Australian sporting events and is a vital part of ensuring that Australian athletes and sporting competitions are fair.

Consider what you have just read and then ask yourself:

- How are the ideas and information connected to what you already know?
- What new ideas did you learn that broadened your thinking or extended it in different directions?
- What challenges or puzzles emerge for you?

Figure 5.35 ASADA officers are present at many professional Australian sport matches and competitions.

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

Example: Detecting substances at a crime scene

Forensic science is based on the idea that nothing vanishes without a trace. You may have heard of luminol, which is a chemical reagent that crime scene investigators spray on a suspicious area to determine if blood is, or was, present. Luminol works by breaking down red blood cells, exposing the iron-containing haemoglobin inside. As a chemical reaction takes place, atoms are rearranged, and a faint blue-white luminescence becomes visible. This process is chemiluminescence, the same process that makes fireflies and glow sticks glow.

Besides detecting the presence of blood, forensic scientists use chemical reactions to detect gunshot residue on clothing, to identify the cause of a fire and to analyse samples of unknown substances. Chemical substances can be identified based on their chemical properties, that is, how they behave when reacted with another substance. Practical 5.6 will give you an opportunity to solve a 'crime' by identifying the mystery substance using chemical reactions.

Practical 5.6

Solving a crime using chemical change

Be careful
Universal indicator can be an irritant. Wear appropriate PPE.

Aim

To use chemical changes to identify a mystery substance found at a crime scene.

Scenario

Chef La De Da runs a three-hatted restaurant in the lovely Victorian town of Castlemaine. One day, he came to work to find his kitchen had been ransacked. He was very upset as he had been working hard on preparing for a big Mother's Day event. In fact, he had been so busy preparing for the event that he had left baking soda and flour all over his workbench and floor.

continued ...

Thankfully, the police were ready to deal with such a 'serious' crime and immediately identified two suspects: the owner of a competing restaurant (suspect 1) and the Mother's Day event organiser (suspect 2). The police found evidence of a white powder in both suspect's houses, and consequently they believe that whoever ransacked the chef's kitchen must have tracked the substance home from the chef's workbench and floor. The substance found at the house of suspect 1 they called 'mystery powder 1'. The substance found at the house of suspect 2 they called 'mystery powder 2'.

Determine who ransacked the chef's kitchen by performing two chemical tests to identify a mystery powder.

Materials

- stirrers or toothpicks
- spatula × 7
- baking soda
- baking powder
- cream of tartar
- corn starch/flour
- powdered milk
- mystery powder 1
- mystery powder 2
- water
- vinegar
- universal indicator
- iodine solution
- ceramic well plate (7 × 4 wells is required)
- tablespoons × 7
- paper cups × 7
- droppers, one for each liquid × 4
- marker pen

Method

1. Place 1 tablespoon of each of the seven powders in seven labelled paper cups.
2. Begin by recording the physical properties of the five known substances and the two unknown mystery powders. You may like to record their odour (using the waft test), colour and texture.
3. Using a spatula, place 1 spatula of baking soda in each of the four wells and label the well plate. Figure 5.36 shows one way to set up your well plate.
4. Repeat with the other four known substances and the two mystery powders.
5. Using a dropper, drop 3–5 drops of water into the baking soda, stir with a toothpick and record your results.
6. Repeat step 5 with the remaining substances, using a new toothpick each time.
7. Using the same technique you used in steps 5 and 6, test the seven substances firstly with vinegar, then universal indicator, and finally with iodine.

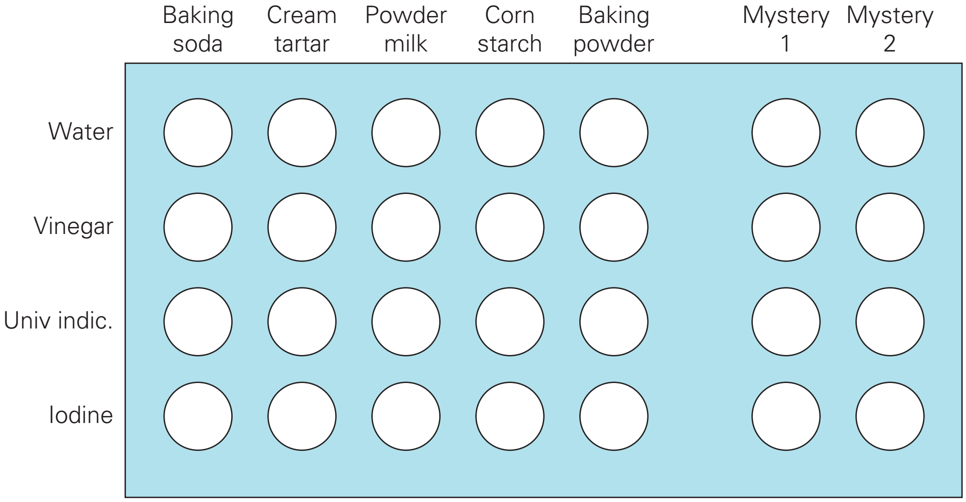

Figure 5.36 Setting up your well plate

continued ...

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Results

Table showing the physical and chemical properties of five known substances and the two mystery powders

Powder	Observations: physical properties	Observations: chemical properties			
		Water	Vinegar	Universal indicator	Iodine
Baking soda					
Cream of tartar					
Powdered milk					
Corn starch					
Baking powder					
Mystery powder 1					
Mystery powder 2					

Discussion: Analysis

1. Define the term ‘physical property’. Give an example.
2. Define the term ‘chemical property’. Give an example.
3. Explain how you know that a chemical reaction has occurred.
4. Were you able to determine who ransacked the chef’s kitchen? Outline the evidence that you used to make this decision.
5. Explain how forensic scientists could use colour change as an indicator that a substance is present in a sample.

Discussion: Evaluation

1. Suggest a source of error for this practical. You may like to think about the variables that need to be controlled and whether this happened.
2. Make some recommendations about how this experiment could be improved.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Quick check 5.10

1. **Describe** two examples where the indicator of a chemical change can be helpful in identifying the presence of a substance in a sample.

Science as a human endeavour 5.2

Using AI to identify useful chemical reactions for drug design

Scientists employ a wide range of chemical reactions to create new and complex molecules, for example in the discovery and development of pharmaceutical drugs. The development of new medications by the pharmaceutical industry is a time consuming and expensive process. However, artificial intelligence (AI) has the potential to change all of this.

continued …

In recent years, AI techniques have been used to improve the efficiency and accuracy of research into development of potential new drug compounds. They are believed to have the capacity to help develop more personalised drug treatments. AI can browse the internet to learn about the relevant chemical reactions, trawl through all relevant literature and documentation and, in minutes, summarise the method needed to perform the necessary reactions. It is believed that some AI systems being developed can also write the code that tells robots how to carry out the chemical reactions outlined.

As with all scientific advances that can deliver such potential benefits, there are challenges and limitations to the use of AI. To be successful, AI requires large amounts of high-quality data and people who are able to interpret the AI models. There are also ethical implications in the use of AI.

Corrosion

Rusting, a type of **corrosion**, is a slow and usually unwanted chemical change that causes iron and steel to go flaky and brown. This is not desirable in construction when building bridges and train tracks, which are made of iron and steel. Rusting occurs when iron reacts with the oxygen in the air to form iron(III) oxide, also known as 'rust'. This is a new chemical substance forming, and the change in colour is evidence of a chemical change.

corrosion
the gradual and natural process of metals reacting with oxygen to form a new chemical substance; an example is rusting

galvanisation
the process of coating iron or steel in zinc to prevent corrosion

We can write what happens during a chemical change like this:

$$\text{iron} + \text{oxygen} \rightarrow \text{iron(III) oxide}$$

You can see that there are two chemical substances that react together to form one new chemical substance. If iron and steel are not exposed to oxygen, then iron(III) oxide cannot be made and rusting does not occur.

There are some methods of stopping the contact of oxygen with iron and therefore preventing rusting:

- A surface protector can be painted onto the iron or steel surface. This is like the paint we put on cars to prevent the metal panels being exposed.
- **Galvanisation** is a process in which the iron or steel is coated in a layer of zinc. If a corrugated iron roof has been galvanised, the zinc coating will corrode before the iron, and so the iron is protected from rusting.

Figure 5.37 Iron metal corrodes to form brown iron oxide after years of exposure to oxygen and water.

Figure 5.38 A galvanised corrugated iron roof: the zinc coating will corrode before the iron underneath, preventing rusting of the iron.

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Investigation 5.1

To rust or not to rust

Aim

To determine the conditions required for the chemical change of rusting

Materials

- iron nails
- sandpaper
- large glass test tubes with stoppers
- vegetable oil
- water

Method

1. Write a rationale about rusting and the factors that affect it. A rationale is essentially the reasons for why you are carrying out the research.
2. Design an experiment that will demonstrate that the conditions you believe to be required for rusting are essential, using iron nails, oil (to prevent air getting access to water or iron nails), stoppers and test tubes. Think about your independent, dependent and controlled variables as you plan. You will need to leave your experiment overnight.
3. Write a specific and relevant research question for your investigation.
4. Identify the independent, dependent and controlled variables.
5. Write a hypothesis for your investigation.
6. Write a risk assessment for your investigation.
7. Draw a diagram of your method, showing what will be added to each test tube.
8. Check your design with your teacher before starting your experiment.

Results

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

Discussion: Analysis

1. Describe any patterns, trends or relationships in your results.
2. Define the terms ‘chemical change’ and ‘rusting’.
3. List any indicators of chemical change you see in this experiment.
4. Write a word equation for the reaction that occurs when rust is produced.

Discussion: Evaluation

1. Identify any limitations in your investigation.
2. Propose another independent variable that could have been tested, to expand on your results.
3. Suggest some improvements for this experiment.
4. For a super challenge, how can you make the iron nail rust faster? You may like to use salt water, vinegar and soft drinks in your experiment.

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered.

Section 5.3 review

Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

WORKSHEET Photosynthesis and respiration

Section 5.3 questions

Remembering

1. **Identify** the gases that are products of combustion reactions.
2. **Recall** the word equation for the reaction called rusting.

Understanding

3. **Outline** the different indicators that a chemical change has occurred.
4. **Explain** why when fire blankets are put over a fire, they cause the fire to go out.

Applying

5. **Identify** the reactants and products in each of the following chemical reactions:
   a) calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide
   b) ammonia is formed from nitrogen and hydrogen
   c) sodium + chlorine → sodium chloride

Analysing

6. **Describe** an example of how the indicators of chemical change can be used to detect the presence of a particular substance in a sample.
7. **Write** the word equations for the following chemical reactions.
   a) Sulfuric acid reacts with black powdered copper oxide to make a solution of copper sulfate and water.
   b) When hydrogen reacts with oxygen, water is made.
   c) Potassium hydroxide reacts with sulfuric acid. Potassium sulfate and water are formed in the reaction.
   d) Silver sulfide is formed in the reaction between silver metal and sulfur.

Evaluating

8. **Construct** a word equation for the combustion of butane (barbeque gas) to form carbon dioxide and water.
9. **Decide** if the following statement is true or false: 'Combustion is a chemical reaction'. Give reasons for your choice.

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Chapter review

Chapter checklist

Success criteria		Linked questions
5.1	I can define the term physical change and provide examples.	1, 3, 14
5.1	I can identify if a physical change has occurred.	2, 3, 9
5.2	I can define the term chemical change and provide examples.	1, 3, 14
5.2	I can identify if a chemical change has occurred.	4, 7, 8, 9, 10, 13, 15
5.3	I can define and identify the reactants and products in a chemical reaction.	5, 6, 12
5.3	I can summarise examples of chemical reactions in everyday life.	7, 11

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **Define** the following key terms: physical property, chemical property, physical change, chemical change, reactant, product.
2. **Recall** the possible evidence that a physical change has occurred.
3. **State** whether each of the following processes is a physical or chemical change.
   a) moth balls evaporating in a cupboard
   b) building a sandcastle
   c) hydrogen burning in chlorine gas
   d) fogging up a mirror by breathing on it
   e) breaking a bone
   f) a broken bone mending
   g) slicing potatoes for making chips
   h) hand sanitiser evaporating
   i) mixing sugar with coffee
   j) making a paper aeroplane
   k) pan frying dumplings
   l) copper turning green when exposed to the air
   m) paper ripping
4. **State** whether the temperature of the surroundings would increase or decrease in an endothermic reaction.

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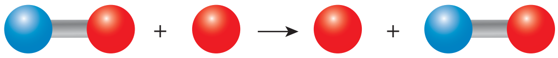
Understanding

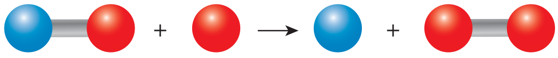
5. When Tori reacts a lump of calcium carbonate with sulfuric acid, she notes that water, carbon dioxide and calcium sulfate form.
   a) **State** the word equation representing the information given.
   b) **Identify** the reactants and the products and give reasons for your answer.
6. **Identify** which of the following are examples of chemical reactions.

A.

B.



C.



7. When a chemical substance containing octane burns, it reacts with a gas in the air and forms another gas.
   a) **Name** the gas produced from this reaction.
   b) **Suggest** how you could test that your answer in part **a** is correct.
   c) **Identify** the type of chemical reaction.

Applying

8. **Explain** what evidence could determine whether a combustion reaction is an exothermic or endothermic reaction.
9. a) **Explain** why baking cookies is not an example of physical change.
   b) **Explain** why bending metal in half is not an example of chemical change.
10. a) **Summarise** the observations you could make if a chemical change had occurred.
    b) **Recall** how you can determine the chemical properties of a substance.

Analysing

11. **Explain** why rusting occurs faster on door hinges of beachfront boat sheds, compared to door hinges a kilometre inland from the beach.
12. **Critique** the following statement: 'Atoms that are not in the reactants can end up in the products of a chemical reaction'.

Evaluating

13. a) When you combine bicarbonate of soda and buttermilk, a gas is produced. **Propose** why the gas is considered evidence that a chemical reaction occurred.
    b) **Propose** whether it is possible to continue adding more and more of only one reactant and expect to get more and more product. Give reasons why or why not.

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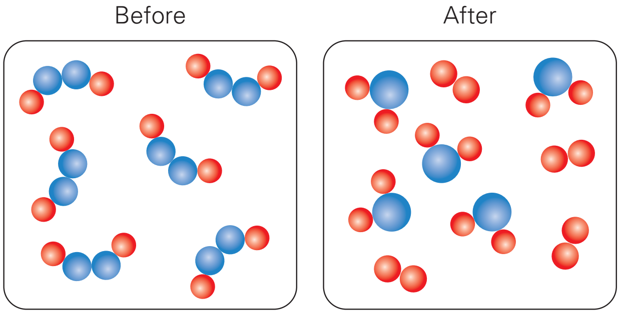
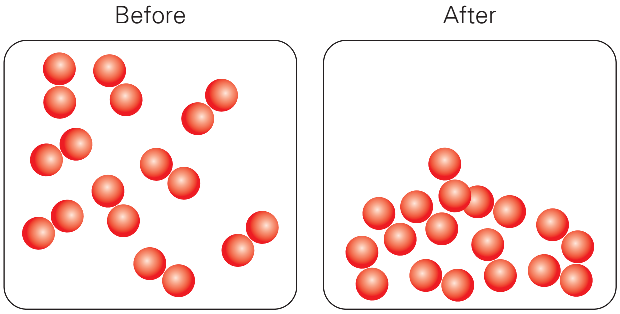
14. **Determine** whether each of the particle diagrams below indicates a chemical or physical change. Justify your answer.

a)



b)



15. Review the indicators of physical change and the indicators of chemical change. Could colour change be considered an indicator of physical and chemical change? **Give reasons** for your answer.

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Data questions

A theoretical chemical reaction occurs such that reactant A reacts to form an intermediate product B, which then reacts to form a product C. The chemical reactions occurring are:

$A \rightarrow B$ reaction 1
$B \rightarrow C$ reaction 2

The mass of each substance is plotted in Figure 5.39, with respect to time passed in the reaction.

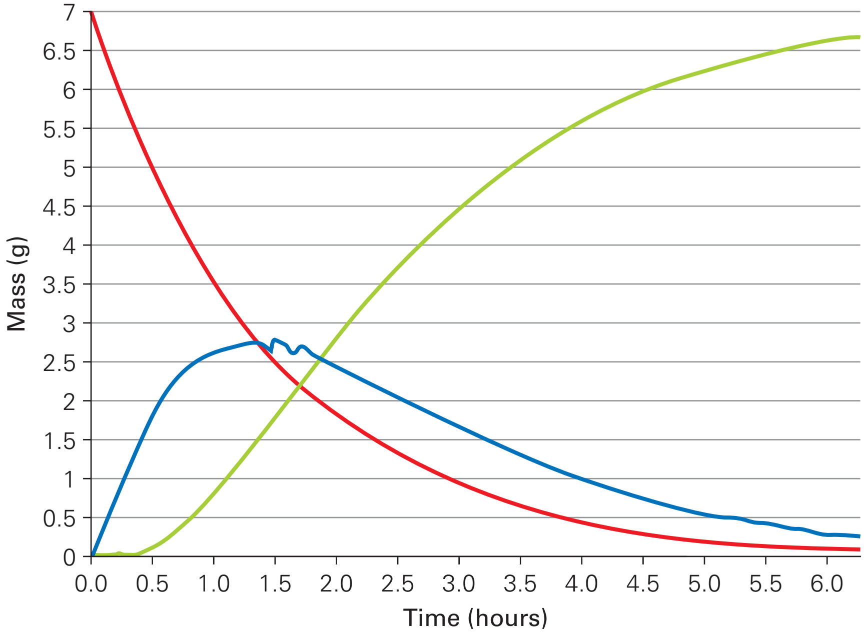

Figure 5.39 Change in mass of the reactant, intermediate and product over time in a chemical reaction

Applying

1. **Identify** the colour of the line that represents the reactant A.
2. **Identify** which coloured line represents the intermediate – substance B.
3. **Identify** the time at which the mass of intermediate B is greatest.

Analysing

4. **Identify** the relationship between the mass of reactant A and the mass of product C.
5. **Contrast** the curves for intermediate B and product C and account for the shape of the blue line.

Evaluating

6. **Infer** why the green line does not increase steadily until after 0.5 h.
7. **Justify** what the total mass of all substances will be at 3.0 h if the mass of reactant A was 7 g at time zero.
8. The intermediate, B, has a yellow colour when it is produced, and in this reaction this yellow colour was only evident when the mass of B was greater than the mass of either of the other two substances. **Deduce** which time period after the start of the reaction the reaction mixture would have appeared yellow.

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STEM activity: Building a rocket

Background information

Rockets are very heavy machines capable of lifting off the surface of Earth and obtaining a height sufficient to reach the orbit of Earth. This lift-off requires a combustion reaction to provide the thrust needed to overcome the force of gravity and shoot up into orbit. Combustion is a rapid, heat-producing (exothermic) reaction between a fuel and oxygen. During a chemical reaction, chemical bonds are broken and new bonds are formed, creating new chemical products. The exhaust from the bottom of the rocket produces a great thrust or force, and the opposing force pushes the rocket upward.

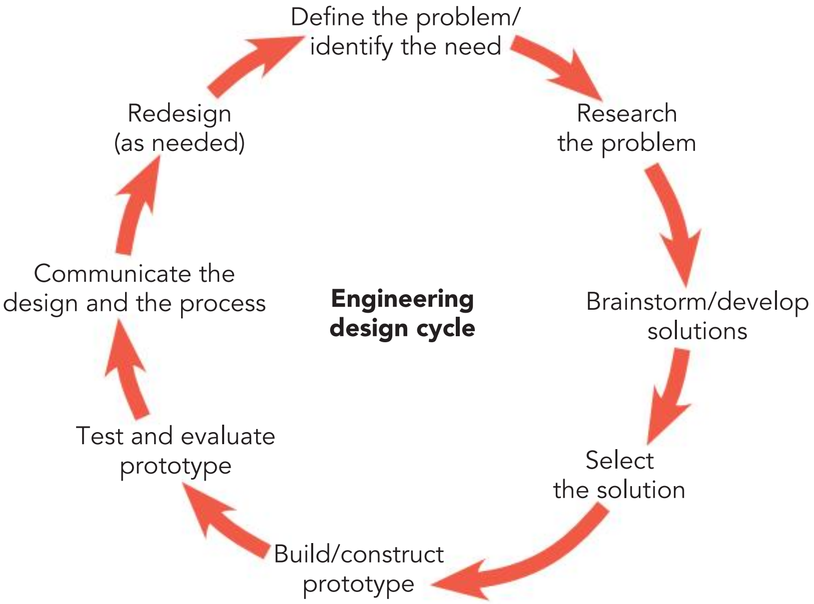

Figure 5.40 Designing and testing of a model comes before construction of the real thing.

In a process known as the engineering design cycle, aerospace engineers design small-scale models to learn from and experiment with. By testing small-scale models, the engineers ensure the rockets will work, without wasting time and money on testing full-size rockets. They can test the thrust and stability and make modifications in order to design the best rocket possible with the materials available.

Figure 5.41 Space launch

DESIGN BRIEF

Design, build, test and evaluate a rocket that will launch in a controlled manner in 10 seconds.

Activity instructions

In teams, you will take on the role of aerospace engineers for the Super-Fast Rocket Company. You have been hired to design, build, test and evaluate a rocket that will launch safely and repeatedly in 10 seconds. There will be two major factors in solving this problem: first, the design of the rocket, and second, the chemical reaction that will provide the thrust for the rocket.

Suggested materials

- Berocca™ canister (or anything similar with an internal popping lid such as some prescription medicine bottles)
- an antacid tablet
- water
- scissors, sticky tape, markers, paper
- chopping board
- mortar and pestle
- knife, spoon
- safety glasses

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Research and feasibility

1. Research the chemical reaction between antacid tablets and water to produce carbon dioxide and find out the impact of temperature, surface area, mass or other factors on the rate of reaction. List these factors in a table.

Factors that affect rate of reaction	Rate of reaction (increase/decrease/no effect)	Ideas on how to use this factor in design
Temperature		
Surface area		
Mass		
Reaction vessel type		

2. Research and discuss, in your team, ideas of how to use the medicine canister and lid as a reaction vessel – good engineers use existing technology, work on improvements and also completely reinvent the concept sometimes.
3. Research rocket design and how the different parts of a rocket are sized, relative to each other.

Design and sustainability

3. Discuss in your group how to make the rocket reaction vessel reusable to minimise waste, and think of methods to limit excess production of carbon dioxide.
4. Sketch multiple possibilities of the rocket design and how the reaction vessel would provide lift or thrust, making sure that your rocket would not be destroyed through the explosion of the reaction vessel.
5. Discuss the sustainability of your design and, as a group, decide on a model V1.0 to build.
6. As a group, use your knowledge of chemical reactions to decide on a combination of tests you will use to launch the rocket in 10 seconds. You may find creating a table a good way to record your tests. You can do this any way you wish.

Mass (g) or surface area (cm^2) of antacid	Volume of water (mL)	Temperature (°C)	Time to launch (s)

Create

7. Break into two groups, a build team and a discovery team. The build team will construct the rocket, and the discovery team will work on identifying the correct amount of antacid and water in the medicine canister in order to ensure the rocket launches at approximately 10 seconds. The build team needs to ensure the rocket can launch safely and sustainably.

Evaluate and modify

8. Discuss the different conditions you investigated and what you found out about the effect of temperature, surface area and mass of antacid tablets on the rocket launch times.
9. Draw a flow chart to show your original design for a 10-second launch and the modifications that followed, ending with your rocket launching at exactly 10 seconds. Highlight the changes or improvements you made at each step along the way.
10. Consider both your rocket and the other rockets you observed being launched. Identify and describe the characteristics that make one rocket perform better than another.
11. Discuss what challenges you faced while designing and testing your rocket and how you overcame these challenges.

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Chapter 6
Our changing Earth

Chapter introduction

Earth is constantly being reshaped by natural forces, including those created by the movement of tectonic plates. Over the course of billions of years, these forces have created and destroyed landforms and reshaped coastlines. In this chapter, you will explore the changing nature of our planet, examining the evidence for plate tectonics and the mechanisms behind plate movement. You will also consider the ways in which plate tectonics can contribute to natural disasters and the strategies that scientists and policymakers are using to predict and manage these events.

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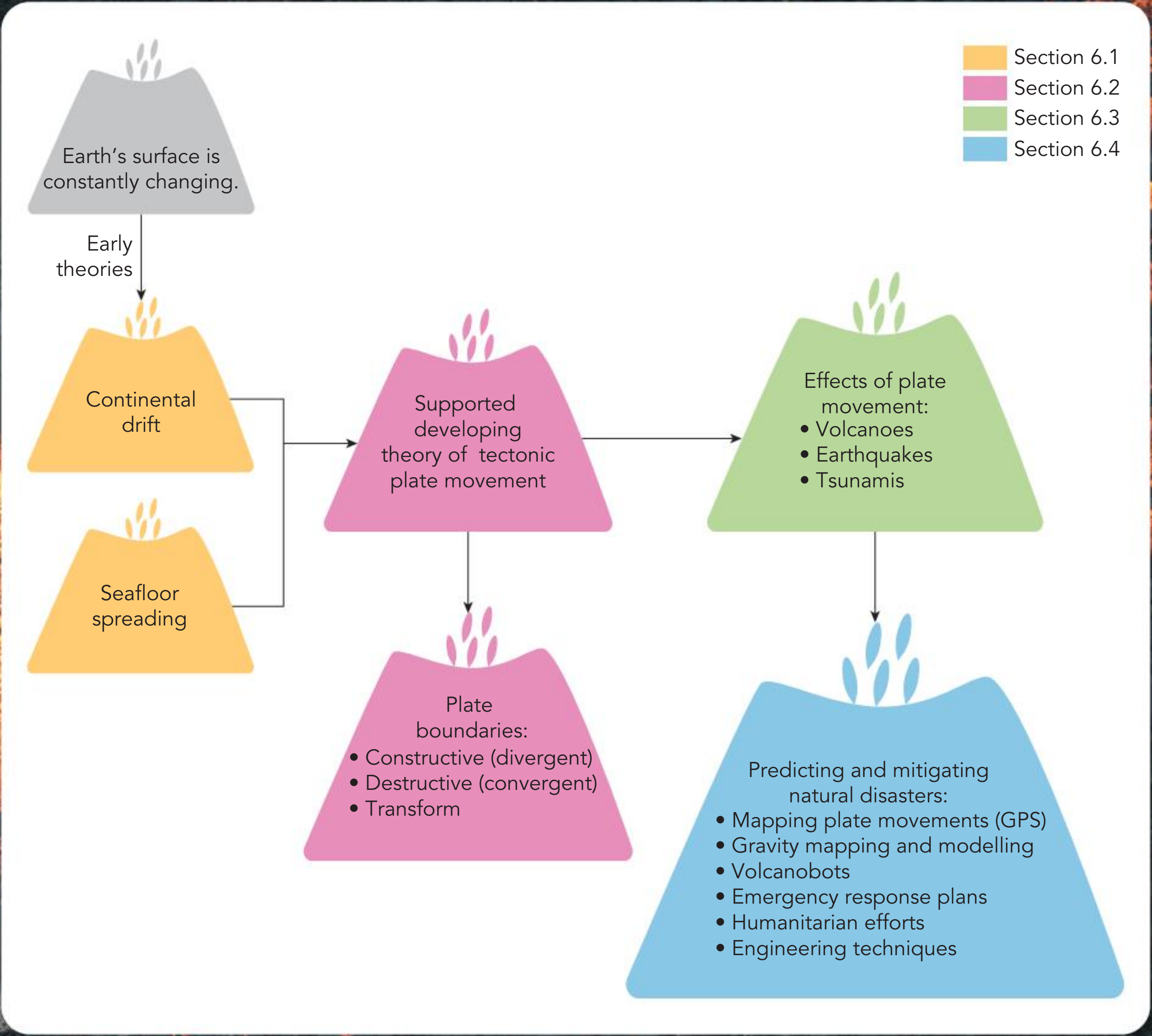
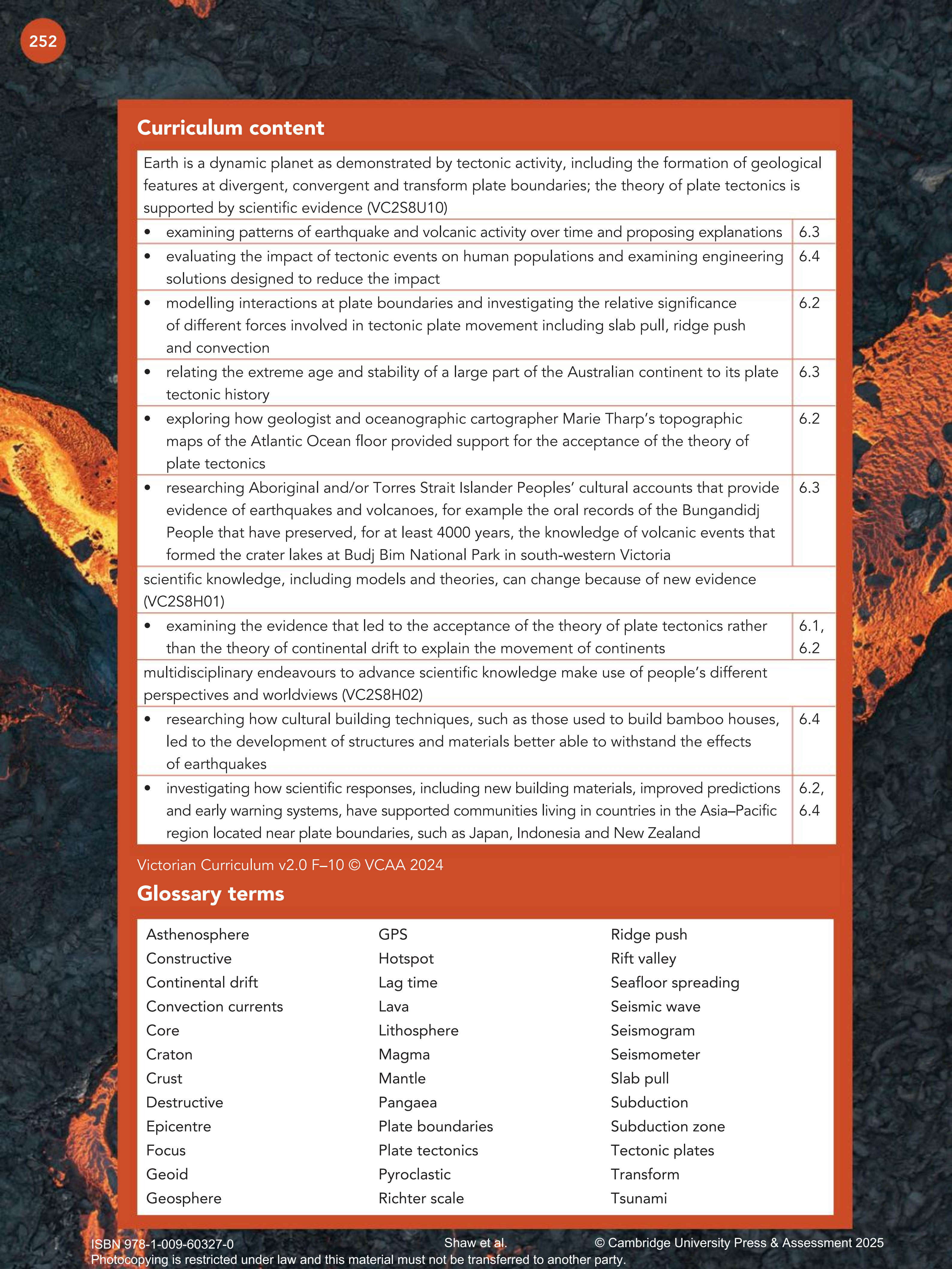
Concept map


Section 6.1
Section 6.2
Section 6.3
Section 6.4
Earth's surface is constantly changing.
Early theories
Continental drift
Seafloor spreading
Supported developing theory of tectonic plate movement
Effects of plate movement:
• Volcanoes
• Earthquakes
• Tsunamis
Plate boundaries:
• Constructive (divergent)
• Destructive (convergent)
• Transform
Predicting and mitigating natural disasters:
• Mapping plate movements (GPS)
• Gravity mapping and modelling
• Volcanobots
• Emergency response plans
• Humanitarian efforts
• Engineering techniques



Curriculum content

Earth is a dynamic planet as demonstrated by tectonic activity, including the formation of geological features at divergent, convergent and transform plate boundaries; the theory of plate tectonics is supported by scientific evidence (VC2S8U10)	
• examining patterns of earthquake and volcanic activity over time and proposing explanations	6.3
• evaluating the impact of tectonic events on human populations and examining engineering solutions designed to reduce the impact	6.4
• modelling interactions at plate boundaries and investigating the relative significance of different forces involved in tectonic plate movement including slab pull, ridge push and convection	6.2
• relating the extreme age and stability of a large part of the Australian continent to its plate tectonic history	6.3
• exploring how geologist and oceanographic cartographer Marie Tharp's topographic maps of the Atlantic Ocean floor provided support for the acceptance of the theory of plate tectonics	6.2
• researching Aboriginal and/or Torres Strait Islander Peoples' cultural accounts that provide evidence of earthquakes and volcanoes, for example the oral records of the Bungandidj People that have preserved, for at least 4000 years, the knowledge of volcanic events that formed the crater lakes at Budj Bim National Park in south-western Victoria	6.3
scientific knowledge, including models and theories, can change because of new evidence (VC2S8H01)	
• examining the evidence that led to the acceptance of the theory of plate tectonics rather than the theory of continental drift to explain the movement of continents	6.1, 6.2
multidisciplinary endeavours to advance scientific knowledge make use of people's different perspectives and worldviews (VC2S8H02)	
• researching how cultural building techniques, such as those used to build bamboo houses, led to the development of structures and materials better able to withstand the effects of earthquakes	6.4
• investigating how scientific responses, including new building materials, improved predictions and early warning systems, have supported communities living in countries in the Asia–Pacific region located near plate boundaries, such as Japan, Indonesia and New Zealand	6.2, 6.4

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Glossary terms

Asthenosphere
Constructive
Continental drift
Convection currents
Core
Craton
Crust
Destructive
Epicentre
Focus
Geoid
Geosphere
GPS
Hotspot
Lag time
Lava
Lithosphere
Magma
Mantle
Pangaea
Plate boundaries
Plate tectonics
Pyroclastic
Richter scale
Ridge push
Rift valley
Seafloor spreading
Seismic wave
Seismogram
Seismometer
Slab pull
Subduction
Subduction zone
Tectonic plates
Transform
Tsunami

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6.1 Continent movement theories

Learning goal

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

1. Describe the evidence for the theory of continental drift.

WORKSHEET
The theory of continental drift

VIDEO
Alfred Wegener

For centuries, scientists have been fascinated by Earth's continents and the puzzle of how they came to be distributed across the planet's surface. The concept of **continental drift**, or the idea that the continents have moved over time, is not a recent discovery. In fact, it dates to the late 16th century when early map-makers noticed that the coastlines of South America and Africa appeared to fit together like puzzle pieces.

Over the centuries, various scientists made contributions to the understanding of the theory. In this section you will explore the historical evolution of the theory of continental drift, from its earliest speculations to the present-day understanding of plate tectonics.

continental drift the theory of how the continents on Earth have moved over millions of years

Pangaea the supercontinent that has since broken into pieces and drifted apart

Alfred Wegener – continental drift

The theory of continent drift was first proposed in 1912 by the German geophysicist and meteorologist Alfred Wegener. He hypothesised that the continents we know today were once part of a giant land mass, which he called **Pangaea**. Wegener suggested that the continents have broken up and drifted apart over millions of years (see Figure 6.3). In justifying this theory to the scientific community, Wegener relied on four separate observations.

Figure 6.1 Alfred Wegener

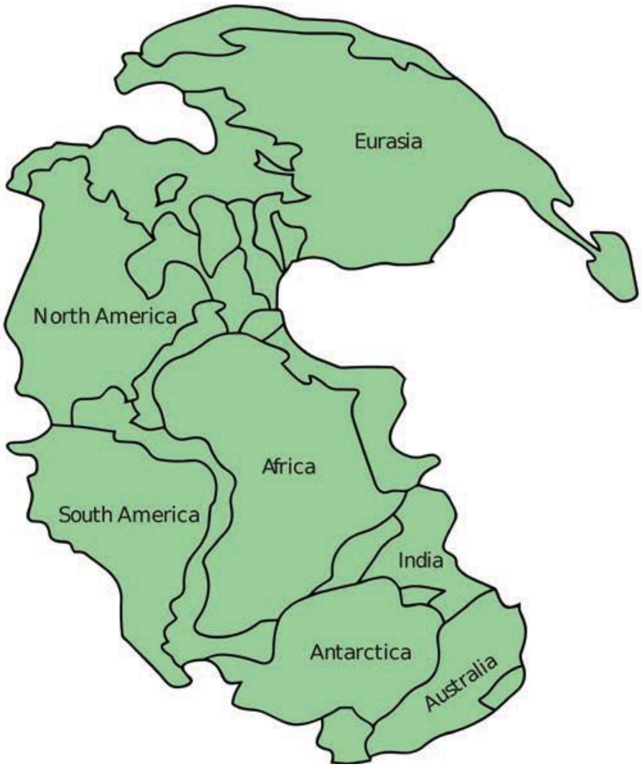

Figure 6.2 Wegener proposed that all the continents were once together in a giant land mass called Pangaea.

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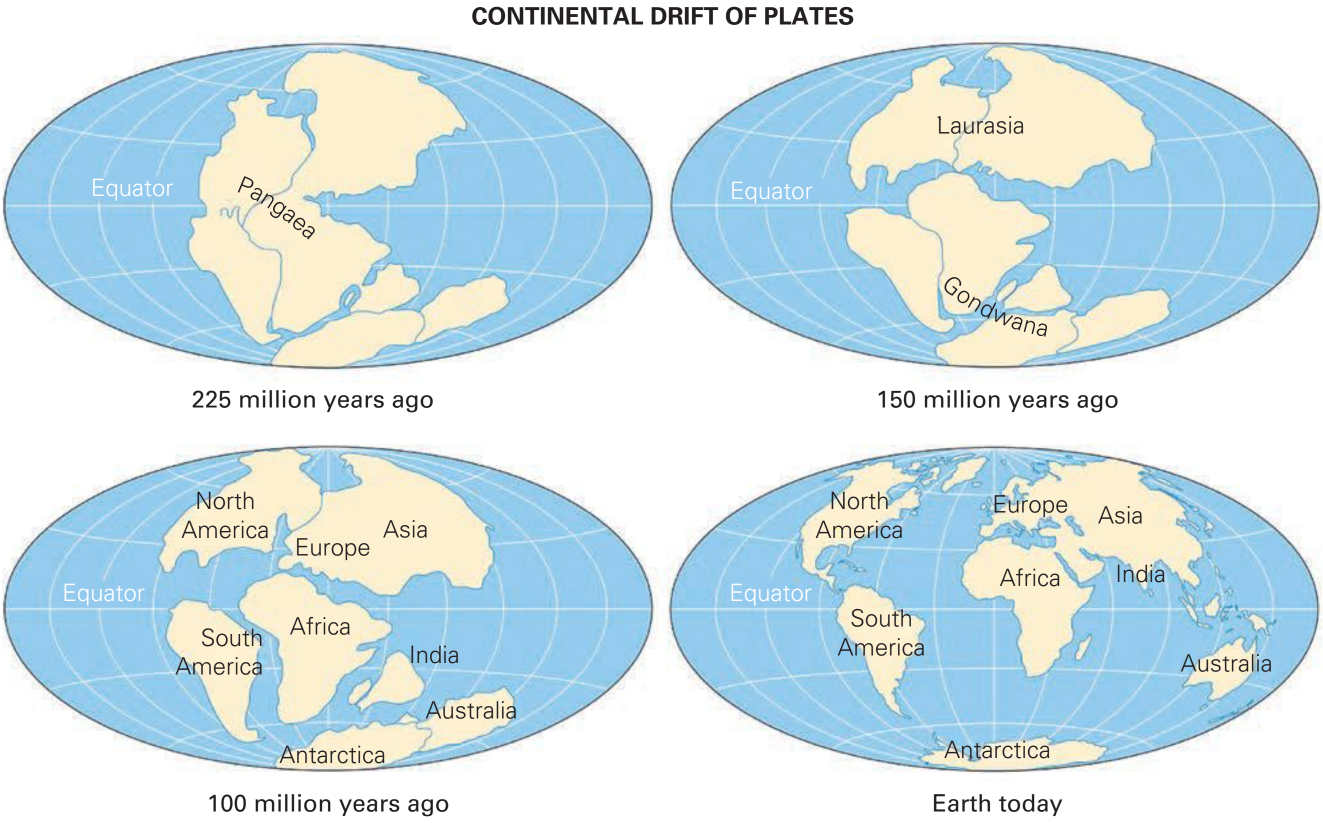

Figure 6.3 The movement of the continents from a single land mass (Pangaea) to their current locations

1. Continental outlines matched

Even the rudimentary maps of early explorers noted that the coastlines of neighbouring continents had complementary shapes. Like pieces of a jigsaw puzzle, some of our existing continents fit together quite snugly when you draw them side by side.

Figure 6.4 The outlines of Africa and South America fit together like pieces in a jigsaw puzzle.

2. Similar fossils were found on different continents

Fossil evidence showed remains of the same plants and land-based creatures on continents which are now separated by oceans. This led Wegener to conclude they were once connected (Figure 6.5). His opponents claimed that the terrestrial animals could have crossed land bridges that were present during times of low ocean levels. However, this was not supported by the fact that the ocean floor had very different geology to the continental crust.

3. Shared geological features

Wegener noticed rocks of the same type and age on either sides of oceans, and when continents were realigned, entire mountain ranges that appeared to be continuous.

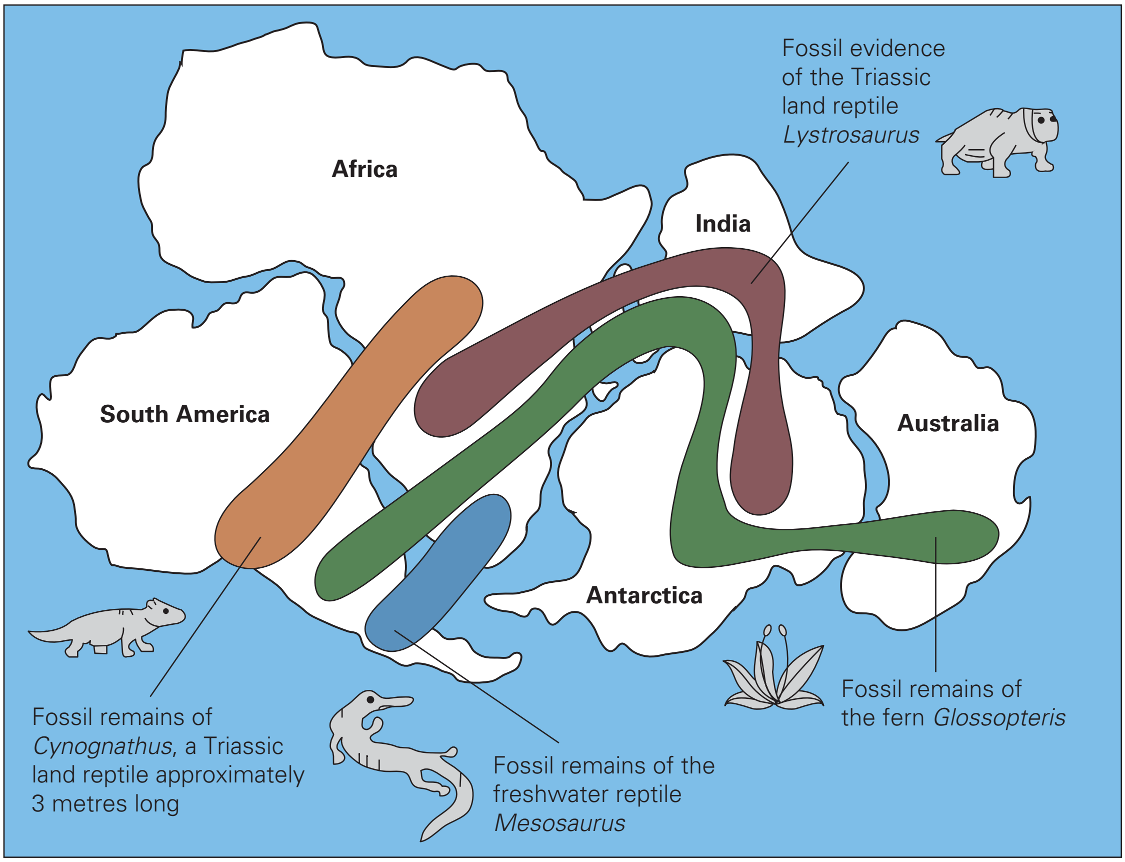

Figure 6.5 Wegener found that fossils on different continents matched up, supporting his theory of continental drift.

4. Coal was found in cold areas and evidence of glaciers was found in the tropics

Wegener studied the geological literature and found evidence of coal in Northern Europe, which would normally only form in hot and humid climates near the equator. He also noted evidence of past glaciers in continents such as Africa, suggesting it had once occupied a polar region (as seen in Figure 6.5), but had since moved to a warmer location.

The scientific community remained skeptical and were not convinced of the validity of Wegener's theory of continental drift. Despite these four persuading pieces of evidence, he could offer no real explanation or mechanism of how the continents moved.

Unfortunately, in 1930, Alfred Wegener and another team member were caught in a blizzard on an expedition in Greenland and did not survive. At the time of his death, his theory was still not accepted by the scientific community.

Figure 6.6 Coal only forms in hot, swampy areas; glaciers only form in cold areas.

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Quick check 6.1

1. **Recall** the name of the scientist who proposed and gave evidence for the theory of continental drift.
2. **List** the four different pieces of evidence he used to support his theory.
3. **Outline** why his theory was not accepted at the time.

Marie Tharp – seafloor mapping

Figure 6.7 Marie Tharp and Bruce Heezen

Marie Tharp was a geologist and oceanographic cartographer (someone who maps the ocean floor) who worked in collaboration with geologist Bruce Heezen to produce the first detailed and three-dimensional maps of the Atlantic Ocean floor.

Beginning in the 1950s, Tharp interpreted and plotted data collected by ships, demonstrating that the ocean floor was not a flat basin as previously thought. Her enormous hand-drawn maps depicted a complex topography of mountains and trenches similar to terrestrial environments and revealed the presence of a continuous rift valley along the axis of the Mid-Atlantic Ridge. The ridge was not a static singular structure. It featured interconnected segments with deep valleys running between, and Tharp hypothesised that new oceanic crust was forming at the site. This proposal was ridiculed by the scientific community, as it lent support to the much-maligned theory of continental drift.

In later years, she worked on projects to plot the epicentres of earthquakes on seafloor maps, which demonstrated that the ridges were seismically active. This observation was critical to the acceptance of the theory of plate tectonics discussed later in the chapter. In 1977, she was awarded the National Geographic Society's Hubbard Medal – the first time the award was given to a woman.

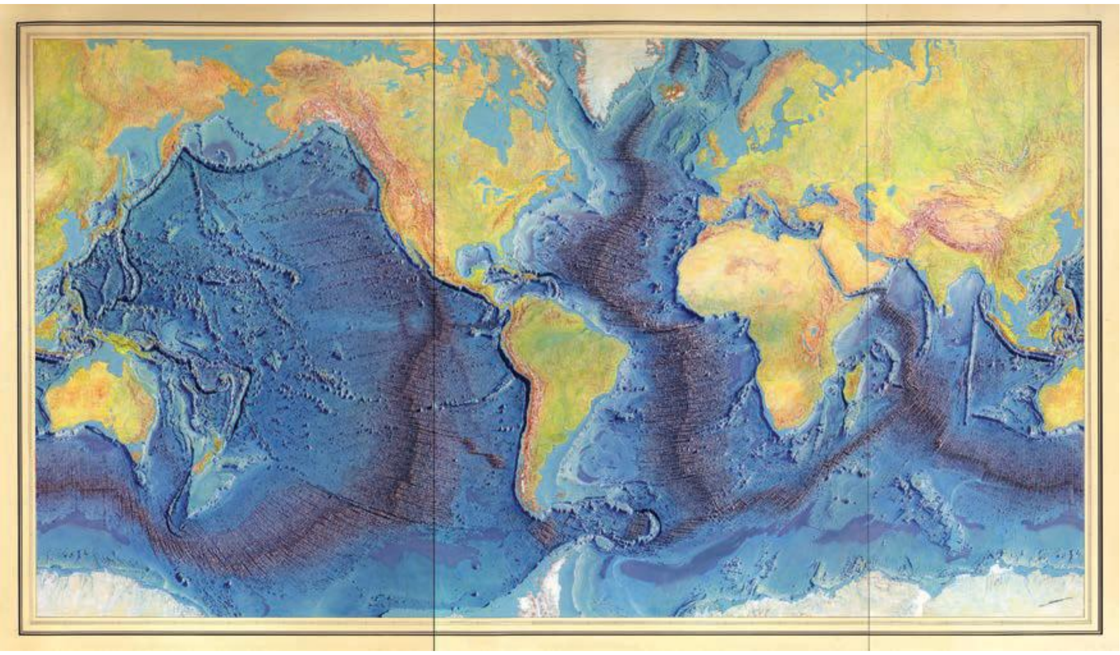

Figure 6.8 A painting of the Heezen–Tharp ocean-floor map

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Harry Hess – seafloor spreading

Some 30 years after Wegener's death, a geology professor named Henry Hess built upon the work of Marie Tharp, and outlined new evidence that appeared to support the theory of continental drift. Hess had served in the US Navy during World War II on a destroyer ship that carried sensitive magnetic equipment designed to detect the steel hulls of German submarines. He first noticed fluctuations in the equipment that led him to studying and mapping the ocean floor. Hess utilised sonar, which involves emitting sound waves and measuring the time it takes for them to reflect back as an echo, as a means of measuring the depth of the ocean floor.

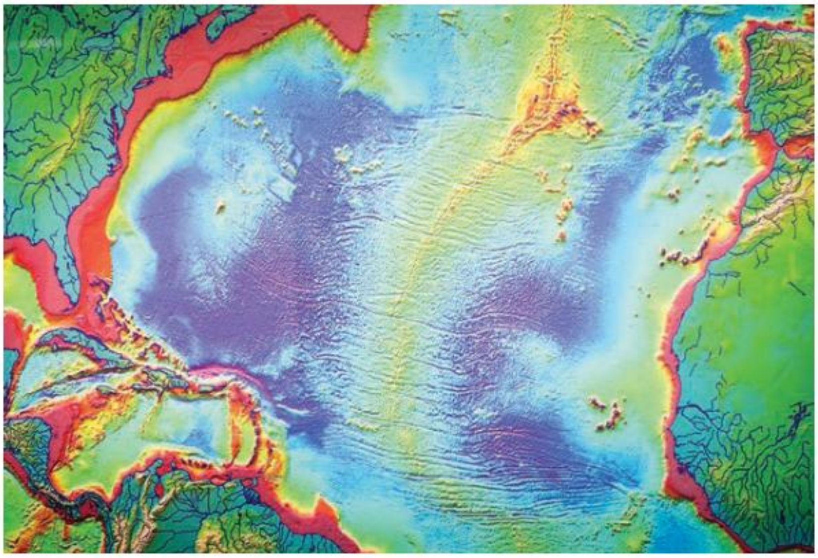

Figure 6.9 A map of the Mid-Atlantic Ridge and its volcanoes running down the middle of the Atlantic Ocean

Through his mapping, Hess demonstrated the ocean floor contained deep trenches, underwater mountain ranges and volcanoes, supporting the maps produced by Tharp and Heezen. He also observed the ocean floor appeared to be changing over time and theorised that the ocean floor was significantly younger than the continents. In his 1962 book, *The History of Ocean Basins*, Hess outlines how volcanoes located along ocean ridges spew up molten rock from beneath Earth's crust, forming new oceanic rock. He proposed that this process, named **seafloor spreading**, offered an explanation for Wegener's hypothesis of moving continents: if the sea floor is spreading, then the continents on either side must be moving too.

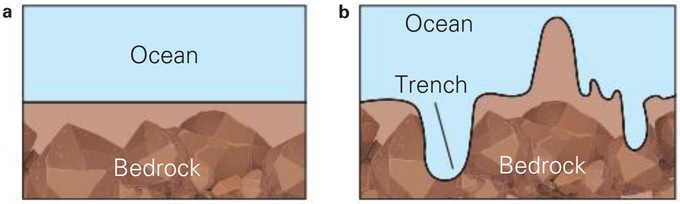

Figure 6.10 (a) The ocean floor was previously thought to be flat. **(b)** Harry Hess's map of the ocean floor indicated otherwise.

seafloor spreading a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

Explore! 6.1

Journey to the bottom of the sea

Victor Vescovo's Five Deeps Expedition was an ambitious project that aimed to explore the deepest points of each of the world's five oceans. Over the course of several years, Vescovo and his team used a specially designed submarine to dive to the bottom of the Atlantic, Southern, Indian, Arctic and Pacific Oceans. The expedition not only provided new insights into the geology and biology of the ocean depths, but it also set several new records.

Figure 6.11 Dr Dawn Wright and Victor Vescovo inside the control capsule of the submersible deep-submergence vehicle (DSV) *Limiting Factor*.

One of the most significant records broken was the deepest manned descent in history, as Vescovo's team reached a depth of nearly 10 925 m in the Pacific Ocean's Mariana Trench. In addition to this, the expedition also set a record for the deepest dive in the Atlantic, Southern and Indian Oceans. The expedition made the first manned descent to the bottom of the Arctic Ocean.

In June 2023, a submersible vessel owned and operated by the American company, OceanGate, suffered a catastrophic implosion while attempting to explore the wreck of the Titanic, instantaneously killing all passengers and crew. Discuss whether deep ocean expeditions should be manned and why people choose to ignore the risks associated with such trips.

Making thinking visible 6.1

See, think, wonder: Vomiting shrimp

The following images show a deep-sea pandalid shrimp, *Heterocarpus ensifer*, and the same animal 'vomiting' light from glands located near its mouth.

- Can you describe what is visible in the photos?
- What thoughts come to your mind when you observe them?
- Are there any questions that arise from your observations?

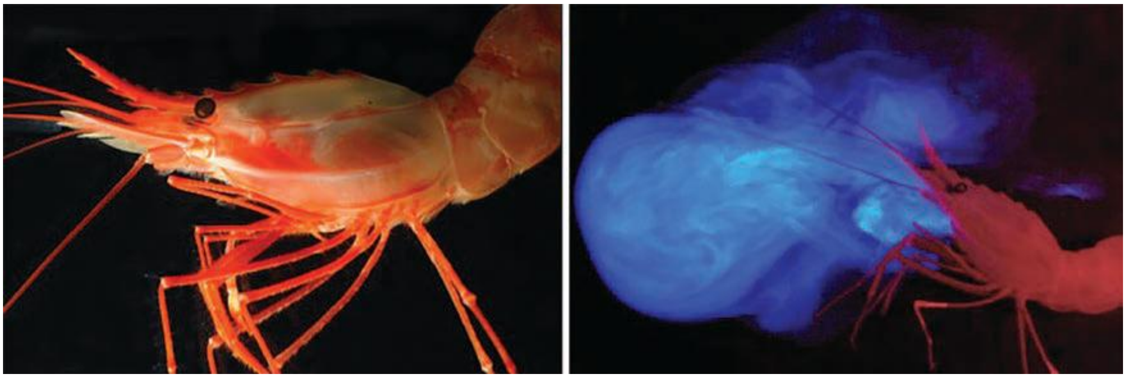

Figure 6.12 The deep-sea pandalid shrimp, *Heterocarpus ensifer*

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

Quick check 6.2

1. **Name** the ridge located in the Atlantic Ocean.
2. **Recall** the name of the technique Harry Hess used to map the ocean floor.
3. **Describe** the results and major discovery of Harry Hess's ocean-floor mapping.

ISBN 978-1-009-60327-0

Did you know? 6.1

Extreme exploration

On a 2020 crewed expedition to the Challenger Deep, some records were set by passengers who accompanied Victor Vescovo on his dives. Former NASA astronaut Doctor Kathryn Sullivan became the first person to both walk in space and descend to the deepest known point on Earth; and Vanessa O'Brien became the first woman to reach Earth's highest (Mount Everest) and lowest points. She was also the first person to reach nearest to and farthest from Earth's core (Challenger Deep and the summit of Chimborazo).

Figure 6.13 Vanessa O'Brien

Frederick Vine, Drummond Matthews and Lawrence Morley – reading the ocean floor

WORKSHEET
Magnetic
striping

Two concurrent scientific projects in the 1960s reinforced Hess's theory of seafloor spreading. British geologist Drummond Matthews and his former PhD student Frederick Vine studied the magnetic intensity on one side of a mid-ocean ridge, and discovered alternating bands of normal and reverse magnetism that were running parallel to each other. This was consistent with the idea that newly formed oceanic crust was spreading away from the ridge. At the same time in Canada, geologist Lawrence Morley independently published evidence of the same phenomenon.

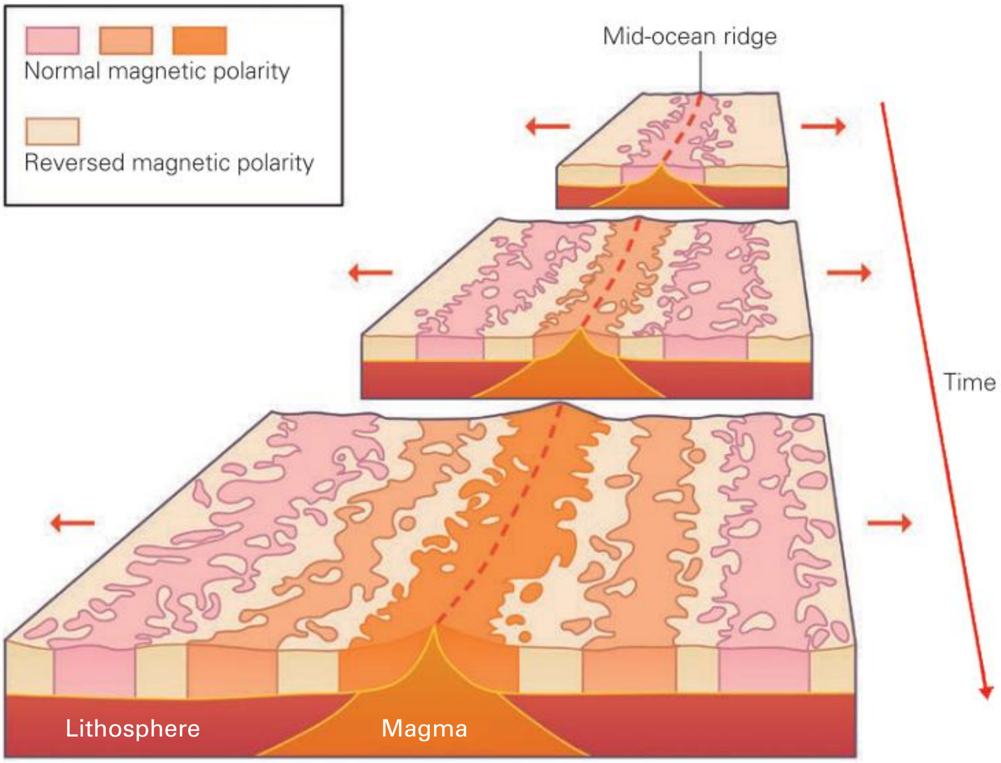

Figure 6.14 The pattern of magnetic stripes on the ocean floor

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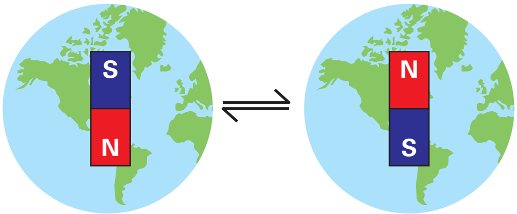


Figure 6.15 According to paleomagnetic records, Earth's magnetic poles have experienced approximately 183 reversals in the last 83 million years and have undergone at least several hundred reversals over the past 160 million years.

Vine and Matthews knew that the new molten rock produced by the ocean ridges contained magnetite, a magnetic mineral. While the molten rock cooled and solidified, the magnetite aligned with Earth's own magnetic field, with its magnetic poles matching Earth's magnetic poles. Earth's magnetic field reverses direction approximately every 300 000 years, and the cooling rock preserves the record of Earth's polarity at that time. For rocks to have their magnetic minerals aligned in different directions, they must have formed at different times. As the pattern of magnetic stripes leading away from the mid-ocean ridges is symmetrical, this led Vine and Matthews to conclude that new sea floor was being added equally to each side of the ridge (see Figure 6.14). Morley also saw the significance of the changes in Earth's magnetic field, magnetism of new oceanic crust and seafloor spreading as a mechanism for continental drift. That is why it is often called the Vine–Matthews–Morley hypothesis.

Further evidence to support the notion of seafloor spreading comes from the age of the rocks on the sea floor. If new rock is forming at the ridge and spreading out equally in opposite directions, you would expect that as you move further away from the ridge, the rock would increase in age. This is exactly what Vine, Matthews and Morley found.

Explore! 6.2

Earth's magnetic field

On average, Earth's polarity switches approximately every 300 000 years. The last time Earth's poles reversed was 780 000 years ago. This means that at any time there could be a reversal in Earth's magnetic field. Interestingly the Sun is a lot less magnetically stable; its magnetic field reverses approximately every 11 years.

1. On average, how long does it take for Earth to complete a full reversal?
2. If you were using a compass to navigate at the time when Earth's poles were reversing, how would this affect the direction you were taking?
3. Research and describe how nature uses Earth's magnetic field.
4. Research and discuss the consequences of Earth's magnetic field weakening for a significant period when it reverses.

Making thinking visible 6.2

Connect, extend, challenge: The auroras

The upper atmosphere of the Sun generates a stream of charged particles called the solar wind.

The Aurora Borealis and Aurora Australis are natural phenomena that occur when charged particles from the Sun, also known as solar wind, interact with Earth's magnetic field and atmosphere. These interactions cause particles in the atmosphere to emit light, creating the colourful displays that we know as the Northern Lights and Southern Lights.

These lights are typically visible in the high-latitude regions near Earth's magnetic poles, including northern Scandinavia, Alaska, Canada and Russia for the Aurora Borealis, and southern Australia, New Zealand and Antarctica for the Aurora Australis. However, during particularly intense geomagnetic storms, the lights can sometimes be seen at lower latitudes as well.

The colours of the auroras depend on the altitude of the aurora, the gas that is being excited and the energy of the particles in the solar wind. Green is the most common colour. Other colours that can be seen include pink, red, yellow, blue and purple.

Consider what you have just read and answer the following questions:

- How do the concepts and details connect to your existing knowledge about auroras?
- Which new insights did you gain from the text that extended your understanding or encouraged you to consider new perspectives?
- What questions do you have after thinking about this information?

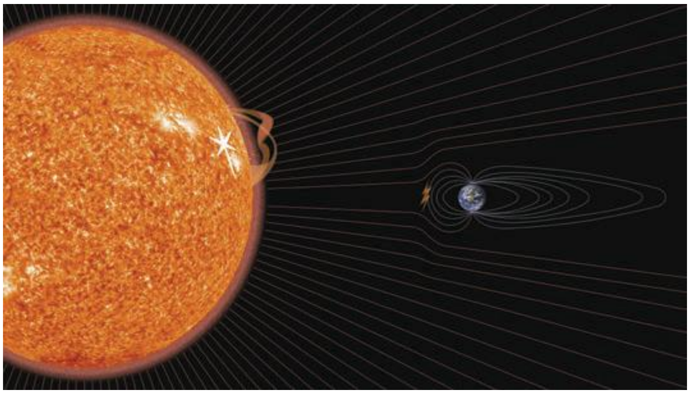


Figure 6.16 Solar wind interacting with Earth's magnetic field

Figure 6.17 The Aurora Borealis

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

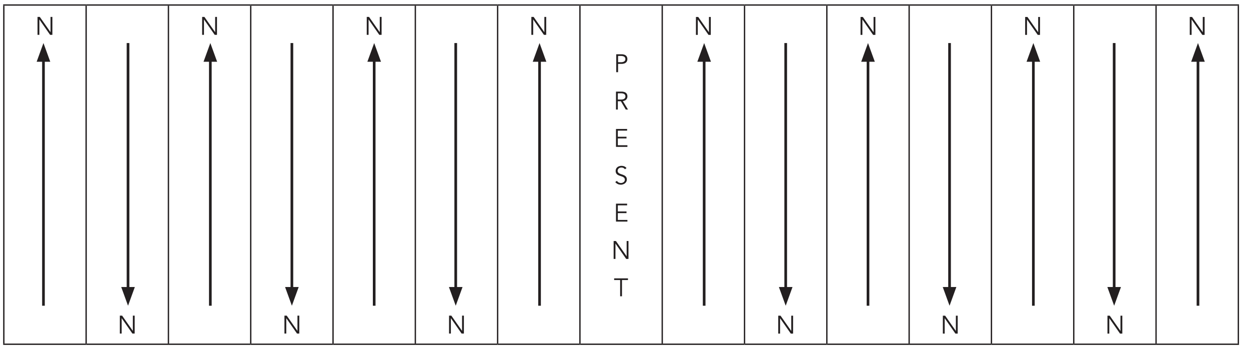
Quick check 6.3

1. **Identify** the name of the mineral in molten rock that is magnetic.
2. **Discuss** what happens to this magnetic mineral when the molten rock cools.
3. **Explain** how the presence of magnetic stripes in rocks parallel to ocean ridges proved that the sea floor was spreading.
4. **State** one additional piece of evidence that supports Hess's theory of seafloor spreading.

Try this 6.1

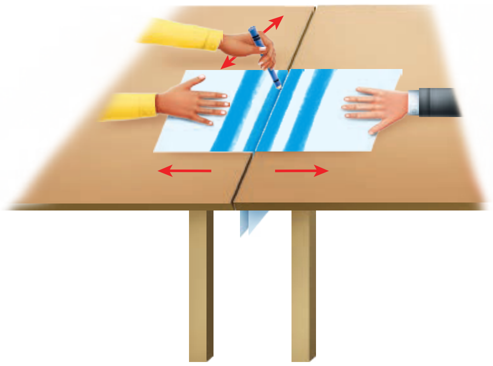
Modelling seafloor spreading

1. Get a piece of paper and re-create the diagram below, which shows Earth's magnetic field changing over time from the present (centre) to the distant past (left and right edges).



2. Fold the paper in half in the middle of the section labelled 'Present'.
3. Put the paper into a gap between two tables with the two short ends of the paper on the tables' edges and the remainder of the paper dropping down into the gap. Push the tables together so that the gap is closed and most of the paper cannot be seen.
4. Pull apart the ends of paper to show the movement of the sea floor away from an ocean ridge.

You have just modelled seafloor spreading!



Practical 6.1

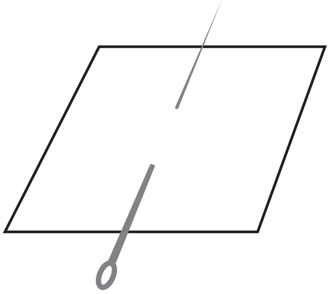
Making a compass

Aim

To make a simple compass

Materials

- 250 mL beaker half full of water
- needle
- small square of paper
- bar magnet



Method

1. Draw the results table below.
2. Thread the needle through the small square piece of paper as shown here.
3. Stroke the needle 20 times with the bar magnet. You must stroke in **one** direction only and with one end of the magnet only.
4. Put the piece of paper with the needle into the water, making sure that it floats.
5. Record in the results table the direction that the needle points.
6. Turn the beaker 90° and record the direction that the needle points in the results table.
7. Turn the beaker a further 90° and again record the direction in the results table.

Results

Table showing the direction that needle points

	First position	Rotated 90°	Rotated a further 90°
Direction			

Discussion: Analysis

1. Describe what happened to the magnetised needle when the beaker of water was rotated.
2. Explain the role of the paper in this experiment.
3. The needle in this experiment is acting as a temporary magnet. What is a temporary magnet and how does it differ from a permanent magnet?
4. Discuss the importance of having the needle magnetised only in one direction.

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Section 6.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 6.1 questions

Remembering

1. **Name** the theory proposed by each of the following scientists.
   a) Alfred Wegener
   b) Harry Hess
2. **Recall** the piece of evidence that supported Harry Hess's theory.

Understanding

3. **Describe** one piece of evidence that Wegener used to back up his theory.
4. **Explain** why Wegener's theory was not accepted during his lifetime.

Applying

5. **Communicate** using labelled diagrams the results of Harry Hess's mapping of the ocean floor.
6. **Describe** how sonar works in relation to ocean-floor mapping.
7. **Summarise** the evidence that supports Harry Hess's theory of seafloor spreading.

Analysing

8. **Organise** these major discoveries (A–E) on the movement of continents into chronological order (the earliest first).
   A. Harry Hess states that the sea floor is spreading outwards from mid-ocean ridges.
   B. Alfred Wegener outlines his theory of continental drift, stating that all the continents were once part of a large land mass, which has split up and drifted apart.
   C. The age of rock confirms that new rock is forming at mid-ocean ridges.
   D. Magnetic striping patterns in the ocean rock confirm that new rock is constantly forming.
   E. Harry Hess maps the ocean floor and confirms that it contains deep trenches, mountains and volcanoes.
9. **Distinguish** between magnetic striping and magnetic field reversal.
10. **Compare** the properties of oceanic rock as you move away from a mid-ocean ridge.
11. **Classify** the following as theory or evidence.
    a) The sea floor spreads away from a mid-ocean ridge.
    b) The rock is older the further away it is from a ridge.
    c) The continents drifted away from one another.
    d) Rock types on different continents match up with one another.

Evaluating

12. **Deduce** what would happen to a compass if Earth's magnetic field was to change direction now.
13. **Justify** by use of a diagram that Earth's magnetic field has switched over time.
14. With the examples of Alfred Wegener and Harry Hess, **evaluate** the impact of currently accepted scientific ideas on the willingness to adopt new theories.

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6.2 Plate tectonics and plate movement

WORKSHEET
Convection currents

VIDEO
Plate tectonics

Learning goals

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

1. Construct a timeline of evidence to show the development of the theory of plate tectonics.
2. Explore how Marie Tharp's topographic maps provided support for the acceptance of the theory of plate tectonics.
3. Investigate the relative significance of different forces involved in tectonic plate movement.
4. Describe the consequence of three types of plate boundaries.
5. Model interactions at plate boundaries.

Evidence for Wegener's theory of continental drift was mounting, thanks to the work of Tharp, Hess, Vine, Matthews and Morley, which had offered a mechanism for seafloor spreading. However, scientists still need to account for how the continental crust behaved, and to do this, they needed a better understanding of the structure of Earth itself.

Earth's **geosphere** is made up of four layers that differ in their composition: the inner **core**, outer core, **mantle** and **crust**.

The inner core is hotter than the surface of the Sun, but the heavy metals that it is composed of (such as iron and nickel) remain solid due to the immense pressure from the layers above. The outer core also contains heavy metals, but they are present in a liquid state.

The mantle is very dense (although not as dense as the core) and is mostly made up of semi-molten rock. The mantle is divided into the lower mantle (shown in yellow, Figure 6.18) and the three layers of the upper mantle, (shown in orange and dark brown). The upper mantle features a transition zone near the lower mantle, a soft fluid layer, and a rigid thin top layer.

The crust is the solid outer layer, and despite being the thinnest, manages to support all the life on Earth. Oceanic crust is found under the oceans, which is thinner and denser than continental crust, made up of the continents and the shelves.

geosphere all Earth's geological materials including the magma, lava, rocks and minerals that make up the crust and layers beneath

core the inner part of Earth's structure

mantle the layer of Earth underneath the crust that is made up of solid and semi-molten rock and surrounds the outer core

crust the solid outer layer of Earth that supports all life on Earth

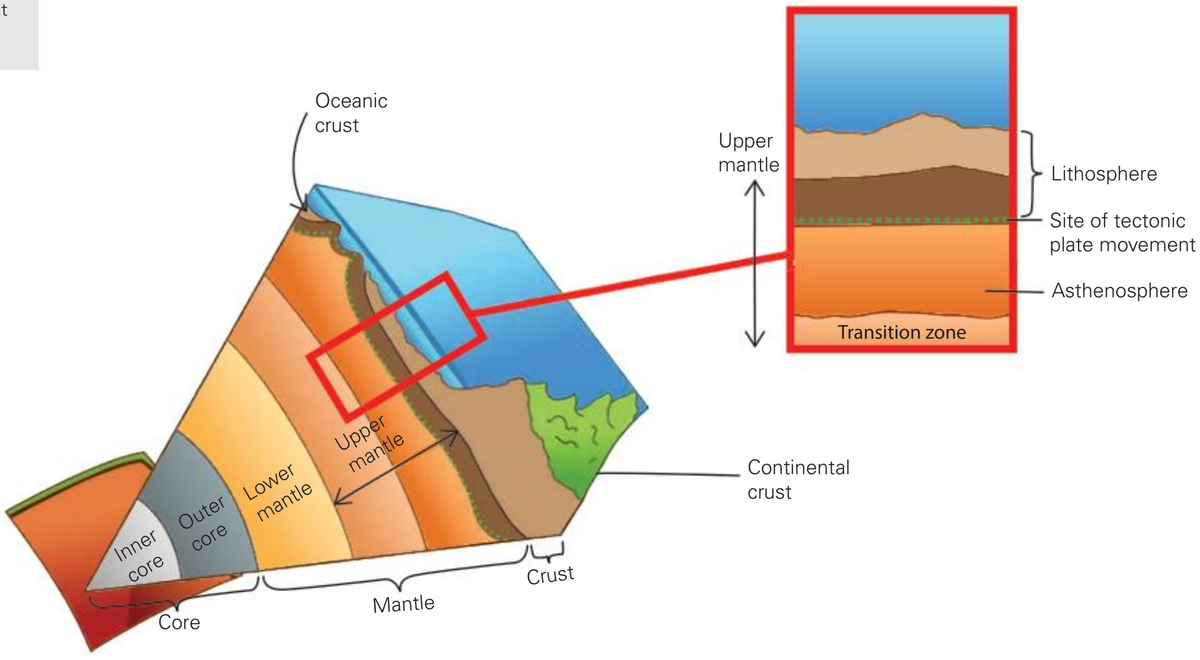

Figure 6.18 Earth's layers

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Scientists often describe the layers that comprise Earth's structure in terms of their mechanical properties rather than their chemical composition. The **lithosphere** consists of the top thin solid layer of the upper mantle, along with the oceanic and continental crust. The **asthenosphere** describes the semi-molten rock underneath the lithosphere, located in the central layer in the upper mantle. These terms are commonly used when discussing the theory of **plate tectonics**, first proposed in the late 1950s and early 1960s, as they allow for a clear articulation of how **tectonic plates** move upon the semi-molten rock below.

lithosphere
the solid outer layer of Earth consisting of the crust and the top layer of the upper mantle; it is split into giant slabs called tectonic plates

asthenosphere
the softer layer of rock under the lithosphere

plate tectonics
the theory that Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

tectonic plates
giant slabs of rigid rock that float on the partially molten rock below Earth's surface and make up the lithosphere

Did you know? 6.2

The innermost inner core

In 2023, scientists proposed another layer, the innermost inner core. Geoscientists first hypothesised that Earth's core might have an additional layer twenty years ago, but new research has finally provided evidence. The new layer was detected using data collected by measuring the seismic waves of earthquakes as they passed through Earth's centre.

Quick check 6.4

1. **List** the layers of Earth from the surface to the centre of Earth.
2. **State** the name given to the giant slabs of rock that make up Earth's lithosphere.
3. **Describe** the differences between oceanic and continental crusts.

Tectonic plates

Tectonic plates are pieces of Earth's lithosphere, which is the outermost and rigid layer of the planet. Tectonic plate movement is driven by several forces, including slab pull, ridge push and convection in Earth's mantle.

There are a few major tectonic plates and dozens of smaller ones, but they all play a role in shaping Earth. The major tectonic plates are commonly named after the continents that lie above them. Australia is situated in the middle of the Australian plate (Figure 6.19).

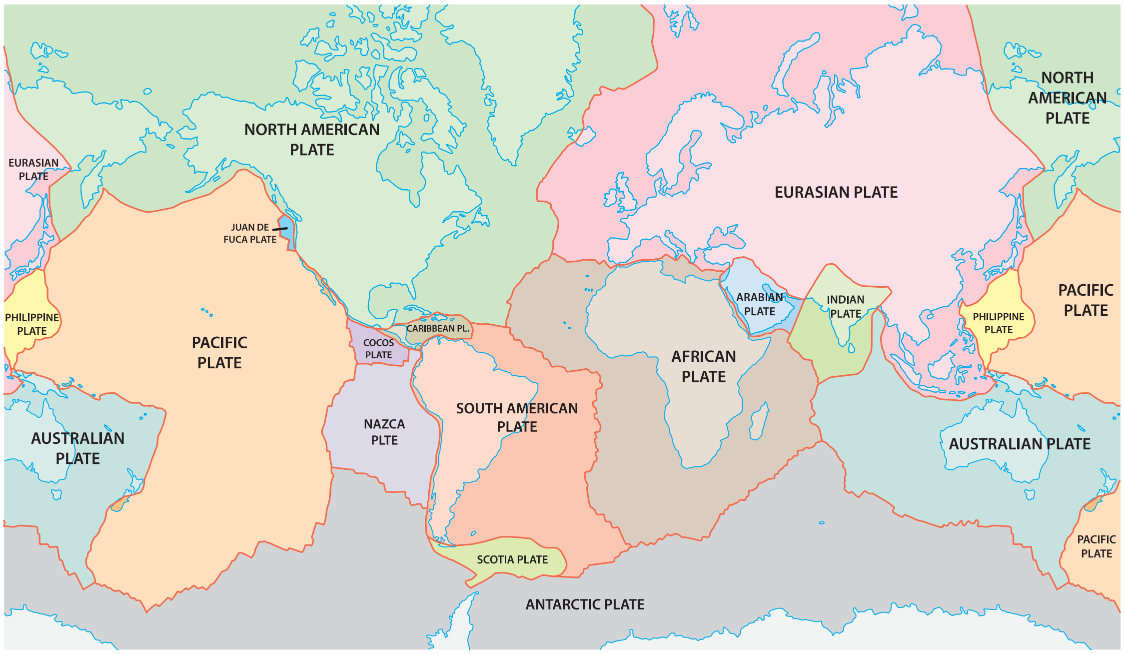

Figure 6.19 The major and some minor tectonic plates on Earth's surface

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slab pull
the pulling force exerted by a cold, dense oceanic plate plunging into the mantle due to its own weight

subduction zone
the area where a collision between two of Earth's tectonic plates causes one plate to sink into the mantle underneath the other plate

ridge push
a force that causes a plate to move away from the crest of an ocean ridge and into a subduction zone

convection currents
the transfer of heat due to temperature differences between the upper and lower layers of Earth's mantle, causing movement of rocks within the mantle

How do the plates move?

Slab pull is the force that results from the sinking of a dense oceanic tectonic plate into the mantle at a **subduction zone**, an area where one plate sinks into the mantle. This sinking motion generates a pulling force on the rest of the plate, causing it to move towards the subduction zone.

Ridge push is the force that results from the elevated position of the oceanic ridges. As new magma rises to fill the gap created by the separating plates, the ridge pushes the plate away from it.

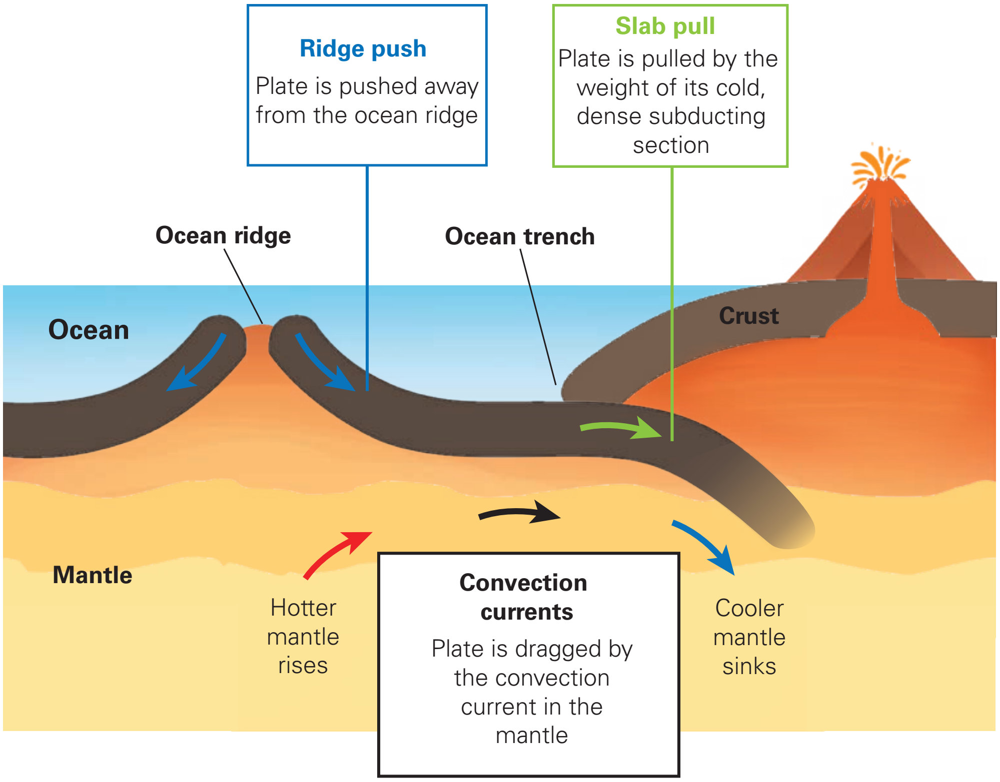

Figure 6.20 Slab pull, ridge push and convection currents all cause tectonic plates to move.

Heat is transferred from Earth's interior to the surface via convection in the mantle. Closer to the radioactive heat-generating core, the temperature is thousands of degrees hotter than near the surface of Earth. Rocks in the lower mantle increase in temperature and rise towards the cooler surface. Here they cool and become more dense, before sinking down again. This creates a cyclical movement of rock in the lower mantle due to **convection currents** (see Figure 6.21).

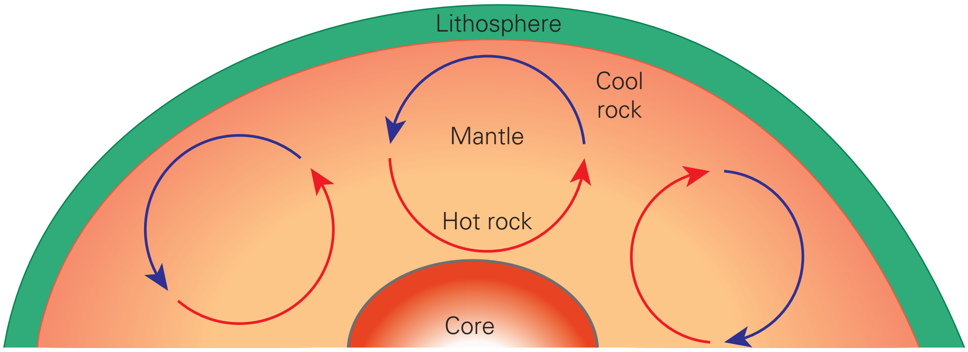

Figure 6.21 Convection currents in Earth's mantle drive the movement of the tectonic plates.

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Quick check 6.5

1. **State** what the major tectonic plates are named after.
2. **Describe** the differences in structure between the rocks in the upper and lower mantle.
3. **Explain** why hot rock rises.
4. **Describe** how this movement of rocks in the mantle drives the movement of tectonic plates.

Practical 6.2

Observing convection currents

Aim

To observe convection currents

Materials

- dark food colouring
- cold water
- 250 mL beaker
- ice cube trays
- Bunsen burner
- gauze mat
- tripod
- heatproof mat

Method

1. Mix 100 mL of water with some food colouring in a beaker (the darker the coloured water the better).
2. Pour this mixture into the ice cube trays and place the trays in a freezer until the water has frozen.
3. Half fill a 250 mL beaker with cold water.
4. Set up your equipment as shown in Figure 6.22.
5. Set the Bunsen burner to a blue flame and concentrate the heat on one corner of the beaker.
6. Drop an ice cube into the beaker and observe the water.

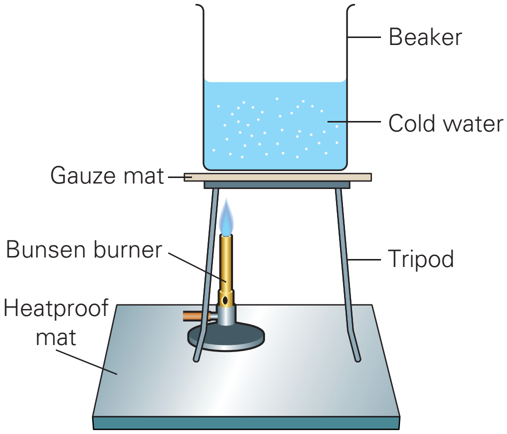

Figure 6.22 Experimental set-up

Results

Record your observations.

Discussion: Analysis

1. Describe what happened to the ice cube when it hit the warm water.
2. Describe the distribution of the coloured water from the ice cube just after it had melted.
3. Explain what you observed.
4. Discuss what happened to the distribution of the coloured water from the ice cube as the Bunsen burner heated up the water.
5. Explain what you observed.
6. Describe and explain the appearance of the water at the end of the experiment.
7. Draw a labelled diagram to show what was happening to the water in the beaker.

ISBN 978-1-009-60327-0 Shaw et al.

How fast is Australia moving?

GPS (Global Positioning System) a radio navigation system that allows land, sea and airborne users to determine their exact location, velocity and time

plate boundary the edge where two tectonic plates meet

Australia is situated in the middle of the Australian Plate. Since the last adjustment was made to **Global Positioning System (GPS)** coordinates in 1994, the continent has moved 1.5 m. That's about seven centimetres a year. In contrast, the North American Plate has been moving roughly 2.5 cm a year. This means that maps drawn after 1994, but still using the pre-1994 data, do not show Australia in its correct position for the time the map was drawn, let alone today. Older maps are even more out in their placement of Australia. Corrections to its geographical location have been made four times over the past 50 years. However, because continents move so slowly, most maps do not need to be updated for continental drift. 1.5 m would make little observable difference to Australia's location on a map. It is only important to the mapping systems, such as the GPS used worldwide for navigation, and other applications that rely on very accurate mapping, such as traffic signal timing and synchronisation of mobile phone base stations.

DOC WORKSHEET Plate boundaries

Try this 6.2

Constructing a timeline

Construct a timeline of evidence to show the development of the theory of plate tectonics.

What happens at plate boundaries?

You will recall that tectonic plates move due to the convection currents in Earth's semi-molten mantle. Where two tectonic plates meet, a **plate boundary** forms, and there are three major types: destructive, constructive and transform. Each type results from the movements occurring at the boundary.

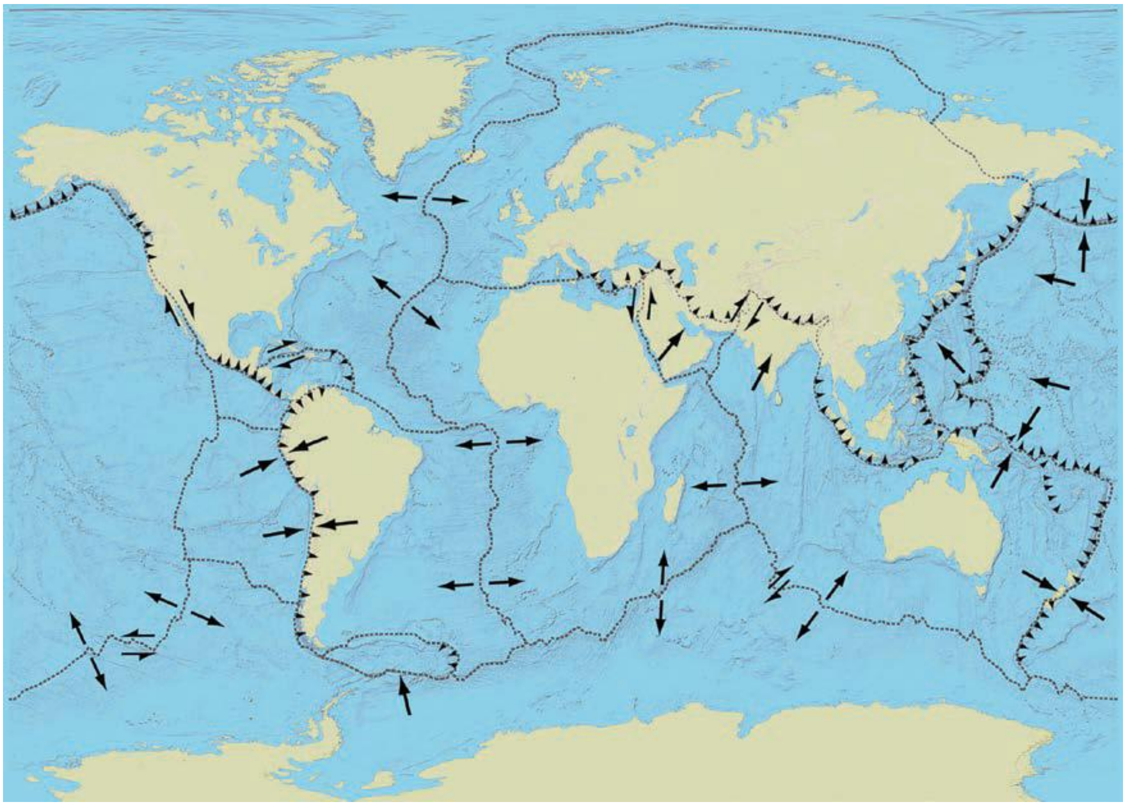

Figure 6.23 This map shows the major tectonic plates and their direction of travel. The small triangles on the lines indicate a convergent plate boundary.

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Explore! 6.3

The Chile Triple Junction

The Chile Triple Junction is located on the sea floor of the Pacific Ocean off the southern coast of Chile. Use the internet to answer the following questions.

1. List which three major tectonic plates meet at the Chile Triple Junction.
2. Discuss why the triple junction is unusual.

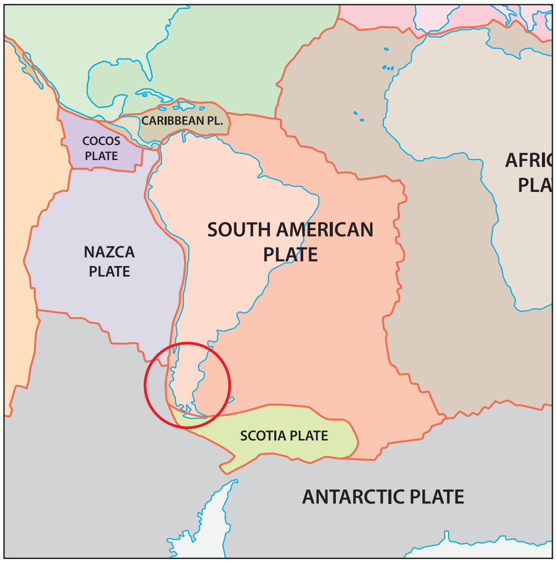

Figure 6.24 The Chile Triple Junction

Destructive boundaries

A **destructive** plate boundary occurs when convergent plates are moving towards each other (see Figure 6.25). The plates are colliding, so they are also called convergent plate boundaries. The effects and the features that form at these boundaries depend on what the two plates are made from. You have already learned that there are two types of crust: oceanic and continental. Oceanic crust is thin and dense; in comparison, continental crust is thicker and less dense. So, what happens when plates with two different types of crust on top of the upper mantle collide?

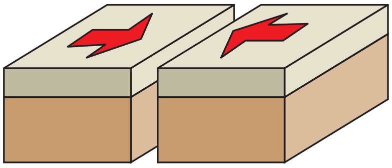

Figure 6.25 A destructive, or convergent, plate boundary

destructive (convergent) a type of plate boundary that occurs when plates move towards one another

subduction when the denser oceanic plate sinks underneath a less dense continental plate

magma hot fluid rock found beneath the Earth's surface

Quick check 6.6

1. **Describe** the movement of plates at a destructive plate boundary.
2. **Explain** what affects the features that form at this type of plate boundary.

When an oceanic plate meets a continental plate

The rocks in the oceanic crust are denser than the rocks in the continental crust, so when they collide, the denser oceanic plate will sink beneath the continental plate in a process called **subduction** (see Figure 6.26). As the oceanic plate moves down into the mantle, it begins to melt, forming **magma**. This magma can rise up through the continental plate to form volcanoes.

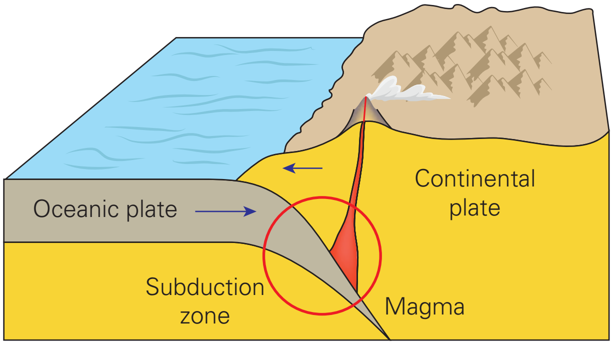

Figure 6.26 A subduction zone forms when the denser oceanic plate subducts underneath the less dense continental plate.

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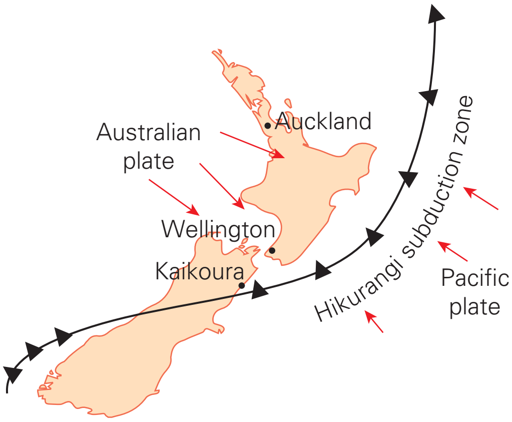

Figure 6.27 The Hikurangi subduction zone is located off the coast of New Zealand's North Island.

The Hikurangi subduction zone located off the east coast of the North Island of New Zealand has formed because of the subduction of the Pacific Plate underneath the Australian Plate (see Figure 6.27). It poses the largest threat of earthquakes and tsunamis to the residents of New Zealand.

Figure 6.28 The Andes Mountains in South America formed due to the subduction of the Nazca Plate underneath the South American Plate.

Mountains and deep ocean trenches form at a convergent or destructive boundary. For example, the Andes Mountains on the west coast of South America continue to grow in size because the Nazca oceanic plate is subducting beneath the South American continental plate.

When two continental plates meet

In this case, both plates have the same density, so when they collide, subduction does not take place. Instead, the pressure of the collision tends to force the crust upwards from both plates (see Figure 6.29). Mountains are formed but without volcanoes, as is the case for subduction.

The Indian Plate and the Eurasian Plate are colliding in this type of boundary. These plates collided over 50 million years ago, causing a huge uplift of the land and forming the Himalayan Mountain range, the highest mountain range in the world.

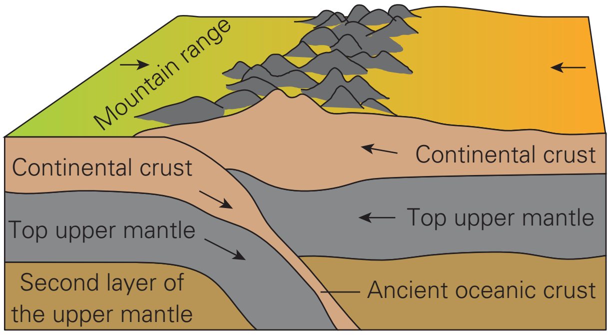

Figure 6.29 The formation of mountains when two continental plates collide

Figure 6.30 The Himalayan Mountain range, the highest in the world, was formed and is continuing to form at a destructive plate boundary.

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When two oceanic plates meet

Several things may happen when two oceanic plates meet. If one plate is less dense than the other, a subduction zone will be created. If they are equal in density, the collision may create a ridge instead, potentially forming islands.

Quick check 6.7

1. **State** the term that describes the action of one plate sinking underneath another.
2. **List** some of the features that can form at destructive plate boundaries.
3. **Discuss** why subduction does not take place when two continental plates collide.

Did you know? 6.3

Mount Everest is getting taller

As the Eurasian and Indian plates are constantly moving towards each other, Mount Everest – the highest mountain in the world at 8849 m tall – is actually getting taller each year, by four millimetres in fact. If your ambition is to climb Mount Everest, then you had better do it sooner, rather than later, if you do not want to have to climb even further!

Constructive boundaries

Constructive plate boundaries occur where two or more plates are diverging (moving away from one another) (see Figure 6.31). This type of boundary can occur under the ocean or on land.

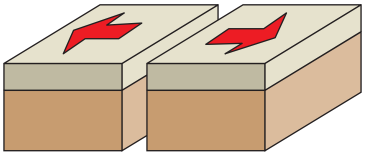

Figure 6.31 At constructive plate boundaries, plates move apart.

constructive (divergent) a type of plate boundary that occurs when plates move away from one another

In the ocean

Think back to the theory of seafloor spreading. The formation of new oceanic crust is the result of magma rising to fill the gap between diverging tectonic plates, and then cooling to form igneous rock. The Mid-Atlantic Ridge, located on the ocean floor between Africa and America, is an example of this type of plate boundary and features a series of underwater volcanoes.

Figure 6.32 A volcanic crater of basalt rocks near Portugal

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Practical 6.3

How dense are different rocks?

Aim

To compare the densities of different rock types

Hypothesis

Make a prediction regarding the densities of the rock types you are testing. You might like to physically organise them from least dense to most dense and take a photo, or note down, your prediction.

Materials

- four different types of rock (basalt, granite, sandstone and chalk)
- 10 mL measuring cylinder
- displacement can
- balance

Method

1. Draw the results table below.
2. Measure the mass of each rock type and record in your results table.
3. Fill the displacement can with water.
4. Holding the 10 mL measuring cylinder at the spout of the displacement can, gently drop in one of the rocks.
5. Record the volume of water expelled in cubic centimetres (cm^3) in the results table. (Note: 1 mL = 1 cm^3)
6. Repeat twice more with the same piece of rock, refilling the can before each procedure.
7. Following the same procedure, repeat for the other rock types.
8. Calculate the average volume of water expelled from the displacement can.
9. Using the formula below, calculate the density of each rock type.

$$\text{density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

Results

Table showing densities of different rock types

Type of rock	Mass (g)	Volume of water expelled (cm^3)			Mean volume (cm^3)	Density (g/cm^3)
		1	2	3		
Basalt						
Granite						
Sandstone						
Chalk						

Discussion: Analysis

1. Organise the rocks from most dense to least dense.
2. Using your results, explain why oceanic crust made of basalt subducts underneath continental crust made predominantly of granite at destructive plate boundaries.

Discussion: Evaluation

1. Explain why the experiment was conducted three times for each rock type.
2. Explain why you should always measure at the bottom of the meniscus when measuring water levels.
3. Compare the density of each rock that you calculated to densities obtained from secondary sources on the internet. How close were you to those values?

Conclusion

1. Draw a conclusion from this experiment about the densities of different rock types, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that _____________.
   Therefore, the hypothesis is/is not supported by these findings.

On land

Constructive plate boundaries that occur on land form **rift valleys**. An active rift valley is currently separating the Horn of Africa from the rest of Africa. This rift valley will eventually be filled with water when it drops below sea level, creating a new island. It is already having damaging effects, with major roads in cities cracking and caving under the strain. Scientists think this rift valley is moving so fast due to a superplume. A superplume occurs when heat from Earth's core rises up through the mantle, intensifying the convection currents and causing the plates to separate much faster.

Figure 6.33 The Laki crater row in Iceland that opened during the eruptive period of 1783–1784 is part of a volcanic fissure running through the country, which is situated on the tectonic plate boundaries of the Mid-Atlantic Ridge

Quick check 6.8

1. **Describe** the movement of plates at a constructive plate boundary.
2. **List** some of the features that can form at this type of boundary.
3. **Explain** why constructive plate boundaries are also known as divergent boundaries.

Transform boundaries

At **transform** plate boundaries, plates slide past each other and move in parallel, opposite directions (see Figure 6.34).

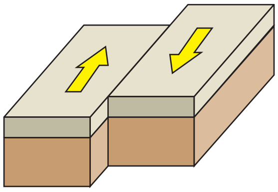

Figure 6.34 At transform plate boundaries, plates slide past one another.

Transform plate boundaries are sometimes referred to as conservative, as crust is neither created or destroyed. Tremendous friction occurs as the plates rub against one another, and the plates may stop moving. Eventually this pressure builds, and the movement might be sudden, triggering an earthquake. The San Andreas Fault is an example of a transform plate boundary between the Pacific and North American plates (see Figure 6.35). It runs down the west coast of North America, and is responsible for the frequent earthquakes in California and other overlying areas.

VIDEO
Causes of earthquakes

rift valley
an elongated depression in Earth's surface formed by the separation of tectonic plates

transform
(conservative) a type of plate boundary that occurs when plates move parallel to one another

Figure 6.35 The San Andreas Fault is the boundary between the North American and Pacific plates.

Figure 6.36 Earthquakes occur at transform boundaries. The earthquake that occurred at the San Andreas Fault in 1906 caused this fence to separate by several metres.

Try this 6.3

Making a documentary

Film a documentary on the dynamic nature of the geosphere to engage a specific audience, making sure you have selected the appropriate language, models or analogies.

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WIDGET
Plate movement at boundaries

Quick check 6.9

1. **Describe** the movement of plates at a transform plate boundary.
2. **List** one of the characteristics of this type of boundary.
3. **Explain** why transform plate boundaries are also known as conservative boundaries.

Try this 6.4

Tectonic plate simulations

Use the internet to navigate to *Tectonic Explorer* by The Concord Consortium. This is a computer model of a plate system on a fictional Earth-like planet. Use it to simulate multiple plate system scenarios and observe the different types of plate interactions responsible for patterns of events and landforms observed on Earth's surface.

Table 6.1 summarises each type of plate boundary.

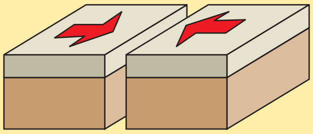
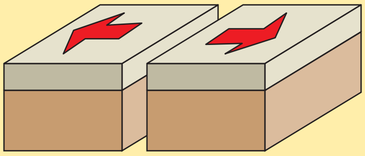
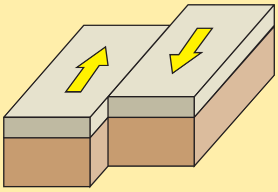
Type of boundary interaction	Diagram	Type of movement	What happens to the crust?	Key features
Destructive (convergent)		Plates move towards each other	Destroyed	Mountains Trenches Subduction zones Volcanoes Earthquakes
Constructive (divergent)		Plates move away from each other	Created	Volcanoes Rift valleys Ocean ridges
Transform (conservative)		Plates move parallel to each other in opposite directions	Conserved	Earthquakes

Table 6.1 A summary of each type of plate boundary

Try this 6.5

Figure 6.37 How might crème-filled cookies be used to model each of the different boundary interactions?

Modelling plate boundaries

You can model plate boundaries in different ways. Your teacher can provide you with a range of materials for you to explore modelling interactions at plate boundaries.

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Section 6.2 review

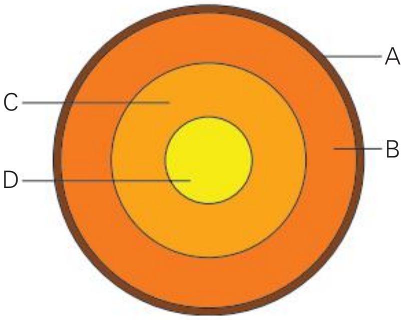
Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 6.2 questions

Remembering

1. **Name** the three types of plate boundaries.
2. **State** the name of the mechanism that causes tectonic plates to move.
3. **Select** the correct words to label the following diagram of the structure of Earth.



4. **Name** a real-life example of each of the three types of plate boundaries.
5. **Name** two types of crust.

Understanding

6. **Identify** the type of plate boundary where the following features would occur.
   - a) trenches
   - b) mountains
   - c) earthquakes
   - d) volcanoes
   - e) ridges
   - f) rift valleys
   - g) subduction zones
7. **Describe** how temperature affects the structure of rocks in the mantle.

Applying

8. **Explain** why the physical states of the inner and outer core differ.
9. At destructive plate boundaries, crust is destroyed. **Explain** why the overall amount of crust on Earth has stayed the same despite this destruction.
10. **Summarise** how magma forms at a subduction zone.

Analysing

11. **Compare** oceanic and continental crusts.

Evaluating

12. **Propose** why mountains and trenches continue to increase in size.
13. **Construct** a labelled diagram to show an oceanic plate subducting underneath a continental plate.
14. **Propose** reasons why countries like Australia do not experience significant amounts of geological activity.
15. **Discuss** why tectonic plates move across the surface of Earth.
16. **Propose** your own reasons why some tectonic plates move faster than others.
17. **Discuss** the evidence that led to the acceptance of the theory of plate tectonics as a development of the earlier idea of continental drift.
18. **Discuss** the role that Marie Tharp's maps had in the theory of plate tectonics.

ISBN 978-1-009-60327-0

6.3 The effects of plate movement

WORKSHEET
Seismic waves 1

Learning goals

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

1. Describe how volcanoes, earthquakes and tsunamis form.
2. Distinguish between S and P waves and the information they provide about earthquakes.
3. Examine patterns of earthquake and volcanic activity over time and propose explanations.
4. Relate the extreme age and stability of a large part of the Australian continent to its plate tectonic history.
5. Describe how Gunditjmara people hold and share knowledge about volcanoes that has been more recently discovered by Western science.

Geological activity is common at plate boundaries, and if you live nearby, you may experience the effects in the form of earthquakes, tsunamis and volcanic eruptions.

Volcanoes

Where do volcanoes form?

Volcanoes can occur at both constructive and destructive plate boundaries.

When two plates move apart at a constructive (divergent) boundary, magma will rise to fill the gaps, as shown in Figure 6.38. However, at a destructive boundary (particularly at subduction zones), intense heat is produced when one plate subducts underneath another. The subducting plate is super-heated, allowing the formation of magma, which then rises to the surface, forming a volcano. If this process occurs under the ocean, the magma eruptions can form a chain of volcanoes called an island arc (see Figure 6.39).

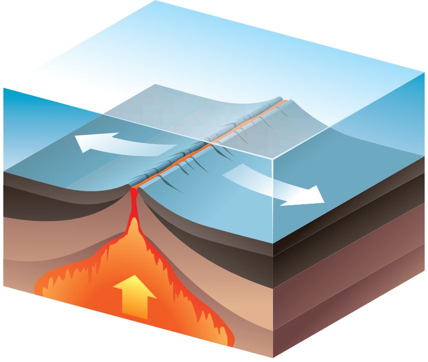


Figure 6.38 A volcano forms at a constructive plate boundary where magma rises to fill the gap when the plates move apart.

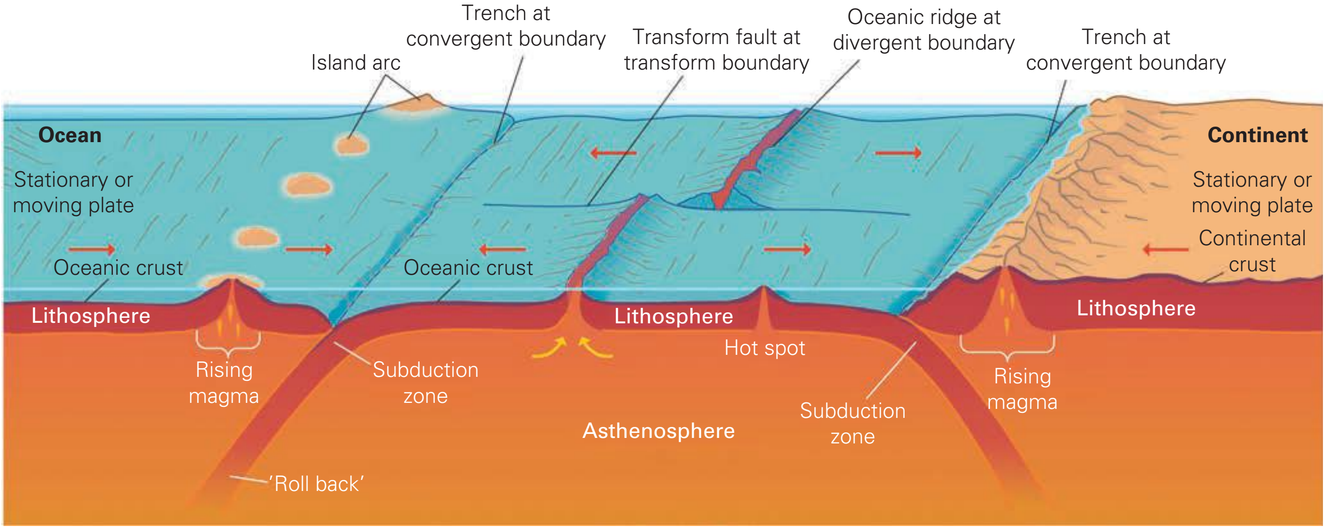


Figure 6.39 Volcanoes can form at destructive (convergent) and constructive (divergent) plate boundaries.

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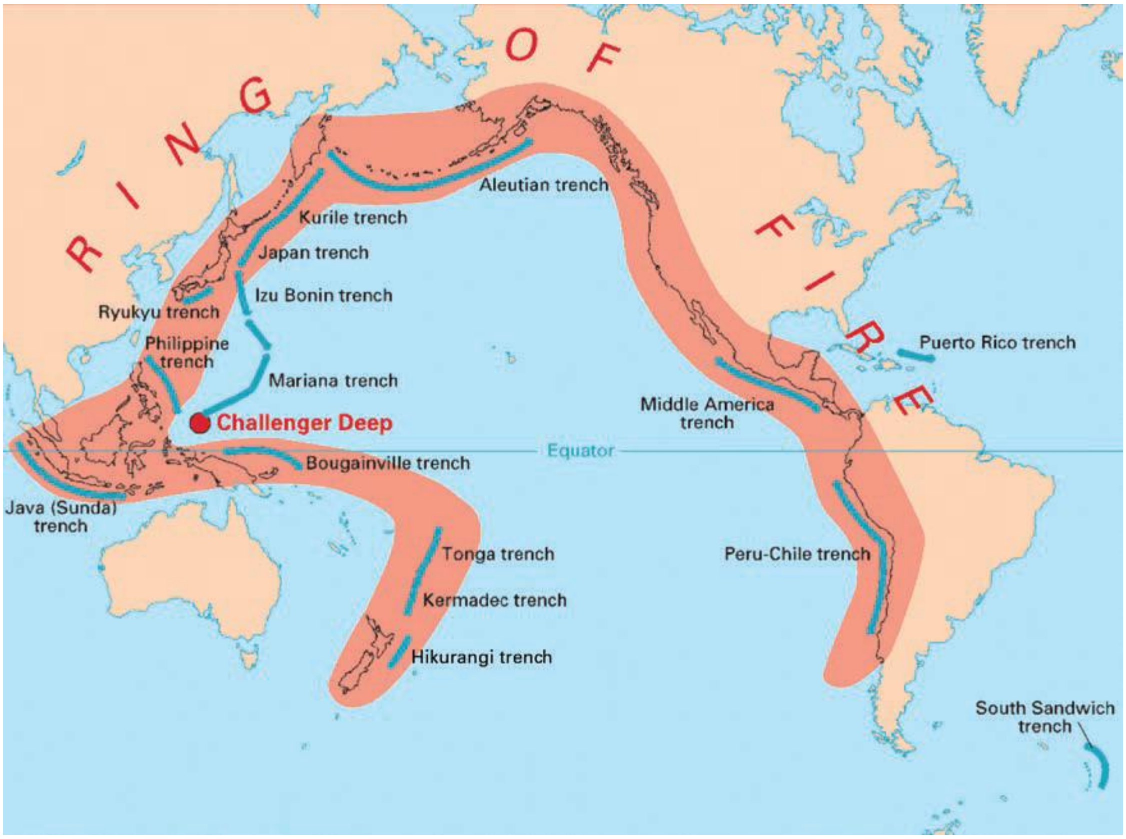

Figure 6.40 The Ring of Fire is an active area of many subduction zones around the Pacific Ocean.

The Ring of Fire, shown in Figure 6.40, is an area that wraps the Pacific Ocean. This area features intense geological activity and is home to over three-quarters of the world's active volcanoes. Refer back to the maps of tectonic plates earlier in the chapter. Can you see why?

VIDEO
Island
hotspots

Volcanoes can form above hotspots, in seemingly random locations which are not above a plate boundary. A **hotspot** is a hot plume of magma inside the mantle. The pressure and heat builds as it rises, eventually forcing magma up through the overlying crust and forming a volcano. As the tectonic plate moves, so does the volcano, which can form a chain of volcanic islands.

hotspot
a pocket of magma that sits just underneath the crust

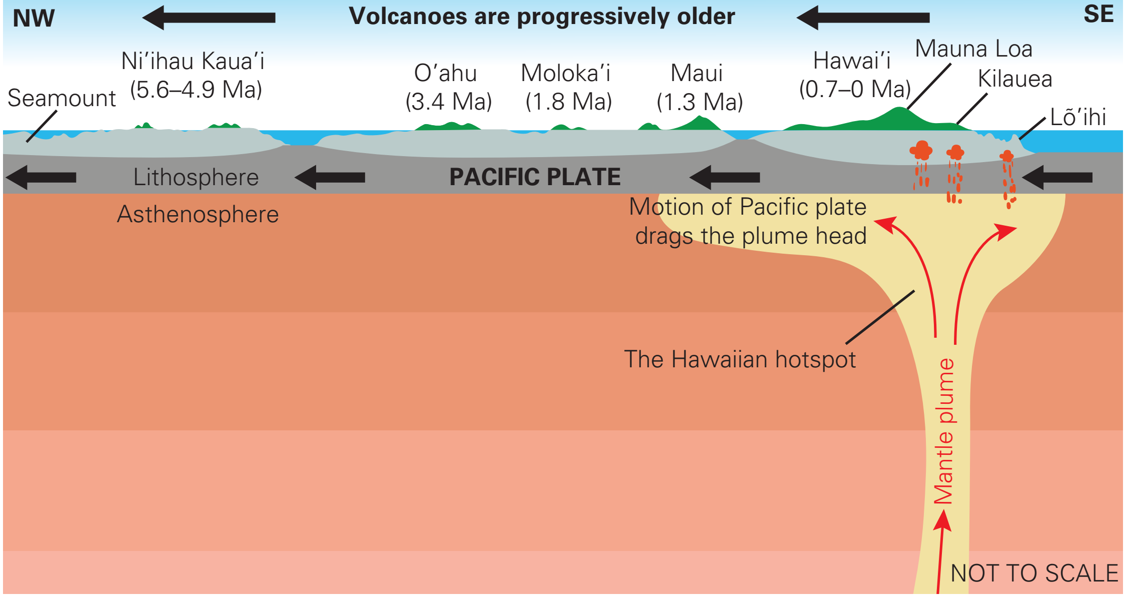

Figure 6.41 The Hawaiian island chain formed as the Pacific Plate moves across a hotspot. The oldest island, Ni'ihau, formed around 5.6 million years ago (Ma) and the top of the newest volcano, Lo'ihi, is less than 1000 m below the sea surface.

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Quick check 6.10

1. **State** the type of plate boundaries where volcanoes occur.
2. **Name** the area of the world that contains the greatest number of active volcanoes.
3. **Discuss** what hotspot volcanoes are and how they differ from volcanoes formed in other ways.

What happens during a volcanic eruption?

lava molten rock from inside Earth (magma) that has reached the surface

pyroclastic consisting of or relating to small pieces of rock from a volcano

Magma is lighter than the surrounding rock, so it rises and collects in chambers. As heat and pressure increase, eventually the magma is forced out a vent and an eruption takes place. Gases, rock and the magma (which is referred to as **lava** once it reaches the surface) are expelled. An eruption is not always hugely explosive, and depends on the type of lava produced. Silica-rich lava is thick and viscous like honey. Gases can become trapped, leading to an explosive eruption. Runnier lava that contains less silica flows more slowly out of the volcano. Lava flows rarely kill people. However, this type of lava can travel further from the site of the eruption, affecting larger areas. Gas and ash clouds, acid rain and **pyroclastic** flows (shown in Figure 6.43) are also major hazards. The volcanic ash cloud that resulted from an eruption in Iceland in 2010 caused a shutdown of most of European airspace for over a week.

Figure 6.42 The damage caused by a volcanic eruption is influenced by the viscosity of the lava.

Figure 6.43 Pyroclastic flows from the eruption of the Sinabung volcano in Indonesia in October 2017

Quick check 6.11

1. **Distinguish** between magma and lava.
2. **Explain** how the viscosity of lava affects a volcanic eruption.

Did you know? 6.4

Eruption in Iceland

In 2024, an increase in volcanic activity caused a number of fissures to open near the Icelandic town of Grindavík. This is because Iceland is located on top of a mid-ocean ridge that is slowly separating. Lava erupted through the fissure and, although most was diverted away from the town by a human-made barrier, several homes were engulfed.

Figure 6.44 Lava erupting from a fissure that threatens the town of Grindavík

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Explore! 6.4

Oral histories about earth movements

Aboriginal and Torres Strait Islander Peoples have deep and rich cultural histories that include detailed oral histories, including songs, stories and other cultural practices, that are passed down unbroken from generation to generation. Many of these accounts provide evidence of earthquakes and volcanoes that have occurred well before the colonisation of the continent we now know as Australia.

Gunditjmara People hold and continue to share knowledge about four enormous giants that arrived in the south-eastern region of the continent now known as Australia. While three of them departed to other parts of the continent, the fourth remained still and transformed into a volcano that came to be known as Budj Bim. The lava that spewed forth from the volcano was formed from the giant's teeth.

Recent Western scientific findings have uncovered evidence to support the timing of this account, which has been passed down for over 4000 years via the oral records of Gunditjmara and Bungandidj People (from neighbouring South Australia). The evidence indicates that Budj Bim, along with another nearby volcano, emerged roughly 37 000 years ago because of a swift succession of eruptions, and led to the formation of crater lakes in the region. This discovery suggests that the ancient knowledge could be the oldest story still in circulation today.

Research the aquaculture systems created by Gunditjmara people at Budj Bim. How was the volcanic landscape manipulated to provide an abundant food source?

Figure 6.45 A nineteenth century drawing of the lake in the crater at the top of Budj Bim

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Explore! 6.5

The Hunga Tonga-Hunga Ha'apai volcanic eruption in 2022

In January 2022, the Hunga Tonga-Hunga Ha'apai volcano erupted underwater with a force that caused a 15 m tsunami that demolished homes and killed at least three people in Tonga.

The eruption also damaged undersea communication cables, cutting Tonga off from the rest of the world for weeks and delaying efforts to help the victims.

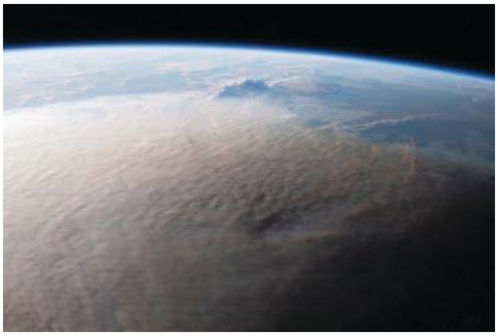

Figure 6.46 This satellite image shows the volcanic ash ejected from Hunga Tonga-Hunga Ha'apai volcano in 2022, due to the force of the eruption.

Complete some research and answer the following questions.

1. What did the eruption rate on the Volcanic Explosivity Index?
2. The eruption was equivalent to a historical volcanic eruption that took place in 1883. Where did this occur?
3. What records were broken by the volcanic eruption?
4. Explain whether volcanic eruptions only affect the surrounding area. Use this case study as an example in your answer.
5. Using the tsunami travel time map shown in Figure 6.47, determine the tsunami travel time to the east coast of Australia.

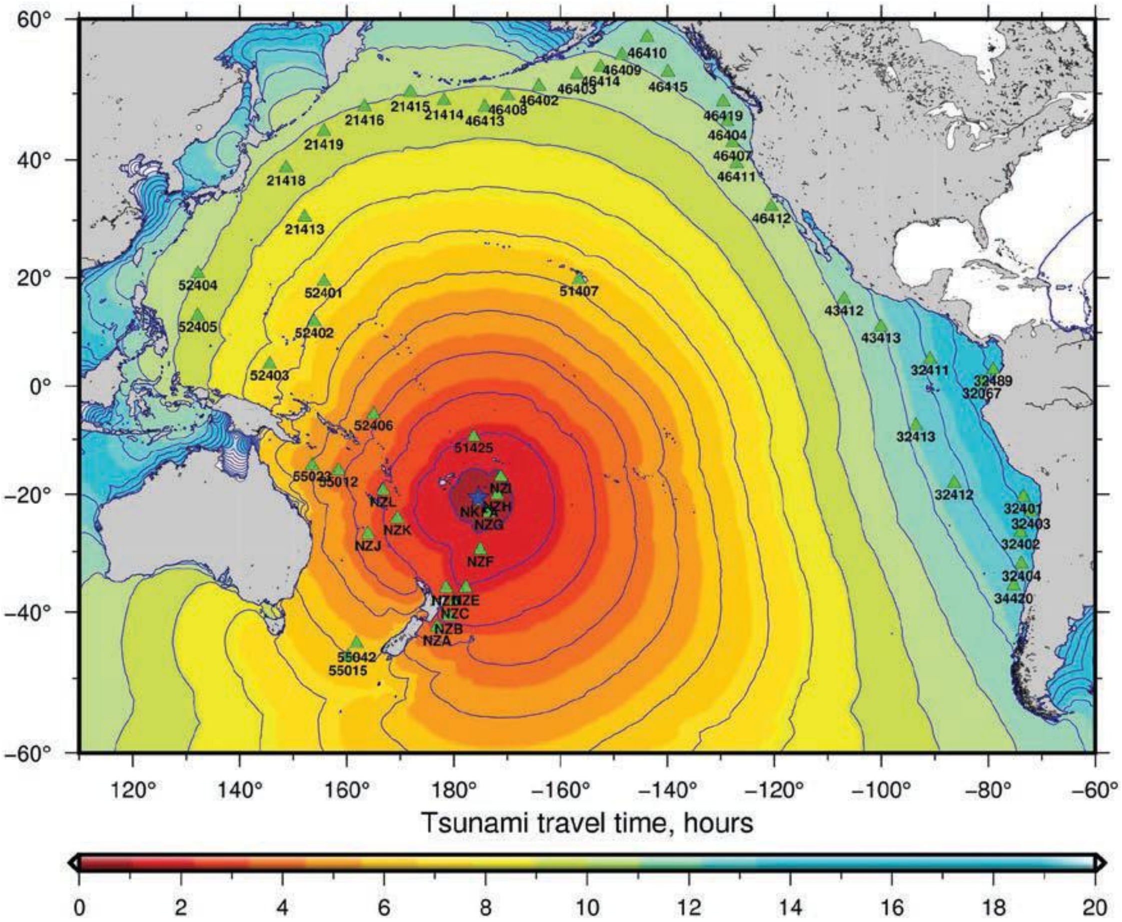

Figure 6.47 Tsunami travel time map of the Hunga Tonga-Hunga Ha'apai volcano eruption and tsunami, 15 January 2022

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Earthquakes

Where do earthquakes occur?

Earthquakes occur when there is a sudden movement of land. This can happen at a transform, constructive (divergent) or destructive (convergent) plate boundary. Friction between two plates must be overcome before the plates can slide past each other. When the driving force is strong enough to overcome this friction, the two plates will suddenly move, sending out waves of energy called **seismic waves**. The exact point under Earth where the earthquake occurs is called the **focus**. The point directly above the focus, on the surface of Earth, is called the **epicentre** (see Figure 6.48).

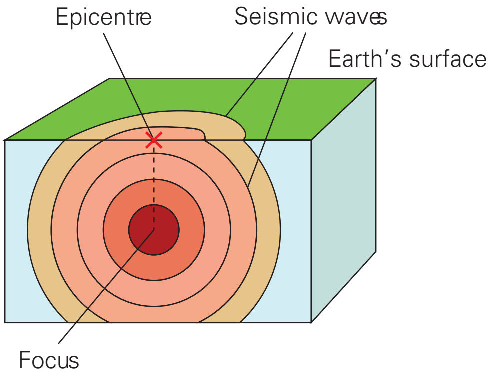

Figure 6.48 A diagram showing the location of an earthquake's focus and epicentre

seismic wave	a wave that moves through Earth during an earthquake
focus	the exact point under the surface of Earth where an earthquake occurs
epicentre	the location on Earth's surface directly above the focus of an earthquake
seismometer	an instrument that measures the intensity and duration of seismic waves during an earthquake
seismogram	the pattern produced when seismic activity is recorded by a seismometer

How are earthquakes detected?

Earthquakes are detected using an instrument called a **seismometer**. A simple seismometer is shown in Figure 6.49. Its basic structure uses a weight hanging from a spring suspended from a frame that moves along with the motion of Earth. A rotating drum is attached to the frame and a pen is attached to the weight.

When the land moves from side to side, the base remains fixed to the ground and moves with it, but the mass on the end of the spring stays in its original position. It is not affected by the movement of the ground. The pen attached to the mass records the movement of the box in relation to the stationary mass. The resulting pattern is called a **seismogram** (see Figure 6.50). Note that digital seismometers are also available for many smartphones.

WORKSHEET
Seismic waves 2

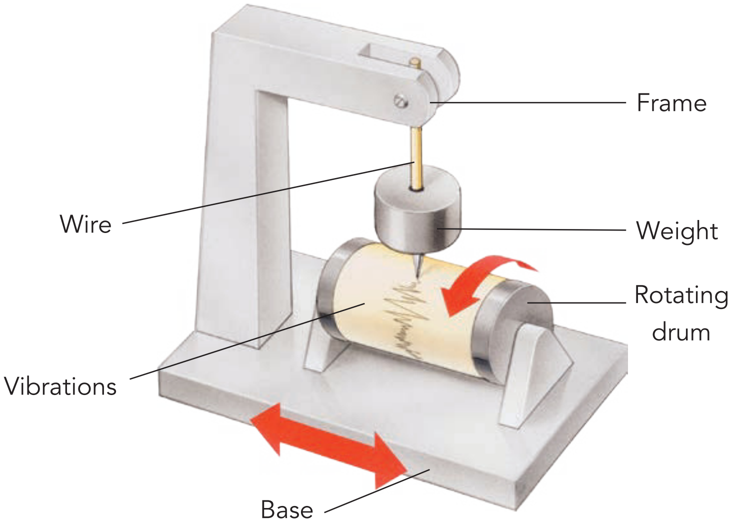

Figure 6.49 A simple seismometer

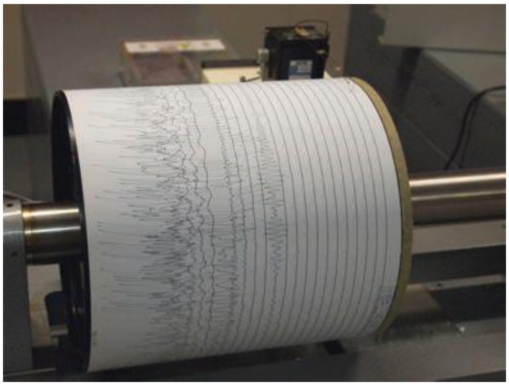

Figure 6.50 A seismogram

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The two main types of seismic waves produced by an earthquake are primary (P) waves and secondary (S) waves (see Figure 6.51). The properties of these waves are summarised in Table 6.2.

	P waves	S waves
Name	Primary	Secondary
Speed	Fast	Slow
Movement	Longitudinal (back and forth)	Transverse (side to side or up and down)
Materials they can travel through	Liquids and solids	Solids only
Level of damage caused	Minimal damage caused	Very destructive due to side-to-side movements

Table 6.2 The properties of P and S waves

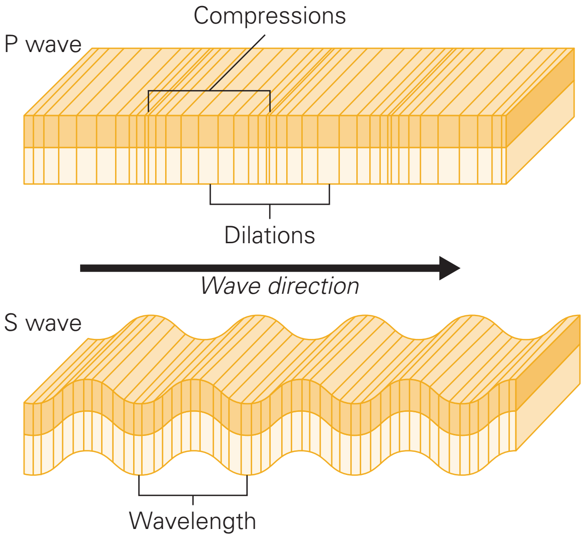

Figure 6.51 P and S waves travelling through Earth

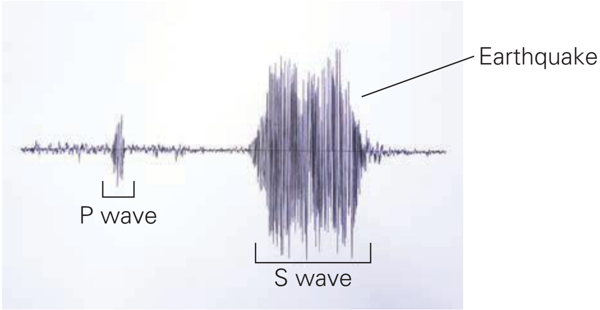

Figure 6.52 A seismogram of seismic activity within Earth

lag time
the time between the arrival of the P and S waves

As P waves are the faster of the two waves, they are detected by the seismometer first. The first seismic activity detected by the seismometer on the seismogram in Figure 6.52 is the P wave. The S waves are slower and so arrive second. S waves are also the most intense and so register larger movements on the seismogram. The time between the arrival of the P and S waves is called the **lag time**.

Quick check 6.12

1. **Identify** the two plate boundaries at which earthquakes occur.
2. **Explain** why earthquakes occur at these types of plate boundaries.
3. **Recall** the name given to the part of Earth where the earthquake is generated.
4. **State** the name of the equipment used to detect seismic activity.
5. **Identify** the type of seismic wave which is faster, and therefore first to arrive during an earthquake.

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Explore! 6.6

How do P and S waves give us evidence for the structure of Earth?

The properties of P waves and S waves generated by an earthquake can be used to determine the properties of the layers of Earth. In 1936, Danish scientist Inge Lehmann inferred that Earth has a solid inner core inside a molten outer core after she analysed data from seismic stations around the world. She noticed some irregularities in the data that disproved the accepted idea that the core was entirely molten. It wasn't until 1970 that her theory was confirmed!

1. What can you conclude about the movements of P and S waves through Earth using the diagram in Figure 6.53?
2. Interpret the properties of the seismic waves listed in Table 6.2 to make conclusions about the physical properties of the outer core and the mantle.
3. When P waves travel through the inner core and outer core, they appear to bend. Discuss why you think this is.
4. What is the S wave shadow zone? Deduce why it occurs.

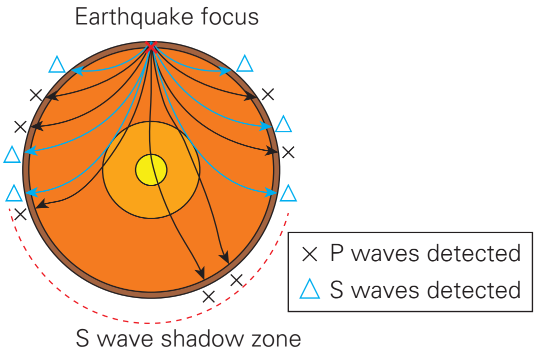

Figure 6.53 The pattern of seismic activity away from an earthquake's focus

Figure 6.54 Inge Lehmann

The effects of earthquakes

The **Richter scale** measures the severity of an earthquake, with higher numbers indicating more severe earthquakes. The scale is logarithmic, *not* linear. This means that an earthquake measured as a 4 is not twice as strong as a 2. Instead, for each increase in number on the scale, the severity increases *ten times*.

Richter scale a system used to measure the strength of an earthquake

Try this 6.6

Formulating a hypothesis

Based on what you have learned in this section, formulate a hypothesis for the research question: 'Do earthquakes of greater magnitude result in greater damage?' Refer to Chapter 1 for assistance with structuring your hypothesis.

Did you know? 6.5

The largest earthquake on record

The largest earthquake ever recorded occurred in Chile on 22 May 1960. It was recorded at 9.5 on the Richter scale. The earthquake killed 1655 people and displaced more than two million from their homes.

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Tsunamis

tsunami
a great wave produced by an earthquake or volcanic eruption in the ocean

A **tsunami** is a devastating natural disaster that can cause massive destruction to coastal areas. The primary cause of a tsunami is an underwater earthquake or volcanic eruption that generates a large amount of energy, resulting in massive waves. The movement of Earth's tectonic plates can cause an underwater earthquake, which can displace large amounts of water and create a series of waves that can travel long distances. Similarly, a volcanic eruption can cause an underwater landslide or an explosive release of gas, which can trigger a tsunami.

Figure 6.55 A tsunami breaching the embankments after an earthquake measuring 9.0 on the Richter scale occurred off the coast of northern Japan in 2011

On Boxing Day of 2004, an earthquake measuring 9.1 on the Richter scale occurred in the Indian Ocean. The tsunami waves that resulted were over 15 m high when they reached land, and more than 14 different countries were affected. A quarter of a million people were killed, and two million were left homeless.

Figure 6.56 An aerial view of the devastation caused by the Boxing Day tsunami in 2004

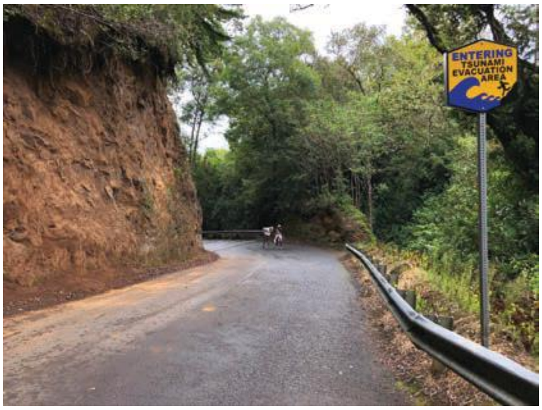

Figure 6.57 A Hawaiian tsunami evacuation zone, located 260 m above sea level

Quick check 6.13

1. **State** how many times more intense a magnitude 7.0 earthquake is, compared to a magnitude 5.0 earthquake (with reference to the Richter scale).
2. **Explain** what a tsunami is and how it forms.

Is Australia at risk?

The extreme age and stability of a large part of the Australian continent can be attributed to its plate tectonic history. Unlike other continents, such as the Americas, Africa and Europe, Australia is in the centre of a tectonic plate, the Australian Plate, which means that it is not affected by the boundary interactions of multiple plates and not directly at risk from major earthquakes and volcanoes.

The Australian Plate, which encompasses the entire continent and parts of the surrounding ocean, has been relatively stable for hundreds of millions of years. The Australian Plate is surrounded by several relatively inactive plates, including the Antarctic Plate, the Pacific Plate and the African Plate.

The age of the Australian continent is also a contributing factor to its stability. Much of the continent is made up of ancient **cratons**, which are large areas of stable, ancient rocks that have not been affected by tectonic activity for billions of years. These cratons make up the core of the continent and have provided a stable foundation for the younger sedimentary rocks and soils that cover much of the continent.

craton
the stable interior portion of a continent

The Australian Plate is moving and colliding with the plates at its northern boundary. This results in a significant amount of pressure building up, which can cause earthquakes in Australia. As a result, although Australia is more stable than other continents, it still has more earthquakes than other regions that sit in the middle of tectonic plates.

Figure 6.58 Rescue workers trying to find survivors under the rubble beneath the Kent Hotel in Hamilton, Newcastle, NSW, after the 1989 magnitude 5.6 earthquake that killed 13 people

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The Newer Volcanics Province is a geological area spanning 15 000 square kilometres, predominantly in south-western Victoria. It includes some of Australia's youngest volcanoes, dating from the Upper Pleistocene to Holocene ages.

Figure 6.59 Australia's largest dry volcanic crater on the dormant volcano of Mount Noorat, Victoria. It last erupted between 5000 and 20 000 years ago. The mountain is a traditional meeting and bartering place for the Kirrae Wuurong people.

Figure 6.60 The last significant volcanic activity on the Australian continent occurred over 4000 years ago, at Mount Gambier in South Australia (an extension of the Newer Volcanics Province).

Go online to access the interactive section review and more!

Section 6.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.3 questions

Remembering

1. **Recall** the name for the volcanic hazard that produces hot, fast-moving gas and rocks.
2. **Name** the equipment used to measure the seismic activity of Earth.
3. **Name** the scale used to measure the magnitude of an earthquake.
4. **Name** the point on Earth's surface directly above the focus of an earthquake.

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Understanding

5. **Describe** how earthquakes cause tsunamis.
6. **Explain** why plates at a transform or destructive plate boundary do not slide past each other all the time.
7. **Explain** how the silica content of lava can affect the outcome of a volcanic eruption.

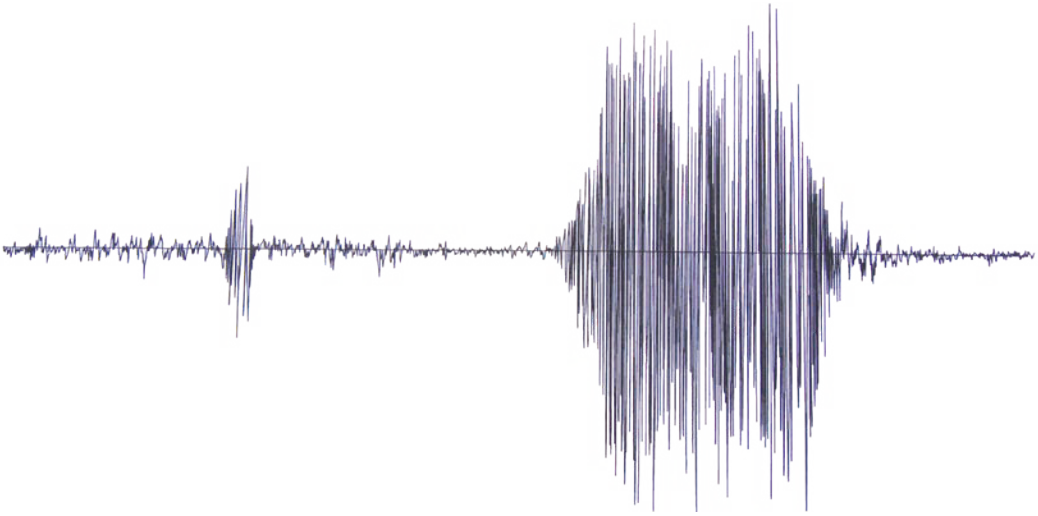
Applying

8. **Summarise** the reasons why the Ring of Fire in the Pacific is so volcanically active.

Analysing

Refer to the seismogram below to answer the following questions.

9. a) **Identify** which is the P wave and which is the S wave.
   b) **Identify** the lag time.



10. **Compare** the properties of P waves and S waves.
11. **Contrast** magma and lava.

Evaluating

12. Hannah says that volcanoes only affect the people who live in the country of the eruption. Rounak thinks that volcanic eruptions can affect many countries. **Decide** who is right and give reasons why.
13. There are many different types of volcanoes. **Deduce** definitions for the following types of volcanoes.
    a) dormant b) extinct c) active
14. **Decide** whether more geological activity is experienced by countries in the middle of a plate or by countries on a plate boundary. **Outline** your reasoning.
15. **Discuss** the intensity and frequency of geological activity in Australia.
16. **Evaluate** the following hypothesis: 'An earthquake of greater magnitude will cause more damage because there is more energy transferred'.

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6.4 Predicting and mitigating natural disasters

WORKSHEET
Investigating tectonic plate movement

Learning goals

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

1. List methods that can be used to map or predict plate movements.
2. Evaluate the impact of tectonic events on human populations and examine engineering solutions designed to reduce the impact.

Improved technology has allowed us to further our understanding and make predictions of geological patterns and changes. Technological advancements have also allowed governments and aid organisations to respond more swiftly and effectively to natural disasters.

Measuring, mapping, planning

Global Positioning System (GPS)

GPS can be used to track and forecast the movements of tectonic plates. Twenty-four satellites orbit Earth, and can be utilised to monitor GPS receivers which are placed at plate boundaries. The receivers can detect the speed and direction of tectonic plate movement with incredible precision. For example, the location can be pinpointed to an area the size of a grain of rice!

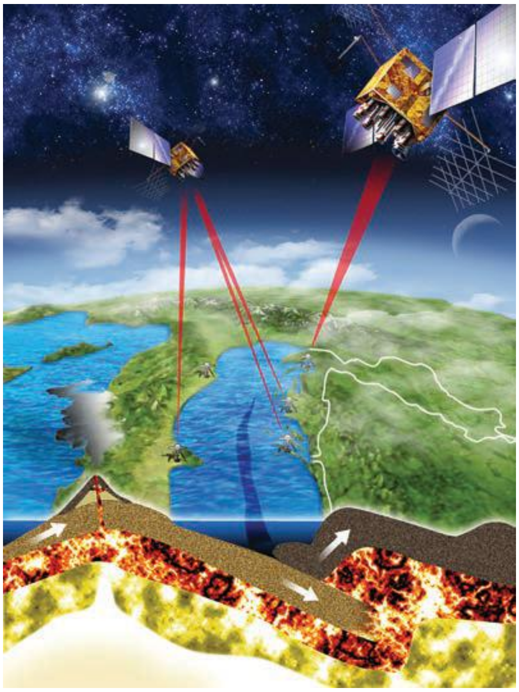

Figure 6.61 GPS is used to measure position and therefore the rate of movement of tectonic plates.

Gravity mapping

Gravity can be stronger and weaker at different points of Earth's surface. Earth's surface is very uneven due to mountains and ocean trenches, both of which affect gravity. Where rocks are denser the gravity is stronger, and where they are less dense it is weaker. The internal structure of Earth can also affect gravity as the materials within the interior do not have a uniform distribution. Scientists can create a gravitational map of Earth, called a **geoid**, using these gravitational measurements (see Figure 6.62).

geoid
a model of Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

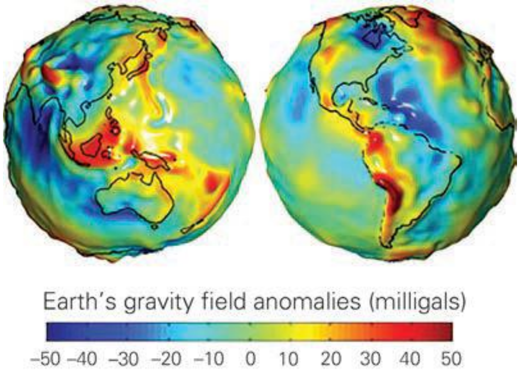

Figure 6.62 A geoid of Earth

Geoids are not typically used to directly show tectonic movement, but changes in Earth's gravitational field can indirectly provide information on tectonic movement. For example, if tectonic plates shift or collide with each other, this can cause changes in the density and thickness of Earth's crust, which can in turn alter the gravitational field. By measuring and mapping these changes in the gravitational field, scientists can infer the movement of tectonic plates.

Satellite gravity mapping can help to create detailed three-dimensional models of Earth's interior structure, which can provide insight into the movement of tectonic plates and the processes that drive them.

Computer modelling

Computer models and simulations of tectonic plate movements are becoming increasingly accurate. They allow scientists to manipulate variables, such as the physical properties of the mantle that can speed up or resist plate movement, to improve predictions.

Figure 6.63 Three-dimensional visualisation and geological modelling suite being used by geologists to interpret seismic data from an oilfield.

The Earthquake Commission (EQC) is funding a new modelling technique pioneered in New Zealand that has the potential to enhance the seismic resilience of buildings worldwide. Researchers at the University of Canterbury are developing a ground-motion simulation model that can predict earthquake damage based on the soil beneath buildings. This simulation provides valuable information to engineers and helps improve the resilience of structures against large earthquakes.

Try this 6.7

Investigating earthquakes

Use the internet to navigate to *Seismic Explorer* by The Concord Consortium. This is a data visualisation tool that shows real-world earthquake, volcanic and plate motion data. Use *Seismic Explorer* to investigate earthquake and volcanic eruption distribution patterns and make connections between the natural disasters and plate boundaries. You can also use cross-sections to investigate earthquake depth patterns.

Quick check 6.14

1. **List** two pieces of technology used in predicting plate movements.
2. **Name** one variable that advanced computer models and simulations allow for so that plate movement can be modelled more accurately.

Explore! 6.7

Sharing information

Seismic data is collected and shared between governments across the Asia–Pacific region through various regional and international networks and organisations. These organisations work to collect data from seismometers and other monitoring equipment located throughout the region to provide information to government agencies responsible for earthquake and tsunami monitoring and warnings.

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Research the following key organisations and complete the table to describe their role in seismic data collection and sharing in the Asia–Pacific region.

Organisation	How does it monitor risk?
Pacific Tsunami Warning Center (PTWC)	
Indian Ocean Tsunami Warning System (IOTWS)	
International Seismological Centre (ISC)	
Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)	

Figure 6.64 DART® (Deep-ocean Assessment and Reporting of Tsunamis) real-time tsunami monitoring systems are positioned throughout the ocean and play a critical role in forecasting tsunamis.

Once seismic data is collected and shared, governments in the Asia–Pacific region use this information in various ways, including for tsunami alerts. When an earthquake is detected, government agencies responsible for earthquake and tsunami monitoring use this data to assess the risk of a tsunami and issue warnings to coastal communities in the affected areas. This may involve sending out alerts through various channels, including radio, television and social media, and mobilising emergency response teams to evacuate coastal areas if necessary.

Volcanobots

The conditions inside or near an active volcano are not safe for volcanologists (scientists who study volcanoes) to measure in person. Instead, they can rely on robots which can withstand the extreme temperatures in crevices and fissures (cracks). NASA's *VolcanoBot 1* (Figure 6.65) reached a depth of 25 m inside a volcano in Hawaii and constructed a three-dimensional model of the interior, allowing scientists to the map the route taken by magma from the mantle to the surface during an eruption.

In 2022, an unmanned surface vehicle (USV) called *Maxlimer*, which was developed by a British company called SEA-KIT International, was used to survey the Hunga Tonga-Hunga Ha'apai volcano in Tonga. The robot boat is remotely controlled from the UK and uses instruments that can be deployed at depths of up to 300 m to collect data from the entire water column. The use of the robot boat for this type of survey is important because it allows scientists to collect data from dangerous and hard-to-reach locations without risking human life.

Figure 6.65 Robots like *VolcanoBot 1* are enabling researchers to safely explore volcanoes.

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Emergency response plans

Emergency response plans are designed to ensure that communities are ready to respond quickly and effectively in the event of a disaster. These plans may include completing risk assessments, using early warning systems, undertaking evacuation planning and providing training and education programs that help residents plan and prepare for disasters.

Figure 6.66 A tsunami evacuation route sign in San Francisco

Explore! 6.8

Reducing natural disaster impacts

Countries located near plate boundaries in the Asia–Pacific region, such as Japan, Indonesia and New Zealand, are particularly vulnerable to geological hazards such as earthquakes, volcanic eruptions and tsunamis. However, scientific responses have helped to support these communities and reduce the impact of these natural disasters.

Produce a presentation on one of the following to show how the impact of natural disasters can be reduced: the use of new building materials, improved predictions or early warning systems.

Figure 6.67 To make concrete more suitable for seismic activity, engineers add steel (in the form of rebar), which is much more flexible.

Evaluating the impact

Evaluating the impact of natural disasters on human populations involves examining the degree and extent of damage caused by the event, including the number of casualties, injuries and homes destroyed. In the aftermath of a disaster, drones can be used to conduct rapid assessments of affected areas and identify potential hazards, such as blocked roads or damaged infrastructure. This information can then be used to prioritise response efforts and allocate resources more effectively.

Figure 6.68 The February 2023 earthquake in Türkiye, which killed more than 43 000 people, will cost the Turkish economy more than US$50 billion.

The socio-economic impact of the event must also be assessed, including the disruption to local infrastructure, the impact on essential services and the cost of recovery and reconstruction efforts. These assessments can help to inform policy decisions and emergency response strategies, as well as guide the allocation of resources to affected communities.

Quick check 6.15

1. **State** the name given to scientists who study volcanoes.

Reducing vulnerability

Natural disasters can have devastating impacts on communities and their infrastructure. It is crucial to have effective strategies in place to reduce vulnerability to these hazards. These strategies involve a range of actions, such as structural engineering designs, land-use planning, and emergency preparedness and response plans.

Land-use planning

Land-use planning can reduce vulnerability to natural disasters by ensuring that development occurs in areas with minimal risk and that appropriate measures are taken to protect people and property. Land planners will consider where to locate critical infrastructure, such as hospitals, schools and emergency response centres, and where to restrict development in high-risk areas.

Land-use planning can also include requirements for building codes and standards that increase the resilience of structures to natural hazards. For example, buildings in earthquake-prone areas may require reinforced foundations and walls, while structures in flood-prone areas may need to be elevated above the flood plain.

Researchers at the University of Adelaide have developed a breakthrough technique for earthquake-proofing heritage-listed buildings. Heritage-listed sites are places of cultural and historical significance and are particularly vulnerable to the effects of earthquakes due to their age and lack of reinforcement. Scientists have developed a technique to determine the bending limits of these fragile buildings and, from this data, have improved their earthquake resistance. These buildings are less likely to suffer damage and collapse, which in turn maximises safety and minimises the cost of repair.

Figure 6.69 Heritage-listed sites, such as the Notre-Dame cathedral in France, are irreplaceable. A fire almost destroyed the building in 2019.

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Construction techniques

Most buildings are designed to support vertical forces; for example, the walls support the roof. However, earthquakes also produce sideways or horizontal forces, which is why many buildings struggle to withstand high-magnitude earthquakes. A building can be made 'earthquake proof' in three ways:

- base isolation – Buildings do not sit directly on the ground, but are supported by ball bearings and springs, which act like shock absorbers.
- vibration control – Mass dampers are built to sway in the opposite direction to the building's sway during an earthquake.
- seismic resistance – The walls, roof and foundations are tied together into a rigid box that holds together when shaken by an earthquake.

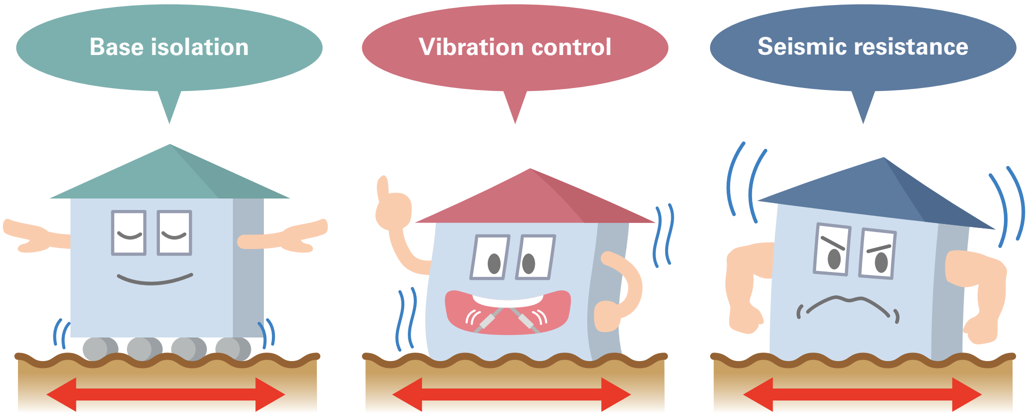

Figure 6.70 Buildings can be made earthquake-proof by three different methods.

Quick check 6.16

1. **Suggest** one way in which a building can be earthquake proofed.
2. **Discuss** why many existing buildings are not able to withstand high-magnitude earthquakes.

Explore! 6.9

Cultural building techniques

Cultural building techniques have led to the development of structures and materials that are better able to withstand the effects of earthquakes. Bamboo has been used for centuries as a building material in earthquake-prone regions, such as South-East Asia, South Asia and Latin America. It is flexible and resilient, which allows it to withstand the forces of an earthquake, and as it is lightweight, making it less vulnerable to damage. Builders have incorporated some bamboo properties, such as the ability to bend without breaking, into modern earthquake-resistant building designs. Researchers have also developed bamboo-reinforced concrete, which is more resistant to breaking during an earthquake.

Figure 6.71 A certified earthquake- and cyclone-resistant bamboo house being built in Martinique

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Adobe is a technique that involves making bricks from a mixture of clay, sand and straw, and then allowing them to dry in the Sun. Adobe structures have been used for centuries in earthquake-prone areas of Latin America, but traditional adobe construction responds poorly to earthquakes. Conduct research and answer the following questions:

1. How have adobe techniques been refined over time to improve their earthquake resistance?
2. What evidence do you think would be necessary to justify a conclusion that all buildings in an earthquake-prone area should be constructed from bamboo?

Investigation 6.1

Investigating how high-frequency earthquakes affect buildings

Aim

To investigate how high-frequency earthquakes affect buildings of different heights

Background research

Complete some research and write a rationale about the effects of earthquakes on buildings of different heights. Hint: Research the 1985 Mexico City earthquake.

Hypothesis

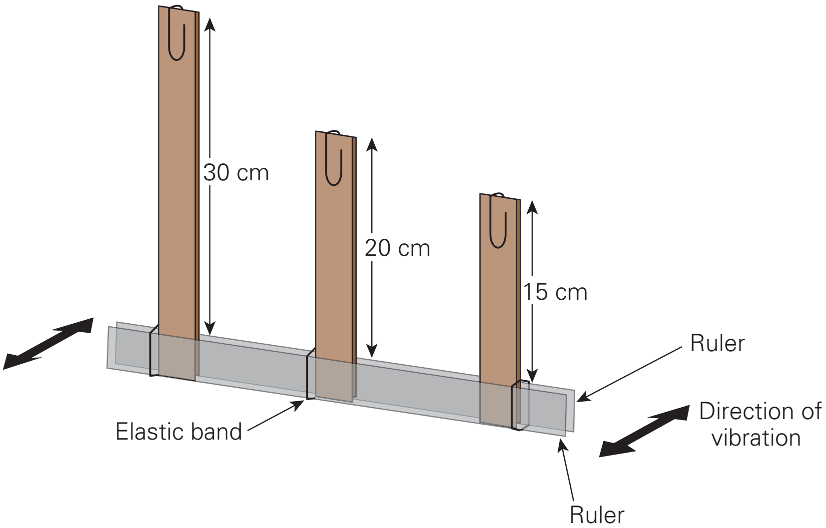
Make a prediction regarding building height and the extent of damage associated with a high-frequency earthquake.

Materials

- rulers × 2
- elastic bands
- pieces of card
- paper clips

Method

1. Draw the results table below.
2. Set up the experiment as shown in the diagram below. Each 'tower' is made of four card strips held together at the top by a paper clip and two rulers at the bottom. The rulers are held in place using elastic bands.
3. Vibrate the rulers in a slow and gentle way in the direction shown in the diagram.
4. Slowly increase the rate of vibration until the cardboard strips begin to resonate (start to regularly and strongly vibrate). Note: This simulates a high-frequency earthquake. The results would differ for low-frequency earthquakes.
5. Count the number of complete vibrations that occur in 10 seconds.
6. Continue to vibrate the rulers until you have recorded the three trials for each strip in your results table.



Results

1. Complete this table of results. Give your table an appropriate title that describes what data it is displaying.
Table showing effect of height on number of vibrations

Height of strip (cm)	Number of vibrations in 10 seconds			Mean number of vibrations	Frequency (vibrations per second)
	1	2	3		

continued ...

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2. Calculate the frequency by dividing the mean number of vibrations by 10.
3. Plot a graph of height of strip against frequency of vibrations.

Discussion: Analysis

1. Identify any trends, patterns or relationships in your results.
2. Determine the height of buildings that would be damaged most by high-frequency earthquakes.

Discussion: Evaluation

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

Conclusion

1. Draw a conclusion from this experiment about the effect of high-frequency earthquakes on buildings of different heights, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that ____________.
   Therefore, the hypothesis is/is not supported by these findings.

Practical 6.4

Using a shake table to design earthquake-proof building bases

Aim

To observe the effect of base isolation on damage to buildings during an earthquake

Background research

Research the base isolation construction technique. Write a short paragraph outlining the benefits it may offer.

Hypothesis

Propose if a building equipped with base isolation will suffer more or less damage during an earthquake than a building without base isolation.

Materials

- 100 g masses
- plastic or paper straws
- masking tape
- cardboard
- string
- wooden block
- wooden dowels or pens

Method

1. Using the equipment provided, except for the wooden block, dowels and pens, design and build two identical earthquake-proof buildings. (You may want to refer to the STEM activity at the end of this chapter for the building creation.)
2. Draw the results table.
3. Put your finished design on a table and shake the table for 20 seconds. Record what happened in your results table.
4. Now lay the pens or the wooden dowels on the table so they align.
5. Place the wooden block on top of the pens or dowels and put your second building on top.
6. Shake the table again for 20 seconds and record what happened in your results table.

continued …

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Results

Table showing effect of base isolation

	Observations
Without base isolation (just on the table)	
With base isolation (on the pens and wooden block)	

Discussion: Analysis

1. Identify which structure was the most earthquake resistant and why.
2. Discuss how base isolation helps the building survive an earthquake.
3. Discuss how design and construction decisions make the building more earthquake resistant.

Discussion: Evaluation

1. Recommend what you would do differently next time in the construction of your building. Explain why.

Conclusion

1. Draw a conclusion from this experiment about the effect of base isolation on building damage during an earthquake, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that ____________.
   Therefore, the hypothesis is/is not supported by these findings.

Go online to access the interactive section review and more!

Section 6.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 6.4 questions

Remembering

1. **Recall** what GPS stands for.
2. **Name** the three methods of earthquake-proofing buildings.
3. **Identify** the name of NASA's first robot used to explore volcanoes.

Understanding

4. **Explain** why scientists need to study the inside of volcanoes.
5. **Explain** how GPS can map the position of tectonic plates.

Applying

6. **Summarise** the advantages of using drones after an earthquake.

Analysing

7. **Compare** the three methods of protecting buildings from earthquakes.

Evaluating

8. **Propose** reasons why humans cannot enter some parts of volcanoes.
9. **Discuss** the benefits and shortcomings of using technologies to map plate movement and Earth's geology, using examples.
10. Recall the various earthquake-proofing methods you have learned about. **Propose** which earthquake-proofing method you would choose and justify your choice.

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Chapter review

Chapter checklist

Success criteria		Linked questions
6.1	I can describe the evidence for the theory of continental drift.	13
6.2	I can construct a timeline of evidence to show the development of the theory of plate tectonics.	10, 13, 14, 17, 19
6.2	I can describe how Marie Tharp's topographic maps provided support for the acceptance of the theory of plate tectonics.	17
6.2	I can describe the consequence of three types of plate boundaries.	11, 12, 20, 21, 22
6.2	I can model interactions at plate boundaries.	16
6.2	I can describe the different forces involved in tectonic plate movement.	3, 7
6.3	I can describe how volcanoes, earthquakes and tsunamis form.	18, 29
6.3	I can distinguish between S and P waves and the information they provide about earthquakes.	8, 15, 24
6.3	I can examine patterns of earthquake and volcanic activity over time and propose explanations.	29
6.3	I can relate the extreme age and stability of a large part of the Australian continent to its plate tectonic history.	28
6.3	I can describe how Gunditjmara people hold and share knowledge about volcanoes that has been more recently discovered by Western science.	9
6.4	I can list methods that can be used to map or predict plate movements.	1
6.4	I can evaluate the impact of tectonic events on human populations and examine engineering solutions designed to reduce the impact.	23

Scorcher competition

Review questions

Data questions

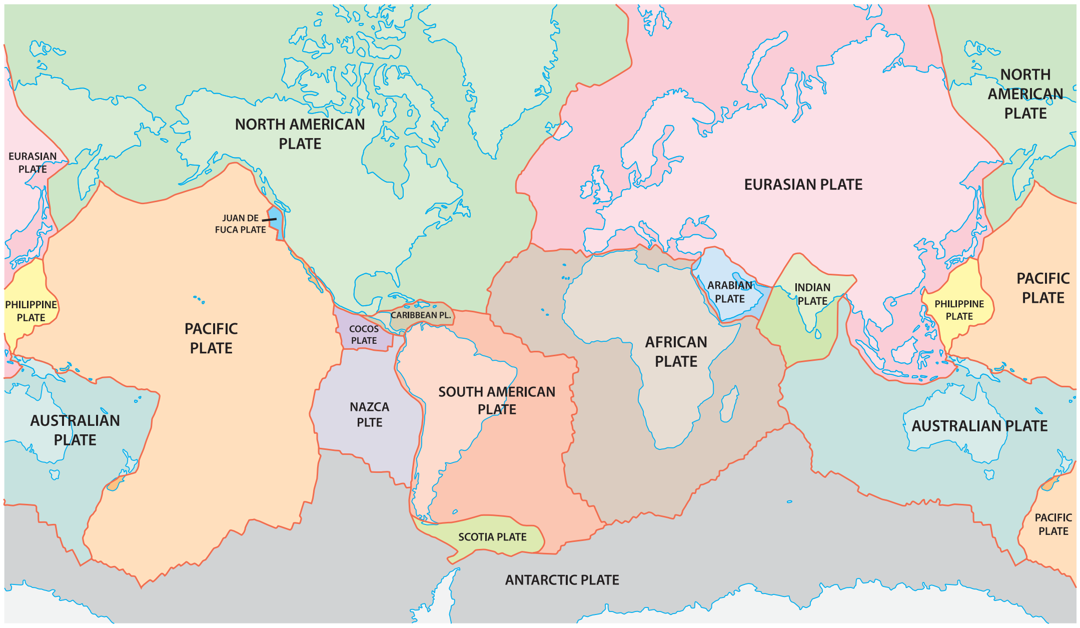
Go online to access the interactive chapter review!

Review questions

Remembering

1. **State** the name of one piece of technology used to measure plate movements.
2. **Name** the tectonic plate that contains Australia.
3. **Name** one mechanism in Earth's mantle that causes tectonic plates to move.

4. **Identify** five major tectonic plates using the image below.



5. **Match** the layer of Earth (A–D) to its physical properties (1–4).

A Crust	**1.** Made of metals (iron and nickel) Very hot temperatures Under intense pressure from the layers above so is a solid structure
B Mantle	**2.** Multi-layered, with both a thin solid uppermost section and a dense semi-molten region where rock flows in hot temperatures
C Outer core	**3.** Thinnest layer Supports all the life on Earth
D Inner core	**4.** Made of metals (iron and nickel) Very hot temperatures Liquid

6. **Identify** the continental and oceanic plates (A and B) at the subduction zone in the diagram in Figure 6.72.

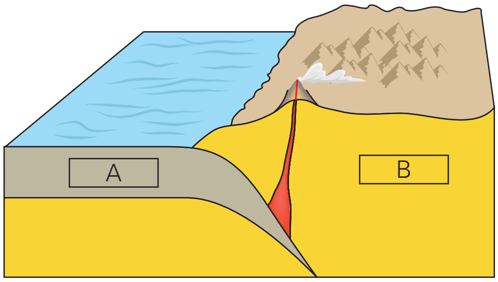


Figure 6.72 Subduction zone

7. **Identify** the source of heat causing convection currents in Earth's mantle.
8. **Identify** the type of seismic wave from the description.
   a) a transverse wave that cannot travel through liquids
   b) a longitudinal wave that can be detected on the opposite side of Earth to the epicentre of an earthquake

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9. In Gunditjmara oral traditions, **recall** what the lava that came from the Budj Bim volcano was formed from.
10. **List** the following scientists in order of when they were involved in the development of the theory of plate tectonics: Marie Tharp, Harry Hess, Alfred Wegener, Frederick Vine, Drummond Matthews, Lawrence Morley.

Understanding

11. **Describe** the three types of plate boundaries and how they affect the amount of crust present.
12. **Explain** how mid-ocean ridges form.
13. **Summarise** the evidence proposed by Alfred Wegener for his continental drift theory.
14. **Explain** why the rocks in the sea floor are magnetised and how this supports Hess's theory of seafloor spreading.
15. **Describe** how a seismometer works.

Applying

16. Using the diagram in Figure 6.73, **model** how convection currents in the mantle move tectonic plates.

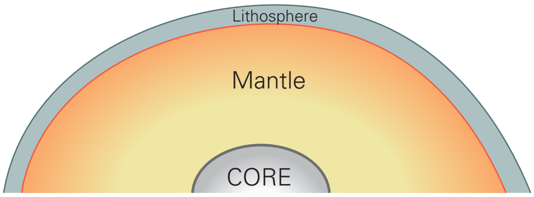

Figure 6.73 Convection currents

17. **Describe** how Marie Tharp's topographic maps provided support for the acceptance of the theory of plate tectonics.
18. **Describe** how a tsunami forms.

Analysing

19. **Examine** the results from Harry Hess's mapping of the sea floor. How did this account for movements of tectonic plates?
20. **Compare** the two types of destructive plate boundaries.
21. **Infer** whether the following effects indicate a constructive, destructive or transform plate boundary.
    a) no mountains form
    b) island arcs
    c) crust is conserved
22. **Classify** the following as constructive, destructive or transform plate boundaries.
    a) The Himalayas
    b) Mid-Atlantic Ridge
    c) Mariana Trench
23. **Analyse** what evidence would be necessary to support the conclusion that all buildings in an earthquake-prone area should be made of bamboo.
24. **Contrast** P and S waves.

Evaluating

25. At the East African Rift zone, the plates are moving away from each other. **Predict** what will happen to the continent of Africa in the next million years.

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26. **Determine** which island is the oldest from the diagram in Figure 6.74. What type of volcano is shown in the diagram?

27. **Predict** what you think will happen to Earth's continents in the next 100 million years.

28. **Discuss** why Australia is considered to be tectonically stable.

29. **Propose** an explanation for the locations of global earthquake and volcanic activity shown in the map in Figure 6.75.

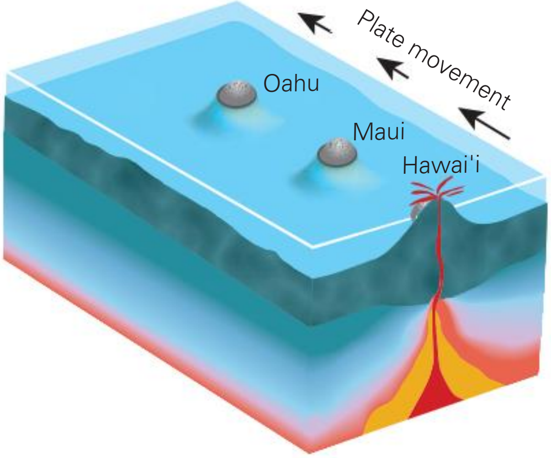

Figure 6.74 The islands of Hawaii

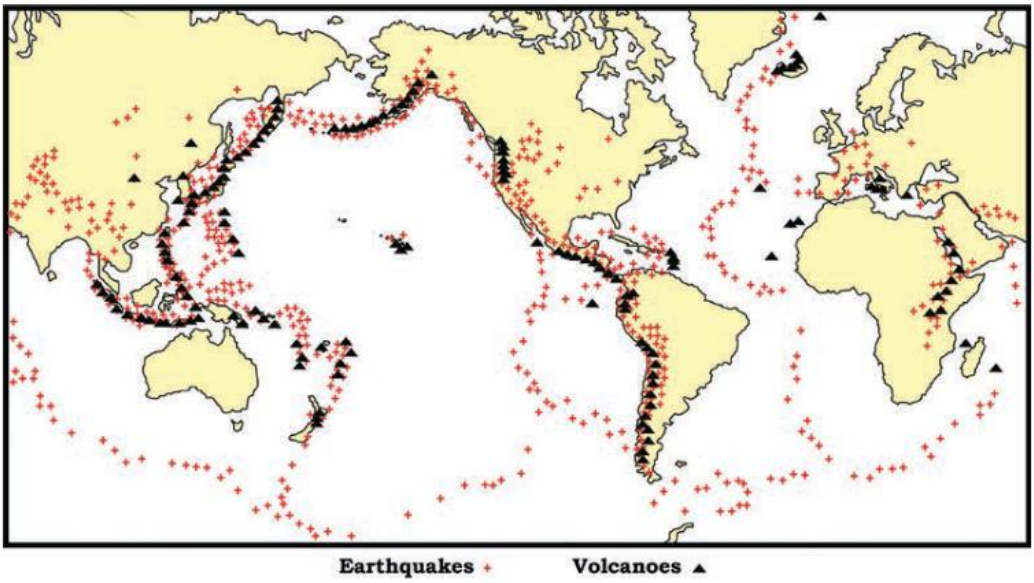

Figure 6.75 Locations of global earthquake and volcanic activity

Data questions

New Zealand is a country that lies very close to a fault boundary and consequently experiences thousands of earthquakes a year. Earthquakes are categorised using the Richter scale, which measures earthquake magnitude on a scale of 0 to 10 (see Table 6.3). The magnitudes of 10 New Zealand earthquakes from 2010 to 2019 are presented in Table 6.4.

Richter scale	Observation
0.0–2.9	Not felt by humans
3.0–4.9	Felt by humans and not damaging
5.0–5.9	Small risk of damage to buildings
6.0–6.9	Moderate risk of damage to buildings
7.0–7.9	High risk of damage to buildings
8.0+	High probability of severe destruction

Table 6.3 Severity of earthquake observed with Richter scale value

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Earthquake reference	Magnitude (Richter scale)
1	4.1
2	7.8
3	4.3
4	2.9
5	5.1
6	6.6
7	2.3
8	6.1
9	1.1
10	7.6

Table 6.4 The magnitude on the Richter scale of 10 earthquakes that occurred in New Zealand between 2010 and 2019

Applying

1. **Identify** the most severe earthquake recorded in Table 6.4.
2. **Determine** the earthquakes that posed a high risk of damage to buildings.
3. The media are reporting a new earthquake in New Zealand that measures 6.5 on the Richter scale. **Identify** the likely observations relating to buildings in the area.

Analysing

4. **Categorise** the earthquakes presented in Table 6.4 as 'not felt' or 'felt'.
5. **Identify** a trend in the Richter scale and severity of earthquakes.

Evaluating

6. Based only on the 10 earthquakes presented, **infer** whether there is a higher chance that an earthquake in New Zealand would not be felt or would damage buildings.
7. There are over 10 000 earthquakes a year in New Zealand. **Justify** whether your answer to Question **6** would be reliable.
8. The largest-magnitude earthquake ever recorded in New Zealand was 8.2 on the Richter scale, while the largest in Japan was 9.0. **Justify** whether it is possible to suggest that Japan is more at risk than New Zealand for severe earthquakes?
9. The media in New Zealand are reporting a mild earthquake that caused a tremor that did not damage buildings but moved furniture in buildings in the area. **Deduce** the magnitude of this earthquake on the Richter scale.

STEM activity: Earthquake-proof structures

Background information

In this chapter, you have gained an insight on the inner workings of our planet. You learned that, contrary to appearances, our planet has been very active for over four billion years. Our planet is constantly changing via many important geological processes over eons, and some of the movements produce earthquakes.

Unfortunately, poorer countries have been greatly affected by earthquakes over the centuries, as whole populations live in earthquake-prone areas (for example, the Pacific Ring of Fire and the Andes). Experts have demonstrated that most deaths in earthquakes occur because buildings and dwellings collapse due to poor construction.

Papua New Guinea (PNG) is located in the Australasia 'ecozone', which includes Australia, New Zealand, eastern Indonesia and several Pacific island groups, such as the Solomon Islands and Vanuatu. PNG is one of the poorest countries in the world and is severely affected by earthquakes. Earthquakes are particularly severe in PNG because of a combination of factors – steep terrain, poor infrastructure and housing, lack of roads and extensive seasonal rains – all of which create an environment that is prone to collapse after an earthquake.

Knowledge has the power to improve people's lives. How can you use technology and your knowledge of geology to improve the lives of people living in these high-risk areas?

DESIGN BRIEF

Design and test building designs to improve durability in earthquake risk zones and present this information in a format that would be useful to a small PNG community.

Figure 6.76 (a) Damage caused by earthquakes in Papua New Guinea. Earthquakes occur all over the world, in developed and underdeveloped countries. They have the power to destroy whole cities, move entire mountains and lift or drop the ground by many metres. **(b)** Scientists analyse data collected during an earthquake.

Activity instructions

In groups (maximum of four people), you will investigate how housing design can affect the stability of a building by building a series of small structures and testing their durability on a shaker table. It will be useful to allocate roles for this activity: project manager, engineer, builder and presenter.

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Role	Responsibility
Project manager	Making sure the project is on time and within a budget. The project manager is responsible for all of the parts of the project.
Engineer	Conducting research on the current models, finding new ways to improve and drawing a sketch of the proposed design
Builder	Creating the proposed design and checking that the design is functional
Presenter	Researching information on cultural awareness of the local community and how to present in the most effective way, and creating a presentation to match this

Together, the group members need to manage their time and help each other through each stage.

Research and feasibility

1. Research current house design in villages and list the features, including types of materials used.
2. Discuss and research as a group how a structure's strength can be improved.
3. Research social and cultural information about PNG communities.

Design and sustainability

4. As a group, discuss some design features you could use in a model house structure and make multiple sketches with ideas.
5. Decide as a group which design will be the most sustainable and suitable to build, with the PNG communities in mind.
6. Decide on and design the format you will use for your presentation for the PNG community.

Create

7. Construct your design using allowable materials such as wooden sticks, tape and glue.
8. Test your design by performing the following tests. Draw a results table.
   - **A.** **Shake test:** Place your design on a table and secure it using tape. Shake the table forwards and backwards four times. Describe how successful your design was. Did it fail? And if so, where and why?
   - **B.** **Weight test:** Your design has survived the shake test! Now, it is time to compare how it behaves when 0.5 kg masses are placed on top of it. Describe how your design behaved under the weights.
   - **C.** **Combination test:** Your design is still standing – that is great! Now, repeat tests A and B at the same time. Describe what happened.
9. Reflect and, if there is time, create and test another design.
10. Create the presentation while building and testing your design.

Evaluate and modify

11. Take time to think about the investment required to change the lives of villagers. Imagine that a 10 cm wooden stick used to build your model costs around $10 to purchase and that the piece that joins them costs $2. Calculate the current cost of building a house using cubes.
12. Evaluate the effectiveness of your design. It is important to remember who your target audience is throughout this project.
13. Give your presentation to the class and reflect on how it demonstrates cultural awareness and how well it communicates effective building methods.

Chapter 7
Rocks

Chapter introduction

Rocks are all around us, from the gravel in our gardens to the mountains that tower over us. They come in many different shapes, sizes and colours and are made up of a variety of different minerals. But what exactly are rocks and how do they form? In this chapter, you will learn about Earth's crust and the rocks that make up its composition. You will distinguish between the three types of rock – igneous, metamorphic and sedimentary – and learn how rocks can change from one form to another via the rock cycle. You will also learn about the mining industry and how resources contained in the rocks are extracted to make useful materials, such as metals for technology, and glass and cement for building.

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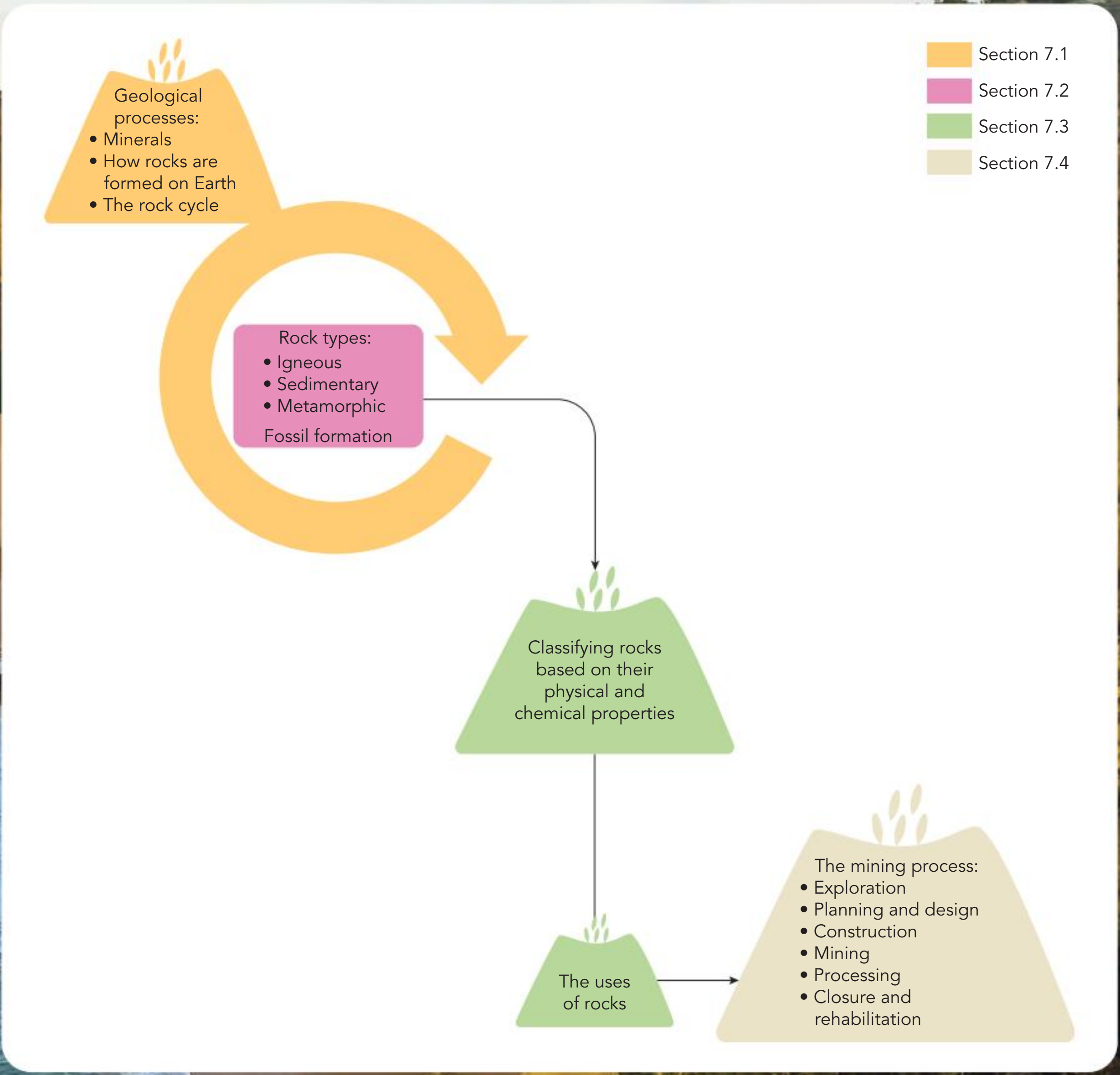
Concept map



🟨 Section 7.1
🟪 Section 7.2
🟩 Section 7.3
⬜ Section 7.4

Geological processes:
- Minerals
- How rocks are formed on Earth
- The rock cycle

Rock types:
- Igneous
- Sedimentary
- Metamorphic

Fossil formation

Classifying rocks based on their physical and chemical properties

The uses of rocks

The mining process:
- Exploration
- Planning and design
- Construction
- Mining
- Processing
- Closure and rehabilitation

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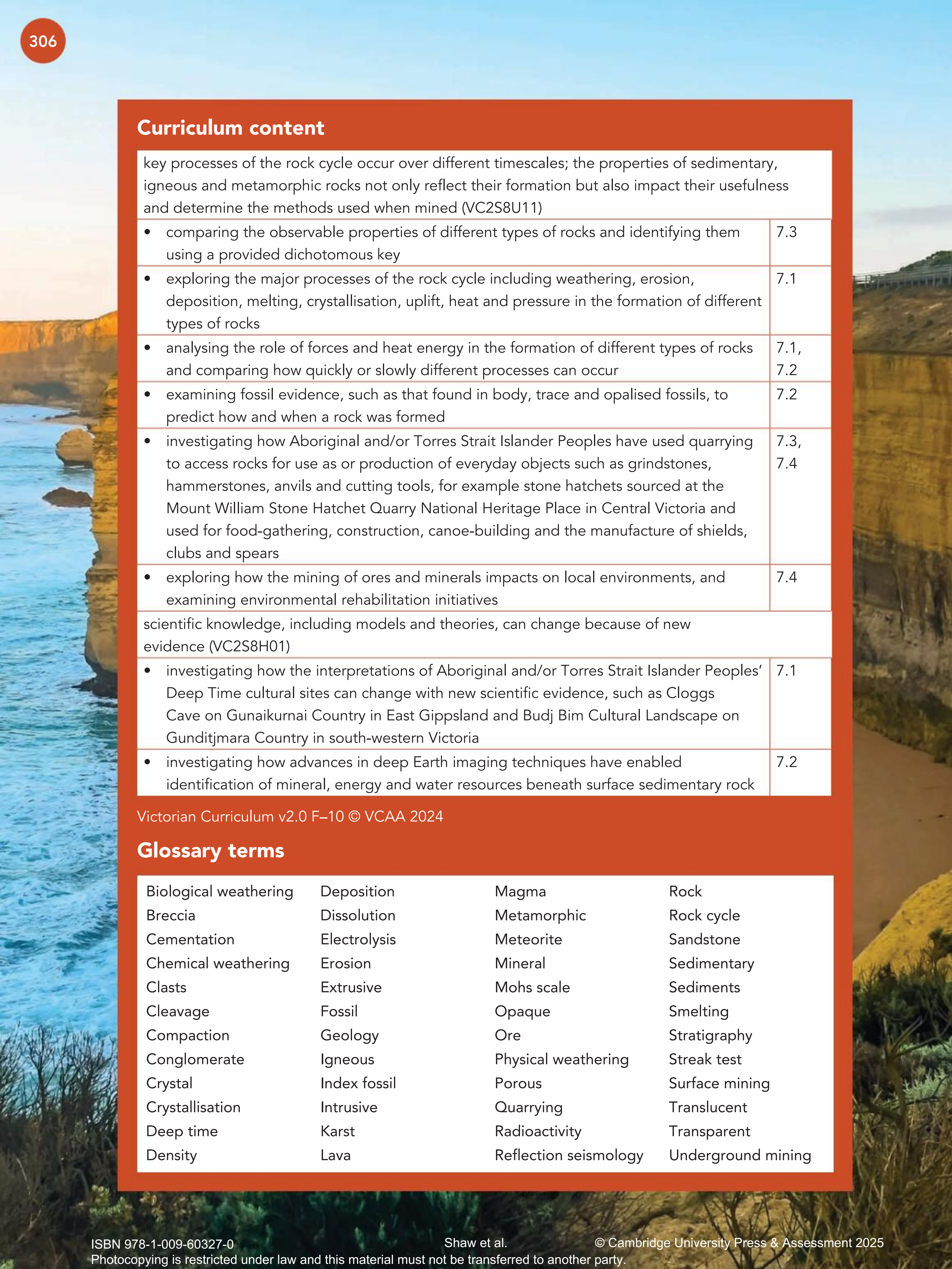

Curriculum content

key processes of the rock cycle occur over different timescales; the properties of sedimentary, igneous and metamorphic rocks not only reflect their formation but also impact their usefulness and determine the methods used when mined (VC2S8U11)	
• comparing the observable properties of different types of rocks and identifying them using a provided dichotomous key	7.3
• exploring the major processes of the rock cycle including weathering, erosion, deposition, melting, crystallisation, uplift, heat and pressure in the formation of different types of rocks	7.1
• analysing the role of forces and heat energy in the formation of different types of rocks and comparing how quickly or slowly different processes can occur	7.1, 7.2
• examining fossil evidence, such as that found in body, trace and opalised fossils, to predict how and when a rock was formed	7.2
• investigating how Aboriginal and/or Torres Strait Islander Peoples have used quarrying to access rocks for use as or production of everyday objects such as grindstones, hammerstones, anvils and cutting tools, for example stone hatchets sourced at the Mount William Stone Hatchet Quarry National Heritage Place in Central Victoria and used for food-gathering, construction, canoe-building and the manufacture of shields, clubs and spears	7.3, 7.4
• exploring how the mining of ores and minerals impacts on local environments, and examining environmental rehabilitation initiatives	7.4
scientific knowledge, including models and theories, can change because of new evidence (VC2S8H01)	
• investigating how the interpretations of Aboriginal and/or Torres Strait Islander Peoples' Deep Time cultural sites can change with new scientific evidence, such as Cloggs Cave on Gunaikurnai Country in East Gippsland and Budj Bim Cultural Landscape on Gunditjmara Country in south-western Victoria	7.1
• investigating how advances in deep Earth imaging techniques have enabled identification of mineral, energy and water resources beneath surface sedimentary rock	7.2

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Glossary terms

Biological weathering
Breccia
Cementation
Chemical weathering
Clasts
Cleavage
Compaction
Conglomerate
Crystal
Crystallisation
Deep time
Density
Deposition
Dissolution
Electrolysis
Erosion
Extrusive
Fossil
Geology
Igneous
Index fossil
Intrusive
Karst
Lava
Magma
Metamorphic
Meteorite
Mineral
Mohs scale
Opaque
Ore
Physical weathering
Porous
Quarrying
Radioactivity
Reflection seismology
Rock
Rock cycle
Sandstone
Sedimentary
Sediments
Smelting
Stratigraphy
Streak test
Surface mining
Translucent
Transparent
Underground mining

7.1 Geological processes

Learning goals

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

1. Describe the role of forces and heat energy in the formation of igneous, sedimentary and metamorphic rocks.
2. Compare how quickly or slowly different rock formation processes can occur.
3. Outline the major processes of the rock cycle.

DOC

WORKSHEET
Formation of rocks

Minerals and rocks

Minerals are solid, naturally occurring substances composed of elements such as oxygen, silicon, aluminium, iron, and calcium, among others. They have a specific chemical composition, and the atoms are arranged in highly ordered repetitive patterns giving a geometric **crystal** structure. There are over 5000 types of minerals, and the most common types (including quartz, feldspars, micas, and silicates) form the majority of the **rocks** in Earth's crust.

mineral
a naturally occurring chemical substance that is formed in the ground, with constant chemical composition, crystal structure and physical and chemical properties

crystal
a substance with a specific chemical composition, in which the atoms are arranged in an ordered way to form a geometric shape

rock
a naturally occurring substance composed of minerals forming Earth's outermost layers, formed as part of the rock cycle

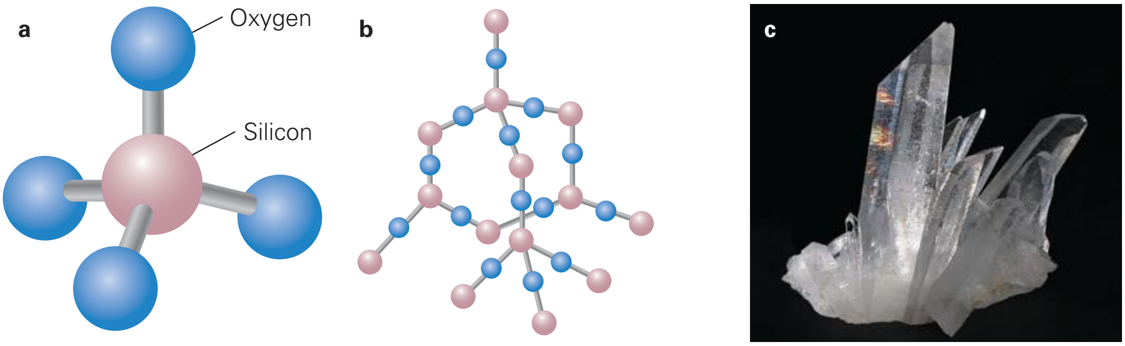

Figure 7.1 (a) Silica molecules are connected into **(b)** a continuous crystal framework which makes up **(c)** the mineral quartz.

Did you know? 7.1

Gemstones

Some minerals have the physical strength to withstand being cut and polished into gemstones. Gemstones can be used in jewellery, and are highly prized for their beauty, rarity and durability. Some examples are diamond, opal and emerald. The mineral beryl is composed of the elements beryllium, aluminium, silica and oxygen and is found in some igneous and metamorphic rocks. Some pieces of beryl are gem-quality and can be polished to produce emeralds.

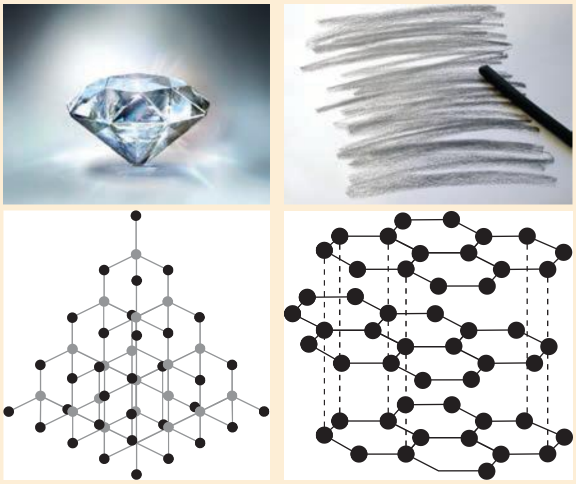

Figure 7.2 Diamond (left) and graphite (right) are both made of carbon atoms. However, the arrangement of the atoms makes a big difference to their properties.

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Rocks are a naturally occurring substance composed of one or more minerals. For example, marble is a rock that is made up one just one mineral, named calcite, whereas granite is composed primarily of quartz, feldspar and mica. Rocks can be broadly classified according to how they form:

- **Igneous** rocks form from molten rock.
- **Sedimentary** rocks form from sediments (the products of erosion).
- **Metamorphic** rocks form other rocks that are affected by heat and pressure.

igneous describes rocks that form from the cooling of magma (below Earth's surface) or lava (above Earth's surface)

sedimentary describes rocks made from deposited materials that are the products of weathering and erosion

metamorphic describes rocks that are changed by being exposed to high temperature, pressure or both

Rocks and Earth

In Chapter 6, you learned about the four layers of Earth's geosphere: the inner and outer core, mantle and crust. You will recall that the core is composed of mostly solid and liquid iron. The core is surrounded by the mantle, which is made of semi-molten rock and a thin, solid uppermost layer. Continental crust, which supports land, is on average 35 km thick, while oceanic crust is around 10 km thick. The crust and the uppermost layer of the mantle form the lithosphere, which is where rocks are constantly formed and reformed through the rock cycle. The heat from rising magma from the semi-molten asthenosphere below, and the movement of the tectonic plates which make up the lithosphere, provide the energy and forces required to drive many of these geological processes.

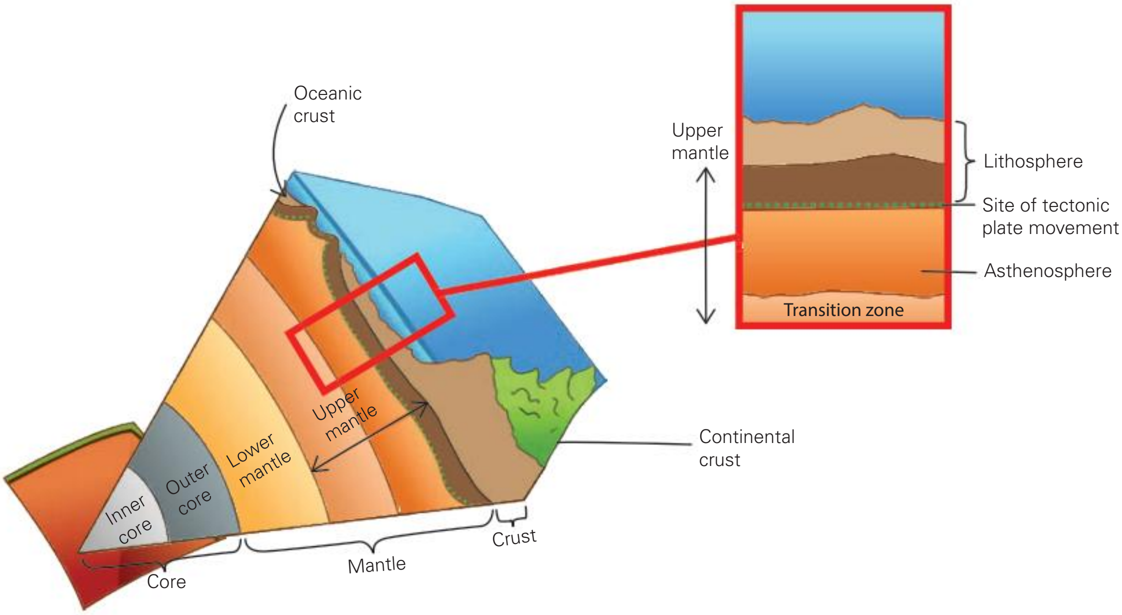

Figure 7.3 Earth's layers

A few key elements make up the bulk of Earth's solid materials, including the rocks and minerals that comprise the planet's crust and mantle. The most common element is iron, followed by oxygen, silicon and magnesium. Each type of rock is unique in its composition and properties. Rocks that contain high levels of the mineral silica (the compound of silicon and oxygen, Figure 7.1) are light coloured. These are called felsic rocks. Rocks that are high in magnesium and iron are darker in colour, and are called mafic rocks.

Element	Proportion of Earth's mass (%)
Iron	35
Oxygen	30
Silicon	15
Magnesium	13

Table 7.1 These four elements make up most of Earth's mass.

Quick check 7.1

1. **Define** and **distinguish** between rocks and minerals.
2. **State** where rocks are formed on Earth.
3. **Identify** which elements make up most of Earth's mass.

The rock cycle

Earth's surface is constantly changing. James Hutton, a Scottish naturalist and doctor also known as the father of modern **geology**, developed the theory that geological features were continually transforming. His attempts to explain the complexity of the surface of Earth yielded two conclusions:

- Earth is very old. This aligned with the thinking of many other geologists and came to be referred to as **deep time**.
- Earth's geological features appear to have formed and reformed in a cyclical process over its entire history. We now refer to this as the **rock cycle**.

geology
the study of Earth's dynamic structure and the processes through which our planet (and other planetary objects) have formed

deep time
the idea that Earth is very old

rock cycle
the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

WORKSHEET
The rock cycle

Did you know? 7.2

Our static Moon

The surface of the Moon has not changed much over its 4.5 billion-year history. The Moon has no atmosphere, so there is no wind or flowing bodies of water to erode geological features. The footsteps of the first astronauts who walked on the Moon are still there!

Figure 7.4 Neil Armstrong, the first man to walk on the Moon (1969)

Science as a human endeavour 7.1

Deep time cultural sites

In 2020, excavations from Cloggs Cave (on Gunaikurnai Country in East Gippsland), uncovered the remnants of fireplaces and fat-smeared wooden artefacts dated to around 12 000 years ago. These charred artefacts are the oldest-known wooden artefacts discovered in Australia A team of Traditional Owners and archaeologists suggest that they are evidence of a specific ritual practised by Mulla Mullung (Gunaikurnai healers/doctors). This knowledge was passed down through around 500 successive generations of Gunaikurnai people.

Excavations originally began at the cave in the 1970s, without the permission of Traditional Owners. In recent times, Monash University has been working cooperatively with Gunaikurnai Land and Waters Aboriginal Corporation (GLaWAC). The discovery of the wooden artefacts is an exciting insight into deep time cultural practices. They will be returned to Country once analysis is complete.

magma
hot fluid rock found beneath the Earth's surface

crystallisation
the formation of solid mineral crystals from a liquid, either by cooling or evaporation

lava
molten rock from inside Earth (magma) that has reached the surface

Melting and crystallisation

As you can see in Figure 7.5, the melting of rock to form magma (molten rock), and then the cooling of that magma, results in the formation of igneous rock. The process of melting takes place beneath Earth's crust at temperatures that can be as low as 500°C and as high as 1600°C. The process of cooling can happen below or above Earth's surface. An interesting characteristic of igneous rocks is that the minerals in them may form crystals. This is because, when **magma** cools, **crystallisation** occurs. Below Earth's surface, magma takes a long time to cool, and the crystals that form in it are large. Magma that reaches Earth's surface is called **lava**. Because lava cools more quickly, the crystals that form are small and may even be microscopic. You will learn more about igneous rocks in the next section of this chapter.

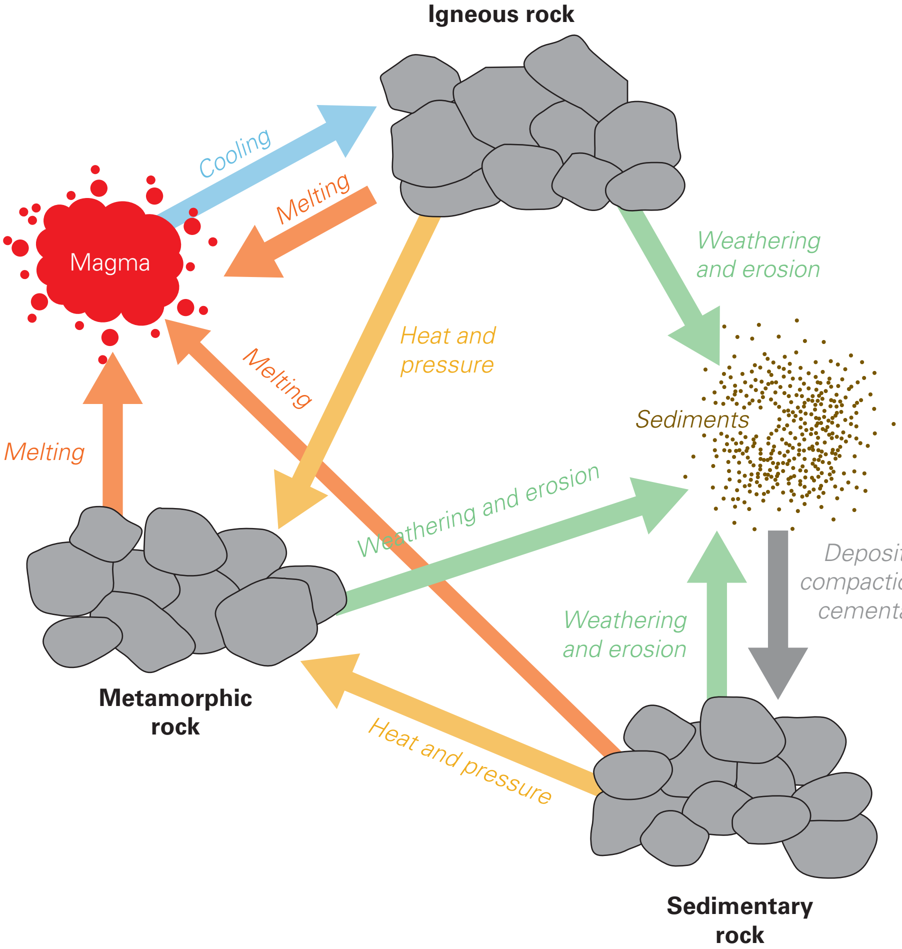

Figure 7.5 In the rock cycle, the three types of rock can change through the action of weathering and erosion, deposition, compaction and cementation, melting and cooling, and heat and pressure.

Figure 7.6 Granite is an igneous rock composed of four types of minerals. The crystals are deemed large, as they are visible with the naked eye, indicating the rock cooled slowly, probably underground.

Figure 7.7 Views from the granite peak of Mount Oberon, Wilsons Promontory National Park

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Did you know? 7.3

Igneous rocks

'Igneous' and 'ignite' come from the same Latin word, *ignis*, which means 'fire'. This is an easy way to remember that igneous rocks are formed from molten rock (magma or lava).

Figure 7.8 'Igneous' comes from a Latin word meaning 'fire'.

Explore! 7.1

What is a meteorite?

From time to time, rocks arrive on Earth from space in the form of **meteorites** that land on the surface. Use the internet to answer the following questions.

1. What is the composition of meteorites?
2. Outline where meteorites originate from.
3. Propose whether meteorites pose a threat to life on Earth. Justify your argument using examples of meteorites that have landed on Earth and their impact.

Figure 7.9 An iron meteorite that landed on Earth from space

Quick check 7.2

1. **State** the three types of rocks formed in the rock cycle.
2. **Describe** the role heat plays in rock formation in the rock cycle.

meteorite	a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground
sediments	sand, stones and other materials that slowly form a layer of rock
physical weathering	the process of breaking down rocks into smaller pieces or particles, without changing the chemical composition

Weathering

Weathering is an important process that contributes to the formation of **sediments**. When rocks and minerals are exposed to the elements, they can be broken down into smaller particles through physical, chemical and biological weathering. The size and composition of sediments can vary widely depending on the type of rock and the weathering processes that created them.

Physical weathering is the process of breaking down rocks into smaller pieces without changing their chemical composition. Temperature changes, pressure and mechanical forces from weathering agents, such as wind, water, ice and gravity, can cause physical weathering. Freeze–thaw action is a specific example of physical weathering caused by the repeated freezing and thawing of water in cracks and crevices of rocks. When water enters a crack in a rock and freezes, it expands and widens the crack. The repeated expansion and contraction due to freeze–thaw action can cause the rock to break apart into smaller pieces.

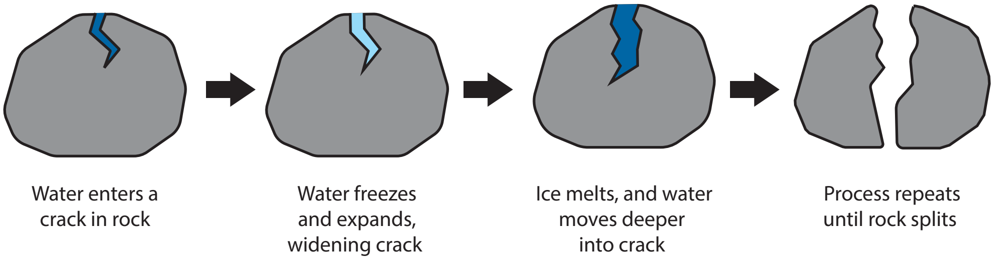

Figure 7.10 The stages of freeze–thaw action

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chemical weathering the process in which rocks are broken down and chemically altered via chemical reactions

dissolution when water dissolves minerals in rocks

Chemical weathering is the process by which rocks are broken down by chemical reactions. Rainwater is naturally slightly acidic because it contains carbon dioxide from the air, which forms carbonic acid when it dissolves in water. This slightly acidic water can react with certain types of rock, such as limestone, to break them down over time. As rainwater seeps through the ground, it can dissolve and carry away minerals from the rock, leading to the formation of underground caves, rivers and other unique geological features. The **dissolution** of the rock can lead to the formation of stalactites and stalagmites, which are mineral formations that grow from the ceiling and floor of the cave, respectively. When they eventually meet, they can form columns.

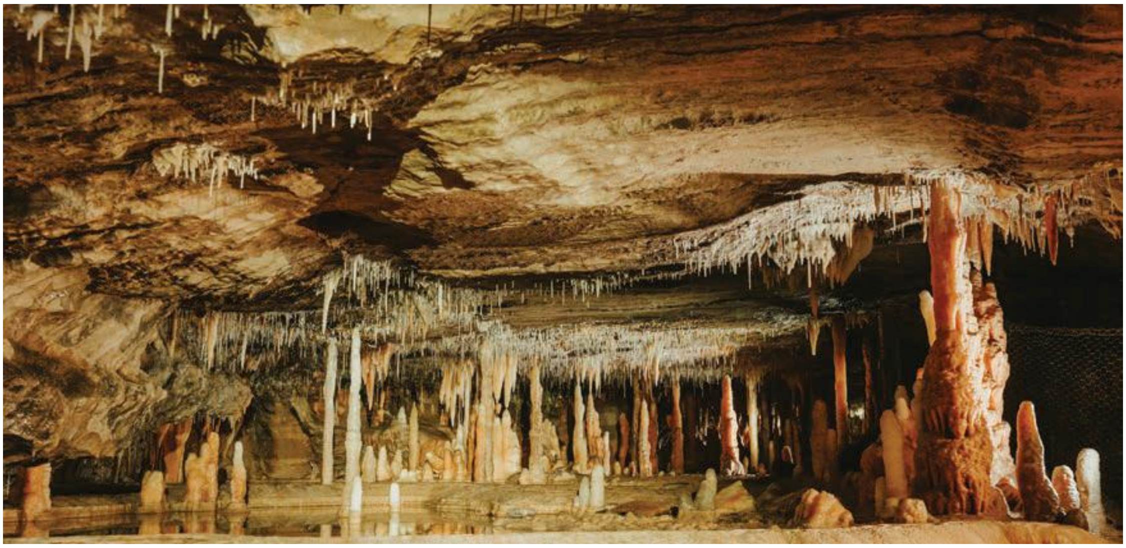

Figure 7.11 Limestone caves such as the Buchan Caves in Gippsland are often developed as tourist attractions because of the beautiful limestone features they contain. These are often formed by the dissolution of limestone by slightly acidic water over many years, and also on the deposition of calcium carbonate to form stalagmites and stalactites.

karst an area of land formed from rock such as limestone that is worn away by water to make caves and other formations

When limestone contains underground rivers, it can give a very characteristic landform called a **karst** landscape (see Figure 7.12), which has caves, sink-holes, limestone outcrops and dry valleys with no water because the river that formed them has gone underground. The Nullarbor Plain between South Australia and Western Australia is the world's largest karst landscape.

Figure 7.12 The entrance to a cave in a typical karst landscape. Rainwater enters the cave and can travel underground for many kilometres.

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Did you know? 7.4

Exploring cave systems

A person who studies caves scientifically is called a 'speleologist', but a person who explores caves as a pastime is called a 'caver' or a 'spelunker'.

Figure 7.13 Cavers explore underground cave systems, looking for amazing rock formations like this.

Science as a human endeavour 7.2

Saving limestone buildings

Researchers from the University of Iowa and Cardiff University have found a way to protect limestone statues and buildings from chemical weathering. A water-resistant coating containing fatty acids from olive oil and other compounds with fluorine additions, is applied in a thin, single layer. This could benefit buildings such as the limestone church shown in Figure 7.14.

Figure 7.14 Pella Lutheran Church, near Rainbow, Victoria, was constructed from limestone sourced from a nearby quarry.

Biological weathering is a form of physical weathering that occurs when rock is broken down into smaller particles by living things. For example, human feet can wear dips into the tops of stone steps (see Figure 7.15), and plant roots grow into small cracks in rocks and make the cracks bigger.

biological weathering the disintegration of rocks that is caused by living things

Figure 7.15 These steps have been 'weathered' by people walking on them. The particles of stone have been washed away or eroded by the rain.

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Quick check 7.3

1. **Distinguish** between physical, chemical and biological weathering, giving an example of each.

Erosion

erosion
the transport of rock fragments (that have resulted from weathering)

Erosion occurs when rock that has been broken loose by weathering is transported or moved to a new location. It includes rocks or rock particles falling due to gravity, being carried away in the wind or moved by waves, ocean currents, running water or even ice in a glacier.

VIDEO
Australian landmarks

Weathering results in rock fragments of various sizes (see Table 7.5), and the particle size determines the way in which it may be eroded. Small particles, such as sand, can be blown by the wind, but larger particles like pebbles and boulders require higher energy forms of transport, such as river currents or ocean waves. Mud, which is a viscous (thick) fluid composed of silt, clay and water, can be carried by a slow moving river. Larger boulders within the river system may only be eroded in times of flood, when the water is moving faster and with greater energy. Glaciers are capable of carrying giant boulders, trapped in ice, for many kilometres. Glaciers are also powerful weathering agents, because the ice leaves a smooth surface as it passes over the bedrock.

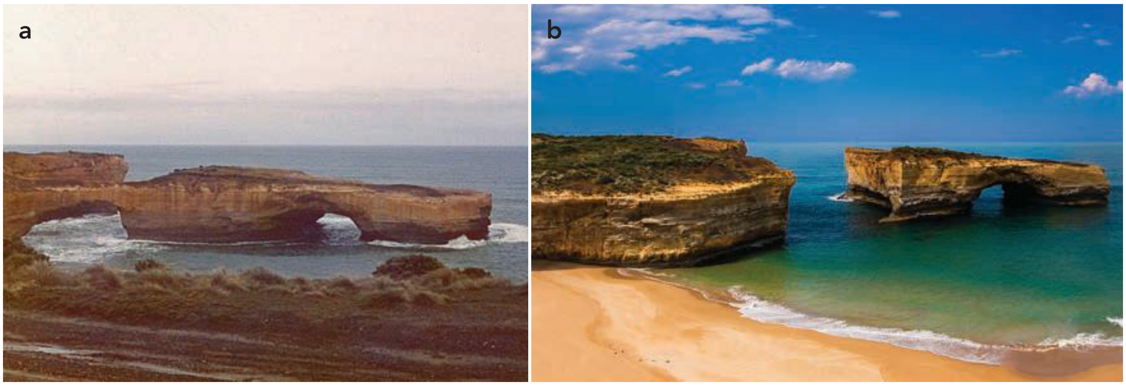

Figure 7.16 (a) The London Bridge formation on Victoria's Great Ocean Road (1973) prior to its collapse. **(b)** The London Bridge formation (present day) following its 1990 collapse. This limestone stack originally formed on the seabed, which has now been raised. Ocean waves weathered and eroded the limestone resulting in the collapse of one of the arches. Two tourists were stranded on the formation, but no one was injured.

During the last ice age, the world, including Australia, was very different. Large quantities of water were trapped in giant ice sheets that spread out from the poles and covered much of Europe and North America. Because of this, the sea level was much lower, and it was possible to walk on land from Victoria to Tasmania and from Queensland to Papua New Guinea. Although neither the Australian mainland nor Tasmania was covered in an ice sheet, glaciers formed on Cradle Mountain in Tasmania and the surrounding areas. The landscape was transformed by the ice moving over the rocks, leaving the characteristic smooth surface.

The profile of Wave Rock in Western Australia (see Figure 7.18) demonstrates the erosive power of wind. Sand grains carried by wind have worn down this rock and carried away the debris. Initially, it was chemical weathering (vegetation breaking down) that weakened the rock, and then the wind-borne sand started its work at the weakened lower levels of rock. Eventually a wave-like shape formed.

Figure 7.17 Dove Lake on Cradle Mountain in Tasmania. The smooth appearance of the rocks is due to the action of glaciers 20 000 years ago.

Figure 7.18 Wave Rock in Western Australia is made of granite that is over two billion years old.

Try this 7.1

Erosion by wind

You will need the following materials:

- Petri dish
- water
- dry sand
- pebbles of various sizes (approximately 5–65 mm in diameter)
- drinking straw
- newspaper

Place the Petri dish on the edge of the newspaper. Moisten the bottom of the Petri dish with just a little bit of water before filling it with sand. Place five pebbles on top of the sand and spread them out evenly. Gently blow through the straw, away from the edge of the newspaper, so the sand lands on the newspaper and does not make a mess.

What do you observe? Which size particles were eroded by the 'wind' and which were not affected?

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Deposition, compaction and cementation

Particles or sediments that are eroded come to rest when the wind or water moves more slowly or the ice melts. When the particles reach their destination, they are dropped, in a process called **deposition**. Often deposition occurs on ocean beds or lake beds. The particles are often deposited in visible layers, which become **compacted** or compressed by the weight of the layers above and **cemented** together. These processes finally form sedimentary rocks.

deposition the process that occurs when eroded particles stop moving and build up to form sedimentary rocks

compaction the process of particles becoming closely positioned together, using very little space

cementation the sticking together of sediment

fossil the remains, shape or trace of a bone, shell, microbe, plant or animal that has been preserved in rock for a very long time

Figure 7.19 Sedimentary rocks are very common, covering over 70% of Earth's surface. Some contain fossils that are billions of years old. Note the different layers of sediment, all cemented together.

Quick check 7.4

1. **Distinguish** between weathering and erosion.
2. **Explain** the processes of deposition, compaction and cementation.

Sometimes animal and plant remains are mixed in with the sediments and preserved as **fossils**. On the seabed, this process can continue in the same place for millions of years. This can create layers of sediment many metres high containing fossils from different time periods, with the oldest at the bottom.

Try this 7.2

Deposits on a lakebed

Aim

To model and observe how sediments are deposited on a lakebed

Materials

- soil
- sand
- gravel
- water
- jar with lid

Method

1. Add soil, sand and gravel to a jar and mix them. Fill the jar halfway.
2. Add water. Fill the jar three quarters full and put the lid on.
3. Make sure the lid is tight and shake the jar for one minute. How do you predict the particles will settle?
4. Observe how the particles settle. Time how long it takes for each layer to form.

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Results

1. Draw a diagram representing the different layers and label them.

Discussion: Analysis

1. Do the larger particles end up on the top layer or the bottom layer?
2. How long does each layer take to settle? Can you explain why this occurred?

Heat and pressure

Rocks that are deep underground may be exposed to extreme pressure, high temperature or both. This can change the nature of the rock, often making it harder and denser. These processes create metamorphic rocks. Mudstone is a sedimentary rock made from mud. When it is exposed to high pressure and temperature it turns into slate, a metamorphic rock. If the temperature and pressure are increased again, it turns into schist, another type of metamorphic rock.

Figure 7.20 Slate is a metamorphic rock formed when mudstone is subjected to high pressure and temperature.

Figure 7.21 Pieces of schist, formed when slate is subjected to high temperature and pressure

Try this 7.3

Metamorphic pasta

You will need the following materials:

- textbooks × 2
- penne pasta (or any long type of pasta)

Scatter the pasta around in a random manner on a flat surface, between the two books, as shown in Figure 7.22. Keeping the book spines parallel to each other, slowly bring the spines together, with the pasta pieces in between. As the pasta pieces are compressed, they should align. How does this demonstrate the way in which metamorphic rock is formed?

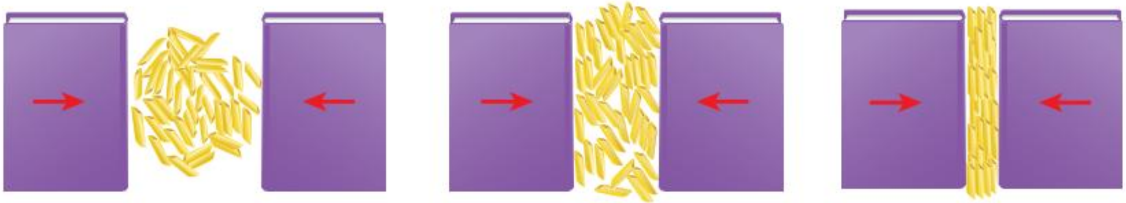

Figure 7.22 As you compress the pasta, the pieces align.

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Quick check 7.5

1. In order to understand the unique characteristics of different types of rocks, it is essential to examine how they are formed. **Distinguish** between the three kinds of rock in terms of how they are formed.

Uplift

Uplift refers to the movement of rocks from deeper parts of Earth's crust to the surface. This occurs through tectonic activity, volcanic eruptions or erosion of overlying rock layers. As rocks are uplifted, they are exposed to environmental processes, including weathering, erosion and deposition. These processes can break down and reshape the rocks, leading to the formation of new sediments and minerals. Uplift is also involved in the creation of mountain ranges, as tectonic forces cause rocks to be pushed upwards and folded into complex structures.

Explore! 7.2

The Great Dividing Range

The Great Dividing Range is a vast mountain range that runs parallel to the east coast of Australia, stretching from the tip of Cape York Peninsula in the north to the Grampians in Victoria in the south. The formation of this mountain range is largely attributed to uplift, which occurred over millions of years.

The uplift was caused by tectonic forces that led to the gradual uplifting of the Australian continent over millions of years. Recent research has suggested that the mantle under Australia's east coast has been uplifted twice. The first time was during the Early Cretaceous Period, around 120 million years ago when Australia was part of the ancient 'supercontinent' Gondwanaland. There was then a second uplift about 50 million years later. As the Australian continent was uplifted, the overlying sedimentary rocks were also uplifted and folded, leading to the formation of the mountain range.

Over time, erosion has also played a significant role in shaping the Great Dividing Range. The forces of wind, rain and ice slowly wore down the mountains, carving out deep valleys and gorges and smoothing out the peaks.

Figure 7.23 The Great Dividing Range

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Energy sources for the rock cycle

It takes a lot of energy to move rocks around, break them up, heat them until they melt, or change them physically or chemically.

Type of rock	Source of energy	Details
Igneous	Earth's formation and elements that are **radioactive**	When Earth was formed, it contained radioactive atoms left over from a supernova. This radioactive energy has been released ever since and is what keeps the centre of Earth at a high temperature.
Metamorphic		
Sedimentary	Sun	The energy of the Sun causes weathering through rain, wind, waves and ice formation. It also causes rocks to heat up during the day and cool down at night.

Table 7.2 The energy required for the formation of the different rock types comes from different sources

radioactivity energy released from the nucleus of an atom when the atom decays

Speed of rock formation

Rock formation processes occur at different rates, and they are dependent on the environmental conditions. Igneous rocks (both volcanic/extrusive and underground/intrusive), form from cooling magma or lava, so the rate of formation depends on the depth and pressure of the magma chamber, the rate of lava flow and the presence of water or other minerals. Metamorphic rock formation speed is dependent on the temperature and pressure involved. Sedimentary rock formation speed is dependent on how quickly the sediment is deposited, and the degree of cementation and compaction. Table 7.3 provides an overview.

Type of rock	General speed of formation
Igneous	Days to months (extrusive igneous rocks) up to millions of years (intrusive igneous rocks) Extrusive: Obsidian and pumice (which are non-crystalline) can cool and form in minutes to days, while basalt takes weeks or months, dependent on the basaltic lava flow. Intrusive: Can take thousands to millions of years due to the slow cooling of magma. Slower cooling leads to larger crystals.
Metamorphic	Millions of years Existing rock has to be heated and sufficiently pressurised in order for recrystallisation to occur. Can occur faster at tectonic plate boundaries due to shearing forces.
Sedimentary	Millions of years Deposition can be extremely quick (e.g. a slumping event such as a landslide) or slower (e.g. coral reef formation from the deposition of shells), but compaction and cementation generally take millions of years.

Table 7.3 Rock formation speeds

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Did you know? 7.5

Radiometric dating

Scientists can measure the amounts of different types of radioactive elements in a metamorphic or igneous rock. They compare them to calculate the age of the rock. So far, the oldest terrestrial rock to be discovered on Earth is a piece of metamorphic rock called gneiss from Canada, that is estimated to be between 3.8 and 4.3 billion years old. It was formed long before there was life on Earth, and it is almost as old as Earth itself.

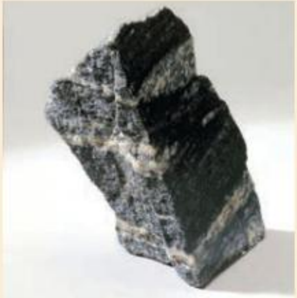

Figure 7.24 This piece of rock is a sample of Acasta Gneiss, the oldest body of rock yet discovered on Earth.

Try this 7.4

Rock cycle poster

Make a poster of the rock cycle and annotate it with details of the different processes you have learned about in this section. You are going to add to this poster in the next section, so make sure you leave space around the outside for extra information about the types of rocks.

Go online to access the interactive section review and more!

Section 7.1 review

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

Section 7.1 questions

Remembering

1. **Recall** the name of the layer on Earth in which rocks are formed and reformed.
2. In Scotland, James Hutton saw igneous rock with millions of years' worth of sedimentary rock lying on top of it. **Recall** two observations that Hutton published after seeing this.
3. **Name** the most common type of rock that is exposed on Earth's surface.

Understanding

4. Copy the image of the rock cycle in Figure 7.25 and label the missing processes. Then **explain** each of the processes.

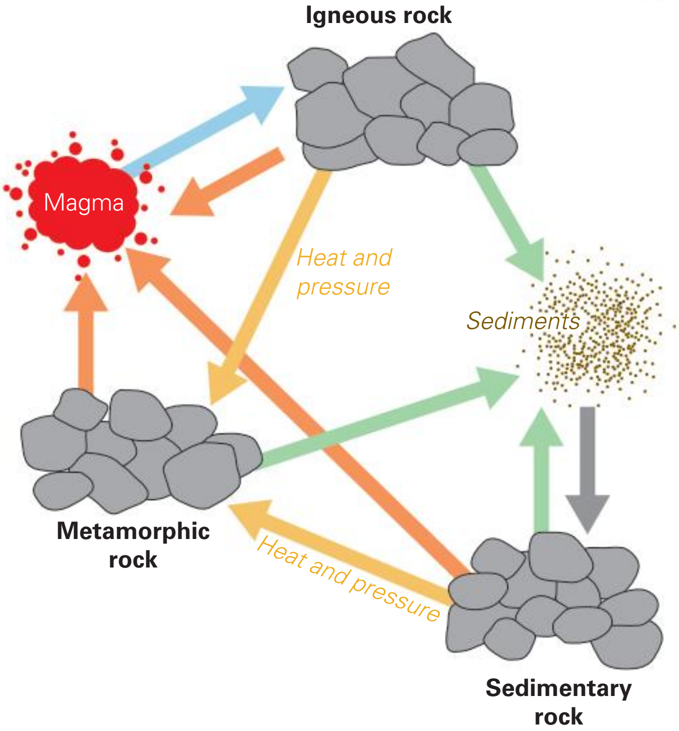

Figure 7.25 The rock cycle

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Applying

5. **Summarise** how the different types of rock from the previous question are formed.

Analysing

6. **Contrast** rocks, minerals and crystals.
7. Make use of what you have learned about weathering to **identify** one reason why weathering is important to the rock cycle and one reason why we might want to stop weathering.
8. Imagine that Earth's core suddenly lost its thermal energy. **Identify** which type(s) of rock formation would be affected and explain why.

Evaluating

9. Examine Figure 7.26 and **decide** whether it is a mineral or a rock. Justify your answer.

Figure 7.26 Is this a mineral or a rock?

10. 'Once igneous rocks are formed, the only physical change they can experience is being broken down into smaller pieces until they are melted again.' **Discuss** whether you agree with this statement and provide your reasoning.

7.2 Types of rocks

WORKSHEET
Types of rocks

Learning goals

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

1. Describe the formation of igneous, sedimentary and metamorphic rocks.
2. Explain how fossil evidence can predict how and when a rock was formed.

Igneous rocks

Beneath Earth's thin outer crust is molten and semi-molten rock, called magma. When the surface crust becomes fractured, thin or weakened, molten magma can reach the surface and a volcano is formed. You may recall from the previous section that igneous rocks are formed when lava cools quickly following a volcanic eruption, sometimes within minutes. Igneous rocks can also be formed when magma cools and solidifies slowly underground in a magma chamber after it has been pushed close to the surface.

Figure 7.27 Igneous rock and lava in Hawaii

The crystals within igneous rocks can be used to identify them. The crystals may be anything from several centimetres long to visible only with a microscope. The size of the crystal gives a clue to how long the igneous rock took to cool and, hence, how close to the surface the rock was formed.

Figure 7.28 The hexagonal pillars of basalt found at the Giant's Causeway in Northern Ireland are an example of lava flowing onto the surface, solidifying and forming igneous rock.

extrusive describes igneous rocks formed on Earth's surface; also called volcanic rocks

intrusive describes igneous rocks formed underground; also called plutonic rocks

Igneous rocks formed on Earth's surface from solidified lava are called **extrusive** igneous rocks. An interesting example is basalt, an igneous rock, which forms large hexagonal pillars as it cools. Pumice, also an extrusive igneous rock, floats on water!

Another way for molten magma to form rocks is if it stops and cools before it gets to the surface and solidifies underground. This rock will cool more slowly and so there is more time for crystals to grow, which means the individual crystals are bigger. Igneous rock formed in this way is called **intrusive** or plutonic. Although this rock is hidden when it is formed, it can be exposed later when the layers above have been eroded. Granite is an example of a plutonic igenous rock formed beneath the surface of a volcano. It has been used in kitchen benchtops.

Figure 7.29 An example of intrusive igneous rock. This unusual landform in New South Wales contains the remains of an ancient volcano. Belougery Spire, on the left, was the magma chamber. The Breadknife, running along the right, was a crack in the volcano that filled with magma.

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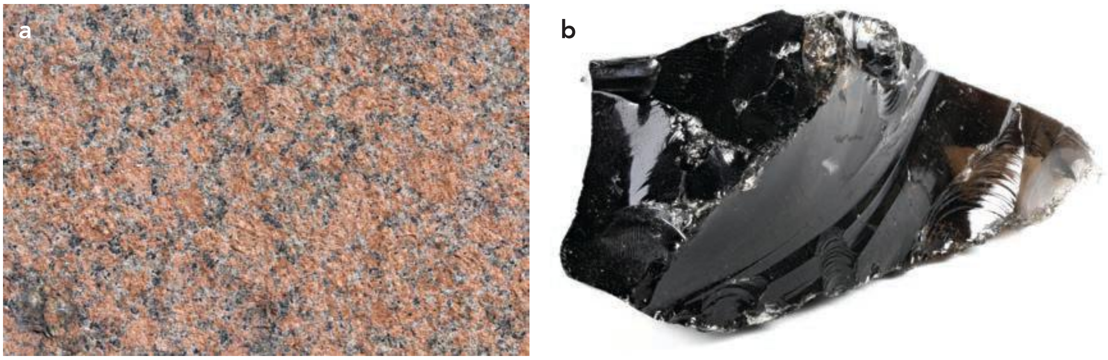

Figure 7.30 **(a)** Granite has a distinctive mosaic of crystals of different colours while **(b)** obsidian has a glassy black surface.

	Mostly light-coloured minerals ***(high silica content = felsic rocks)***	**Mostly dark-coloured minerals** ***(low silica content = mafic rocks)***
Glassy (very fast cooling/ quenching)	Obsidian, pumice	Obsidian, scoria
Small crystals (fast cooling)	Rhyolite	Basalt
Large crystals (slow cooling)	Granite	Gabbro

Table 7.4 Summary of igneous rocks characteristics

Did you know? 7.6

Picnic at… a volcano?!

Hanging Rock, located near the traditional boundary of the Woi Wurrung (Wurundjeri), the Djaara and the Taungurung Peoples, is the famed setting for the novel (and later film) *Picnic at Hanging Rock*, which told the tale of a group of schoolgirls who went missing. Hanging Rock is a type of extinct volcano known as a mamelon, meaning it was created by incredibly viscous (thick) lava that erupted and was not able to flow very far away. The lava cooled and contracted into steep-sided structures, which have been enlarged over time by weathering. The result is many pinnacles, craggy overhangs and boulders on the slopes, which tourists can now climb.

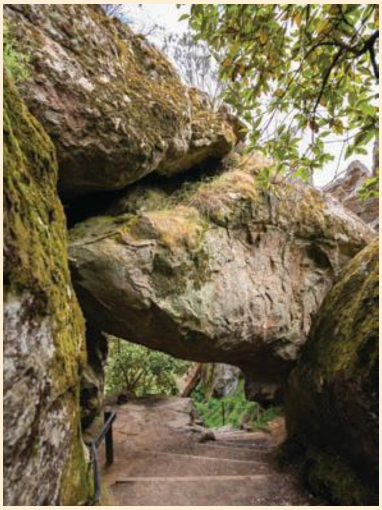

Figure 7.31 A ‘hanging rock’ boulder suspended over the path, which gives the famous summit its name.

Quick check 7.6

1. **List** four examples of igneous rocks.
2. **Describe** how intrusive and extrusive igneous rocks are formed.
3. **Relate** crystal size to the time taken for crystals to form.

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Investigation 7.1

Crystals and cooling rate

Aim

To determine the effect that cooling rate has on the size of crystals formed

Background research

1. Write a rationale about crystal growth and the factors that can affect it.
2. Write a specific and relevant research question for your investigation.
3. Write a risk assessment for your investigation.

Hypothesis

Write a hypothesis for this investigation. Ensure you define your independent, dependent and controlled variables.

Materials

- saturated potassium nitrate or magnesium sulfate solution
- water
- test tubes
- beakers
- ice
- hand lens

Method

Using the materials above, design an experiment to investigate how cooling rate affects the size of crystals formed from saturated potassium nitrate or magnesium sulfate.

Hint: To create crystals, you need to use a saturated solution of potassium nitrate or magnesium sulfate.

Results

Record your results. Consider different ways your results could be presented.

Discussion: Analysis

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

Discussion: Evaluation

1. Identify any limitations in your investigation.
2. Suggest some improvements for this experiment.

Conclusion

1. Draw a conclusion from this experiment about the effect of cooling rate on the size of crystals formed, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that _____________.
   Therefore, the hypothesis is/is not supported by these findings.

Sedimentary rocks

There are three different types of sedimentary rocks: clastic, organic (biological) and chemical. Each type is formed from pieces of other existing rock or organic material and can take thousands to millions of years to form.

clasts
small pieces of pre-existing rock that form a sedimentary rock

Clastic sedimentary rocks are made up of small pieces of other rocks, which are called '**clasts**'. Over time, clasts can be transported by wind, water, ice or other forces and then deposited in a new location. Eventually, the layers of clasts become compacted and cemented together to form a solid rock. Sedimentary rocks can be classified based on their texture, composition and origin (refer to summary Table 7.6 on page 329).

The Wentworth grade scale (Table 7.5) is a tool used by geologists to classify the size of particles in rocks.

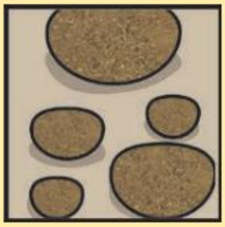
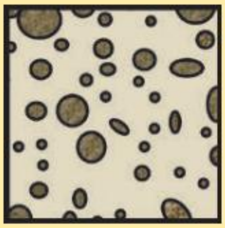
Type	Size (mm)	
Boulders	>256	
Pebbles	256–4	
Gravel	4–2	
Coarse sand	2–0.5	
Fine/medium sand	0.5–0.06	
Silt	0.06–0.004	
Clay	<0.004	

Table 7.5 Wentworth grade scale for classifying particles

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Clastic sedimentary rocks

Sedimentary rocks mainly made of gravel

conglomerate sedimentary rock composed of rounded rock fragments larger than two millimetres

breccia sedimentary rock composed of angular broken pieces of rock larger than two millimetres

sandstone sedimentary rock composed mainly of sand-sized silicate grains

Conglomerate is a poorly sorted coarse-grained sedimentary rock that is composed of large, rounded clasts that are greater than 2 mm in size, along with sand and clay-sized particles in a cementing matrix of quartz or calcite. The clasts in a conglomerate are usually well rounded as they have been transported a long distance from their source, indicating a high-energy environment, such as a river or beach.

Breccia is also a coarse-grained sedimentary rock, but it is made up of large, angular clasts that have been cemented together. The clasts in a breccia are usually less rounded than those in a conglomerate and have been transported a shorter distance. Breccia often forms in areas where there has been a lot of tectonic activity or landslides, as the rocks are broken into angular fragments during these events.

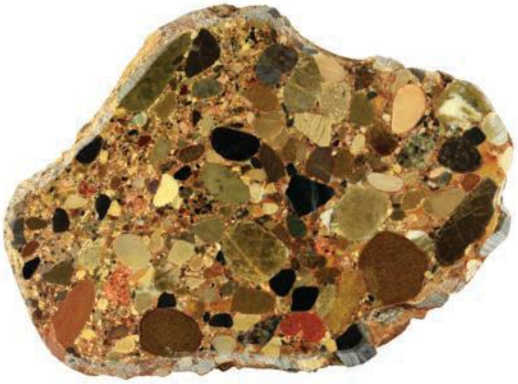

Figure 7.32 Conglomerate displays a random pattern of rounded clasts.

Figure 7.33 Sedimentary rock made from angular pebbles is called breccia.

Sedimentary rocks mainly made of sand

Sandstone is a medium-grained sedimentary rock that is made up of sand-sized silicate grains. The sand grains are typically well rounded, indicating a long period of transport and weathering. Sandstone varies in colour and composition depending on the minerals that make up the sand grains. Most sandstone is composed of quartz or feldspar.

Figure 7.34 Melbourne's iconic Flinders Street Station is largely built of yellow sandstone.

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Uluru is a sedimentary rock made of sandstone, but the layers are almost vertical. The rock that forms Uluru would originally have been horizontal, but over time the movement of Earth's crust tilted it. The top of the rock has been weathered and eroded, until today just the end is showing. This is evidence that Earth is very old.

Figure 7.35 Uluru is an ancient sedimentary rock located on the lands of the Anangu People. The rock tilted nearly 90° by the movement of Earth's crust.

Figure 7.36 Wulingyuan in China is notable for having more than 3000 quartzite sandstone pillars and peaks.

Sedimentary rocks mainly made of silt or clay

Mudrocks are fine-grained sedimentary rocks composed of silt and clay-sized particles, which are abundant on Earth's surface. Mudstone is typically deposited in low-energy environments, such as swamps or lakes, where the water is calm enough for fine particles to settle out. The particles in mudstone (see Figure 7.37) are too small to be visible to the naked eye. Shale is another type of mudrock that can be easily split into layers, or laminations, due to the flat shape of the clay particles. When exposed to high temperatures and pressure, it becomes the metamorphic rock slate, which can be used as a roofing material in some parts of the world.

Figure 7.37 Fossilised leaves in mudstone

Biological sedimentary rocks

Organic or biological sedimentary rocks are formed from the remains of living things, such as plants, animals or shells. Over time, these remains can accumulate and become buried and, with high pressure, they become compacted and cement together to form a solid rock. For example, chalk is made up almost entirely of the microscopic skeletal remains of plankton, called coccolithophores. These organisms are covered in small plates made of calcium carbonate, which accumulate on the ocean floor when they die and sink. Over time, these plates are compacted and cemented together to form chalk.

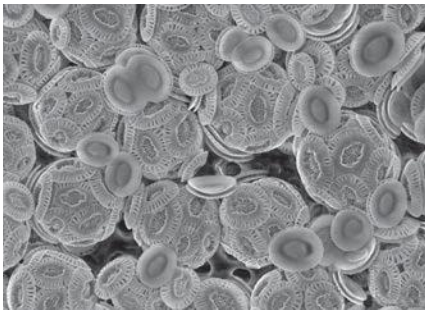

Figure 7.38 Coccolithophore cells covered with calcium carbonate scales

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Sometimes, gaps in the chalk fill with dissolved silica (from sea creatures with silica-rich skeletons) and form flint nodules. Flint was one of the first substances used to make tools.

Other examples of organic sedimentary rocks include coal, which is made from compressed plant material, and limestone, which is formed from the deposition of calcium carbonate sediments from the shells and skeletons of sea creatures.

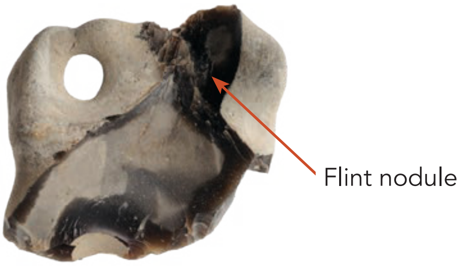

Figure 7.39 A flint nodule (shown with arrow) found in chalk. Flint is a chemical sedimentary rock as it is formed from dissolved silica.

Explore! 7.3

How coal is made

Organic material from living creatures can also form sedimentary layers. Layers of plant material form coal, while oil is formed mostly from plankton. Research the following questions.

1. List three different uses for coal.
2. Coal is a non-renewable resource. Are there any alternatives to coal for the uses you listed in the previous question?

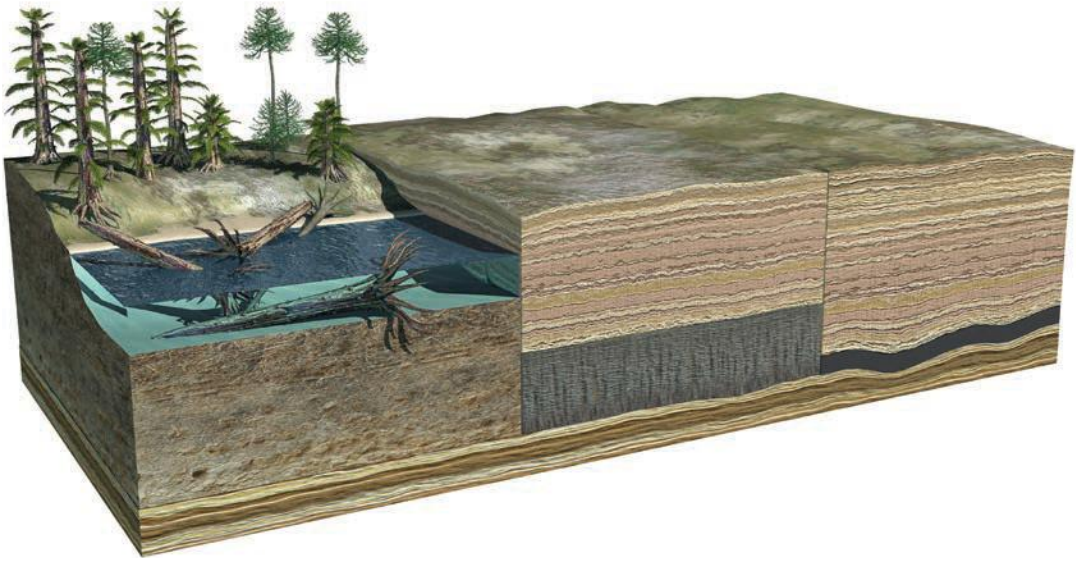

Figure 7.40 How coal is formed. Left: In the Carboniferous Period, trees died and formed a layer of wood. Middle: The wood was compressed by the layers of sediment above. Right: The compressed wood was transformed by heat and pressure into coal.

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Chemical sedimentary rocks

Chemical sedimentary rocks are formed when minerals dissolved in water (such as calcium carbonate or salt) precipitate out and form solid crystals. Over time, these crystals can accumulate and become cemented together to form a solid rock. Limestone can also form from the precipitation of calcium carbonate, and when it does so, is considered a chemical sedimentary rock rather than a biological one. Rock salt is another chemical sedimentary rock made of halite, a mineral composed of sodium chloride (NaCl). Gypsum is a soft mineral that forms within layers of sedimentary rock. It is mined throughout north-western Victoria, and is used in agricultural soil conditioning and cement manufacturing.

Figure 7.41 The UNESCO World Heritage site of Hạ Long Bay in Vietnam features some 1600 limestone monolithic islands that seem to rise out of the ocean.

Figure 7.42 Gypsum crystals

Sedimentary rock type	Example	Features
Clastic	Shale	Mostly compacted clay minerals, easily split into layers
	Mudstone and siltstone	Very fine grains of sand and silt
	Sandstone	Fine to coarse grains
	Breccia	Angular fragments of pebbles and/or boulders held together by a matrix of clay, silt and/or sand
	Conglomerate	Rounded fragments of pebbles and/or boulders held together by a matrix of clay, silt and/or sand
Biological	Coal	Compacted plant remains, composed mostly of carbon
	Limestone	Composed of broken shell fragments, corals, composed mostly of calcium carbonate (calcite)
Chemical	Limestone	Formed by the precipitation of calcium carbonate
	Rock salt	Formed by the evaporation or precipitation of sodium chloride
	Gypsum	A crystalline mineral composed of calcium sulfate that is found in sedimentary rock

Table 7.6 A summary of sedimentary rocks

Did you know? 7.7

Identifying underground resources

Advances in deep earth imaging techniques have greatly enhanced our ability to identify and locate mineral, energy and water resources beneath surface sedimentary rock. One technique is seismic reflection imaging, which uses sound waves to create images of subsurface structures. By analysing the way that these sound waves bounce off different layers of rock and other geological features, detailed three-dimensional models of Earth's interior can be built. This technique has been particularly useful for identifying oil and gas reservoirs, as well as underground aquifers.

Another technique is magnetotelluric (MT) imaging, which measures variations in Earth's natural electromagnetic field to identify subsurface structures. This has proven especially effective for identifying mineral deposits, as different minerals have unique electrical properties.

Did you know? 7.8

Coral beaches

While most beaches are made of quartz sand, some beaches near coral reefs are entirely composed of tiny fragments of coral made of calcium carbonate. Some sands contain concentrated amount of important minerals, which can be mined for rare earth elements like the metal titanium. Victoria's mineral sand deposits occur a long way from modern coastlines and reflect the presence of former inland seas.

Figure 7.43 Fragments of coral found on a coral beach

Quick check 7.7

1. **State** an example of each type of sedimentary rock (clastic, biological and chemical).
2. **Outline** how a sedimentary rock forms.

Metamorphic rocks

The third type of rock in the rock cycle is metamorphic rock. Earth's crust is very thin in proportion to its size, and the rocks that lie beneath the surface are subjected to high pressure and temperature. Metamorphic rocks are either igneous or sedimentary rocks that have been irreversibly changed by being subjected to these conditions. For example, if limestone (sedimentary) is subjected to high pressure and temperature, it turns into marble (metamorphic).

Rocks that have been changed into metamorphic rock tend to be denser and harder than before. Layers may become twisted when rocks are metamorphosed. Over millions of years, buried metamorphic rocks can eventually make their way to the surface again. These rocks are found all over the world, and they constitute about 10% of Earth's surface.

Foliated metamorphic rocks have a layered or banded appearance, with the mineral grains arranged in parallel layers. This banding is the result of the intense pressure and heat that the rock experienced during its formation. The pressure causes the mineral grains in the rock to realign, giving the rock a distinct pattern. Examples of foliated metamorphic rocks include schist, gneiss and slate.

Figure 7.44 **(a)** Foliations in schist, **(b)** gneiss and **(c)** slate

Non-foliated metamorphic rocks, on the other hand, do not have a layered or banded appearance. Instead, they have a more uniform texture and composition. Examples of non-foliated metamorphic rocks include marble and quartzite.

VIDEO
Igneous, sedimentary and metamorphic rocks

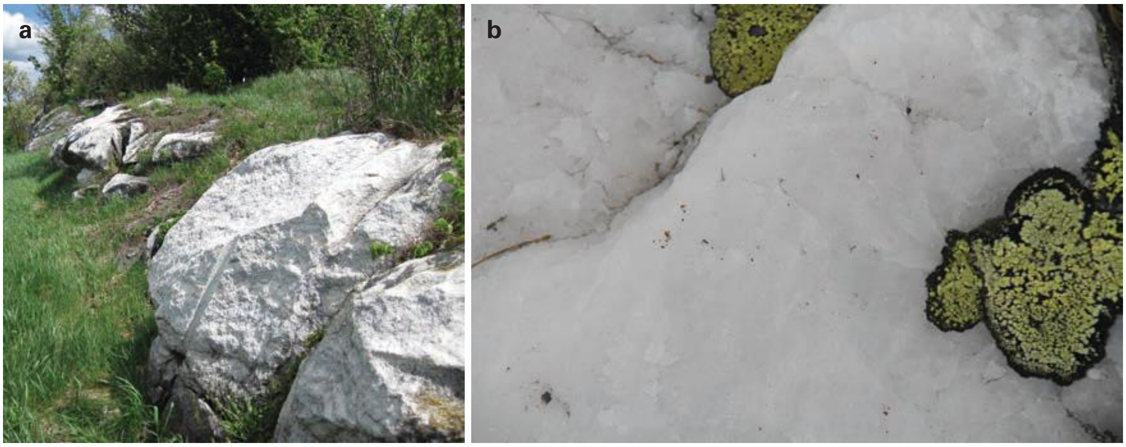

Figure 7.45 **(a)** Marble and **(b)** quartzite

Parent rock		
Igneous rock	**Undergoes metamorphosis to form**	**Metamorphic rock**
Granite	→	Gneiss
Sedimentary rock	**Undergoes metamorphosis to form**	**Metamorphic rock**
Limestone	→	Marble
Sandstone	→	Quartzite
Shale	→	Slate
Metamorphic rock	**Undergoes FURTHER metamorphosis to form**	**Metamorphic rock**
Slate	→	Phyllite
Phyllite	→	Schist
Schist	→	Gneiss

Table 7.7 A summary of the formation of different metamorphic rocks

Metamorphism generally begins to occur when temperatures exceed 150°C. This temperature, combined with increasing pressure, triggers low-grade metamorphism, and the parent rock changes to become stable in the new conditions. This occurs in the solid state. If temperature and pressure continue to increase, the rock may undergo high-grade metamorphosis and change structure again. Table 7.7 shows that shale can form slate, which can in turn form phyllite, schist and then gneiss.

Metamorphosis typically occurs when rocks become buried deeper in the Earth as a result of tectonic processes such as subduction or continental collisions. Here, they may become heated by and infiltrated with adjacent magma in a process known as contact metamorphism. This results in non-foliated rocks such as marble. Dynamic metamorphism occurs along fault lines, meaning there are high levels of heat as a result of friction between tectonic plates and high pressure due to the large shearing forces. Regional metamorphism occurs on a larger scale during tectonic events, which causes mountain formation, resulting in deformed foliated rocks such as gneiss and schist.

Quick check 7.8

1. **Describe** how metamorphic rock is formed.
2. **Recall** three examples of metamorphic rock, and state which parent rock they originate from.
3. **List** the three types of metamorphism.

Try this 7.5

Chocolate rock cycle

You can model the rock cycle using chocolate, which can be easily weathered, heated, cooled and compressed, unlike rocks. By creating 'sedimentary', 'metamorphic' and 'igneous' chocolate, you can model the transformations that rocks undergo over time.

Be careful

Do not consume food items in the laboratory.

You will need blocks of dark and white chocolate, aluminium foil or cupcake holders, hot water and a plastic knife or scraping device.

To create the 'sedimentary' chocolate, scrape small shavings from the chocolate blocks and put them onto a piece of aluminium foil. Fold over the foil and press down, creating chocolate that represents sedimentary rock.

To make the 'metamorphic' chocolate, place a small pile of sedimentary chocolate, unused shavings and small chunks of chocolate into aluminium foil or a cupcake holder and float this on *warm* water. The heat from the water will melt the chocolate, and after removing the foil, the partially melted and cooled chocolate will resemble metamorphic rock.

To create 'igneous' chocolate, place a small pile of sedimentary and metamorphic chocolate, along with chunks of chocolate, into aluminium foil or a cupcake holder and float this on *hot* water. Watch as the chocolate melts into a smooth liquid, then carefully remove the foil and allow the molten chocolate to cool. This melted and cooled chocolate represents igneous rock.

Try this 7.6

Summing up

Using the poster you began in Section 7.1, annotate it with information about the three different rock types you have learned about and their characteristics and examples.

Explore! 7.4

Stone pigments

Aboriginal and Torres Strait Islander Peoples use paints, dyes and pigments originating from plant, animal and mineral sources.

1. Investigate one of these pigments and what rock (sedimentary/metamorphic/igneous) or mineral is used, as well as the chemical and/or physical processes involved:
   - red pigment
   - black pigment
   - white pigment
2. Fixatives can be applied to paints, enabling the pigment to bind to surfaces and increase the durability of the paintings. Name some fixatives used by Aboriginal and Torres Strait Islander Peoples.

Figure 7.46 Bunjil shelter near Gariwerd/Grampians National Park is a significant rock art site and thought to be over 1000 years old.

Fossils

The bodies of different organisms may be deposited in sediment and form part of the sedimentary rock – this is how they become fossils. Fossils can include footprints of animals or faeces (coprolites).

Explore! 7.5

Fossil formation

The Danakil Depression, in the state of Afar in northern Ethiopia (see Figure 7.47), is a plain that sits more than 100 m below sea level. It was formed due to the divergence of three tectonic plates in the Horn of Africa. Here, sedimentary rocks are overlain by rock salt, which is still traditionally mined by hand, despite daylight temperatures reaching upwards of 50°C! The dry, salt-crusted landscape is punctuated by volcanoes with active lava lakes and hypersaline lakes that have formed above tectonic hot springs. Tourists float in Gaet'ale Pond, which is 43% dissolved salt, making it the saltiest body of water on Earth. Hydrothermal springs like the system at Dallol, which is situated around a volcano, display brilliantly coloured mineralisation, and their acidic ponds allow scientists to study extremophiles (organisms that can exist in extreme heat and acidity).

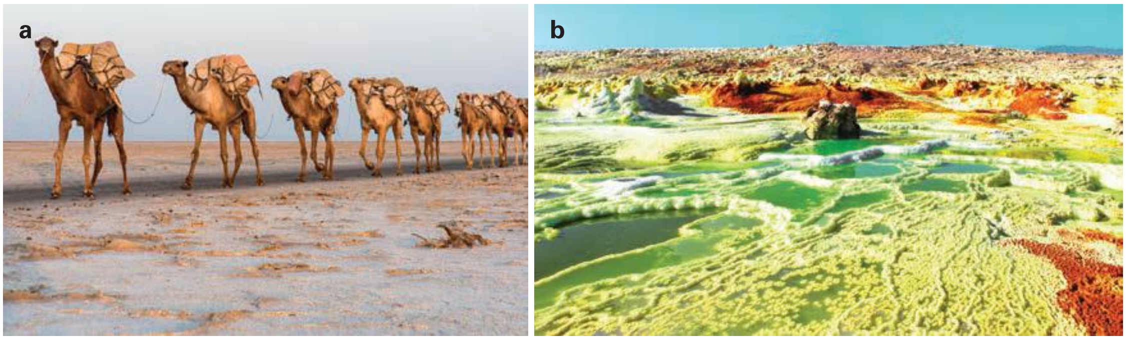

Figure 7.47 **(a)** Camels transport slabs of salt crust that have been broken up by hand. **(b)** Salt pillars in the acidic hydrothermal system of Dallol. The colours represent the age of springs, which can become active or inactive from day to day.

This region of Ethiopia is famous due to the notable fossil discoveries that have occurred here, including that of 'Lucy' (*Australopithecus afarensis*) in 1974. Her skeleton is dated to around 3.18 million years old.

Figure 7.48 **(a)** A cast of Lucy's skull and **(b)** a reconstruction of a female *Australopithecus afarensis*

Research the process of fossilisation and answer the following questions.

1. Not all living things become fossils. Describe the conditions necessary for fossils to form.
2. How did conditions in the Afar region of Ethiopia lead to the preservation of Lucy?
3. What are some key findings scientists have inferred from fossils?

Types of fossils

There are various types of fossils, depending on how the impression was formed. Some common types are listed in Table 7.8.

Fossil type	Details	Image
Mould	When a plant or animal decays in sediment, it may leave a hollow impression of itself.	 **Figure 7.49** The mould of an ammonite
Cast	When an animal or plant dies, its body creates a space in the sediment. This gap fills with minerals, such as silica, over time, and the shape of the animal is preserved as rock.	 **Figure 7.50** A fossilised trilobite, an extinct creature that once dominated life on Earth
Imprint	These fossils leave behind a two-dimensional (flat) print.	 **Figure 7.51** Leaves are pressed flat by the pressure in the sedimentary layers and all that is left is a dark area, like a shadow.
True form/ whole body	This is the most common type of fossil. It consists of parts of the remains of living things, mainly the hard parts, e.g. teeth, shells, bones.	 **Figure 7.52** True form fossils are also found intact in a medium such as amber (tree resin that has become fossilised).
Indirect or trace	These fossils do not consist of part of the organism. They are indirect records of biological activities, such as footprints, teeth marks or burrow marks.	 **Figure 7.53** From a set of footprints, scientists can tell how fast the animal was moving, whether it was solitary or moved in groups, and how heavy it was. One of the most famous examples of this is at Lark Quarry, near Winton, Queensland.

Table 7.8 Five common types of fossils

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Did you know? 7.9

Opal fossils

Opalised fossils are a type of fossil that has been replaced by opal. These fossils are formed when minerals in the surrounding rock dissolve and are replaced by silica-rich solutions that penetrate the spaces in the original organic material. Over time, the silica hardens into opal, preserving the details of the original organism. They are particularly abundant in Australia. The discovery of 100-million year old opalised jawbone fragments in New South Wales has led to paleontologists naming three new species of monotreme in 2024. One is termed the 'echidnapus' because it shares characteristics with both the echidna and the playpus.

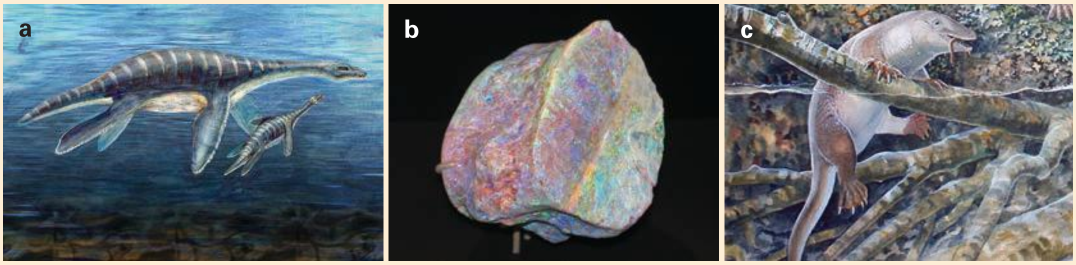

Figure 7.54 An artist's impression of plesiosaurs **(a)**; an opalised fossil plesiosaur vertebra found in Australia **(b)**; and **(c)** an artist's impression of one of the newly named monotremes, the *Opalios splendens*, or 'echidnapus'

Finding information from fossils

Fossils provide a snapshot of the past, and can provide scientists with valuable information, including the following:

The climate and environmental conditions at the time when the organism died and became fossilised, e.g. terrestrial versus marine environment.	The single-celled marine organism foraminifera has a fossil record that extends back 500 million years. Scientists have used it to infer information about ocean temperature and salinity and to map ancient coastlines.  **Figure 7.55** A scanning electron micrograph of a foraminiferan microfossil, measuring under 2 mm in size
How land masses have changed over time. When identical fossils are unearthed across different continents, it indicates that those land masses were connected when the organism was alive. This provides evidence of tectonic plate movement.	Fossilised foliage of the giant conifer *Fitzroya tasmanensis* has been found near Cradle Mountain in Tasmania, but the only living tree in the *Fitzroya* genus currently grows in Chile. This provides evidence that Australia and South America were once connected in the giant supercontinent Gondwanaland, where they shared temperate rainforests.
The feeding behaviours of now extinct animals. The form and structure of animal teeth and jaws provide clues about their diet; however, tooth indentations can provide more reliable insights.	*Australopithecus africanus* is a more evolutionary recent species than Lucy (see Figure 7.48 on page 334) show wearing of the teeth that is similar to modern fruit-eating animals. This suggests they had a largely plant-based diet of soft fruit, with some occasional meat.

As sediments have been laid down and compressed over millions of years, the layers of sedimentary rock trace the passage of time and preserve a record of ancient climates and lifeforms. Fossils are found in many sedimentary rocks including limestone, sandstone, mudstone and shale. Because igneous rocks form from cooled magma and lava, they do not contain fossils. Fossils located in rock that is subjected to the heat or pressure required to metamorphose are typically destroyed in the process, but they survive on rare occasions. Much of the fossil record has been obliterated due to weathering and erosion.

The law of superposition states that within the layers (strata) of sedimentary rock, the oldest layer is at the bottom and the layers are progressively 'younger' as you move upwards.

Fossil evidence can also be used to predict how and when a rock was formed. Organisms have evolved and become extinct at different times throughout Earth's history, and the fossil record provides a timeline of the evolution of life. **Stratigraphy** allows geologists to estimate the age of a rock layer relative to other rock layers via the use of **index fossils**.

stratigraphy
a branch of geology that studies rock layers

index fossil
a lifeform that existed for a narrow and known period of geological time, which can be used for the purposes of relative dating

Fossils found in the same layer must have lived at the same time in the same location, and hence were part of the same ecosystem. Fossils found in different layers must have lived in the same location, but at different times (with fossils in higher layers being newer). By using index fossils that were geographically widespread and alive during known geological periods, scientists can estimate the age of the rock that the fossils are found within. This is a process known as relative dating. Importantly, it also allows scientists to infer and compare the ages of rocks found in different locations. If rock samples from two different places in the world contain the same index fossil, we can infer the rocks are of similar age. This allows scientists to reconstruct the geological history of a region.

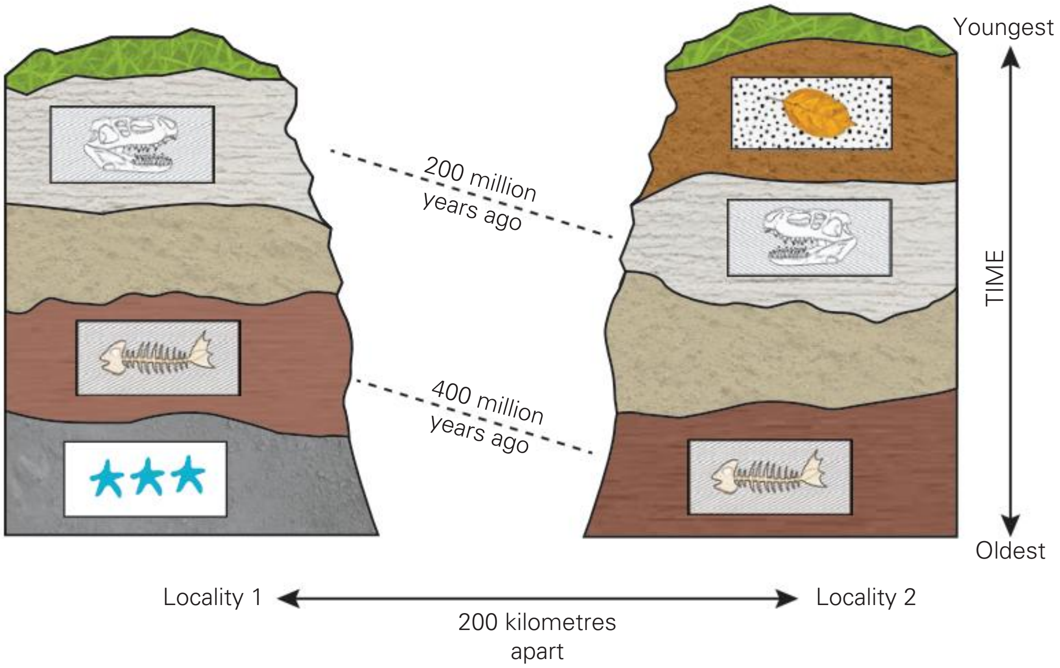

Figure 7.56 The use of index fossils allows for the relative dating of rocks from different geographical areas.

Evidence of extinction events can be seen when a certain type of fossil suddenly disappears from the fossil record. For example, from studying sedimentary rocks, it was established that all the dinosaurs became extinct at approximately the same time, around 60 million years ago.

Figure 7.57 The Tepees in Petrified Forest National Park, Arizona. This area is known for its fossils, especially fallen trees that lived about 225 million years ago. The fossil logs contain colourful sediment formations.

Did you know? 7.10

Dating Lucy

When the fossil skeleton of the *Australopithecus afarensis* nicknamed 'Lucy' (see Figure 7.48 on page 334) was initially discovered, her age was estimated with reference to other local index fossils. Found in the same layer of sedimentary rock as her skeleton were three extinct pig species: *Nyanzachoerus kanamensis*, which occurred 5.1–2.4 million years ago, *Kolpochoerus afarensis*, which occurred 3.5–2.9 million years ago, and *Notochoerus euilus*, which occurred 3.8–1.8 million years ago. Paleontologists estimated Lucy's age by narrowing down the only overlapping period when all three species lived: between 3.5 and 2.9 million years ago. Advances in absolute dating (which involves chemically analysing the radioactive atoms in the rock sample) placed Lucy's age at 3.18 million years old, indicating the estimate based on stratigraphy was accurate.

Science as a human endeavour 7.3

How did it become extinct?

The fossil record is the history of life as it is seen from fossils. It can tell us about groups of animals that are extinct, such as dinosaurs, and how animals and plants relate to each other. Unfortunately, the fossil record is incomplete because, as you investigated in Explore! 7.5, specific conditions are required for fossilisation to take place. Not all dead things become fossils.

Interpretation of the fossil record has always presented difficulties for palaeontologists (scientists who study fossils). For example, for many years it was believed that the extinction of dinosaurs was gradual, but in 1980 evidence was found of a meteor impact that is now thought to have caused mass extinction. Also, disappearance from the fossil record does not always mean that a species is extinct; there may be many other reasons for its absence from the record.

Palaeontologists Steven Holland and Mark Patzkowsky designed computer models to aid the study of mass extinction, and are using the models to decipher the fossil record more accurately. Their work is still in progress; however, it provides an initial guideline for analysis and assessment of extinction events.

continued …

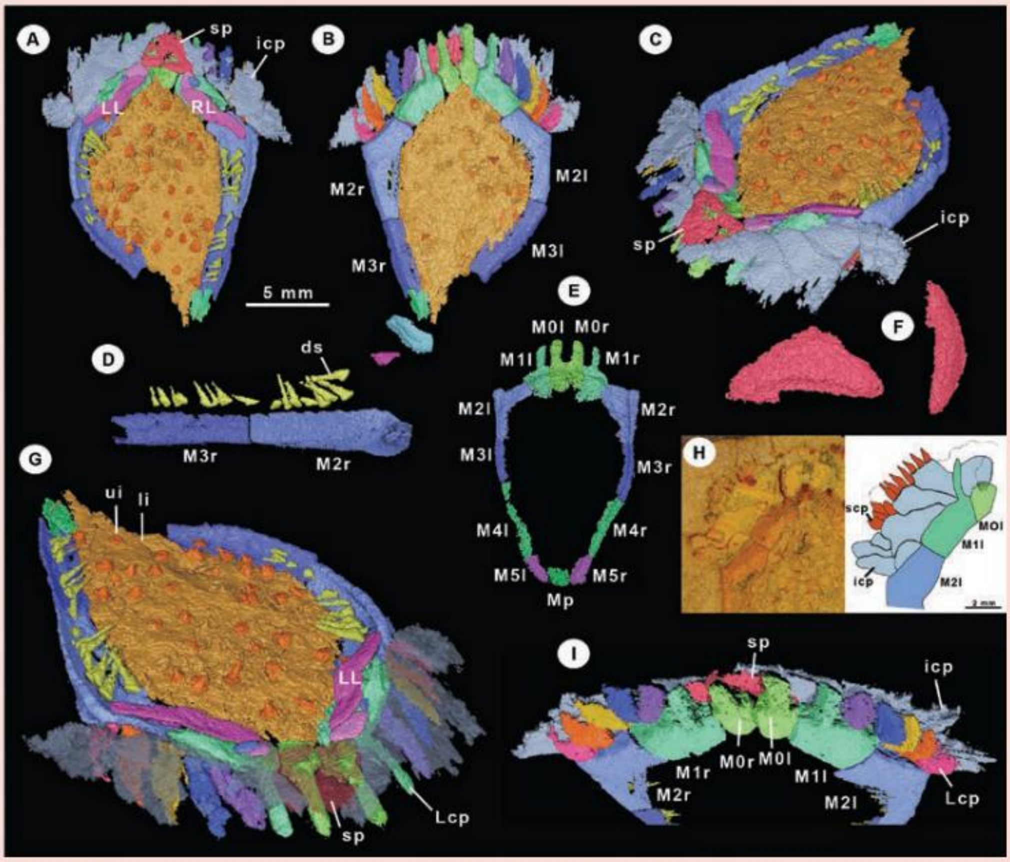

Figure 7.58 Computer models can aid research in various fields, including the study of fossils.

Section 7.2 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 7.2 questions

Remembering

1. **Recall** the name that is given to rocks formed during a volcanic eruption.
2. **Recall** the name given to rocks formed when sedimentary rocks change due to high temperature and pressure.
3. **Recall** the name of sedimentary rocks formed from small, rounded rocks.
4. **Name** five common fossil types.

Understanding

5. **Summarise** how marble is formed and what type of rocks are involved.
6. **Explain** how the vertical layering of the rock forming Uluru indicates that Earth is old.

Applying

7. Figure 7.59 shows a rock formation at Organ Pipes National Park in Victoria. Use what you have learned about igneous rocks to **explain** how this formation came to be.

Figure 7.59 A set of basalt columns at Organ Pipes National Park in Victoria

8. Look at the igneous rocks in Figure 7.60. **Identify** which one is intrusive and which is extrusive. **Explain** your reasoning by first recalling the difference between intrusive and extrusive.

Figure 7.60 Which one is intrusive, and which is extrusive?

Analysing

9. **Classify** the types of fossils shown in Figure 7.61.

Figure 7.61 Types of fossils

Evaluating

10. **Discuss** why the water in the Yarra River is brown (see Figure 7.62). Use the following terms in your explanation: particles, sediment, weathering, erosion, deposit, rock.

Figure 7.62 Why is the water brown?

11. 'This rock is clearly seen to be made of distinct and different layers. Therefore, it must be a rock, not a mineral.' **Evaluate** this statement and explain your reasoning.

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7.3 Classifying and using rocks

Learning goals

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

1. Compare the observable properties of different types of rocks and identify them using a dichotomous key.
2. Describe the tests available to classify rocks.
3. Explore the traditional geological knowledges of Aboriginal and Torres Strait Islander Peoples that are used in the selection of different rock types for different purposes.

WORKSHEET
Identifying rocks

Classifying rocks is a skilled job that depends upon a thorough knowledge of the different types of minerals and rocks, their physical characteristics and the tests that can be used to differentiate them. Dichotomous keys provide a framework for objectively evaluating the sample and classifying it based on observable characteristics and a series of yes/no questions.

Did you know? 7.11

Dangerous rocks

Most minerals and rocks are harmless. However, some can pose a hazard and need to be handled with care. Beware of handling some metal **ores**, especially those containing mercury, lead or copper, and always wash your hands after handling rocks. Asbestos, which contains crystals in the form of fibres, is dangerous when airborne and is known to cause cancer of the lung.

Figure 7.63 Asbestos is a dangerous mineral and should not be handled.

ore
a rock that can be mined to obtain a valuable mineral or metal

Identifying minerals

Minerals can appear similar to one another, so geologists use a series of tests that can identify minerals based on their properties.

Colour

Minerals exist in brightly varied colours but cannot be correctly identified based on this characteristic alone for two reasons:

- the same mineral can exist in different colours, due to impurities
- two different minerals can appear the same colour.

Figure 7.64 Three polished translucent samples of quartz. The yellow form is often referred to as citrine and the purple form as amethyst. Amethyst can be found inside all three types of rocks – igneous, metamorphic and, less commonly, sedimentary.

Lustre

In addition to colour, the mineral may be described according to its lustre – how dull or shiny the surface is and how it interacts with light. You may sometimes hear minerals described as resembling other materials, such as 'pearly' or 'metallic'.

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opaque	blocking light completely
translucent	allowing some light through, but no clear image can be seen through the substance
transparent	allowing light to pass through, and a clear image can be seen through the substance
streak test	a test used to help identify a mineral by scratching a rock on a hard ceramic tile
Mohs scale	a scale from 1 to 10 that indicates the relative hardness of a mineral

Minerals may be **opaque**, which means no light passes through them. Others are **translucent**, allowing the passage of some light, or **transparent**, allowing light to pass through and a clear image to be seen through them.

Streak

When a mineral is scratched onto a hard, ceramic surface, it can leave behind a coloured streak, which is a more reliable indicator of its colour than the colour of its surface. For example, gold and pyrite (fool's gold) have a similar surface colour, so a **streak test** is useful to distinguish between them.

Figure 7.65 Examples of a streak test

Figure 7.66 The streak test for gold (left) shows up as gold, while the streak test for pyrite (right, also known as 'fool's gold') shows up as a dark green-grey.

Hardness

Geologists use the **Mohs scale**, developed by Friedrich Mohs in 1812, as a measure of mineral hardness. Minerals are rated according to their ability to scratch each other, on a scale from 1 to 10. Any mineral with a high Mohs scale number can scratch any mineral with a lower number. The softest mineral, with a 1 on the Mohs scale, is talc (metamorphic), and the hardest is diamond (metamorphic) with a 10. Your fingernail is about 2.5 and a steel knife is about 5.5. A set of tools called Mohs picks can be used to determine where on the Mohs scale a mineral in an unknown rock lies. For example, if a mineral can be scratched by pick number six and not by pick number seven, then it has a hardness of 6.

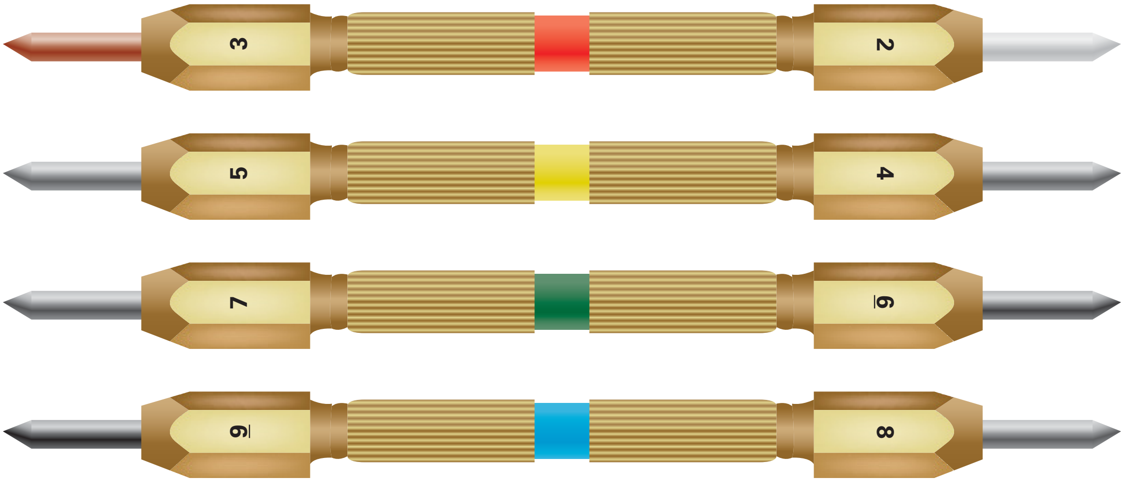

Figure 7.67 A set of Mohs hardness picks for assessing minerals using the Mohs scale

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Cleavage

The way in which atoms are arranged in a mineral will determine how the mineral breaks, or fractures, when struck. **Cleavage** is the tendency of a mineral to break (cleave) along identifiable lines of weakness according to its crystalline structure.

cleavage the tendency of a mineral or rock to break in a particular way because of its structure

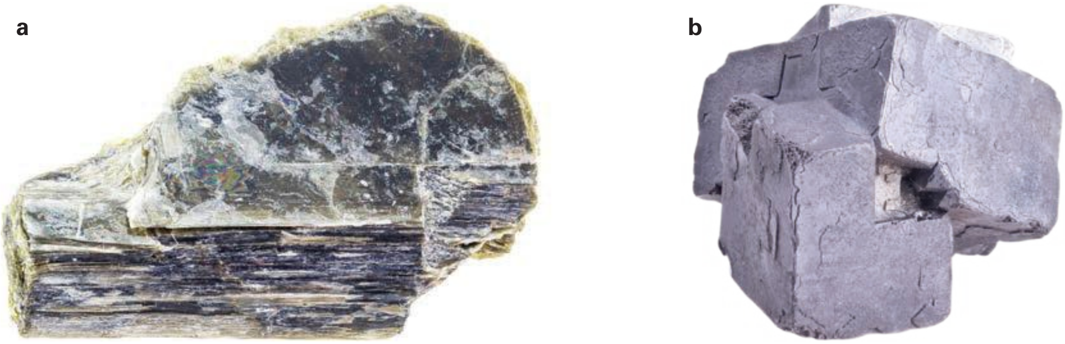

Figure 7.68 **(a)** Muscovite (the most common mica mineral) features flat cleavage planes like the pages of a book. **(b)** Galena is a mineral that cleaves into identifiable cubes.

Behaviour in acid

Weak hydrochloric acid can be used to test for the presence of a common mineral called carbonate. The surface of the mineral/rock sample will bubble or fizz when acid is applied.

Magnetism

A few minerals are naturally magnetic, such as the iron-rich magnetite. You can test this by placing a magnet near the sample and seeing if it is attracted.

Figure 7.69 Magnetite is a mineral found in igneous, metamorphic and sedimentary rocks. It is also found in meteorites.

Quick check 7.9

1. **Define** an ore and **explain** why some ores are harmful.
2. **List** the seven characteristics of minerals that can be used to help classify them.
3. **Identify** which of the characteristics from Question **2**. involves a chemical property.

Did you know? 7.12

So you think you've found a space rock?

Meteorites are notoriously dense and often magnetic due to their high iron content. A telltale sign that your rock is actually a recent meteorite is the presence of a dark-grey/black 'fusion crust', which results from the rock burning as it enters Earth's atmosphere.

Figure 7.70 The dark-coloured fusion crust on a meteorite weathers away over time. The interior often features shiny metallic flakes.

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Classifying rocks

The seven mineral identification tests are useful for helping you to identify specific rocks according to their chemical composition. However, the physical properties of a rock, such as the presence and size of crystals and grains, and their density and overall colour, allows you to classify them according to how they have been formed.

Igneous rock

Formed from cooling molten rock, either intrusive or extrusive. They can differ in colour and texture but tend to be hard and homogeneous (no layers). Some have holes because of gas that is trapped as the lava cools. Some are characterised by visible crystals and holes.

Figure 7.71 Examples of igneous rock are pumice (left) and diorite (right).

Sedimentary rock

Formed from layers of sediment being compacted and cemented together. They often appear grainy and may contain fossils. They may be easy to crumble.

Figure 7.72 Examples of sedimentary rock are rock salt (left) and limestone (right).

Metamorphic rock

Igneous, sedimentary or other metamorphic rocks that have been subjected to high pressure and/or temperature. They often appear layered (foliated) and may have crystals arranged in bands. Metamorphic rocks are typically hard and dense.

Figure 7.73 Examples of metamorphic rock are gneiss (left) and granulite (right).

Crystal size and shape

Most igneous and metamorphic rocks are constructed of crystals. Some crystals are visible to the naked eye whilst others require the use of a microscope or hand lens to be seen. Fast-cooling lava produces small crystals in extrusive igneous rocks, while slow-cooling magma produces larger crystals in intrusive igneous rocks. If the crystals are intergrown (knitted together throughout the rock sample) then it is likely to be igneous, whereas if the crystals are arranged in layers or bands, your sample is likely to be a metamorphic rock.

Figure 7.74 Gabbro is an intrusive igneous rock with dark crystals that are visible to the naked eye.

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Grain size and shape

If your rock sample contains visible grains, then it is likely to be a clastic sedimentary rock. Coarse-grained sedimentary rocks feature grains >2 mm in size and include conglomerate and breccia. Sandstone, mudstone and siltstone feature moderately sized grains, while shale is composed of fine grains. The Wentworth grade scale (see Table 7.5) is a useful reference.

The size and shape of grains in sedimentary rock gives clues about its history. When the grains are all roughly the same size, the rock is referred to as 'well-sorted'. This indicates the sediment has travelled a long distance from the source, as larger grains are deposited closer to the source and finer grains are eroded and travel further. A 'poorly sorted' sedimentary rock sample indicates the sediment has not travelled far.

Colour

The presence of layers within the rock sample is highly suggestive of sedimentary rock. However, if the layers are folded or deformed, this can indicate a sedimentary rock that has been subjected to heat or pressure and is now a foliated metamorphic rock.

Felsic rocks are light-coloured igneous rocks that have a high silica content. They are enriched with lighter elements such as silicon, oxygen, aluminium, sodium and potassium, and feature >50% light-coloured crystals. Mafic rocks are rich in magnesium and iron, and feature >50% dark-coloured crystals.

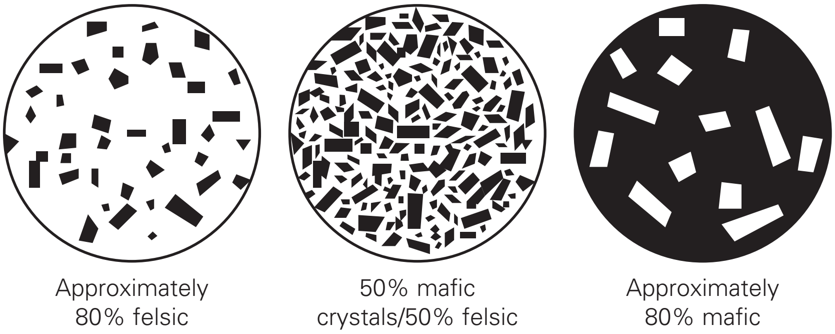

Figure 7.75 Visual tools for estimating the percentage of light (felsic) and dark (mafic) mineral crystals in a rock sample

density
a substance's mass per unit of volume

porous
a material that allows liquid or air to pass through it

Density and porosity

While specific rock types differ in their **density**, the following general rules apply:

- Sedimentary rocks tend to be less dense than igneous and metamorphic rocks, as they are more **porous**. Sedimentary rocks with larger grains (and more space in between) – particularly well-sorted sedimentary rocks – are more porous than fine-grained rocks.
- Mafic (dark-coloured) igneous rocks tend to be more dense than felsic (light-coloured) rocks.
- Extrusive igneous rocks may have holes (called vesicles) formed from hot gases that were trapped during rapid cooling. Vesicular rocks – such as pumice (Figure 7.76), scoria and some basalt – are less dense that other igneous rocks.
- Metamorphic rocks, which have been formed under high heat and/or pressure, are often the most dense.

Figure 7.76 Pumice is an extrusive igneous rock with many holes and low density.

Density can be calculated by finding the rock's mass and dividing this by the volume. To find the volume, you can submerge the rock in a vessel with a known volume of water and measure the new volume. The difference between the two measurements approximates the volume of the rock sample.

Table 7.9 gives an overview of the general characteristics of the three different rock types.

Igneous rock	Sedimentary rock	Metamorphic rock
• May contain holes • Often contains crystals • Crystals vary in size from small (invisible with the naked eye) to large • Usually hard and dense	• Usually contains grains • Grains are cemented together • Grains vary in size from small to very large • Usually soft • Flat layers may be visible	• May feature layers (which can be folded/deformed) • Often cleaves into a straight plane • More dense than sedimentary rocks

Table 7.9 General characteristics of rocks

WIDGET
A key to identifying rocks

Identifying rocks

Now that you've explored the mineral identification tests and the physical properties of different rock types, it's time to challenge yourself to identify specific rocks and minerals. There is no one standardised dichotomous key or branching flowchart that is used. See Figure 7.77 for an example.

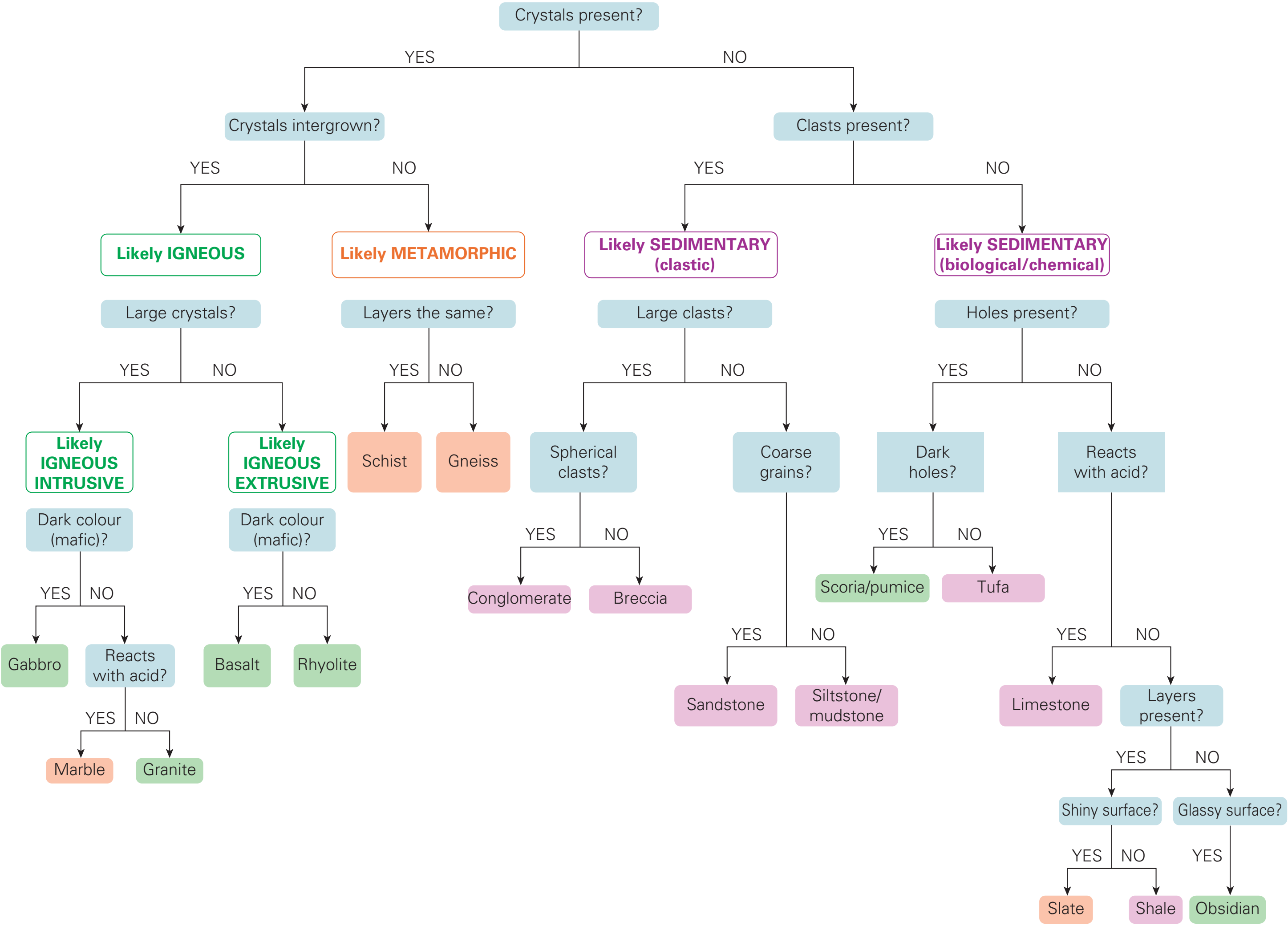

Figure 7.77 A dichotomous key for identification of rocks, presented as a flowchart

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Try this 7.7

Identifying rocks

With a sample rock from your teacher, work in pairs using the flowchart in Figure 7.77 and try to identify the rock. To begin, consider whether the rock is likely to be igneous, sedimentary or metamorphic. Then, with reference to its colour, density and crystal or grain structure, try to identify it by name.

Practical 7.1

Practical report: Identifying 12 common rocks and minerals

Aim

To practice identifying and finding patterns, by classifying 12 of the most common rocks and minerals found in Earth's crust. You will document your findings in a practical report. Refer to Section 1.4 in your Year 7 resource to assist in structuring this report.

Materials

- 0.1 mol L^{-1} hydrochloric acid
- dropper
- beaker of water
- hand lens
- disposable gloves
- Petri dishes for the hydrochloric acid test × 12
- two of each of the following rocks: basalt, chalk, gneiss, granite, limestone, mica, pumice, quartz, quartzite, sandstone, schist, slate

Figure 7.78 Twelve common rocks found in Earth's crust, in random order

continued …

Method

1. Use this dichotomous key to identify the rock and the rock type. You can work in 12 groups, each group being responsible for one rock type (each group will hold two rocks: one for the general test and one for the hydrochloric acid test).

   Rocks are composed of one or more minerals. For this practical, if a rock is made up of only one type of mineral, identify the rock as a 'mineral'.

1	Is the rock composed of crystals?	Yes	Go to 2
		No	Go to 5
2	Are the crystals flat and silvery?	Yes	Mica (igneous, metamorphic)
		No	Go to 3
3	Are the crystals large and transparent?	Yes	Quartz (igneous)
		No	Go to 4
4	Are the grains small, easily removed by rubbing, and layered?	Yes	Sandstone (sedimentary)
		No	Granite (igneous)
5	Do bubbles appear when acid is placed on the rock? You will need to place the rock in the Petri dish and use the dropper to place 1–2 drops of hydrochloric acid on the rock. Do not handle the rock after hydrochloric acid has been added to it.	Yes	Go to 6
		No	Go to 7
6	Using a fresh rock, can the rock be scratched easily with a fingernail?	Yes	Chalk (sedimentary)
		No	Limestone (sedimentary)
7	Place the rock in a beaker of water. Does the rock float on the water?	Yes	Pumice (igneous)
		No	Go to 8
8	Is the rock translucent (allows some light to pass through)?	Yes	Quartzite (metamorphic)
		No	Go to 9
9	Does the rock have visible layers that may be curved or bent?	Yes	Gneiss (metamorphic)
		No	Go to 10
10	Does the surface of the rock appear to be made up of plates?	Yes	Schist (metamorphic)
		No	Go to 11
11	Does the rock cleave to form layers with a flat surface?	Yes	Slate (metamorphic)
		No	Basalt (igneous)

Table 7.10 Dichotomous key for rock identification

2. Once you have identified your rock, label it. When all the rocks have been identified, sort them into the four groups: igneous rocks, metamorphic rocks, sedimentary rocks and rocks made up of only one type of mineral.

Results

Copy and complete this table.

Table showing common characteristics of the different types of rocks

	Rocks made up of only one type of mineral	Igneous rocks	Sedimentary rocks	Metamorphic rocks
Common characteristics				

continued ...

Discussion: Evaluation

1. Recall what the hydrochloric acid test reveals about the rock material.
2. Discuss why you think pumice floats on water.
3. Design some rules and a different dichotomous key or chart to classify rocks as minerals, or igneous, sedimentary or metamorphic rocks. Identify any difficulties you encounter in doing this.
4. Discuss any assumptions or possible sources of error that may have impacted your results in this practical.

Conclusion

1. Draw a conclusion from this experiment about the difference between types of rocks, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that ____________.

Science as a human endeavour 7.4

It used to be hotter

Studying the first billion years of Earth's evolution has always been uncertain. It is difficult to compare ancient rocks with modern rocks, as the original rocks have often been destroyed or changed over time. Researchers at Louisiana State University have shown that komatiites (three-billion-year-old volcanic rocks) were formed from the hottest lava that ever erupted on Earth. Temperatures were close to 1600°C, which is about 400°C hotter than the volcanic eruptions in modern-day Hawaii!

Figure 7.79 Komatiite

Using rocks

VIDEO
Using rocks

The way that rocks are formed determines their physical properties, and this in turn, determines their usefulness and value to humans.

Rock type	Examples	Properties	Uses
Igneous (intrusive)	Gabbro	Gabbro has high durability, scratch resistance and compressive strength.	Building materials Sculptures
	Granite	Granite is non-porous (withstands spills on benchtops). It also doesn't react with acidic food. It is hard (resists scratching) and features a range of colours and patterns.	Benchtops  **Figure 7.80** A granite kitchen benchtop

Table 7.10 Some common uses of rocks and minerals

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Rock type	Examples	Properties	Uses
Igneous (extrusive)	Basalt	Basalt is hard, tough, dense, and resists fracturing. It has a porous structure which allows water drainage.	Road construction, building materials  **Figure 7.81** A basalt building in Germany
	Pumice	Due to its holes, pumice is lightweight, porous and soft.	Abrasive in cleaning and polishing products
Sedimentary (clastic)	Sandstone	Sandstone is abrasive and has been traditionally used as a grinding stone. Sandstone is durable and can be easily split along its sedimentary planes for use in construction.	Construction and building materials
Sedimentary (chemical)	Limestone	The carbonate in limestone neutralises acids in soil, raising the pH. Limestone is a source of calcium, used to make Portland cement (which is mixed with gypsum, water, sand and gravel to make concrete). Limestone is dense, meaning it blocks heat and sound transfer in buildings.	Construction Production of cement, glass and fertilisers  **Figure 7.82** The exterior of the Great Pyramid (Giza, Egypt) is clad in limestone.
	Rock salt	Rock salt lowers the freezing point of water, so it can be used to melt ice and snow on roads. It can be processed to form sodium chloride (table salt) for consumption.	De-icing roads, food preservation and flavouring
Sedimentary (biological)	Coal	Coal is abundant, and relatively easy to mine and extract energy via combustion.	Fuel  **Figure 7.83** A coal-fired power station
	Chalk	Chalk is soft and porous, meaning it can be washed off surfaces. Its fine-grained texture makes it smooth and comfortable to hold.	Writing on a chalkboard (which used to be made from slate).

Table 7.10 *(continued)*

Rock type	Examples	Properties	Uses
Metamorphic (foliated)	Slate	Slate is dense and non-porous making it an ideal roofing material in wet and windy climates.	Building materials Decorative stones  **Figure 7.84** Slate roof tiles
Metamorphic (non-foliated)	Marble	Marble is hard and durable, in addition to being heat and fire resistant. It is cool to touch and features beautiful patterns/colours.	Building materials Decorative stones  **Figure 7.85** A marble staircase at Brisbane City Hall
Pure minerals	Quartz	Pure quartz is very hard. When melted, the silica crystal structure breaks down. It becomes clear and can be formed while molten.	Producing glass  **Figure 7.86** Traditionally made blown glass

Table 7.10 *(continued)*

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Aboriginal and Torres Strait Islander geological knowledge

Aboriginal and Torres Strait Islander Peoples' geological knowledge is developed from generations of careful observation, experience and relationships with Country. This knowledge has been carried through oral histories, cultural practices and spiritual connections to the land, reflecting an enduring understanding of its changes and stories over time.

When different rock types are used, Aboriginal and Torres Strait Islander Peoples rely on their geological knowledge of the properties of rocks, as well as their understanding of the cultural significance of different rock types (many of which have spiritual or ceremonial value). For example, certain types of rocks have been selected for use because their structural and chemical properties have practical uses for certain tasks. Grinding stones are used to grind and crush various materials, and they are typically made from abrasive rocks such as sandstone or basalt. In northern Queensland, Bama people use a specialised grindstone, known as a morah stone, to process toxic plants such as the Zamia palm, black bean and cycad. This grooved grindstone is formed from slate, which is hard and non-porous, meaning it does not absorb the toxic chemicals in the plants. The grooves are likely made with an even harder rock, such as granite or the mineral quartz.

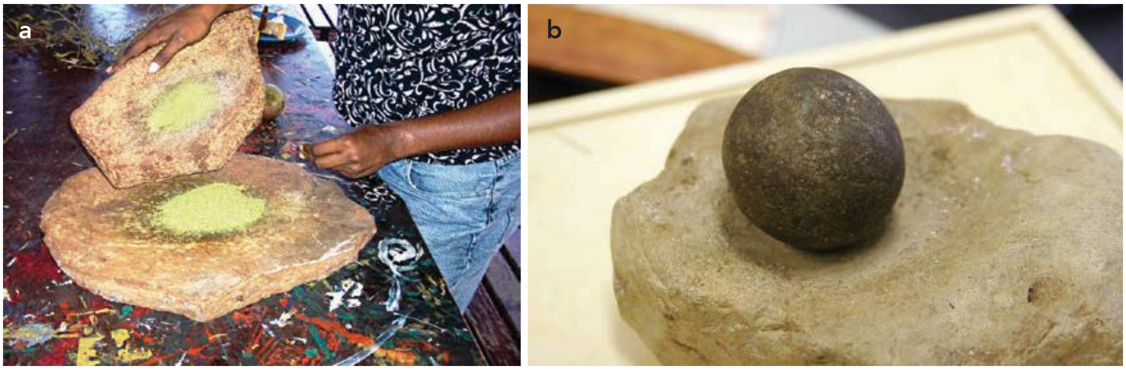

Figure 7.87 Grinding grain using **(a)** rocks and **(b)** traditional grinding stones

quarrying the removal of rock, sand and minerals from the surface of Earth without deep excavation

Across Australia, Aboriginal and Torres Strait Islander Peoples have developed varying techniques of **quarrying** and crafting stone tools for various purposes. Stone tools are used in day-to-day life for activities such as hunting, harvesting and preparing food. Hand quarrying involves identifying and extracting suitable rocks from natural outcrops or from boulder fields. Aboriginal and Torres Strait Islander Peoples use a variety of rocks – such as basalt, sandstone, quartzite, chert and flint – depending on what is available on their Country. These rocks are then shaped and transformed into a variety of objects, such as grindstones, hammerstones, anvils, cutting tools and weapons. Analysis of stone tools has revealed elemental composition that is very different from local quarry sites and rock outcrops, which suggests that prior to colonisation, specialty stones and tools were carried for use over hundreds of kilometres.

Flaked stone tools are produced by striking a hard and brittle silica-rich rock (such as quartzite or flint) with a hammerstone in order to remove a sharp fragment. These sharp tools are then used as knives and spear-tips. Stone artefacts do not rust or biodegrade, so they provide a valuable source of information about where and how Aboriginal people lived, hunted and prepared food prior to colonisation.

Explore! 7.6

Stone tools

Aboriginal and Torres Strait Islander Peoples have used a variety of rocks, such as basalt, sandstone, quartzite, chert and flint, depending on what is available on their particular Country. These rocks are then shaped and transformed into a variety of objects, such as grindstones, hammerstones, anvils, cutting tools and weapons. The techniques involved in creating stone tools require knowledge from the various disciplines of science.

Conduct research to investigate the following questions.

1. Explain how having knowledge of the geological, biological, chemical and physical sciences helps to create stone tools that are fit for the intended purpose.
2. Determine why the following rock types are used as the named tools in various Aboriginal and Torres Strait Islander Peoples' cultures.
   a) the use of flint as a cutting tool
   b) the use of quartzite as an anvil
   c) the use of limestone as a hammerstone
   d) the use of sandstone as a grindstone
   e) the use of silcrete as a knife blade
   f) the use of basalt as an axe head
3. Examples of techniques and methods for toolmaking are knapping, lithic reduction, percussion flaking, pressure flaking and grinding. Describe what each of these processes involves and how they help create stone tools from the raw material.

Figure 7.88 Wil-im-ee Moor-ring (Mount William stone axe quarry) on Wurundjeri Country in western Victoria is a significant cultural site where, prior to colonisation, highly valued greenstone was carefully extracted and shaped into ground-edge axes. These axes were an important part of trade networks that extended across south-eastern Australia, reflecting sophisticated knowledge of geology, tool-making and trade. Greenstone is a type of metamorphic rock, prized for its durability and strength.

Explore! 7.7

Rocks and culture

Rocks and rock formations hold particular cultural significance for Aboriginal and Torres Strait Islander Peoples. Uluru is a place of great spiritual significance for the Anangu peoples. Many Anangu peoples go to Uluru to connect with their ancestors and to perform traditional ceremonies and rituals.

Research the spiritual and cultural connection that certain Aboriginal and Torres Strait Islander Peoples have with the following rock formations:

- Gariwerd/Grampians: Djab Wurrung and Jardwadjali Country
- Wurdi Youang: Wadawurrung Country
- Taungurung Rock Wells: Taungurung Country

Section 7.3 review

Online quiz

Section questions

Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 7.3 questions

Remembering

1. **List** the seven characteristics of minerals that can be used to help identify them.

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Understanding

2. Igneous rocks may contain holes. **Explain** why this is the case.
3. Sedimentary rocks often look like the grains are cemented together, and they are often soft. **Explain** why this is the case.
4. Metamorphic rocks sometimes have a layered look. **Explain** why this is the case.

Applying

5. **Identify** the following rocks, using the dichotomous key in Practical 7.1.

   a) The rock in Figure 7.89 does not bubble when acid is placed on it. It sinks when placed in water.

Figure 7.89 Rock A

   b) The rock in Figure 7.90 does not bubble when acid is placed on it. It sinks when placed in water.

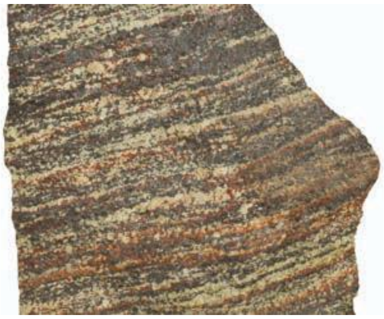

Figure 7.90 Rock B

   c) The rock in Figure 7.91 bubbles when acid is placed on it. It cannot be scratched easily with a fingernail.

Figure 7.91 Rock C

   d) The rock in Figure 7.92 is composed of crystals which are not easily removed.

Figure 7.92 Rock D

Analysing

6. Using the rocks in Question 5 and the dichotomous key in Practical 7.1, **determine** the rock type for each example, and explain how the appearance of each rock links to the rock type.

Evaluating

7. 'All types of rock can be classified according to their physical characteristics only.' **Discuss** whether you agree with this statement.

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7.4 The mining process

Learning goals

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

1. Outline the six stages of the mining cycle.
2. Describe how the mining of ores and minerals impacts on local environments and examine environmental rehabilitation initiatives.

WORKSHEET
The mining process

VIDEO
The mining process

Some minerals are useful to humans and can be mined. Mining is the process by which minerals and other useful materials are extracted from Earth. Salt, slate, gold, marble and coal can be used as they are found. Others need to be processed to make useful products, such as metals or building materials like cement.

The extraction of metals, ores and other materials from Earth has a very long history. Archaeologists have named two periods of human history, the Bronze Age and the Iron Age, according to the metals that people were producing at that time.

The mining process has several stages: exploration, planning and design, construction, mining, processing, and closure and rehabilitation.

1. Exploration

Before any mining project begins, mining companies enlist the expertise of geologists to scout areas and search for mineral deposits. It is important that they find out the quality of the mineral and the size of the deposit. This is to determine whether it would be cost effective for the mineral to be mined, as a mining project is extremely expensive once it has started.

Mining companies should also communicate with the Traditional Owners of the land to ensure that they are aware of any important cultural or archaeological sites so that the sites can be protected. In 2020, mining company Rio Tinto blasted a 46 000-year-old sacred site Juukan Gorge, in the Pilbara region, Western Australia. This led to an unreserved apology to the Puutu Kunti Kurrama and Pinikura Traditional Owners and a call for legislative change to protect Aboriginal and Torres Strait Islander Peoples' heritage sites at risk of demolition.

Figure 7.93 Geologists sampling rocks during iron-ore exploration in the outback (Pilbara, Australia)

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Science as a human endeavour 7.5

PMI guns

In modern mining, new technology is available to confirm a geologist's identification of a rock in just a few seconds. A positive material identification (PMI) gun uses high-energy radiation (X-rays) to excite the material in a rock and records the response. Each different element has a unique response, like a fingerprint. By analysing the signal given out by the rock, the percentage of each element can be found.

reflection seismology the use of shockwaves to investigate the structure of rocks underground

Geologists and geophysicists use a technique called **reflection seismology** to determine the structure of the rocks that lie beneath the surface. An explosive charge, or other methods, is used to make a loud sound and, as the sound travels down, it is reflected from the layers beneath the surface. Once an area has been identified, a thin cylinder of rock, called a core sample, is extracted to positively identify any minerals found.

Figure 7.94 Miners can use a PMI gun to determine the composition of a rock.

Figure 7.95 Core samples taken from a diamond mine

2. Planning and design

If the results of the exploration strongly suggest that mining in a certain area would yield good results, then the project moves into the planning stage. Collaboration occurs among project managers, mining engineers, ecologists, environmental scientists, finance consultants and other experts to design safe, sound, economically viable and socially responsible plans.

Figure 7.96 Social responsibility in planning includes considering how a new mine will affect society and the natural environment.

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Explore! 7.8

Environmental impacts of mining

Mining of ores and minerals can have significant impacts on local environments. Some of the issues caused by mining are listed below.

- soil and water contamination
- deforestation and habitat destruction
- land subsidence and sinkholes
- air pollution
- greenhouse gas emissions
- water overuse

These impacts can be long lasting and can have significant consequences for local ecosystems, wildlife and human communities. Mining companies are required to follow regulations and guidelines to reduce these impacts.

The environmental impacts and benefits of mining can be both short-term and long-term. Conduct research on recent applications for new projects in your region. What role did government, both state and federal, play in allowing or blocking the application?

3. Construction

After research is carried out, planning is completed and permits are approved, the project moves to the construction stage. This may involve building roads, mining facilities and housing.

Figure 7.97 Constructing a mining site involves many people, such as construction workers, builders, landscape architects and engineers.

4. Mining

Mining is the process by which minerals are recovered, using various tools and machines. When you think of mining, most people imagine an underground tunnel, which is a technique of mining that goes back to Roman times. **Underground mining** is highly skilled and can also be dangerous. The advantages of underground mining are that there is generally little impact on the environment, and minerals can be extracted from much larger depths than surface mining.

Figure 7.98 An underground coal mine

underground mining traditional method of mining by digging tunnels underground to extract ore

surface mining a method of mining that extracts a mineral from the surface, such as by digging an open pit

Another method of mining is called **surface mining**, such as strip mining and open-cut mining. Large quantities of a mineral can be extracted using this technique. Surface mining can only be used if the mineral is close to the surface. This method has become much more common in recent years, especially for the extraction of metal ores. It is relatively safe compared with underground mining, but there is a significant impact on the environment. Coal and iron ore are usually mined in this way in Australia. Quarrying refers to the removal of rock, sand and minerals from the surface of the Earth. It does not involve excavating pits to the depth of open-cut mining, and a key difference is the rock collected is the target material

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and is not highly processed in order to extract minerals. Quarrying can be undertaken on a small scale with hand tools, and has been used by humans for millions of years for the collection of stone for various tools.

There has been interest in mining deep-sea deposits, such as manganese–cobalt nodules in the Pacific Ocean; however, there are strong environmental concerns associated with deep-sea mining, and to date, it is too difficult and expensive.

Figure 7.99 An open-cut coal mine in New South Wales. Australia supplies about 20% of the world's coal and about 40% of the world's iron ore.

The depth of mineral deposits and the physical properties of the rock – such as the strength, porosity and density – determine the mining method used. Open-cut mining involves removing the waste rock (called overburden) that overlies the target ore and blasting, which is the use of explosives to break up the hard waste rock and ore. Next, this is processed to extract the valuable mineral.

Did you know? 7.13

Eureka!

Discovery of gold in Ballarat in 1851 heralded the beginning of the Victorian gold rush. In the early days, eager prospectors could be found camped in shanty towns along creek banks, digging by hand and panning for gold (Figure 7.100b). In 1858, the introduction of steam-driven machinery led to the discovery of the Welcome Nugget (Figure 7.100c) in the roof of a tunnel 55 m underground. Weighing in at 68 kg, it remains the second-largest gold nugget ever found.

Ballarat is now Victoria's third largest city, and the central business district (and many homes of its 115 000 inhabitants) sit directly on top of an active gold mine that stretches for kilometres and operates 24 hours a day (Figure 7.100a). Occasionally residents can detect the vibrations of explosive detonations deep underground, which are used to expand tunnels and extract ore for processing. In March 2024, one miner was tragically killed and another rescued from the Ballarat mine after a rockfall occurred at a depth of around 500 m, leaving them trapped underground. This highlights the importance of workplace safety practices in a modern industry that is not without risks.

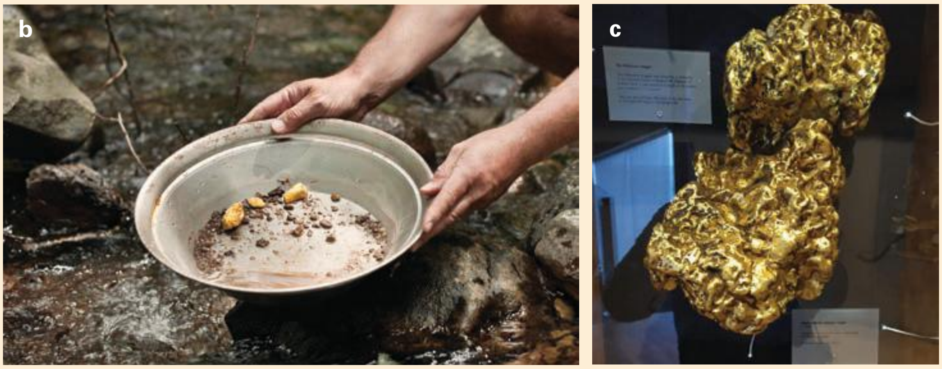

Figure 7.100 **(a)** White lines indicate tunnels currently in use, deep below the city of Ballarat, Victoria. **(b)** The traditional method of panning for gold. **(c)** A replica of the Welcome Nugget. It is almost half a metre long!

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Making thinking visible 7.1

Here now/there then: Coal mining

Coal mining in Australia is controversial for several reasons, including issues surrounding the environmental impact, Indigenous land rights and climate change. Attitudes to coal mining have changed over time.

- Create a two-column table.
- In column A, list **present** ideas and values about the topic.
- In column B, list **past** ideas and values about the topic.
- Compare columns A and B.
- Why do you think ideas and values have changed?
- How could we find out more about the ideas and values people had in the past?

The *Here now/there then* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Explore! 7.9

Mining extraction processes

There are different types of mining. Underground mining and surface mining are two of these; another two methods are placer mining and in-situ leach mining. Research these methods and answer the following questions.

1. What is involved in placer mining and in-situ leach mining?
2. List some advantages and disadvantages of the types of mining.
3. Which of the mining types has the smallest environmental impact? Justify your answer.
4. Describe some of the ethical issues that need to be considered with regard to mining.

Explore! 7.10

Fully automated mines

Australia has the largest number of autonomous mining trucks in the world. Use the internet to search for ‘Christmas Creek automated mine’. Do some research with regard to advances in mining technology and automation and answer the following questions.

1. Identify the advantages of fully automated mining technology.
2. Assess the concerns that have been raised for fully automated mining. Do you think these concerns are justified?

Figure 7.101 Christmas Creek Mine

Quick check 7.10

1. Copy and complete the following table to **summarise** what you have learned about the mining process so far. Remember, there are still two stages to go, so leave space in your table for stages 5 and 6.

Mining process	Details	Examples of people involved
1 Exploration		
2 Planning and design		
3 Construction		
4 Mining		
5		
6		

5. Processing

Recall that ore is rock that contains the metal being mined. There are several ways to process the ore so that only the intended metal is extracted.

Grinding

The ore is usually first crushed so that the pieces are smaller and easier to process.

Smelting

smelting
the process of extracting a metal from rock by heating it in the presence of carbon

electrolysis
a method of extracting a metal from its ore or purifying it using electricity

Smelting is a process that allows a metal to be extracted from its ore. The ore is heated in the presence of carbon (charcoal) and a chemical reaction takes place that frees the metal from the oxygen it is bound to in the ore.

$$\begin{matrix}\text{metal}\\\text{oxide}\end{matrix} + \text{carbon} \xrightarrow{\textit{yields}} \text{metal} + \begin{matrix}\text{carbon}\\\text{dioxide}\end{matrix}$$

Purifying

Electricity can be used to purify an impure sample of metal in a process called **electrolysis**. The sample is connected to a positive terminal and a pure piece of the metal is connected to the negative terminal. The terminals are placed in a solution containing the metal and, when the circuit is connected, the metal in the impure sample slowly moves through the solution from positive to negative. Any impurities are deposited near the positive terminal. When this is done with copper ore, the impurities may contain valuable metals, such as gold.

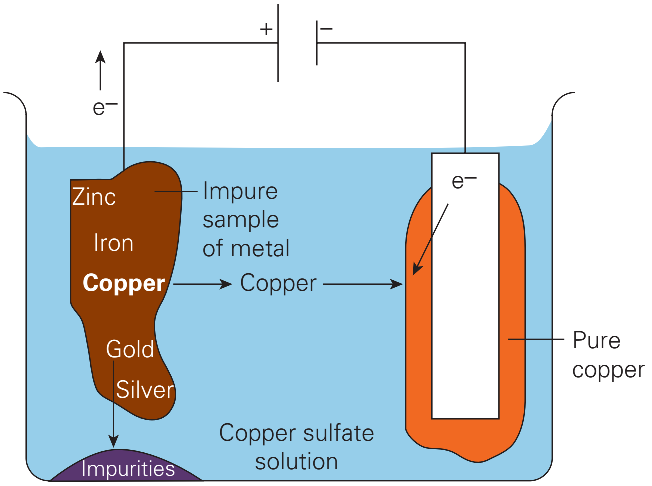

Figure 7.102 Use of electrolysis in purifying copper

Remining

Remining involves extracting valuable minerals from waste materials that have already been mined. Remining critical metals, such as lithium, cobalt, tin, tungsten and indium, can reduce the need for new mining sites. In addition, remining limits the impact on pristine areas, while also providing economic benefits by unlocking additional value from previously mined sites. While remining has not yet been widely adopted in Australia, it is a promising approach that aligns with the growing sustainability priorities of mining companies.

Practical 7.2

Electrolysis of copper

Aim

To see how metals can be purified using electricity and to demonstrate electroplating

Materials

- copper plates to act as electrodes × 2
- alligator leads × 2
- a stainless steel fork or spoon
- 0.5 mol L^{-1} copper sulfate solution
- beaker
- 3 V DC power supply

Be careful

Ensure personal protective equipment is worn.
Electrical shocks may occur.
Ensure the recommended voltage output is not exceeded. Turn off the power supply when changing the circuit.

Method

Part 1

1. Place two copper electrodes in a beaker containing a solution of copper sulfate.
2. Connect the electrodes to a battery or low-power direct-current supply (make sure it is switched off when you do this) using alligator leads.
3. Switch it on and leave it for a while (it may take 20–40 minutes). The cathode will slowly grow, and the anode will become smaller.
4. Switch the power supply off.

Part 2

1. Replace the copper plate connected to the negative terminal with a fork.
2. Switch the power supply on. Copper will move from the other plate to the fork. When it reaches the fork, it will be deposited on the surface and a thin layer of copper will appear. This is called electroplating.

Results

Record your observations for each part of the experiment.

Discussion: Analysis

1. Describe what you think happened when the power supply was switched on in Part 1 of the experiment.
2. Deduce some uses for electroplating, which you saw in Part 2 of the experiment.
3. Distinguish between electrolysis and electroplating.

6. Closure and rehabilitation

The final step in mining is closure and rehabilitation. When the resources in a mining site have been exhausted, the site closes down, all facilities are packed up and often removed, and a rehabilitation plan is developed. The purpose of this is to return the land to the state it was in before the mine was built. For example, if it was agricultural land, then the plan would involve trying to restore the land to its original level of productivity. Rehabilitation involves scientists, government personnel, bush regenerators and local wildlife experts, among others.

Phytomining can be used as a tool for rehabilitating areas that have been impacted by mining activities. In many cases, mining can leave behind soils that are contaminated with heavy metals and other pollutants, which can have long-term negative impacts on the environment and surrounding communities. Phytomining can be used to help remediate these contaminated soils by using hyperaccumulator plants to absorb and accumulate the contaminants. Once the plants have accumulated the pollutants, they can be harvested and removed from the site, effectively removing the contaminants from the soil. This process not only reduces the amount of pollutants in the soil, but it can also provide a potential source of revenue through the recovery of valuable metals.

Figure 7.103 The sap from *Pycnandra acuminata*, found in New Caledonia, contains up to 25% nickel by weight.

Did you know? 7.14

Rehabilitation and biodiversity

Rehabilitation of the land also takes into consideration the native plants and animals that were in the site before it was mined. Disturbed areas are reshaped to reflect their original state as closely as possible, and care is taken to preserve plant species. In 2022, the Chuwar coal mine near Ipswich became the first open-cut coal mine in Queensland to be fully rehabilitated and relinquished. The Queensland Government accepted surrender of a company's mining leases for the site, after concluding that all rehabilitation requirements had been met in full. The site, which was mined in the 1980s, has been backfilled, reshaped and rehabilitated to meet community expectations. The area is now safe, stable, non-polluting and able to support grazing.

Figure 7.104 The rehabilitated Chuwar coal mine

The mining industry in Australia

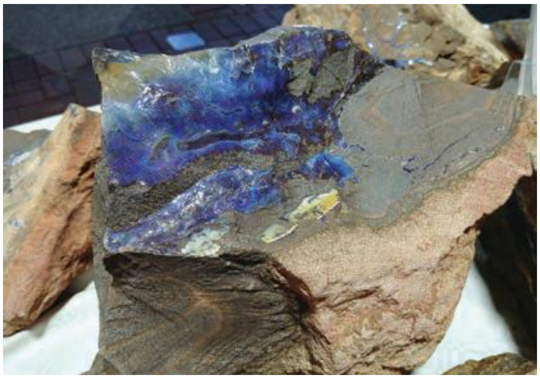

Figure 7.105 An Australian uncut opal. Australia produces around 95% of the world's opals.

The mining industry is one of the most important industries in Australia. Table 7.11 shows a summary of some of the metal resources mined in this country.

It is not just metals that are mined or quarried. Stones are used to make roads. Coal (sedimentary) is mined as a source of energy; Australia is ranked fourth in the world in terms of coal supply. Limestone (sedimentary) is used to make cement. Also, when sand is combined with small amounts of limestone and sodium carbonate, heated until it melts and allowed to cool, it becomes glass.

Gemstones such as diamonds and opals are mined in Australia, and gemstone mining is a major source of income for some Australian towns. Coober Pedy, for example, is the largest opal-mining area in the world.

Resource	Details
Iron	Australia is the world's largest exporter of iron ore.
Uranium	The worldwide nuclear power industry needs uranium ore as fuel. There are no nuclear power stations in Australia, but about 10% of the world's uranium is mined here.
Gold	Australia's early history was highly influenced by gold, as many immigrants came during the gold rush days. Gold mining is still a large industry, and ore containing even a small amount of gold is mined, due to the high value of the gold. Gold mines in Australia account for 9% of the world's production and some of these mines are huge operations, occupying many hectares.

Table 7.11 Some important metals mined in Australia

Explore! 7.11

Coal mining in Victoria

Australia is one of the world's largest exporters of coal (both black and brown). Brown coal, which is also known as lignite, is particularly abundant in the Gippsland Basin of Victoria. The Victorian Government has made a commitment to transition to renewable energy sources and to decommission the existing coal-fired power stations in the Latrobe Valley. Conduct some research and answer the following questions.

1. Describe the cost and energy advantages of coal.
2. Describe the environment impacts of mining and burning coal.
3. Suggest some future uses of brown coal.

Explore! 7.12

Sustainable mining

Many mining companies are making sustainability a core element in their business strategies. Research how the following practices have increased efficiency and limited environmental impact at mine sites.

- use of renewable energy sources
- waste reduction and recycling
- use of digital technologies such as automation, artificial intelligence and advanced analytics
- regeneration of mine sites
- adoption of circular economy practices

Quick check 7.11

1. **Summarise** the last two mining processes by adding to your table from Quick check 7.10.

Mining process	Details	Examples of people involved
5 Processing		
6 Closure and rehabilitation		

2. **List** some of the metals, rocks and minerals mined in Australia.

Go online to access the interactive section review and more!

Section 7.4 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 7.4 questions

Remembering

1. **Recall** the steps of the mining process, in chronological order.
2. **Name** three processes that can be used in the processing stage of mining to obtain the intended metal.
3. **Recall** some metals and resources that are significant for the Australian mining industry.

Understanding

4. **State** an example of technological progress in the mining industry and explain how it helps the mining process.

Applying

5. **Explain** the importance of performing the exploration stage before designing a mine.
6. **Summarise** how geologists determine the content and structure of the rocks under the surface.

Analysing

7. **Compare** surface mining with underground mining, giving at least two advantages and disadvantages of each.

Evaluating

8. **Propose** why electroplating with silver or gold is a very popular technique in jewellery making.

Chapter review

Chapter checklist

Success criteria		Linked questions
7.1	I can describe the role of forces and heat energy in the formation of igneous, sedimentary and metamorphic rocks.	3, 4
7.1	I can compare how quickly or slowly different rock formation processes can occur.	9
7.1	I can outline the major processes of the rock cycle.	12
7.2	I can describe the formation of igneous, sedimentary and metamorphic rocks.	1, 3, 4, 5, 13, 17
7.2	I can explain how fossil evidence can predict how and when a rock was formed.	11
7.3	I can compare the observable properties of different types of rocks and identify them using a dichotomous key.	8, 13, 14, 15, 16
7.3	I can describe the tests available to classify rocks.	6
7.3	I can describe some traditional geological knowledges of Aboriginal and Torres Strait Islander Peoples that are used in the selection of different rock types for different purposes.	18, 19
7.4	I can outline the six stages of the mining cycle.	2, 7
7.4	I can describe how the mining of ores and minerals impacts on local environments and examine environmental rehabilitation initiatives.	10

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **Name** the two types of igneous rock.
2. **Name** the process that involves heating an ore in the presence of carbon to extract a metal.
3. **Recall** the stages in the formation of sedimentary rock.
4. **Name** the two conditions that allow metamorphic rocks to form.

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5. Figure 7.106 shows limestone in the Naracoorte Caves of South Australia.
   a) **Identify** the property of the limestone that allows the caves to form.
   b) **Name** the geological name for this type of weathering.

Figure 7.106 Naracoorte Caves, South Australia

6. **Recall** the test for a rock that contains carbonates.
7. **Recall** the six stages of the mining cycle.

Understanding

8. **Describe** how you can physically distinguish between a rock and a mineral.
9. **Describe** the difference between igneous rocks that have cooled slowly and those that have cooled quickly.

Applying

10. **Describe** one impact that mining has on local environments.
11. **Describe** how fossil evidence can predict how and when a rock was formed.
12. **Illustrate** a diagram of the rock cycle.

Analysing

13. a) **Infer** the geological process that occurred to produce the formation shown in Figure 7.107.
    b) One feature of metamorphic rock is that it can appear layered. The rock shown in Figure 7.108 is layered. However, it is sedimentary rock. **Evaluate** why this might be the case.

Figure 7.107 Rock formation

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Figure 7.108 Layers in a sedimentary rock

14. **Contrast** breccia and conglomerate.

Evaluating

15. Examine the image in Figure 7.109 and **determine** whether it is a rock or a mineral.

Figure 7.109 Rock or mineral?

16. A geological sample is made of a single crystal. **Deduce** whether or not this sample is a mineral and explain your reasoning.

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17. a) The sedimentary rocks in Figure 7.110 are lying at an angle. **Determine** the geological event that might have caused this to happen.
    b) Figure 7.111 shows a fossil lying on a beach. **Deduce** where it would have come from.

Figure 7.110 Angled sedimentary rocks

Figure 7.111 Fossil on a beach

18. The photo in Figure 7.112 shows grooves in sandstone due to many years of Aboriginal and Torres Strait Islander Peoples using it for a particular purpose. **Deduce** why these grooves have been formed.

Figure 7.112 This rock shows evidence of use over thousands of years

19. **Propose** the type of rock that would be the best for use as an axe by Aboriginal and Torres Strait Islander Peoples.

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Data questions

Iron ore is a key Australian export, and an Australian iron-ore deposit commonly contains the minerals hematite, magnetite and pyrite, among others. The iron content of these minerals is presented in Table 7.12, and an example of the percentage of mineral components at different depths of an iron-ore deposit drill sample is shown in Figure 7.113.

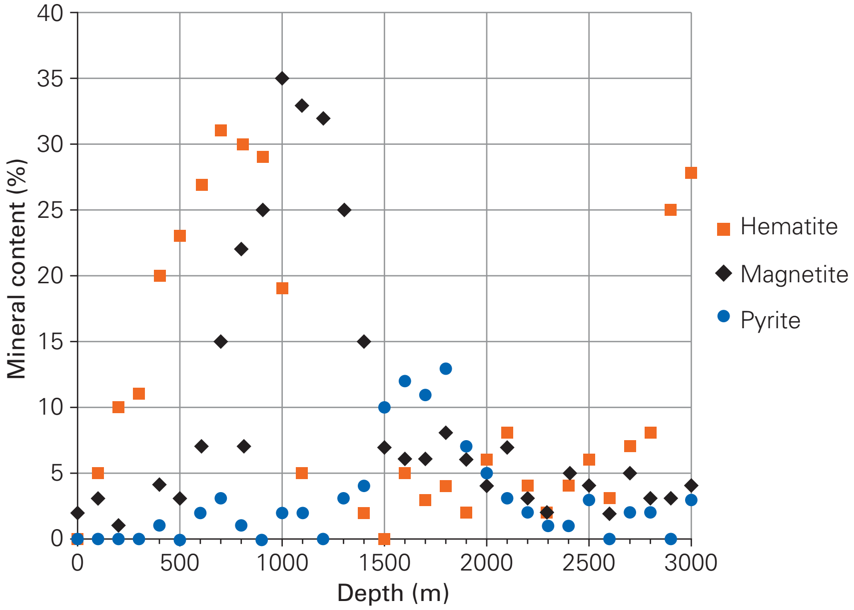

Figure 7.113 Mineral content of an iron-ore exploration extract, depending on the depth of drilling

Mineral	Formula	Iron content	Colour
Hematite	Fe_2O_3	70%	red
Magnetite	Fe_3O_4	72%	black
Pyrite	FeS_2	47%	yellow

Table 7.12 Examples of minerals found in Australian iron ores

Applying

1. **Identify** which mineral described in Table 7.12 presents the highest iron content.
2. **Identify** the mineral with the highest content in the ore at 400, 1100 and 1800 m.

Analysing

3. **Classify** the minerals hematite, magnetite and pyrite as 'oxides' or 'sulfides', according to whether the iron is bonded to oxygen or sulfur.
4. **Contrast** the iron content in hematite, magnetite and pyrite, and suggest which of these minerals is the least sought after.

Evaluating

5. **Deduce** which mineral has the lowest overall content in the ore at depths 0–3000 m.
6. Given the response to Question 5, **infer** a reason why the mining company has concerns about mining beyond 1500 m in depth.
7. Some miners had thought that they had found gold at a depth of 1800 m, but analysis revealed an iron-based mineral. Which mineral did they find? **Justify** your answer with reference to the colours of the minerals, and their abundance at a depth of 1800 m.
8. At close to 3000 m depth, the content of hematite is raised again. **Predict** the percentage of hematite content at 3100 m in this drill sample.
9. **Predict** the colour of the rock sample taken at 1200 m depth.

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STEM activity: Underground bunkers and asteroids

Background information

A bunker is a structure built underground for people to shelter or live in, protecting them from dangers on the surface of Earth. For example, many homes in parts of the world that are prone to tornados have a bunker to protect the homeowners. During World War II, many major cities had huge bunkers built beneath them to protect residents from bombs.

When designing a bunker, engineers need to think about how people live and what requirements exist for people to be able to live underground for a period of time. They obviously do not need to take creature comforts into account, but people will still need to have access to food, fresh water and toilets, and somewhere to sleep. Engineers calculate the amount of space that will be required for the number of people intending to use the bunker.

Engineers also need to consider the type of rock and soil that the bunker will be built beneath. They work alongside geologists to determine suitable locations, with rock that is not too soft, so it will support the structure of the bunker, and not too hard, so it is not too difficult to cut into.

Figure 7.114 A bunker provides protection from dangers above.

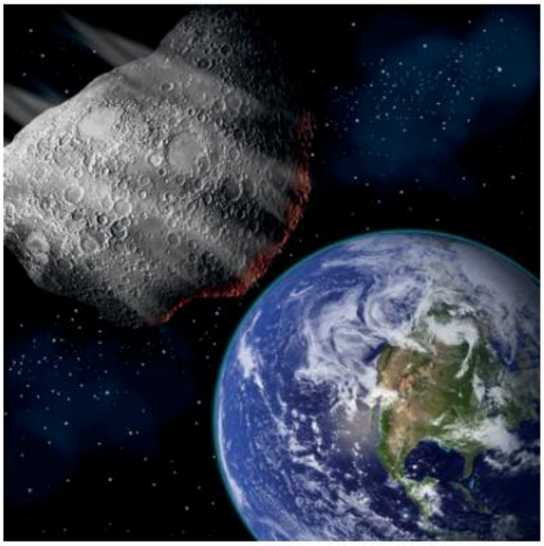

Figure 7.115 Only 20 days to find cover!

DESIGN BRIEF

Design an underground bunker to survive the imminent impact of an asteroid.

Activity instructions

BREAKING NEWS: AN ASTEROID IS HEADING FOR EARTH!

Scientists have calculated that the asteroid will collide with Earth in 20 days. The impact will be so destructive that all humans will need to stay in bunkers underground for at least three months. Your team of engineers has been tasked with building an underground bunker for the people in your local suburb.

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Suggested materials

- large plastic container
- soil and crushed rock
- cardboard
- icy pole sticks
- scissors
- sticky tape
- glue
- slotted masses/weights

Research and feasibility

1. Research how many people are in your local suburb and decide as a group if multiple bunkers will have to be built. Decide as a group how many people you will build a bunker for.
2. Research the local rock formations in your area. Decide whether your bunker needs to be built underground or into local rock formations. You will need to research the common types of rock and the difficulty in excavating/drilling using the Mohs hardness scale. You may need to consider other factors of the rock type that may be important when considering strength.

Design and sustainability

3. Decide as a group the volume of your bunker, based on the number of people, and what your group believes are the space requirements, then sketch proposed local area locations and a design for your bunker. Include annotations on your sketch for the bunker design, giving additional information on the thought processes behind it.
4. Discuss as a group how you can build a model of your proposed bunker for testing. Think about the type of local rock, your bunker shape and how to make an effective model. Include in your discussion how you are planning to test your bunker to show its durability.

Create

5. Build the model of your bunker, and then test it using varying weights or methods.

Evaluate and modify

6. Describe some of the difficulties you encountered while calculating and estimating the amount of space people will need to live in.
7. Did you need to make compromises on quality of life for the people living in your bunker, to save space? Explain how you came to your decisions.
8. Describe some modifications you could make to your bunker to withstand more force.
9. Evaluate the feasibility of constructing a bunker located within the rock type you have chosen.

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Chapter 8

Energy

Chapter introduction

Your senses can detect several types of energy – your eyes detect light, your ears detect sound, and your skin can feel heat. You use your muscles to move and to give objects kinetic energy, or to lift objects, giving them gravitational potential energy. The food you eat contains chemical energy, which is used by your cells. The cells in your brain are constantly exchanging electrical energy, and your nervous system uses electrical energy to send messages between your brain and the rest of your body. In this chapter, you will explore the different types of energy, how energy can be transferred or transformed and the concepts of energy efficiency.

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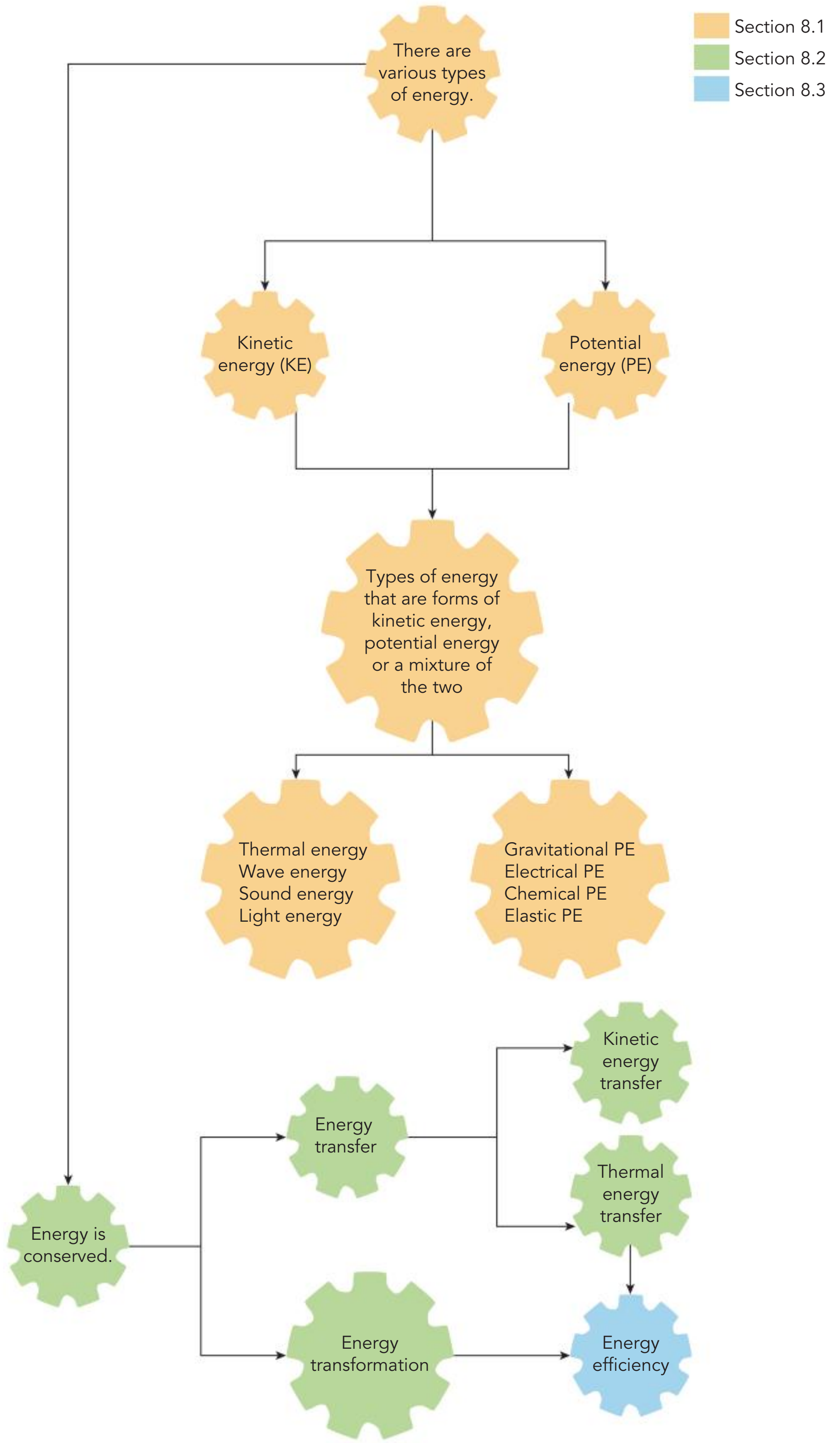
Concept map



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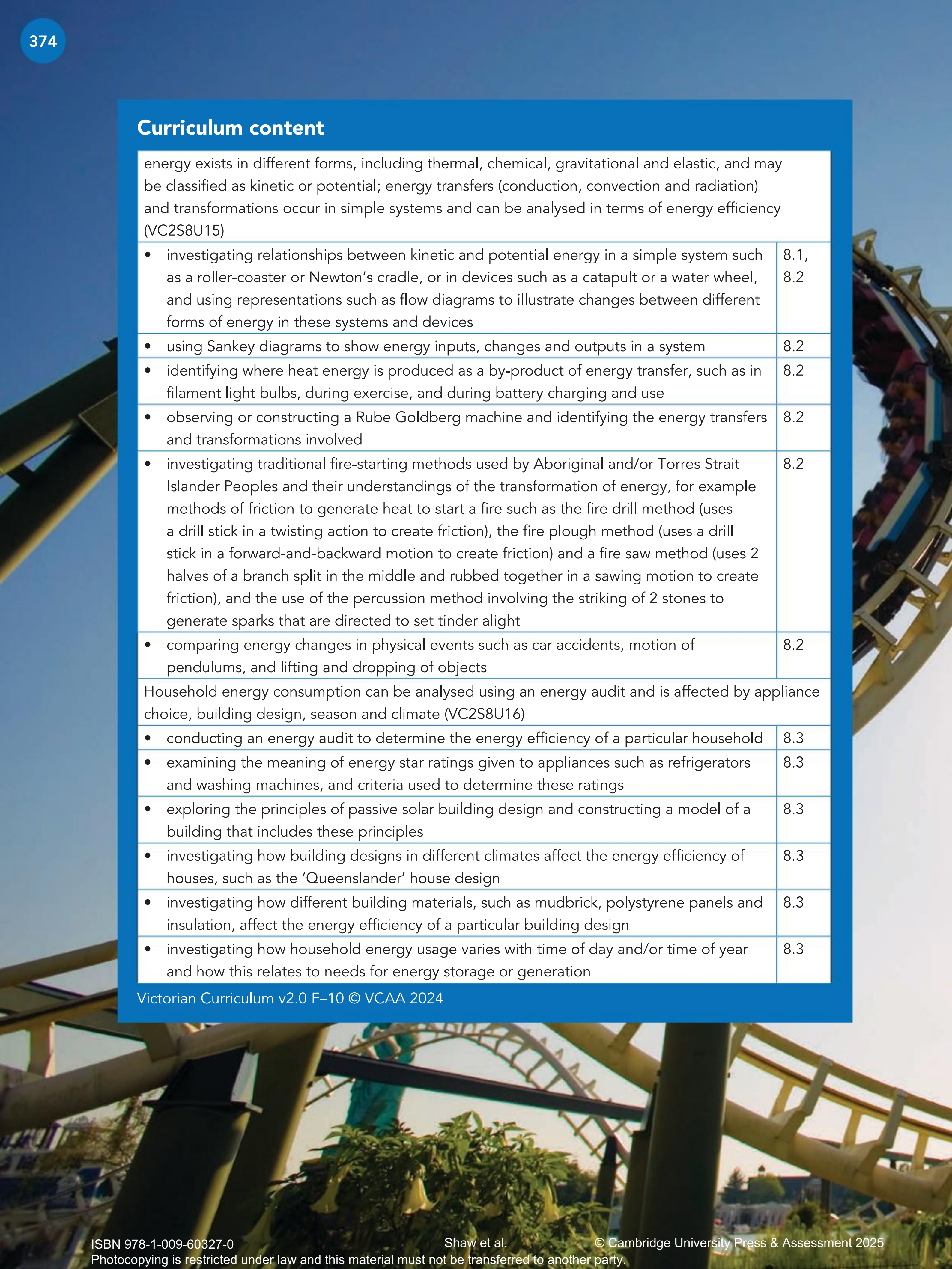

Curriculum content

energy exists in different forms, including thermal, chemical, gravitational and elastic, and may be classified as kinetic or potential; energy transfers (conduction, convection and radiation) and transformations occur in simple systems and can be analysed in terms of energy efficiency (VC2S8U15)	
• investigating relationships between kinetic and potential energy in a simple system such as a roller-coaster or Newton's cradle, or in devices such as a catapult or a water wheel, and using representations such as flow diagrams to illustrate changes between different forms of energy in these systems and devices	8.1, 8.2
• using Sankey diagrams to show energy inputs, changes and outputs in a system	8.2
• identifying where heat energy is produced as a by-product of energy transfer, such as in filament light bulbs, during exercise, and during battery charging and use	8.2
• observing or constructing a Rube Goldberg machine and identifying the energy transfers and transformations involved	8.2
• investigating traditional fire-starting methods used by Aboriginal and/or Torres Strait Islander Peoples and their understandings of the transformation of energy, for example methods of friction to generate heat to start a fire such as the fire drill method (uses a drill stick in a twisting action to create friction), the fire plough method (uses a drill stick in a forward-and-backward motion to create friction) and a fire saw method (uses 2 halves of a branch split in the middle and rubbed together in a sawing motion to create friction), and the use of the percussion method involving the striking of 2 stones to generate sparks that are directed to set tinder alight	8.2
• comparing energy changes in physical events such as car accidents, motion of pendulums, and lifting and dropping of objects	8.2
Household energy consumption can be analysed using an energy audit and is affected by appliance choice, building design, season and climate (VC2S8U16)	
• conducting an energy audit to determine the energy efficiency of a particular household	8.3
• examining the meaning of energy star ratings given to appliances such as refrigerators and washing machines, and criteria used to determine these ratings	8.3
• exploring the principles of passive solar building design and constructing a model of a building that includes these principles	8.3
• investigating how building designs in different climates affect the energy efficiency of houses, such as the 'Queenslander' house design	8.3
• investigating how different building materials, such as mudbrick, polystyrene panels and insulation, affect the energy efficiency of a particular building design	8.3
• investigating how household energy usage varies with time of day and/or time of year and how this relates to needs for energy storage or generation	8.3

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Glossary terms

- Chemical potential energy
- Conduction
- Conductor
- Convection
- Elastic potential energy
- Electrical energy
- Electromagnetic spectrum
- Energy
- Energy transfer
- Generator
- Gravitational potential energy
- Heat
- Input energy
- Insulator
- Joule
- Kinetic energy
- Law of Conservation of Energy
- Light energy
- Nuclear energy
- Output energy
- Photovoltaic
- Potential energy
- Radiation
- Radioactive
- Rotational kinetic energy
- Sankey diagram
- Solar energy
- Sound energy
- System
- Temperature
- Thermal energy
- Travelling wave
- Turbine
- Waste energy
- Wave energy

8.1 What is energy?

WORKSHEET
Types of energy

VIDEO
Types of stored energy

Learning goals

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

1. Define energy.
2. Provide examples of different forms of kinetic and potential energy.
3. Distinguish between heat, thermal energy and temperature.

Energy is the capacity to do work, and it cannot be created or destroyed. That is, the amount of energy in our universe is always the same. However, energy can change form; it can be transferred from one object to another, or it can be stored for later use. For all the different types of energy, the unit of measurement is the **joule** (J). One joule is equal to the work done by a force of one newton (N) over one metre – that is, 1 J = 1 Nm.

While we experience energy in different ways, including light, heat, sound and movement, all types of energy can be categorised as either kinetic or potential energy.

energy
the capacity to do work; the total amount of energy is conserved in any process

joule
the unit of energy or work done by a force of one newton over one metre

kinetic energy
the energy of moving matter

rotational kinetic energy
the energy an object has because it is rotating

potential energy
the energy stored in something because of its position, shape or composition; e.g. due to height above the ground, being stretched or compressed, or in chemical form

Kinetic energy

The energy an object has when it is moving is called **kinetic energy** (KE). The amount of KE depends on the mass of the object and its speed. Objects that are spinning or rotating also have kinetic energy, but this energy is called **rotational kinetic energy**.

Potential energy

Some objects can store energy until it is ready to be used. This stored energy is called **potential energy** because it has the potential to do work. For example, a stretched rubber band has stored elastic potential energy. The energy is not being used at that point, but it has the potential to make something happen. Some forms of stored energy are summarised in Table 8.1.

Figure 8.1 A jumping kangaroo has kinetic energy. What potential energy might it have?

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Form of potential energy	Description
Gravitational potential energy (GPE)	Energy stored when an object is lifted up; energy released when the object falls
Electrical energy	Energy stored in electrostatic situations (e.g. thunderclouds, capacitors); energy released when current flows (includes sparks like lightning)
Chemical potential energy	Energy stored in chemicals such as food, fuel and batteries. For example, the chemical energy in batteries is released when connected to an electric circuit, in which the chemical energy is converted to electrical energy.
Elastic potential energy	Energy stored when an object is stretched or compressed; energy released when an object returns to its original size and shape
Nuclear energy	Energy stored in unstable (radioactive) nuclei of atoms; energy released when radioactive atomic nuclei decay or undergo fission or fusion

Table 8.1 Potential energy is a form of energy that can be stored.

Try this 8.1

Kinetic and potential energy

Observe the image in Figure 8.2. How might the kinetic and potential energy in this system interact as Newton's cradle is in full swing?

Figure 8.2 Newton's cradle in action

WORKSHEET
Boiling point of water

Forms of energy

Thermal energy

Heat is related to the kinetic energy of particles of matter. As heat increases, particles of matter gain this energy and have more kinetic energy to move more rapidly. In this chapter, we will use the more technical term for 'heat', and that is **thermal energy**. To change an object's **temperature**, thermal energy needs to be either added (to raise it, i.e. heating) or removed (to lower it, i.e. cooling). The total amount of thermal energy in an object is influenced by three factors:

- temperature – Objects with higher temperature have more thermal energy than identical cold objects.
- 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.

heat
thermal energy that is transmitted due to differences in temperature

thermal energy
the energy contained within a material that is responsible for its temperature

temperature
a measure of the degree of heat present in a substance; gives an indication of the average kinetic energy of the particles

The total thermal energy depends on all three factors. For example, a warm bath contains a lot more thermal energy than a burning match. This is because, even though the match has a higher temperature, the hot bath is much bigger, and water is very good at storing thermal energy.

Increasing the temperature of water is one of the most expensive energy costs in the home, because heating water requires a lot of energy.

Did you know? 8.1

Forms of energy we can detect with our senses

The types of energy that we can detect with our senses are listed in Table 8.2.

Form of energy	Description
Thermal energy	We can sense both hot and cold temperatures with our skin.
Sound energy	Our ears can hear sound energy.
Light energy	Our eyes can see light energy.

Table 8.2 Types of energy, other than kinetic energy, that we can sense

wave energy
the energy carried by a travelling wave (e.g. an ocean swell) or trapped in a standing wave (e.g. a guitar string)

travelling wave
a wave that can carry energy from one place to another

Figure 8.3 The energy of an earthquake damaged this road in Christchurch, New Zealand, in 2011.

Wave energy

Water waves carry **wave energy**. As waves appear to move across the surface of the water, the particles are not moving forward but rather up and down. Both kinetic and potential energy are being transformed in this process. The waves can vary in size, from small ripples formed when a stone is thrown into water, all the way up to ocean swell – long waves that travel along the surface of the ocean. Although there is no net movement of particles, because waves in water are generally able to move from place to place, they are called **travelling waves**.

Water waves are not the only type of waves that can carry energy. Waves can travel through Earth after an earthquake. These are also an example of a travelling wave. They occur when the ground suddenly moves and can transmit a huge amount of energy.

Figure 8.4 A warm bath contains more thermal energy than the flame of a candle.

Figure 8.5 These water waves at Portsea beach have wave energy.

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Sound energy

Sound energy is a form of wave energy. When sound is emitted from an object, the particles in the surrounding air are repeatedly compressed and then stretched. This disturbance travels through the air at about 330 m/s. Sound energy consists of a travelling wave of vibrating air particles.

Figure 8.6 Sound energy travels as vibrational waves in the air.

Light energy

Light energy is a special kind of wave that is part of the **electromagnetic spectrum**. Unlike sound waves, light waves are an interplay of potential energy in the electric and magnetic fields, so the waves do not require particles and can also travel in a vacuum, such as space. Light waves include all the colours of the visible spectrum: red, orange, yellow, green, blue, indigo and violet. The electromagnetic spectrum also includes waves that humans cannot see. Gamma rays emitted from radioactive materials, X-rays used in hospitals, ultraviolet light that causes sunburn, infrared radiation (also called heat), microwaves used by mobile phones and radio waves used for long-distance communication are all components of the electromagnetic spectrum.

Figure 8.7 5G communication is possible due to radio waves, a form of light energy.

Making thinking visible 8.1

Think, feel, care: The Matilda effect

Ruby Payne-Scott was an Australian radio engineer and astronomer who worked throughout the 1940s as a respected and prominent scientist. Up until 1966, the Australian Public Service required women to resign from their profession when they married. Payne-Scott married in 1944, and in 1950 she was made to resign from her role as a scientist. In the process, her work in the field was often discredited and overlooked by her male colleagues. The 'Matilda effect' is a term coined to describe the systematic and historical tendency to undervalue or disregard the contributions of women in science.

Figure 8.8 Ruby Payne-Scott was an Australian researcher in radioastronomy.

What do you know about Ruby Payne-Scott and the Matilda effect, and what further questions do you have?

Do you think the Matilda effect could still be an issue today?

Why is it important to acknowledge and celebrate the contributions of all scientists, regardless of gender or context? What can you do to raise awareness about the Matilda effect and support the recognition of women in science?

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

sound energy	a form of travelling wave; sound consists of vibrations in the air
light energy	a form of energy that travels as electromagnetic waves and can travel in a vacuum
electromagnetic spectrum	a way of organising electromagnetic waves according to their energy and wavelength

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Quick check 8.1

1. **List** five examples of objects that could have kinetic energy.
2. **Give** two types of wave energy.

Gravitational potential energy

When an object is lifted above the ground, it gains **gravitational potential energy**. 'Gravitational' means related to the pull of Earth, and 'potential' means the energy is stored. The gravitational potential energy (GPE) gained by an object when it is lifted depends on three things:

- the strength of gravity
- the mass of the object
- the height to which the object is lifted.

As an object falls towards Earth, it loses GPE and gains KE.

gravitational potential energy a type of potential energy; the energy an object has because of its height; GPE = mgh, where m is the mass of the object in kg, h its height in metres and g is acceleration due to Earth's gravity, 9.8 m/s^2

Figure 8.9 The water at the top of Beauchamp Falls, along the Great Ocean Road, has gravitational potential energy that is converted to kinetic energy when falling 20 m to the pool below.

Did you know? 8.2

Sir Isaac Newton's apple

There is a story that has been told for hundreds of years regarding the situation that led to Sir Isaac Newton's discovery that gravity is a universal law applying to planets and the Moon as well as objects on Earth. There isn't enough evidence to determine whether it is true or not, but, in any case, it is a fun story!

Figure 8.10 Sir Isaac Newton wondering whether the Moon falls towards Earth

The story goes that in the mid-1600s, Sir Isaac Newton was sitting under a tree when an apple fell onto his head. In this moment he pondered, 'If this apple falls towards Earth, could the same law of physics be holding the Moon in its orbit?'. This thought sparked years of work that culminated in the publication of his book *Philosophiae Naturalis Principia Mathematica* in 1687. His work included his laws of motion, now known as Newton's laws of motion, and the universal law of gravitation.

To answer his original question, Newton confirmed that the Moon is constantly falling towards Earth and is attracted according to the same law that attracts the apple, but rather than collide with Earth, it stays in orbit. Can you imagine the amount of GPE that the Moon has?

Try this 8.2

Investigating energy with a bouncy ball

Take a bouncy ball and hold it above your head. Drop the ball and let it bounce twice.

Describe the transformations involved as GPE changes to KE over the two bounces. Explain where elastic potential energy fits in.

Electrical energy

electrical energy energy carried by electricity moving in a wire; voltage is used to measure how much energy is carried by each unit of electricity

Electrical energy is carried by charged particles, called *electrons*, that can transport charge from one atom in a wire to the next, carrying energy as they do so. The rate of movement of charge through an electrical circuit is called current (I) and is measured in amperes or amps (A). Circuits often contain resistance (R), which restricts the movement of charge. Resistance is measured in ohms (Ω).

Voltage (V) is related to the amount of electrical energy each unit of charge carries. For example: AAA batteries supply 1.5 joules of electrical energy per unit of charge, so they have a voltage of 1.5 volts; smartphones operate at 5 volts; car batteries are 12 volts; and in Victoria, electricity in the home is 230 volts. You will learn more about electrical energy in Chapter 9.

Explore! 8.1

Transmission lines

Transmission lines carry electrical energy long distances to all parts of Victoria and the rest of Australia.

1. Use the internet to research the types of materials used in transmission lines.
2. If materials with less resistance are used, would there be less heat energy produced?

Figure 8.11 Transmission lines deliver electrical energy to all parts of Victoria, losing a minimal amount as heat.

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Did you know? 8.3

Lightning strikes

Electrical energy can be very dangerous when it causes a large electric current to flow through the body. The highest voltages on Earth are in lightning strikes, which can be hundreds of millions of volts. Think about thunderstorms: what other forms of energy are released when lightning strikes?

Figure 8.12 A lightning strike in Melbourne city

Quick check 8.2

1. **State** some types of energy that can be stored.
2. Examine the following image. **Explain** where you would stand to have the greatest gravitational potential energy.

Figure 8.13 Where is GPE greatest?

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3. Figure 8.14 shows a roller-coaster. Roller-coasters are a great example of GPE. Answer the following questions, remembering that as an object loses GPE, it gains KE (kinetic energy).

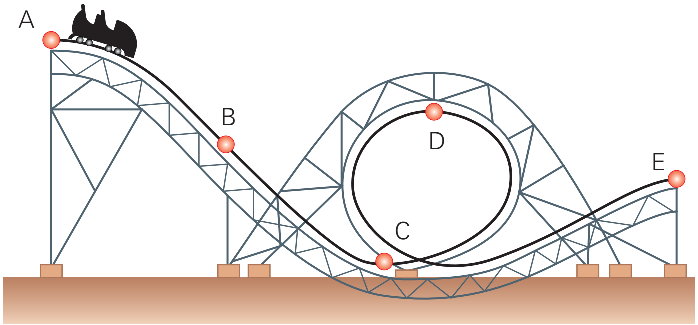

Figure 8.14 A roller-coaster

a) **Identify** the step (A, B, C, D or E) where the cart would have the greatest GPE.
b) **Identify** the step where the cart would have the greatest KE.

Chemical potential energy (chemical energy)

Many substances contain stored **chemical potential energy**, which can be released in a chemical reaction. For example:

- Trees store chemical potential energy in their wood, which is released when the wood is burned.
- The food we eat contains chemical potential energy, which is released slowly in our bodies, giving us the energy we need to keep warm and move around.
- Cars have engines that convert the chemical energy in petrol to kinetic energy, heat and sound.
- Batteries store chemical energy that can be used to power household devices when required.

chemical potential energy the energy stored in the chemical bonds between atoms

Figure 8.15 Fireworks along the Yarra River in Melbourne. Fireworks contain chemical potential energy, which is released when the fireworks are lit.

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Elastic potential energy

elastic potential energy the energy stored when an elastic material is compressed or stretched

Elastic potential energy is energy that is stored whenever an elastic material is either stretched or compressed by a force. For example, energy is stored in a rubber band when it is stretched and in a rubber ball when it is compressed. Trampolines, bungee cords and metal springs are all examples of objects that can store elastic energy. Another name for elastic potential energy is 'spring energy'.

Figure 8.16 An archery bow stores elastic potential energy when it is stretched.

Try this 8.3

Exploring elastic potential energy

Take a rubber band and stretch it as tightly as possible. Explain how the stretched rubber band is an example of potential energy. Point the rubber band at the wall and let it go. Explain how the potential energy stored in the band was converted to a different form of energy.

Figure 8.17 A bungee cord stores elastic potential energy when it is stretched.

Nuclear energy

nuclear energy a non-renewable source of energy that uses the energy released by the nucleus of radioactive atoms

radioactive having or producing the energy that comes from the breaking up of atomic nuclei

radiation the transfer of energy without requiring the presence of particles

The *nucleus* (plural *nuclei*) of certain atoms contains **nuclear energy**, a form of potential energy. Most nuclei are stable and do not release nuclear energy, but the **radioactive** nuclei of some atoms can undergo radioactive decay, emitting electromagnetic wave energy and/or particles with kinetic energy. The electromagnetic **radiation** emitted is high-energy gamma rays, part of the electromagnetic spectrum. One source of radioactive energy is fission, in which an atomic nucleus splits into smaller fragments, releasing energy as it does so. Nuclear power stations use the *fission* reactions of a radioactive material such as uranium to produce thermal energy, which in turn is used to generate electricity.

Unfortunately, such radiation can be hazardous to health, as high-energy gamma rays and particles with high kinetic energy are capable of damaging human cells. Great care must be taken to prevent people being exposed to it in nuclear power stations.

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Making thinking visible 8.2

The explanation game: Types of energy

Observe the scene in Figure 8.18.

Figure 8.18 A pool party always involves energy!

What are the types of energy, and where do you **notice** them, in Figure 8.18?

Explain why you think those types of energy are present.

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

Explore! 8.2

The relationship between mass and energy

In 1893, physicist Nikola Tesla and philosopher Swami Vivekananda met at the Congress of the World's Religions in Chicago. They discussed the interrelatedness of energy and matter, with Vivekananda being interested in the relationship between matter and spiritual energy and Tesla interested in physical mass and energy. Their collaboration was not only significant in bridging the gap between the perspectives of scientists and those of spiritual leaders around the world, but also in highlighting the potential relationship between mass and energy.

Use the internet to explore how Albert Einstein's theory of special relativity provided more information on the relationship between mass and energy in 1905.

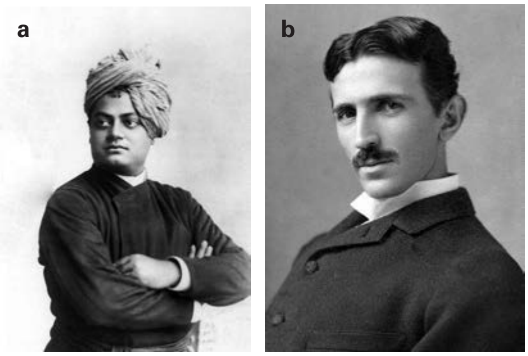

Figure 8.19 (a) Swami Vivekananda and **(b)** Nikola Tesla met for the first time in Chicago in 1893.

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Quick check 8.3

1. **State** three examples of chemical potential energy.
2. **Explain** what is happening to a material if elastic potential energy is being stored.
3. **State** the name of the process in which energy is released from the nucleus when it breaks apart or releases a particle.

Try this 8.4

A world without energy

Think about a world in which there is no electrical energy. Suppose there was no light or sound energy either. Could life exist in such a world? Write down a few sentences to say if you think it could and what it would be like. Now imagine that there is no potential or kinetic energy of any type. What would that world be like? Discuss and collate your ideas as a class and see if you agree.

Go online to access the interactive section review and more!

Section 8.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 8.1 questions

Remembering

1. **Recall** the correct energy forms and definitions to complete the table below.

Form of energy	Definition	Is this an example of potential energy?
Kinetic		
	Energy an object possesses when it is lifted	
Chemical		Yes

2. **Recall** the three factors that determine how much thermal energy an object contains.
3. **State** the form of energy contained in a piece of wood.
4. **State** the forms of energy a piece of wood gives out when it burns (Figure 8.20).

Figure 8.20 Wood stores energy that can be released in a form of useful energy when burned.

5. **Identify** a form of energy that is *not* a form of wave energy.

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Understanding

6. **Describe** a situation that involves elastic potential energy.
7. **Describe** how sound energy travels.
8. **Explain** what is meant by the term ‘potential energy’.
9. **Explain** which balloon in Figure 8.21 has the most elastic potential energy.

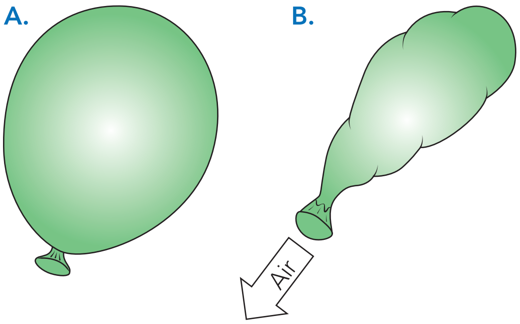

Figure 8.21 Elastic potential energy of balloons

Applying

10. **Identify** the form of energy gained when a person climbs a ladder (see Figure 8.22).

Figure 8.22 Person climbing a ladder

11. **Identify** the forms of energy emitted by lightning (see Figure 8.23).

Figure 8.23 Lightning

12. **Identify** the forms of energy possessed by a helicopter as it hovers in the air (see Figure 8.24).
13. **Identify** the main form of energy that peanuts contain.

Figure 8.24 A hovering helicopter

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Analysing

14. Look at the diagram in Figure 8.25 and use it to answer the following questions.

- **a)** **Identify** which letter represents the position where the ball has the most GPE.
- **b)** If the ball moved from C to A, **state** if there would be an overall gain or loss of GPE.

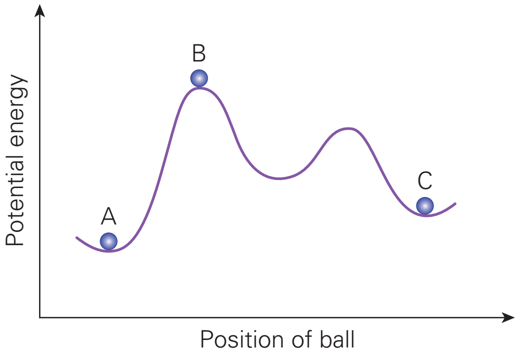

Figure 8.25 Gravitational potential energy

15. Look at the following list of energy sources and **organise** them from most used to least used in your household:

- electrical energy
- chemical energy
- sound energy
- light energy
- thermal energy

16. Examine Figure 8.26 and **identify** all the different forms of energy that you can see evidence of.

Figure 8.26 A laundry contains many different forms of energy.

Evaluating

17. List the devices in your home that use energy. Include at least two that don't use electricity, and at least one of these should be a manual (unpowered) device. For each device in the list, **determine** the form of energy used as the input (that operates it) and the forms of energy that it outputs (include the 'useful' output as well as the outputs that represent wasted energy).

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8.2 Energy is conserved

Learning goals

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

1. Define the Law of Conservation of Energy.
2. Explain heat transfer by conduction, convection and radiation.
3. Describe how energy is transferred and transformed using flow diagrams.
4. Calculate energy efficiency using energy inputs and outputs.
5. Explore energy transfers in pendulums, cranes and car crashes.

WORKSHEET
Energy transfers and transformations

Energy can be transferred from one object to another or even transformed into another type of energy. However, when energy is transferred or transformed, it always obeys the **Law of Conservation of Energy**: energy can neither be created nor destroyed. In any process, the amount of energy present at the beginning must equal the amount of energy present at the end.

Law of Conservation of Energy
the law that states that energy cannot be created or destroyed

Figure 8.27 City lights in Melbourne. The Law of Conservation of Energy means the amount of electrical energy used by each light is exactly the same as the sum of the amounts of thermal energy and light energy given out.

Did you know? 8.4

Where does the Sun get its energy from?

Einstein stunned the world when he proposed that mass can be converted into energy (and vice versa), according to a simple and famous formula:

$$E = mc^2$$

In this formula, E = energy, m = mass and c = the speed of light (3×10^8 m/s). Basically, the formula means that a small amount of mass can be converted into a lot of energy, or the reverse.

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This explains where the Sun has been getting its energy from, to shine so brightly for so long. Deep inside the Sun, nuclear reactions are converting five billion kilograms of matter into energy every second. This energy is emitted at the Sun's surface as light and heat.

Figure 8.28 The Sun will not run out of fuel any time soon.

Will the Sun ever run out of fuel? Luckily for us, the answer is: not for a very long time. The Sun is so big that, even at its current rate, much less than 1% of its mass has been radiated away since it was formed. As the Sun loses mass, its luminosity increases and it is estimated that in a billion years, a 10% brighter Sun will have rendered Earth inhospitable to life. It will take a few more billion years before it runs out of fuel.

Quick check 8.4

1. **State** the Law of Conservation of Energy.
2. **Explain** the meaning of the Law of Conservation of Energy.

Energy transfer

Kinetic transfer

Energy is the ability of an object to do work, and this energy can be transferred from one object to another. This is known as an **energy transfer**. For example, a golf club has kinetic energy when it swings through the air. When the club hits a golf ball, some of this kinetic energy is transferred to the ball, making it move.

energy transfer the movement of energy from one place or object to another

Figure 8.29 When a golfer hits a golf ball, they transfer kinetic energy from the golf club to the ball.

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Heat transfer

Thermal energy is another type of energy that can be transferred. If an object of high temperature is placed in contact with an object of lower temperature, thermal energy will flow from the hot object to the cold object. This flow will continue until the objects are the same temperature.

There are three ways in which heat can be transferred: conduction, convection and radiation.

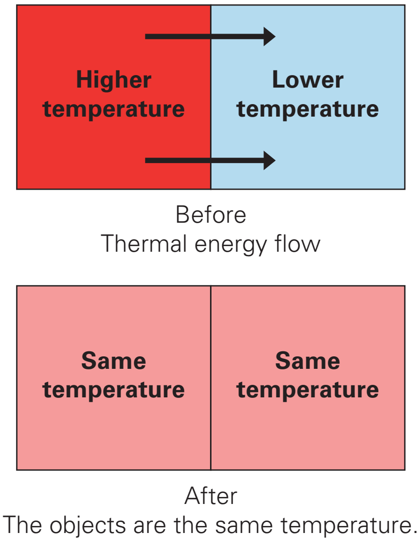

Figure 8.30 Heat (thermal energy in transit) flows from an object of higher temperature to one of lower temperature, until the objects are at the same temperature.

Conduction

Conduction occurs when an object or region with higher thermal energy transfers this energy to an object or region with lower thermal energy through the vibration of particles. The particles of the hotter object have more kinetic energy. This kinetic energy is transferred to the cooler object through the direct collision of particles. The transfer of thermal energy occurs until both objects reach the same temperature. Have you ever accidentally burned yourself on the handle of a metal pan, or a metal cup? Some substances, such as metals, are good **conductors** of heat. This means heat energy travels quickly through the material, and it is why metal handles often have a plastic or rubber covering. Materials such as plastic, wood or cloth are called **insulators** because thermal energy does not flow easily through them.

conduction	the transfer of thermal energy through collisions between particles
conductor	(heat) a substance that allows heat to pass through it easily
insulator	(heat) a substance or material that does not allow heat to pass through easily
convection	the transfer of thermal energy due to the movement of particles in a liquid or gas

Figure 8.31 You can hold the handle of a metal pan without burning yourself if it has a plastic covering.

Figure 8.32 A metal cup will heat up much faster than a ceramic mug because metal is a good conductor of heat.

Convection

Convection occurs when heat energy is transferred from one place to another due to the flow of a liquid or gas. Have you ever heard the saying, ‘hot air rises’? This can be seen in the example of hot air balloons. When the air inside the balloon is heated, the increased movement of the particles cause it to expand and become less dense than the colder air outside the balloon. This causes the balloon to rise. When it is time to come down, the heat is turned off and the particles of air have less kinetic energy. The particles move closer together and the density of the air increases, causing the balloon to gradually fall.

Figure 8.33 A hot air balloon over Melbourne CBD. A flame heating the air inside the balloon can be seen.

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Radiation

The third type of heat transfer, radiation, does not require a medium to travel through. Think about a time when you sat outside and felt the warmth of the Sun. For much of the distance between Earth and the Sun, there is no matter because space is a vacuum. The thermal energy reaching your skin does not need particles to transfer the energy; rather, it travels at the speed of light in electromagnetic waves. Energy transferred by electromagnetic waves is called electromagnetic radiation. Radiant thermal energy, also known as infrared radiation, is an example of this. Energy transfer via waves will be covered in detail in Year 9.

Figure 8.34 Radiant energy from the Sun warms us up and melts our ice cream!

Quick check 8.5

1. **State** the type of heat transfer that occurs when you burn your hand on a hot plate.
2. **Describe** thermal conduction in a solid object.
3. **Explain** how thermal energy travels around a liquid or gas.

Practical 8.1

Investigating thermal energy

Be careful

Ensure safety equipment is worn at all times. Do not stand over the beaker once it has been heated.

Aim

To investigate the relationship between thermal energy and different volumes of water

Materials

- Bunsen burner
- gauze
- tripod
- heatproof mat
- glass beaker
- thermometer

Method

1. Put 200 mL of water in a beaker and measure the temperature. Record this in your results table.
2. Heat this water for one minute using a Bunsen burner.
3. Stir the water and measure the final temperature after it has been heated. Record in your results table.
4. Repeat steps 1–3 using 300 mL, 400 mL and 500 mL of water. Make sure the glass beaker is cooled between experiments so that the initial temperature is the same. It might save time to start with four identical beakers with water at room temperature.

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Results

Complete the following table with your results.

Table showing temperature of different volumes of water

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

Calculate the thermal energy in each volume of water using the equation:

Volume in mL × specific heat capacity × change in temperature

The specific heat capacity of water is 4.2 J/mL/°C.

Discussion: Analysis

1. Describe how the change in temperature differed between volumes of water.
2. Describe how the thermal energy differed between volumes of water.
3. Referring to your results, explain the relationship between volume of water and thermal energy.

Discussion: Evaluation

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

Conclusion

1. State whether the aim was achieved.
2. Support your statement by summarising the data you gathered, and include potential sources of error.

Energy transformations

There are many ways in which energy can be converted from one form to another. Combustion involves burning and converts chemical energy into thermal and light energy. Machines use fuel or electrical energy and convert it into kinetic energy. **Generators**, powered by steam **turbines**, can convert kinetic energy into electrical energy. In leaves, the biological processes in photosynthesis convert light energy from the Sun into chemical energy in the form of carbohydrates, such as sugars. Thermal energy or sound energy is often produced as a by-product of energy transfers and transformations.

generator
a device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

turbine
a device that converts the kinetic energy of a fluid into useful work, e.g. a windmill

Energy transformations can be represented in a flow diagram (see Figure 8.35). On the left-hand side of the flow diagram are the energy inputs. On the right-hand side are the energy outputs. Sometimes, a device can transform the input energy into more than one type of output energy. The output energy may be a useful form of energy or a waste. Waste energy may be included as an energy output, but is sometimes omitted. If a large amount of the input energy is transformed into waste, the device is not considered energy efficient. A brief description of how the machine works may be placed between them, and arrows can be added to show the flow of energy.

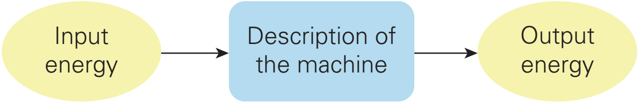

Figure 8.35 A simple energy flow diagram

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For example, Figure 8.36 shows the energy flow diagram for a candle that has been lit.

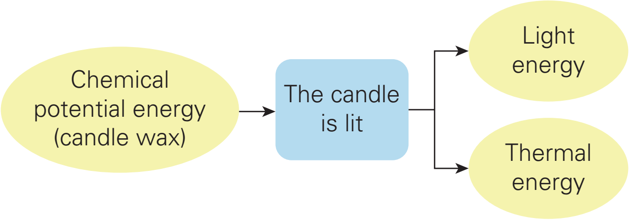

Figure 8.36 Energy flow diagram for a burning candle

Some energy flow diagrams may have intermediate steps involving another form of energy. For example, a battery-powered torch has a more complex energy flow diagram (see Figure 8.37).

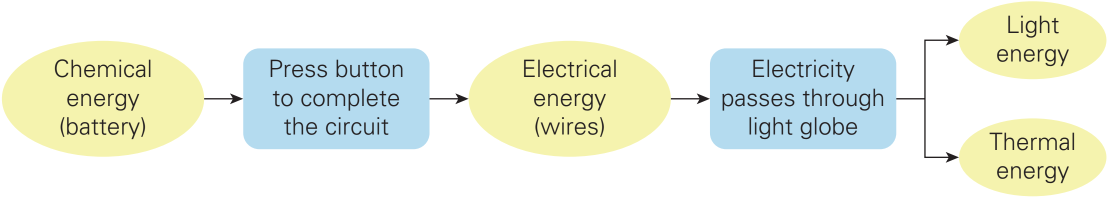

Figure 8.37 Energy flow diagram for a battery-powered torch

Investigating an electric kettle

An electric kettle uses electrical energy to boil water. It contains a heating element that converts electrical energy to thermal energy when electricity passes through it. The heating element then heats the water in the kettle to 100°C, at which point the water boils.

Figure 8.39 shows a flow diagram representing the changes in energy in the example of the kettle.

Figure 8.38 An electric kettle converts electrical energy into thermal energy.

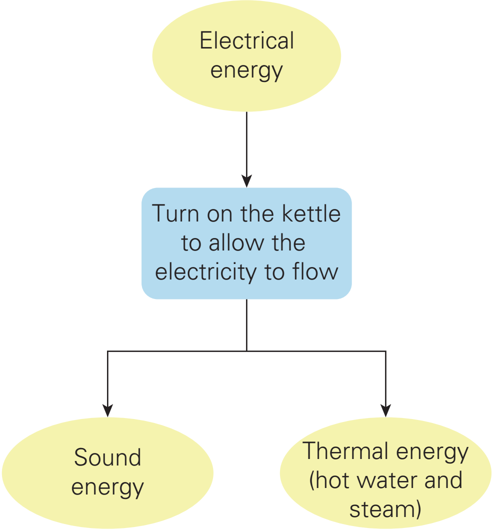

Figure 8.39 Energy flow diagram for an electric kettle

Quick check 8.6

1. **Explain** what occurs during an energy transformation.
2. **List** two examples of an appliance that transforms energy.

Explore! 8.3

Fire-starting

Aboriginal and Torres Strait Islander Peoples use several different methods to light fires. Specific practices differ among communities. The most common are called the *fire drill* and *fire saw* methods.

For the fire (or hand) drill method, a V-shaped notch is cut into a flat piece of wood (called the hearth). Bark or dried grass is placed under the hearth to catch embers and a long, thin stick (called the drill stick) is pushed into the notch and twirled vigorously by rubbing it between the hands. The friction between the two pieces of wood causes the end of the drill stick to glow red and embers are formed. The hearth is tapped to move the embers to the bark or dried grass, and then they are blown on until a flame forms.

The fire saw method works by rubbing two pieces of wood together in a sawing motion. One piece of wood has a notch at the end of it (or a split branch can be used), while the other is a piece of hardwood with a sharp edge (for example, a boomerang). The hardwood saws the notched piece until embers form, which ignite flammable material placed beneath it.

Figure 8.40 Can you identify the drill method and the saw method in this illustration?

Two other methods used less commonly are the *fire plough* and *percussion methods*. The first method is mainly used by people in the north-west of Australia. It involves rapidly rubbing a stick back and forth within a trough or groove cut into the base timber to create embers. Percussion methods of fire starting are used by groups in south-central Australia and involve striking stones together to create sparks that can then ignite dried grass.

1. Which method do you predict is the most efficient to start a fire?
2. Conduct some research and find out whether your prediction was correct or not.
3. Draw an energy flow diagram for the fire drill method.

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Investigating a car accelerating from rest

A petrol-powered car accelerating on a flat road uses its engine to convert the chemical potential energy of the fuel into kinetic energy as the car increases its speed.

Figure 8.41 An accelerating car is gaining kinetic energy.

Figure 8.42 shows a flow diagram for a petrol-driven car accelerating from rest.

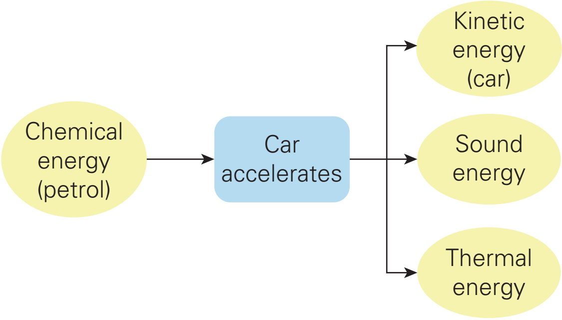

Figure 8.42 Energy flow diagram for a petrol-driven car accelerating from rest

If the car was powered by an electric battery, then the energy flow diagram would be slightly different (see Figure 8.43).

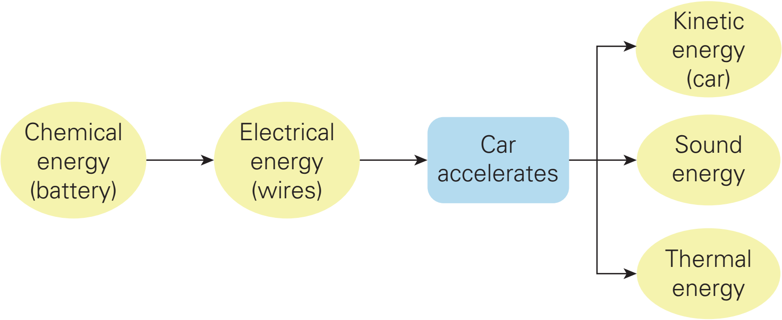

Figure 8.43 Energy flow diagram for a battery-powered car accelerating from rest

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Try this 8.5

Water wheels and catapults

A water wheel is a machine used to convert gravitational potential energy stored in water positioned above the ground into the kinetic energy of the spinning wheel.

Figure 8.44 shows a flow diagram representing this transformation.

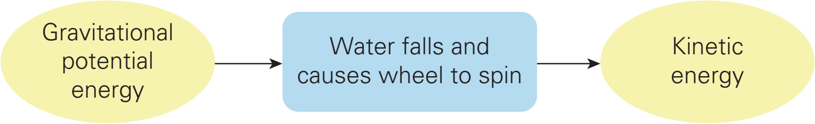

Figure 8.44 A flow diagram for a water wheel

Figure 8.45 A water wheel

Figure 8.46 Children playing with a catapult

Research how a catapult works and draw a flow diagram to represent the energy transformations occurring in the machine.

Investigating a bow and arrow

When a bow is stretched to shoot an arrow, the wood and bowstring bend with an elastic force, and this stores energy. The further the bow string is pulled, the more energy is stored. When the arrow is released, the elastic potential energy is converted to kinetic energy as the arrow increases its speed (Figure 8.47).

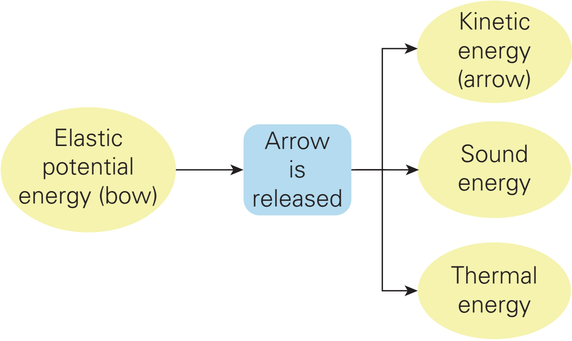

Figure 8.47 Energy flow diagram for an arrow being shot from a bow

ISBN 978-1-009-60327-0 Shaw et al.

VIDEO
Energy transformations in a hot air balloon

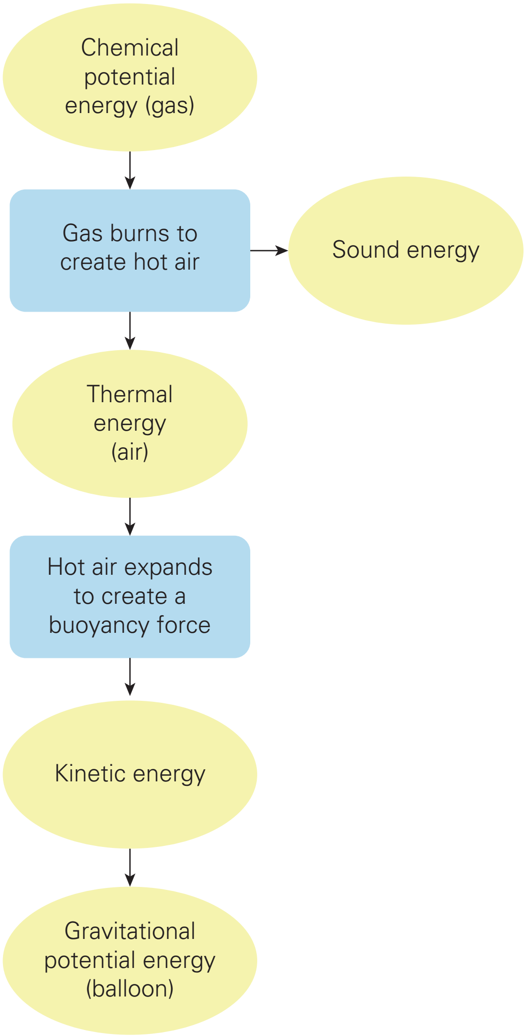

Figure 8.48 Energy flow diagram for a hot air balloon

Investigating a hot air balloon

Sometimes a machine can convert a source of energy into two or more forms at the same time. The operation of a hot air balloon involves multiple energy changes. When the hot air balloon first takes off, chemical potential energy is stored in the form of natural gas (in the gas cylinder in the basket of the balloon). When the gas is burned, it releases thermal energy, which heats the air in the balloon, as well as some waste sound energy. The air in the balloon expands as it warms up, and this makes the air inside the balloon lighter than the air around the balloon. The balloon then rises, due to buoyancy forces, gaining kinetic energy and gravitational potential energy as it gains altitude.

Investigating an aircraft taking off

When an aircraft takes off, it starts moving slowly from one end of the runway and then accelerates under full power until it leaves the ground at the other end. When it first starts its take-off, the jet has chemical potential energy stored in the form of aviation fuel in its tanks. The fuel is ignited in the jet engines to create a force that accelerates the aircraft along the runway, gaining kinetic energy as it does so. When the aircraft reaches sufficient speed, it lifts off and gains gravitational potential energy as it rises into the air.

An aircraft in flight is burning fuel and making noise while in movement. This thermal and sound waste energy can even be quantified in an energy flow diagram. In Figure 8.51, the approximate percentages of the two forms of waste energy have been added to the flow diagram for the jet aircraft. These can be included if they are known. Remember, the total amount of **input energy** must exactly equal the total **output energy** when waste energy is included.

input energy the energy that a machine or device uses as its source of energy

output energy the energy that a machine or device provides or wastes

Figure 8.49 A hot air balloon converts chemical energy to thermal energy, then kinetic energy as it moves and then gravitational potential energy as it gets higher.

Figure 8.50 An aircraft converts chemical potential energy to kinetic energy and gravitational potential energy.

In this example, the useful energy is kinetic energy (45%) and gravitational potential energy (15%), which adds up to 60%. This means that 60% of the energy input is converted to useful energy, and the efficiency rating of the aircraft's engines is 60%. The other 40% is wasted through thermal and sound energy.

WIDGET
Energy forms and transformations

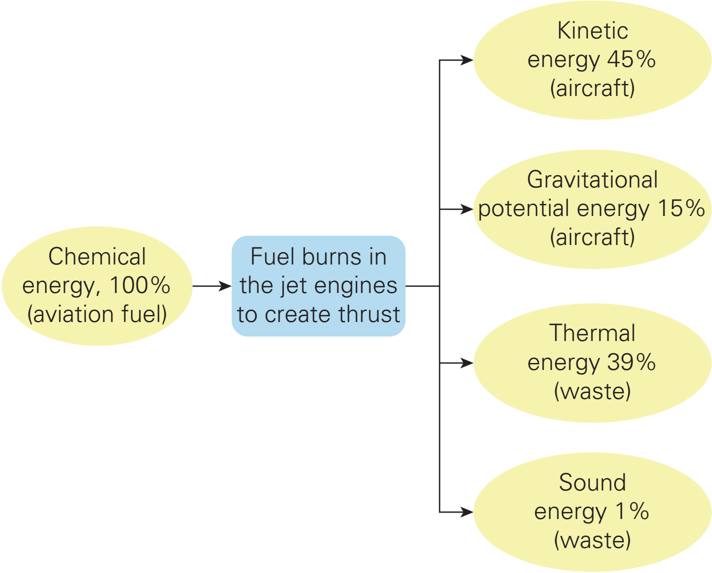

Figure 8.51 Energy flow diagram for a jet aircraft taking off

Quick check 8.7

1. **Draw** flow diagrams for the following energy transformations.
   - a) a television converting electrical energy to sound, thermal and light energy
   - b) a light globe converting electrical energy to light and thermal energy
   - c) a human converting chemical potential energy from food into kinetic energy when moving

Waste energy

Useful energy is the output energy that the process is designed to produce. **Waste energy** is any other form of energy, usually thermal energy or sound, that is not wanted. An electric filament light globe uses electrical energy to create light as useful energy; any thermal energy produced is waste energy. A petrol-driven lawnmower converts chemical energy in the petrol into kinetic energy and rotational kinetic energy, with thermal energy and sound as waste forms of energy.

waste energy the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy and sound

When a candle burns, chemical potential energy is converted by combustion into light, with thermal energy released as waste energy. A hurdler converts chemical energy in food to kinetic energy but releases thermal energy as waste energy.

A two-step example is a battery-powered torch. The input energy source is chemical potential energy in the battery. This is converted first to electrical energy and then to light energy in the globe with some waste thermal energy also. In the same way, a battery-powered radio converts chemical energy (in the batteries) to electrical energy then to sound.

Figure 8.52 A filament light globe emits light energy but also thermal energy as waste.

Figure 8.53 The chemical energy in petrol is converted into kinetic energy to move the lawnmower.

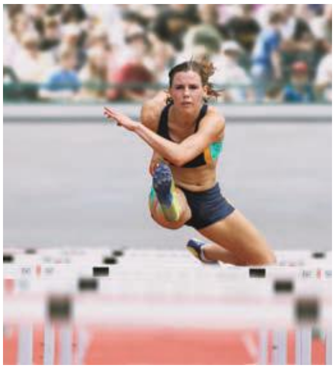

Figure 8.54 A hurdler has kinetic energy but may release waste energy as heat or sound.

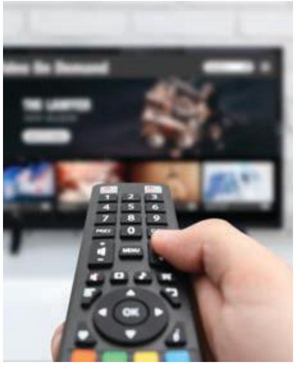

Figure 8.55 A TV remote converts chemical energy to light energy (infrared).

ISBN 978-1-009-60327-0 Shaw et al.

Explore! 8.4

Sankey diagrams

A **Sankey diagram** is a special type of flow diagram that shows the amount of input energy converted into each form of output energy. A Sankey diagram provides a visual representation of how energy efficient a device is. The horizontal arrow represents useful energy, while the downward arrow represents waste energy. The size of the arrow represents the proportion of energy transformed.

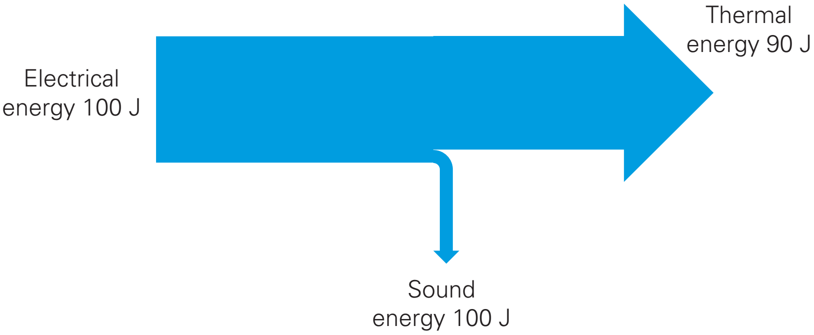

Figure 8.56 A Sankey diagram for a reverse cycle heater

For example, Figure 8.56 shows a Sankey diagram for a reverse cycle heater. Around 90% of electrical energy is converted into useful energy, which is thermal energy in this case. 10% of the electrical energy is wasted (converted into sound energy, which is not useful in a heater). This heater would be considered energy efficient because most of the electrical energy is transformed into a useful form.

Use the internet to research different types of light globes such as LED (light-emitting diode), halogen and compact fluorescent lamps (CFLs) and compare their efficiencies.

Sankey diagram a flow chart that represents the flow of energy through a system

Explore! 8.5

Battery recharge cycles

Have you ever noticed that an older model of mobile phone or laptop runs out of battery faster than when it was new? Perhaps the chemical energy stored is just not as much as it used to be? Is energy lost as a by-product, such as heat?

Use the internet to find a credible source of information to answer the question: how does battery energy output change over many recharging cycles?

Figure 8.57 Does a smartphone battery really recharge to 100%?

Try this 8.6

Energy transformations on roller-coaster rides

Observe the roller-coaster ride in Figure 8.58. Construct an energy flow diagram to represent the energy transformations in this ride.

Figure 8.58 What energy transformations occur on a roller-coaster ride?

ISBN 978-1-009-60327-0 Shaw et al.

Exploring energy in systems

Our understanding of energy conversions can be applied to systems. In this context, a **system** is defined as a portion of the universe that is being analysed. Within a system, energy is conserved, and thus all energy conversions can be accounted for.

Let's have a look at the energy conversions of physical events in some everyday systems.

WORKSHEET Exploring energy in systems

system
a portion of the universe that is being analysed

Pendulums

The pendulum is a classic example of the Law of Conservation of Energy in action.

When we talk about a pendulum, we are referring to a massless string attached to a pivot point with a bob on the other end. The bob is a dense object that accounts for all of the mass of the system. In this scenario, we will ignore the effects of air resistance acting on the pendulum and friction in the pivot. So this is an idealised system.

Figure 8.59 A pendulum

The pendulum can be explored as a system where energy is successively transformed between gravitational potential energy and kinetic energy. When the bob containing the mass is drawn upwards or outwards, the system gains gravitational potential energy. When the mass is released, the energy is converted into kinetic energy due to gravity pulling the bob down. Kinetic energy in the bob causes it to swing up in the opposite direction, during which its kinetic energy is once again converted into gravitational potential energy. This cycle repeats itself a number of times until, in a real pendulum, the bob comes to a rest.

The reason that the bob slows down and eventually stops is that, with each successive energy conversion, energy is lost to the system as heat and sound, primarily due to air resistance.

Figure 8.60 A pendulum tracing circles in sand decreases its motion before coming to a stop due to friction.

Explore! 8.6

Perpetual motion machines

A perpetual motion machine is a hypothetical machine that remains in motion indefinitely. Many people have attempted to make a perpetual motion machine, but none will ever succeed as perpetual motion machines are physically impossible because we are unable to remove all forms of friction.

According to the Law of Conservation of Energy, energy cannot be created or destroyed, and therefore energy needs to be applied to keep a machine moving indefinitely because of wasted energy. We are not able to remove all forms of friction – except in the microscopic world. Therefore, if no energy is applied to a system that eternally produces energy, that system will violate the Law of Conservation of Energy.

Research perpetual motion machines to answer the following questions.

1. Is it possible to create a perpetual motion machine? Why or why not?
2. In superconductors, charge can flow without any resistance. It is possible to make a superconducting ring with a persistent current that will continue to circulate forever. Is this an example of a possible perpetual motion machine? Can we use this to do any useful work? Explain your reasoning.

ISBN 978-1-009-60327-0 Shaw et al.

Quick check 8.8

1. **Describe** how a playground swing can be considered a pendulum.
2. **Explain** why a person needs to be pushed on a swing to continue to reach the same height.
3. Using the Law of Conservation of Energy, **explain** what happens to the energy lost in a system involving a pendulum.

Figure 8.61 A container lifted by a crane in a shipyard has kinetic and gravitational energy.

Cranes

A crane is used to lift and lower heavy or large objects, such as the containers in a shipyard (as in Figure 8.61). Let us look a bit closer at the energy conversions that are taking place.

While a container is being lifted, it will have some kinetic energy as the object is in motion. Additionally, the container increases its height above the surface of Earth, so it gains gravitational potential energy. The Law of Conservation of Energy states that energy cannot be created or destroyed, so where does this energy come from?

Remember, work is defined as the amount of energy transferred when an applied force causes an object to move some distance. So we can conclude that the energy gained by the container is due to work being done on it. The applied force in this situation would be the tension force in the chain lifting it up. Some initial work is required to set the container in motion, thus transferring kinetic energy to the system. As more work is done on the container, it gains more energy – gravitational potential energy.

What would happen if the chain broke and the container dropped to the ground? Naturally, there would be a change in gravitational potential energy as the container's height decreases. As there is a change in energy in the system, work is being done, so a force must be being applied. The force doing work on the container when it falls is the gravitational force, arising from gravity pulling the container down. From the Law of Conservation of Energy, we know that the total energy in a system must be conserved. Thus, gravitational potential energy is converted into kinetic energy as the object accelerates towards the surface of Earth. Upon landing, the gravitational potential energy is reduced to zero and all of the kinetic energy is converted into thermal energy and sound energy.

Quick check 8.9

1. Use a flow chart to **illustrate** the changes in energy that occur when a weightlifter lifts a barbell and then drops it.
2. **Explain** how work is done on a falling object.

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Car crashes

Moving cars have large amounts of kinetic energy due to their motion. What happens to all this energy if the car crashes?

During a collision, the objects involved in the collision transfer energy to each other and to the rest of the system. According to the Law of Conservation of Energy, energy cannot be created or destroyed and can only be transferred to other objects or transformed into other forms. This holds true for collisions, so the large amounts of kinetic energy that moving objects hold have to go somewhere. The damage caused by collisions results from the transfer of large amounts of energy over very short distances and time intervals. Remember that work is defined as the amount of energy transferred when an applied force causes an object to move some distance. The size of the force is proportional to the amount of work done, and thus proportional to the amount of energy transferred. In other words, the more energy transferred, the more force that is applied. As the distances and the time involved are reduced, the forces involved increase.

In Figure 8.62, a car has crashed into a tree. What energy changes would have occurred in that collision? The car had kinetic energy from its initial motion, the magnitude of which depended on its mass and speed. After the collision, both the car and the tree are stationary, and thus have no kinetic energy. From the Law of Conservation of Energy, we know that energy is not destroyed, so work must have been done on the car to transfer that energy. It is the force of the tree on the car that brings it to a stop; therefore, it is the work done by the tree on the car that reduces the car's energy to zero.

Figure 8.62 What happens to the car's kinetic energy in a collision?

As the force produced in a collision is the primary danger and cause of injury, what can we do to reduce it, and thus reduce injury? Many safety features built into the design of cars aim to do just that, for example crumple zones, seatbelts and airbags.

Crumple zones

Crumple zones, as the name suggests, are sections of the car designed to crumple in a collision. They crumple when they absorb some of the energy transferred during the collision. This results in less energy being transferred, and thus less force applied, to the occupants of the car, reducing the severity of injuries.

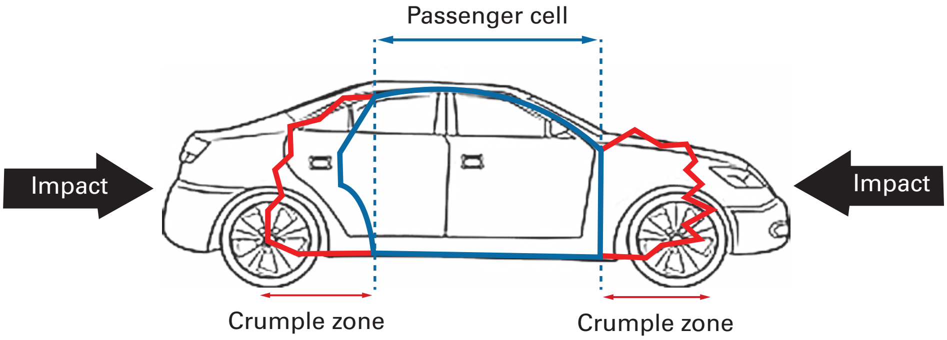

Figure 8.63 Crumple zones are usually located at the front and back of cars, and are designed to absorb some of the energy in a collision.

To protect the driver and passengers, the passenger cell or cabin is made of stronger materials that are not designed to crumple. Crumple zones are usually, but not limited to, the front and back of the car, as these are the sections of the car that are most likely to be affected by a crash.

ISBN 978-1-009-60327-0 Shaw et al.

Figure 8.64 A seatbelt is a safety device in car that prevents injuries by helping you come to a stop safely.

Figure 8.65 An airbag inflating on impact protects a head from hitting the steering wheel or windscreen.

By deforming, crumple zones not only absorb some energy (as work is being done to crumple the car) but also increase the time (and thus the distance) over which the collision occurs. Force is inversely proportional to displacement; therefore, for a set amount of work, by increasing the displacement we are decreasing the force applied.

Seatbelts

In a collision or sudden stop, an unrestrained object will continue to move in its original direction until a force is applied to make it stop – this is Newton's first law of motion (you will learn more about Newton's laws in your Year 9 studies). Seatbelts make sure that the passenger stops moving in a collision by applying that force. As discussed above, the main purpose of car safety features is to reduce the size of the applied force and in doing so reduce the severity of injuries caused during collisions. Seatbelts have a three-point anchor system and are designed to increase the area over which the force is applied – by spreading the force, the potential for injury is reduced significantly. They also stretch slightly, and this increases the stopping distance and reduces the force on occupants.

Airbags

Airbags are another car safety system designed to protect you in a collision by reducing the force applied in bringing you to a stop. As seatbelts only apply a force to the body, the head will continue in its original path of motion. Therefore, airbags are in place primarily to protect the occupants' heads from hitting the dashboard, steering wheel or windscreen.

Airbags are cushions that inflate with a gas in the event of a collision. The inflated airbag increases the area over which the force is applied, as well as increasing the time and distance over which the force acts. All of these factors reduce the size of the force experienced by the occupant, which reduces the severity of injuries caused in a collision.

Quick check 8.10

1. **Discuss** what would happen if a car stopped suddenly and the occupant was not wearing a seatbelt.
2. **Explain** how energy is conserved in a collision.

Section 8.2 review

Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 8.2 questions

Remembering

1. **Define** thermal energy.
2. **Recall** the three factors that determine how much thermal energy is present in an object.
3. **Define** waste energy.

Understanding

4. **Describe** the difference between an energy transfer and an energy transformation.
5. **Describe** the energy transformation that occurs in the Sun.
6. **Describe** four situations that involve potential energy.
7. **Draw** an energy flow diagram for each of the following situations.
   - a) A stone is dropped from the top of a building.
   - b) A car is slowing down as it moves up a hill.
   - c) A charcoal fire is burning in a barbeque.
   - d) A bungee jumper jumps from the top of the jump to the bottom.
   - e) An electric train starts from rest and builds up to full speed.
   - f) A person rides on an escalator from the bottom to the top.
   - g) A dog is sprinting.

Figure 8.66 Cooking food on a charcoal fire barbeque

Figure 8.67 An electric train

Figure 8.68 People riding escalators

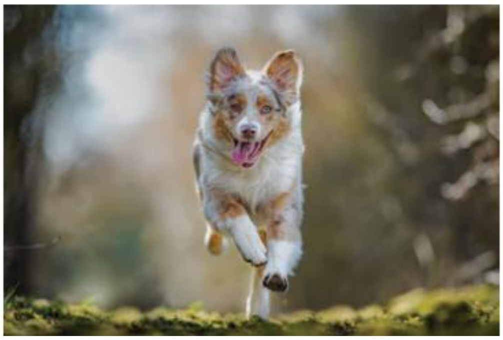

Figure 8.69 An Australian shepherd in full flight

Applying

8. Look closely at Figure 8.70.
   a) **Identify** the components of the playground that involve gravitational potential energy.
   b) **State** a way in which elastic potential energy could be incorporated into this playground setting.

Figure 8.70 A playground

9. **Differentiate** between the forces felt by occupants in a car collision in a car with and without an airbag.

Analysing

10. Think about all the different types of energy we encounter every day; driving a car is one example. Pick another example and **consider** how you can make the process more energy efficient.
11. When an object is dropped, energy is being transformed, and thus work is being done. However, for work to be done, a force needs to be applied to the object. **Propose** the force that is responsible for work being done.
12. Sports cars often have more crumple zones than other cars. **Propose** a reason for this.

Evaluating

13. Cars are energy inefficient.
    a) **Determine** the input form of energy and the useful and wasted forms of energy output.
    b) **Propose** some other forms of transport that are more energy efficient.

8.3 Energy efficiency

Learning goals

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

1. Describe the significance of energy ratings of household appliances.
2. Describe the principles of passive house design.

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 in the case of **photovoltaic** solar panels, or thermal energy in the case of solar thermal panels.

solar energy a renewable source of energy that converts the light energy from sunlight directly into another useable type of energy

photovoltaic able to produce electricity from light

Figure 8.71 This house has photovoltaic solar panels on the roof to generate electricity. It also has two solar thermal panels for heating water.

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 8.72 – a rating out of 6 stars, a rating out of 10 stars for super-efficient appliances, or a 10-star pool pump rating.

ISBN 978-1-009-60327-0 Shaw et al.

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.

Figure 8.72 Three types of energy rating labels found on appliances in Australia

Try this 8.7

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 8.11

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.

Explore! 8.7

Energy-efficient homes

Ensuring that you choose energy-efficient devices in your home is not only beneficial for the environment but will also save you money. Use the Government Energy Rating website to learn more about energy rating labels and list some considerations you should take before buying a new appliance such as a washing machine or refrigerator.

Science as a human endeavour 8.1

Clean energy breakthroughs

In 2024, Australian scientists at CSIRO set a new efficiency record for printed solar panels. Taking light energy from the Sun and transforming it into electrical energy for household use, traditional solar panels can be seen on the roofs of many Australian houses. Though these solar panels will continue to be part of Australia's clean energy future, they are rigid and heavy, which limits where they can be used. A new generation of solar panels can be printed onto thin plastic films, meaning they are flexible and highly portable. Using an advanced material called perovskite and replacing expensive metals such as gold with carbon-based inks, the team at CSIRO have been able to significantly decrease the cost and increase the rate of production. These solar panels can be transported to anywhere there is sunlight, making them more widely available. They have even been sent into space!

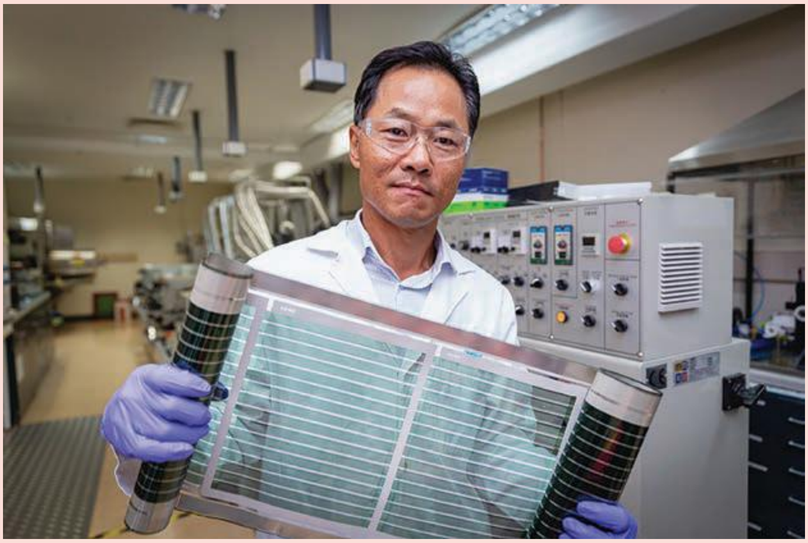

Figure 8.73 Dr Doojin Vak holding CSIRO's flexible solar panels

Sustainable homes

From heating and cooling to operating all our appliances, running a home takes a lot of energy. A household's energy usage varies depending on its location, the time of day or year, and the design of the house. For example, Melbourne households use a lot of energy to heat their homes in winter due to the low outside temperatures. When building a house, using certain materials can increase the cost-effectiveness of keeping a house cool in summer and warm in winter. This concept is called **passive design** and aims to work with the local climate to keep the house at a comfortable temperature, with limited need for a heater or air conditioner. Passive design can be as simple as ensuring that the main living areas face north so that the winter sunlight can keep these rooms warm in winter. Similarly, avoiding east or west-facing windows will keep a room cooler in summer.

Figure 8.74 Large, north-facing windows allow the sun to heat a room during winter.

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Try this 8.8

Home energy usage

Home electricity and gas plans often have different prices for ‘on-peak’ and ‘off-peak’ usage. This price difference reflects the changes in energy usage during the day and night. Typically, energy usage increases during the days and hours people are at home, that is, at night and on weekends.

Make a list of the appliances that are in use during the day when no one is at home, and at night when everyone is at home. Analyse both lists and identify areas where you can reduce your energy usage.

Did you know? 8.5

Queenslander architecture

Houses in Queensland are designed to stay cool due to the hot and humid summers experienced in that state. A specific type of architecture that emerged in the 1800s is called ‘Queenslander’ architecture, which aimed to build houses that suited the Queensland climate. All traditional Queenslanders are constructed from a timber frame and have a metal roof. These materials prevent heat from being retained in the structure and cool down quickly overnight. Queenslander houses are typically raised off the ground, providing an area under the floor that increases ventilation and keeps the house cool. Another common feature is a veranda that limits the amount of sun entering the windows and heating rooms.

Figure 8.75 A typical Queenslander with a veranda and area under the house

Insulating materials reduce heat transfer and keep houses at a comfortable temperature all year round. Insulation is usually installed in the ceiling or walls of a home and works by trapping pockets of air, which resists heat flow. Figure 8.76 shows polystyrene sheets being installed beneath the floor as a form of insulation. Materials such as wool and polyester can also be used.

Figure 8.76 Polystyrene sheets being installed beneath a floor

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Practical 8.2

Insulation

Aim

To test different materials for their insulating properties

Materials

- empty soft drink cans × 6
- thermometers × 6
- a range of materials to test insulation
- hot water
- sticky tape
- measuring cylinder
- funnel

Method

1. Cover each can in a different material, leaving one can with no covering.
2. Fill each can with 100 mL of hot water using a funnel. Ensure the water is as close to 80°C as possible when you start measuring.
3. Measure the temperature in each can every 5 minutes, for 20 minutes.
4. Record your results in the results table.

Results

Copy and complete the following table.

Table showing temperature of different can-covering materials

Can covering	Temperature (°C)				
	0 min	5 min	10 min	15 min	20 min
None					

Discussion: Analysis

1. Which material was the best insulator? How did you know this?
2. Which of the three methods of heat transfer is responsible for the most heat loss from the can?

Discussion: Evaluation

1. How can the results from this experiment be used in the construction industry when considering energy-efficient/passive housing?
2. Are you confident that you would get the same result if you repeat the experiment? Were there any sources of error and, if so, how could you reduce or minimise these?

Conclusion

1. Draw a conclusion from this activity about the insulating properties of different materials, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that _____________.

Try this 8.9

Building a home

Use the internet to research materials used to build houses. Summarise three different building materials and how they contribute to the efficiency of a home.

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Go online to access the interactive section review and more!

Section 8.3 review

Online quiz	Section questions	Teachers can assign tasks and track results

Section 8.3 questions

Remembering

1. **Define** the term 'solar energy'.
2. **Recall** the meaning of passive design.

Understanding

3. **Explain** how the energy star rating system works.
4. **Explain** why it would benefit a company to make appliances with a higher energy rating.

Applying

5. **Summarise** ways in which you can make your house more energy efficient. For each suggestion, explain how it works.

Analysing

6. The following information applies to two different models of fridge. Note that the cost of electricity in Victoria 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.

7. Consider what the tradesperson is doing in Figure 8.77. **Explain** why the homeowners have hired him to do this job.

Figure 8.77 What is this tradesperson doing?

Evaluating

8. **Propose** one drawback of using solar energy for powering your home.

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Chapter review

Chapter checklist

Success criteria		Linked questions
8.1	I can define energy.	1, 6
8.1	I can describe the different types of kinetic and potential energy.	2, 3, 15, 16
8.1	I can distinguish between temperature, thermal energy and heat.	5
8.2	I can define the Law of Conservation of Energy.	12
8.2	I can explain heat transfer by conduction, convection and radiation.	19, 20c
8.2	I can describe how energy is transferred and transformed using a flow diagram.	11, 14, 20b
8.2	I can explain energy transfers in pendulums, cranes and car crashes.	9, 17
8.3	I can describe the significance of energy ratings of household appliances.	8
8.3	I can describe the principles of passive house design.	21

Scorcher competition

Review questions

Data questions

Go online to access the interactive chapter review!

Review questions

Remembering

1. **Define** energy and its units.
2. **Recall** the term for energy that is stored when a spring is compressed.
3. **Select** the correct description for each term in the table below.

Term	Description
Sound energy	The energy that moving objects have
Kinetic energy	A form of wave energy that can travel through space
Wave energy	A form of wave energy consisting of vibrations in the air
Thermal energy	Energy carried by a wave travelling on or through a substance
Light energy	The energy that moves between two objects of differing temperatures

4. **Name** an object that transforms:
   a) electrical energy into thermal energy.
   b) elastic energy into kinetic energy.
   c) chemical potential energy into kinetic energy.
   d) chemical potential energy into thermal energy.
5. **Describe** how energy rating labels on appliances provide useful information to consumers.
6. **Identify** where on a car you would find the crumple zones and describe why they are located there.

7. **Describe** the difference between heat and temperature.
8. Look around your environment and **identify** as many examples of energy as you can see.
9. As you go about your day, **identify** all the different types of energy transformations that occur.

Understanding

10. **State** whether each of the following sentences is true or false.
    a) When bouncing a ball, elastic potential energy is involved.
    b) An object can have energy even when it is stationary.
    c) An object must be moving to transform energy from one form to another.
    d) When driving a car, chemical potential, gravitational potential and kinetic energy are involved.
11. **Draw** a flow diagram showing the energy transformation that occurs in a gas stove.
12. **Explain** why a light globe with an input energy of 1200 J cannot produce 1500 J of light energy.
13. **Explain** the difference between an energy-efficient light globe and a less efficient light globe.
14. Use the diagram of a waterwheel in Figure 8.78 to **draw** an energy flow diagram for this process.

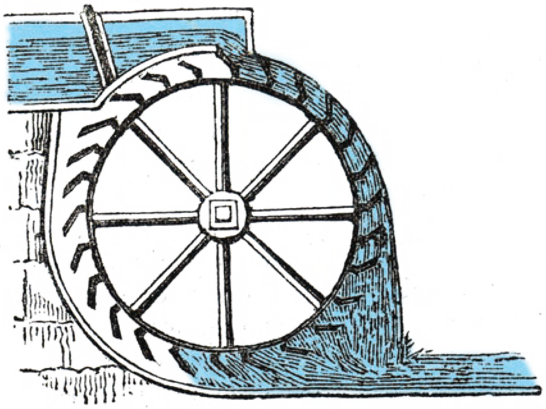

Figure 8.78 An overshot waterwheel

Applying

15. **State** the kind of energy you increase if you climb a mountain.
16. **State** the energy transformations that occur when someone climbs a set of stairs.
17. **Explain** why a real pendulum's motion is not infinite and will eventually come to a stop.

Analysing

18. **Consider** the Sun's role in life on Earth. Explain why there would be no life on Earth without the Sun.
19. **Contrast** convection and radiation in terms of thermal energy transfer.

Evaluating

20. 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) **Draw** a Sankey diagram for the ceiling fan.
    c) **Describe** how thermal energy is transferred between the metallic parts.
21. **Justify** why houses in different climates should differ in terms of their room and window placement.

Data questions

A group of students is testing the advertising claims of 10 different brands of rechargeable AA batteries, which are a source of chemical energy. A battery is able to transform chemical energy into electrical energy to power a device. When recharging a battery, the opposite energy transformation occurs. The amount of potential energy that a battery can transform is measured in volts (V). Each AA battery is claimed to provide at least 1.50 V when new. The initial voltage for three new batteries of each brand was recorded by preparing a circuit with a multimeter, and the data are presented in Table 8.3.

Battery brand (V)	Initial voltage (V)		
	First battery (V)	Second battery (V)	Third battery (V)
1	1.63	1.60	1.61
2	1.57	1.55	1.57
3	1.24	1.29	1.45
4	1.48	1.50	1.47
5	1.52	1.50	1.51
6	1.53	1.53	1.53
7	1.50	1.55	1.50
8	1.60	1.61	1.64
9	1.65	1.65	1.65
10	1.61	1.62	1.60

Table 8.3 Recorded voltage for three new AA batteries of different brands

Applying

1. **Identify** the battery with the highest initial voltage.
2. A 'flat' AA battery can be considered, in this case, to have a voltage of less than 1.3 V. **Determine** whether any of the newly purchased AA batteries are already flat.
3. For the first battery tested of each brand, remove any flat batteries as outliers and **calculate** the mean initial AA battery voltage.

Analysing

4. With respect to the initial voltage claim of at least 1.5 V, **identify** any patterns that appear in the observed initial voltages.
5. **Classify** the battery brands as those that meet their claim of an initial voltage of 1.5 V and those that don't consistently meet their claim.
6. Now **categorise** the battery brands that do meet their claim into those with an initial voltage much higher than the claim (1.60 V+) and those consistently just above the claim (1.50–1.59 V).

Evaluating

7. Battery brand 9 also claims to have the 'longest-lasting AA battery'. **Justify** whether the data in Table 8.3 supports this claim.
8. After complaints to battery brand 3 about the quality of their batteries, a spokesperson revealed that there was a 10% chance of a battery in their packs being sold with a voltage of less than 1.5 V. **Justify** this claim with respect to the reliability of the data presented in Table 8.3.
9. **Predict** whether these AA batteries would return to their 'as new' initial voltage after being recharged from flat.

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STEM activity: Constructing a model of an energy-efficient building

Background information

The Sun is the primary source of energy for our planet. Without the Sun, Earth would be a very different place. For example, almost all the water on the planet would be frozen; the constant darkness would make the process of photosynthesis impossible; there would be no sunsets, sunrises or seasons. In summary, life as we know it would not be possible on our planet.

Solar energy has been harvested by organisms on Earth for billions of years. All the diversity and beauty you see in our biosphere today started when small organisms began to photosynthesise.

We have recently developed technology capable of capturing solar energy through solar cells to produce electricity. In addition to this, technology using solar thermal (heat) energy to heat up water and generate electricity is being developed.

Many new houses now utilise thermal energy from the Sun to maintain comfortable indoor living temperatures. This design process is called passive solar building design. The principles of passive solar design include ensuring that a house is tightly sealed and highly insulated. This minimises 'thermal bridges', which are areas where heat can enter or exit the house, leading to a consistent indoor temperature no matter what the outdoor temperature is.

DESIGN BRIEF

Design and construct a model home using passive solar building design principles.

Activity instructions

In this activity, you and your classmates will collaborate and build a prototype of a building that utilises passive solar building design principles.

Figure 8.79 Harnessing solar energy to make housing more energy efficient has the potential to revolutionise the energy sector worldwide as we work towards mitigating the effects of climate change.

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Suggested materials

- assorted materials to build a house, such as cardboard, plastic, glad wrap, aluminium foil, Styrofoam
- sticky tape
- hot glue gun
- Blu Tack®
- thermometer that reads between 0°C and 100°C

Suggested location

School oval or soccer pitch on a sunny day

Constraints

Your building must be no larger than 30 cm × 30 cm × 30 cm. It must have a door and at least five windows. The roof will need a hole to insert a thermometer. Blu Tack® can be used to prevent air from flowing through the hole.

Research and feasibility

1. Research the principles of passive solar building design. Make a list of features you will include in your model house.
2. Research the number of sunny days in your area and sunlight hours available for energy capture.
3. Describe how you will use the materials available to include the features you listed in step 1.

Design

4. Draw a desgin of your model building, incorporating the passive solar design principles you researched.
5. Annotate your design with measurements, features of passive solar design and the materials that are used.

Create

6. Build your prototype.
7. Test your building design by placing your model in the Sun and recording the temperature at regular intervals.

Evaluate and modify

8. Present your model building to the class with a graph of the change in temperature over time.
9. Discuss the effectiveness of the passive design features incorporated into your building.
10. Discuss improvements you could make to your model to improve the energy efficiency of your building.

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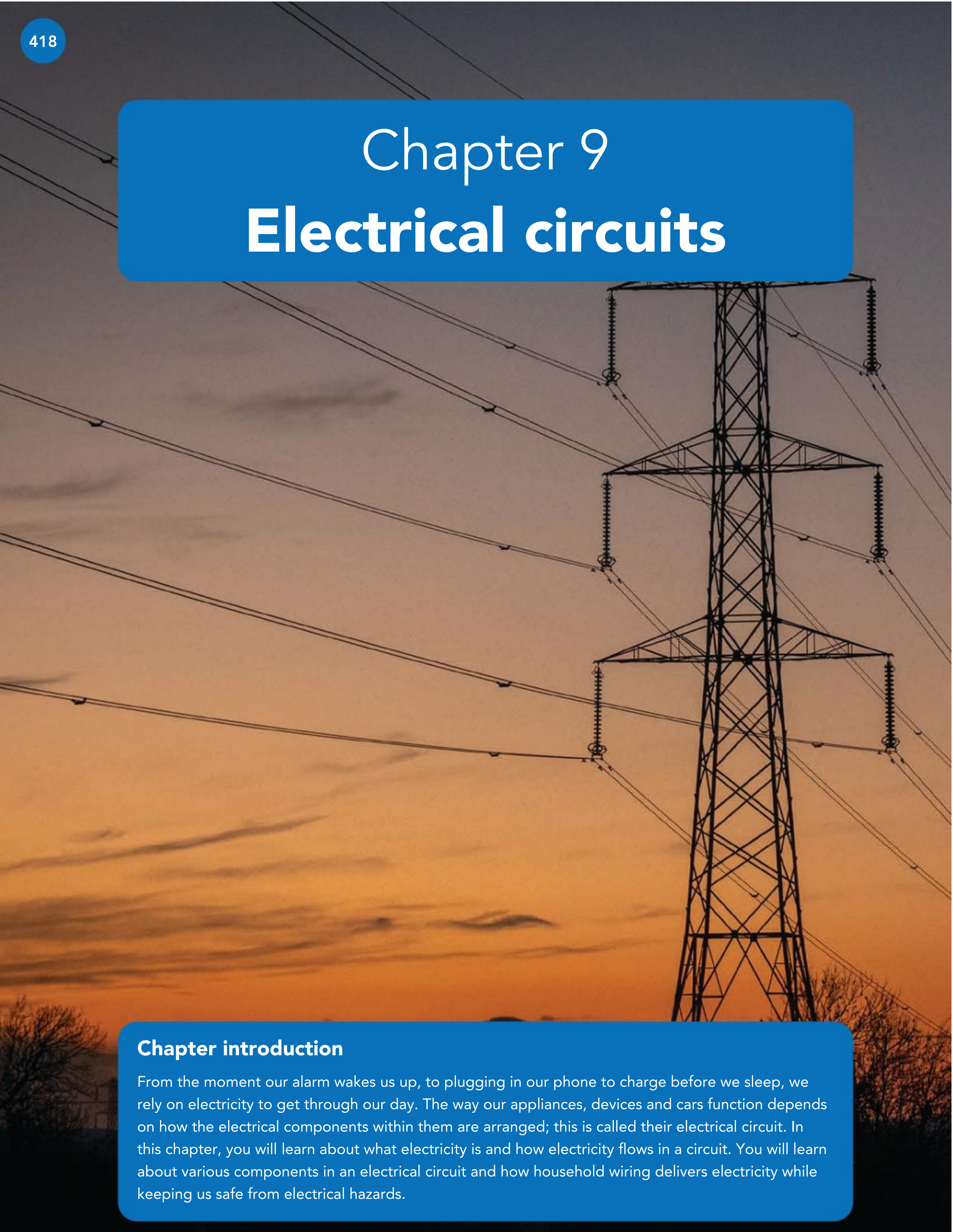


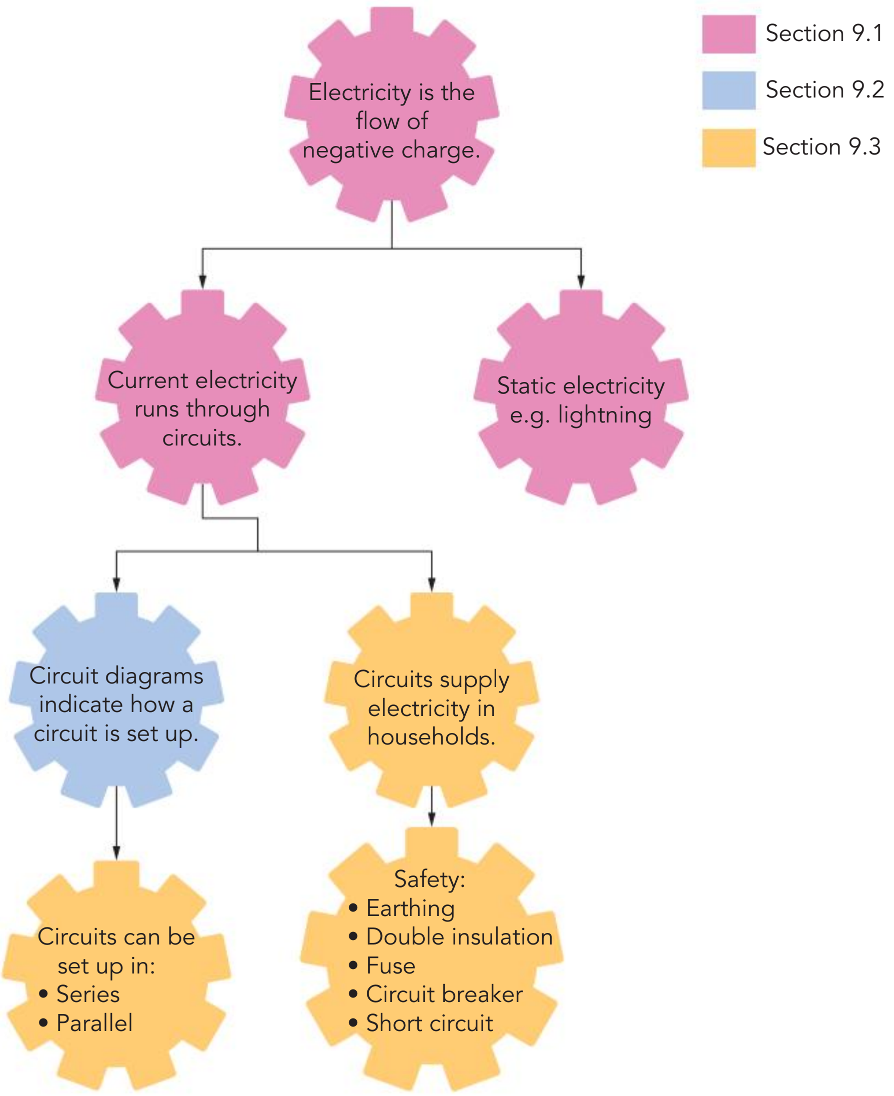
Chapter 9

Electrical circuits

Chapter introduction

From the moment our alarm wakes us up, to plugging in our phone to charge before we sleep, we rely on electricity to get through our day. The way our appliances, devices and cars function depends on how the electrical components within them are arranged; this is called their electrical circuit. In this chapter, you will learn about what electricity is and how electricity flows in a circuit. You will learn about various components in an electrical circuit and how household wiring delivers electricity while keeping us safe from electrical hazards.

Concept map



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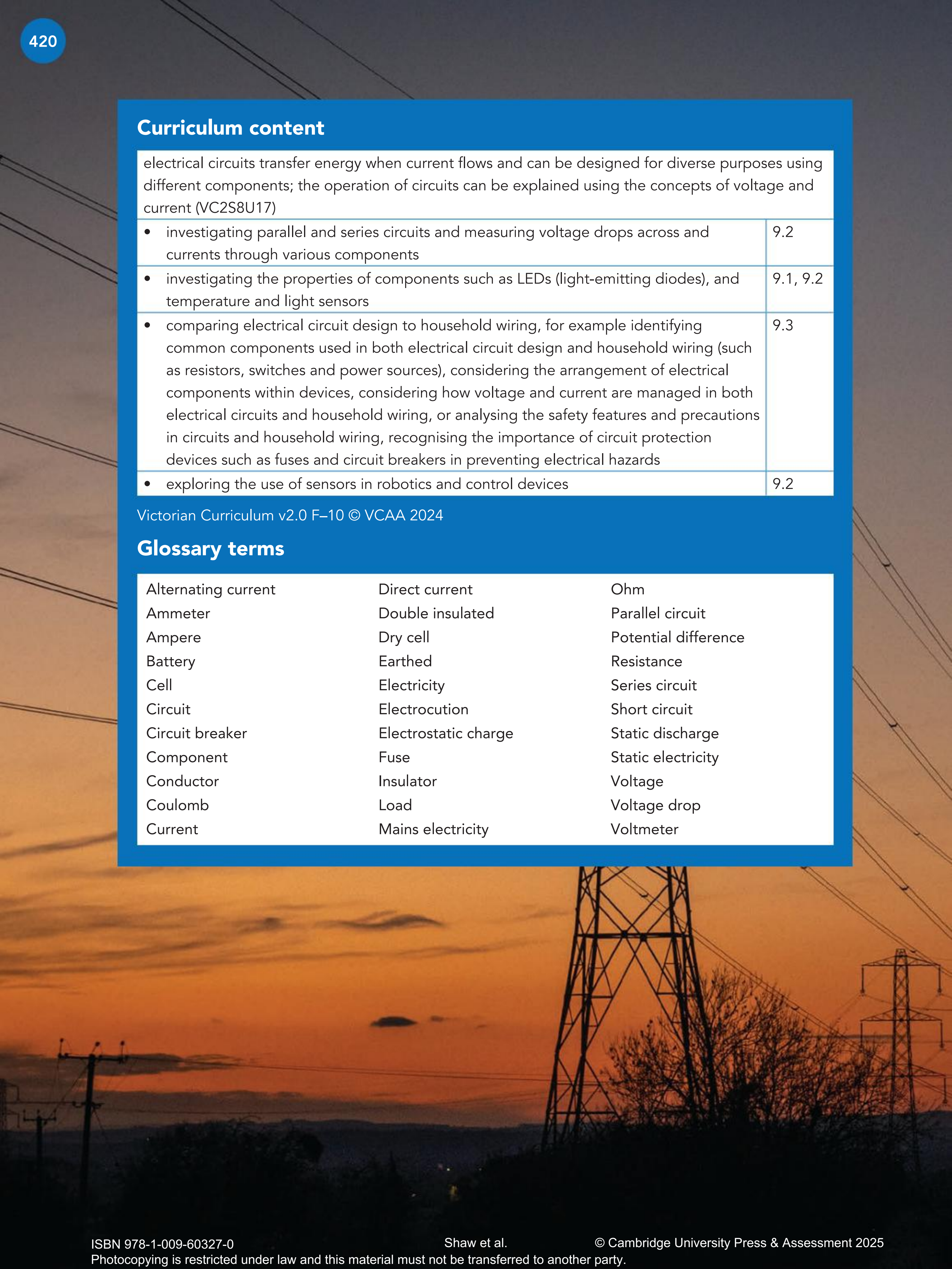

Curriculum content

electrical circuits transfer energy when current flows and can be designed for diverse purposes using different components; the operation of circuits can be explained using the concepts of voltage and current (VC2S8U17)	
• investigating parallel and series circuits and measuring voltage drops across and currents through various components	9.2
• investigating the properties of components such as LEDs (light-emitting diodes), and temperature and light sensors	9.1, 9.2
• comparing electrical circuit design to household wiring, for example identifying common components used in both electrical circuit design and household wiring (such as resistors, switches and power sources), considering the arrangement of electrical components within devices, considering how voltage and current are managed in both electrical circuits and household wiring, or analysing the safety features and precautions in circuits and household wiring, recognising the importance of circuit protection devices such as fuses and circuit breakers in preventing electrical hazards	9.3
• exploring the use of sensors in robotics and control devices	9.2

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Glossary terms

Alternating current
Ammeter
Ampere
Battery
Cell
Circuit
Circuit breaker
Component
Conductor
Coulomb
Current
Direct current
Double insulated
Dry cell
Earthed
Electricity
Electrocution
Electrostatic charge
Fuse
Insulator
Load
Mains electricity
Ohm
Parallel circuit
Potential difference
Resistance
Series circuit
Short circuit
Static discharge
Static electricity
Voltage
Voltage drop
Voltmeter

ISBN 978-1-009-60327-0

9.1 Electricity

Learning goal

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

1. Define 'electricity', 'static electricity' and 'current electricity'.

WORKSHEET What is electricity?

VIDEO Electricity

VIDEO Static electricity

In Chapter 8 you learned about different types of energy, one of them being electrical energy. **Electricity** is a form of energy that results from either the accumulation of charge or the flow of charge. Charge can be positive (+) or negative (–). In Chapter 4, you learned that atoms are the particles that make up matter. Atoms contain positive charge in the form of protons and negative charge in the form of electrons (see Figure 9.1). Electricity is the movement of the negatively charged electrons carrying energy from atom to atom in a conductor.

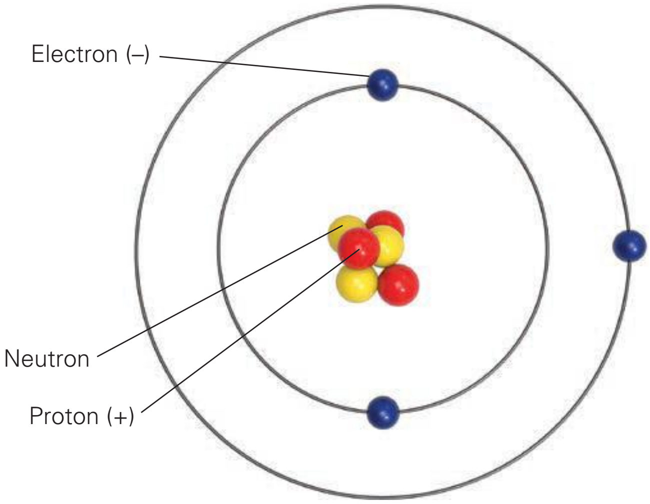

Figure 9.1 A diagram of an atom showing the positive and negative charges. It is the negatively charged electrons that carry electrical energy.

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

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 9.2 This lightning strike in Melbourne, Victoria, is an example of a powerful static discharge.

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Explore! 9.1

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.

Figure 9.3 When the difference in electrical charge becomes too great, lightning discharges between clouds.

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.

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 9.4).

Figure 9.4 The aeroplane is connected to earthing wires during refuelling to avoid sparks and a possible explosion.

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Try this 9.1

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 9.5 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? 9.1

History of static electricity

The Ancient Greek philosopher Thales of Miletus, in about 600 BC, 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 9.6 Amber rubbed on fur produces static electricity.

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Quick check 9.1

1. **Outline** the structure of an atom.
2. **Define:**
   a) electricity
   b) charge
   c) static electricity.
3. **Explain** how rubbing two different materials together can create static electricity.
4. **Explain** how static electricity is created by combing your hair.

Current electricity

Static electricity occurs 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 globe, it transfers energy to that component. The component then transforms 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 9.2

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 9.7 Electricity is used to run many household items.

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Circuits

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** (a device that uses the energy, such as a light globe)
- connecting wires (carry the moving electrons).

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

dry cell
a battery in which the electrolyte is absorbed in a solid to form a paste

Power source

Figure 9.8 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).

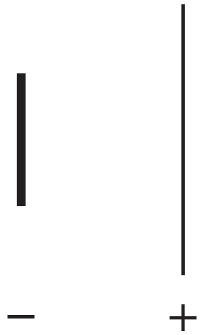

Figure 9.8 The symbol for the power source in a circuit has two lines. The shorter line represents the negative terminal, while the longer line represents the positive terminal of the power source.

Did you know? 9.2

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.

Figure 9.9 The dry cell is typically in the form of non-rechargeable AA and AAA batteries.

Let's all do our part and recycle disposable batteries!

Science as a human endeavour 9.1

Electric vehicles

Recent advancements in battery technology are improving the efficiency and cost-effectiveness of batteries, which is hoped to increase the adoption of electric vehicles (EVs) in the future.

Most EVs today run on lithium-ion batteries, which have a high capacity for energy storage but contain flammable liquids that burn when overheated. While EV battery fires are rare, they still pose risks of electric shock and exposure to toxic gases from damaged batteries. In addition, many of these batteries contain cobalt, which is scarce and harmful to the environment when extracted from the earth.

Researchers have designed a material that could replace cobalt and significantly lower the cost of producing EV batteries while maintaining the efficiency of the cobalt-containing lithium-ion batteries. The material is made from layers of a small molecule called TAQ (bis-tetraaminobenzoquinone). TAQ is highly stable and will not corrode when exposed to the harsh chemicals in the battery. In addition, the material has a similar capacity to conduct electricity and store energy when compared to traditional EV batteries and has been shown to charge faster. In the future, not only will EVs be able to recharge faster, but the batteries are estimated to cost half as much to produce.

Figure 9.10 An electric vehicle charging station

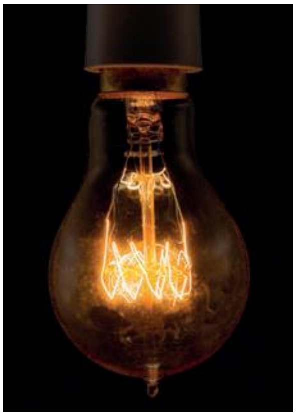

Figure 9.11 An older-style light globe transforms electrical energy into light and thermal energy. These are typically only 3–4% efficient in transforming electrical energy into light.

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 9.12 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 globes that are not very energy efficient can get quite hot!

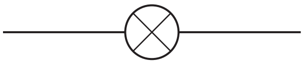

Figure 9.12 One of the circuit symbols for an incandescent light globe is a circle with a cross in the middle.

LEDs

Light-emitting diodes (LEDs) are tiny light globes that fit into electric circuits, as shown in Figure 9.13. They transform electrical energy into light energy much more efficiently than incandescent light globes, 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 9.14.

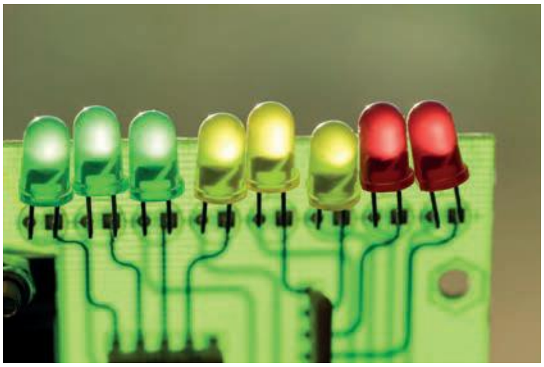

Figure 9.13 LEDs (light-emitting diodes) are tiny light globes that fit into electric circuits.

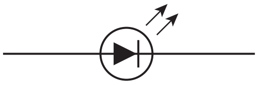

Figure 9.14 The two arrows on the circuit symbol for an LED indicate that light is being emitted.

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 9.15). This is called conventional current, and follows the direction defined in the 1700s when electricity was first being experimented with. At that time, atomic structure and electrons were unknown, so scientists assumed it was 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

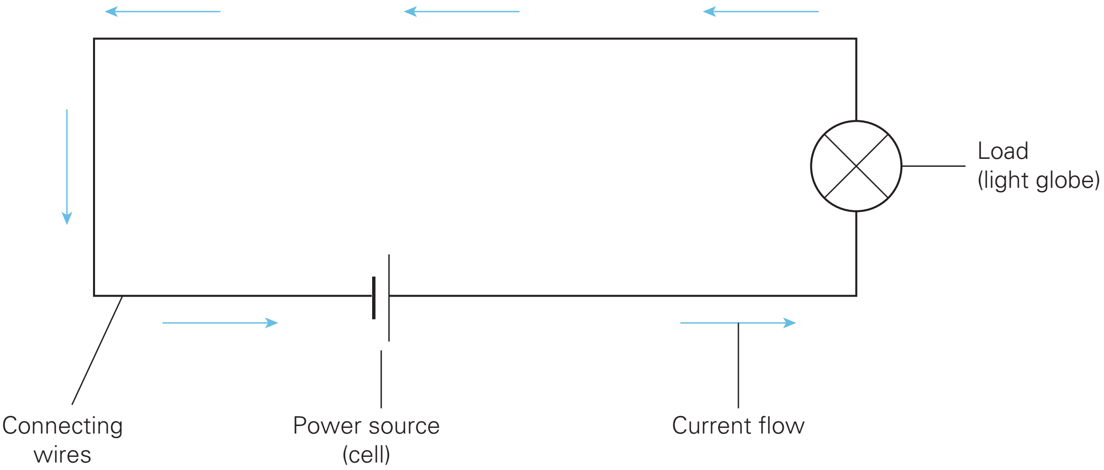

Figure 9.15 In this simple circuit, conventional current is indicated as flowing from the positive terminal to the negative terminal of a cell. The connecting wires are drawn as straight lines.

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Try this 9.3

Constructing a simple circuit

Using a 2.5 V torch light globe, a 1.5 V battery and two connecting wires, try different arrangements to see how many ways you can make your light globe light up.

Remember, do not use the connecting wire to connect the positive terminal to the negative terminal directly as it will get very hot and can flatten or damage the batteries. Draw a circuit diagram for each successful arrangement.

Quick check 9.2

1. **Contrast** current electricity and static electricity.
2. **Contrast** direct current and alternating current.
3. **Explain** why a circuit must be ‘closed’ or complete for it to work.

Go online to access the interactive section review and more!

Section 9.1 review

Online quiz

Section questions

Teachers can assign tasks and track results

Section 9.1 questions

Remembering

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.

Understanding

5. **Explain** how rubbing amber produces electric sparks.
6. **Explain** what happens to charges when static electricity builds up.

Applying

7. **Explain** why contact with large amounts of electricity can be dangerous.

Analysing

8. **Contrast** static electricity and current electricity and give examples of each.

Evaluating

9. 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.
10. 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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9.2 Simple circuits

Learning goals

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

1. Draw a circuit diagram, using correct symbols for components.
2. Define 'voltage', 'current' and 'resistance' and their units.

WORKSHEET
Simple circuits

Circuit diagrams

The circuit in Figure 9.16 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.

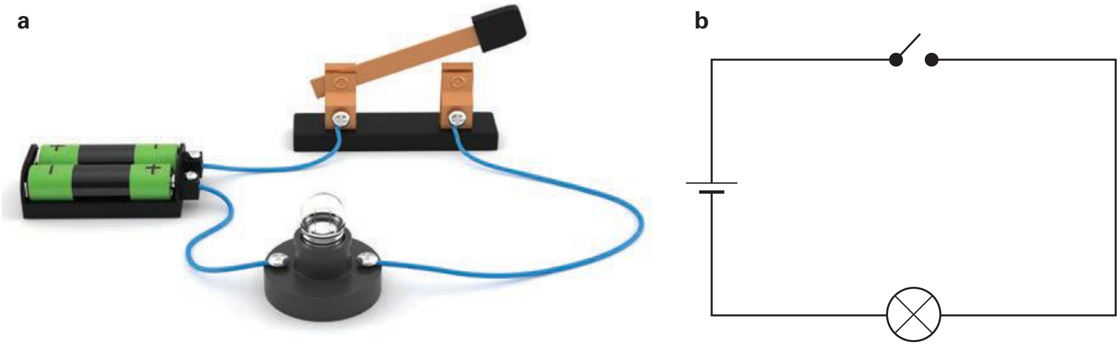

Figure 9.16 (a) A simple circuit can be made with a power source, light globe and switch. **(b)** The same circuit represented by a circuit diagram. Straight lines represent wires connecting the three parts together.

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 9.16 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 9.1 (battery, load and connecting wires). Table 9.1 shows several other useful electrical components and their circuit symbols.

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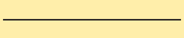
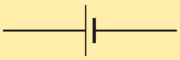
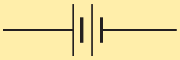
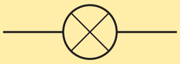
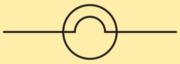
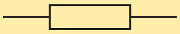
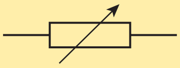
Component	Image	Symbol
Connecting wire		
Open switch		
Closed switch		
Cell		
Power supply or battery pack		
Load (e.g. light globe)		 or 
Ammeter		
Voltmeter		
Resistor		 or 
Variable resistor		 or 

Table 9.1 Some common electrical components and their circuit symbols

ammeter
a device for measuring electric current

voltmeter
a device for measuring voltage between two points on an electric circuit

Making thinking visible 9.1

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?

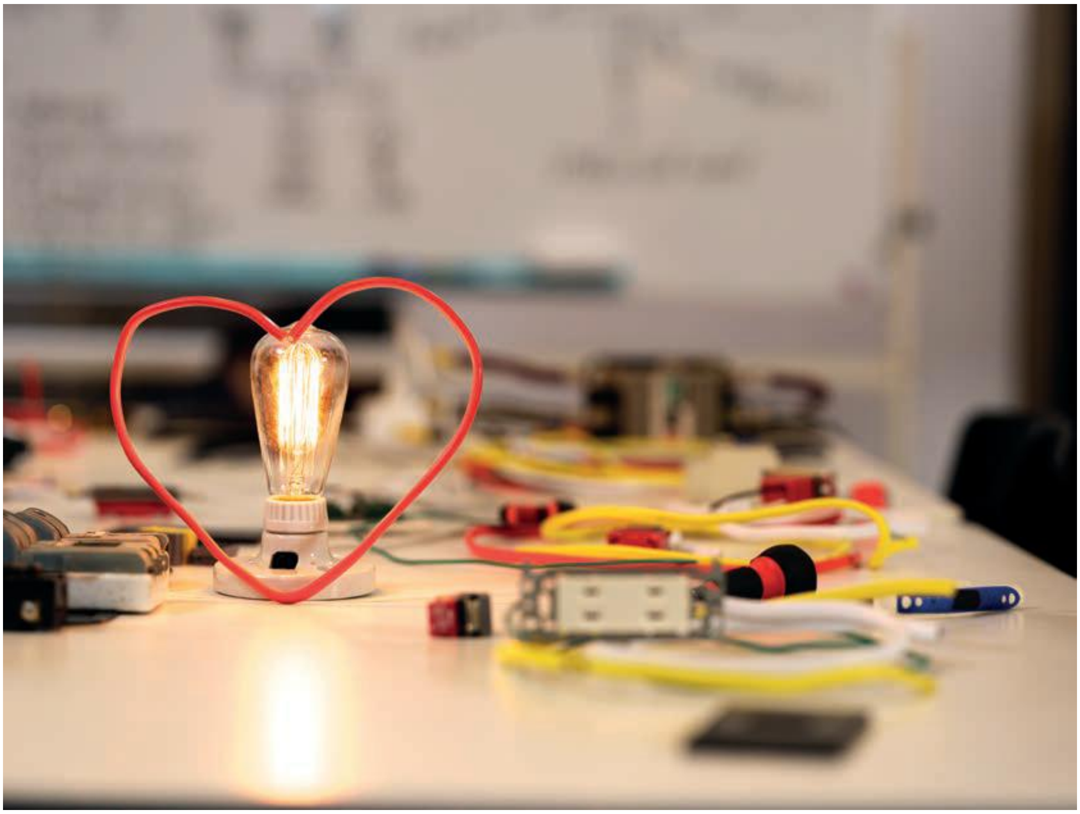


Figure 9.17 Electric circuits can be complex.

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.

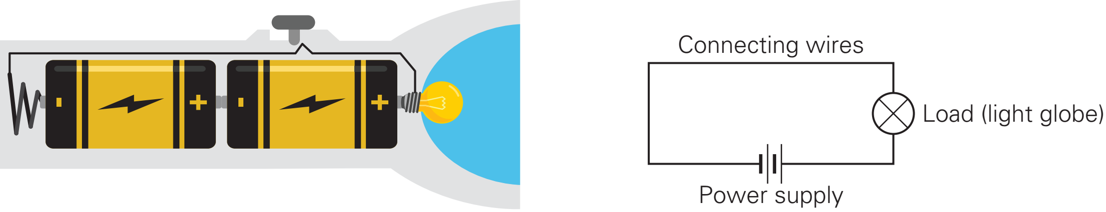


Figure 9.18 The left drawing shows the inside of a torch, but you use a simplified diagram like the right one to represent the circuit. The batteries are the energy source and the light globe is the load. Can you think of one component that needs to be added to the diagram?

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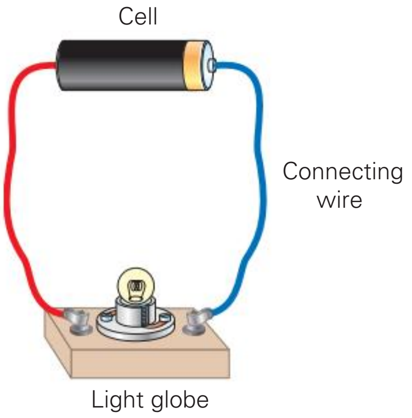
Try this 9.4

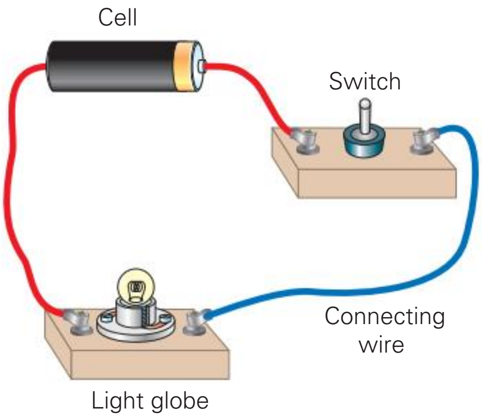
Circuit diagrams

Draw circuit diagrams for the following circuits.

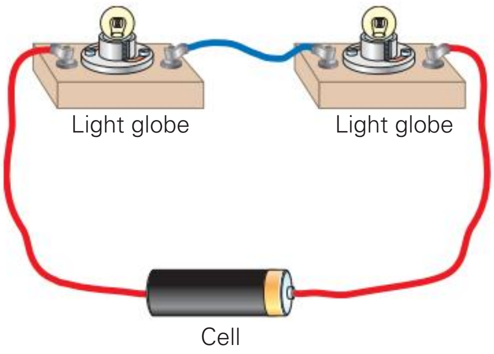
a)



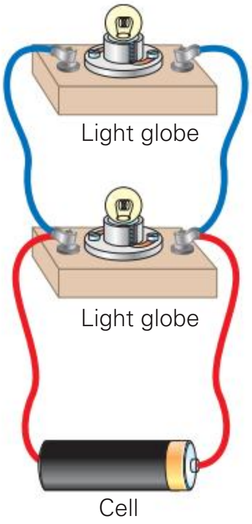
b)



c)



d)



Quick check 9.3

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

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
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 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 9.19.

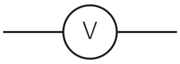


Figure 9.19 The circuit symbol for a voltmeter is a circle with a capital V in the middle.

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 that aren't across the load can reduce the efficiency and performance of electrical systems.

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

Current

Current is the movement of negative charges (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.

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 9.20.

An ammeter can measure current in amperes (A) or in milliamperes (mA):

$$1\text{ A} = 1000\text{ mA} \quad 1\text{ mA} = \frac{1}{1000}\text{ A}$$

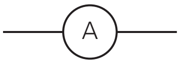


Figure 9.20 The circuit symbol for an ammeter is a circle with a capital A in the middle.

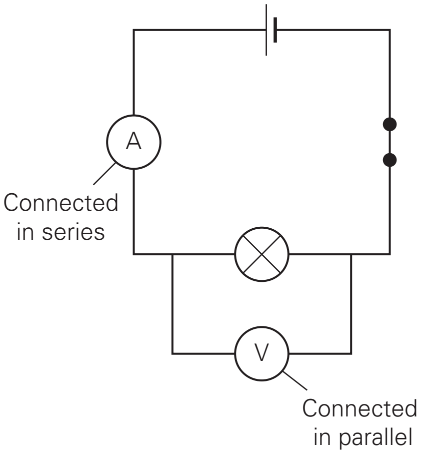


Figure 9.21 When building a circuit, you need to place the ammeter in series and the voltmeter in parallel.

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Practical 9.1

Measuring current and voltage

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. The power supply is to be turned off when changing the circuit.

Aim

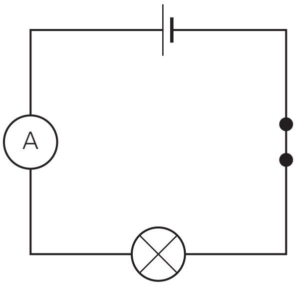
To practise measuring current and voltage in simple circuits

Materials

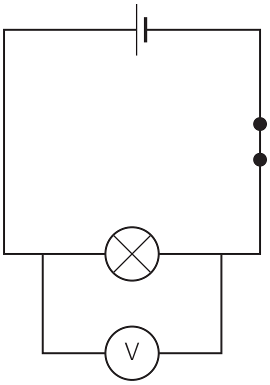
- power supply (6 V DC)
- 6 V light globe and light holder
- connecting leads with alligator clips or other connectors × 4–6
- switch
- ammeter
- voltmeter

Method

1. Set up circuit A, which is shown in the diagram to the right.
   a) Use the ammeter to measure the electric current in circuit A with the switch **open**. Record your measurement in the results table.
   b) Repeat with the switch **closed**. Record your measurement in the results table.
   c) Move the ammeter to the other side of the globe. Repeat with the switch **closed**. Record your measurement in the results table.
2. Remove the ammeter from the circuit.
3. Now set up the circuit using the voltmeter as shown here in circuit B.
4. Set the switch to **open** and use the voltmeter to determine the following measurements.
   a) Measure the voltage across the light globe. Record your measurement in the results table.
   b) Measure the voltage across the power supply. Record your measurement in the results table.
   c) Measure the voltage across the switch. Record your measurement in the results table.
5. Now repeat steps 4a, b and c with the switch **closed**.



Circuit A



Circuit B

Results

Table showing current measurements

Circuit A	Current
Switch open	
Switch closed	
Ammeter on other side	

Table showing voltage measurements

Circuit B	Voltage when switch is open	Voltage when switch is closed
Across light globe		
Across power supply		
Across switch		

Discussion: Analysis

1. Is there any difference between the current measurements when the ammeter is either side of the globe in circuit A? Explain.
2. Compare the voltage across the terminals of the power supply with the voltage across the light globe when the switch is **open** in circuit B.

continued ...

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3. Compare the voltage across the terminals of the power supply with the voltage across the light globe when the switch is **closed** in circuit B.
4. Deduce the form of energy most of the electrical energy converted to in circuits A and B. Explain the energy conversions.

Conclusion

1. Draw a conclusion from this experiment about the properties of current and voltage, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that ____________.

Quick check 9.4

1. **Define** the following terms in your own words:
   - a) voltage
   - b) voltage drop
   - c) voltmeter
   - d) current
   - e) ampere
   - f) ammeter.
2. **Explain** how current differs in a circuit when the switch is open and when the switch is closed.

Resistance

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).

resistance
the degree to which a substance resists the flow of current; measured in ohms (Ω)

ohm
the unit of electrical resistance (Ω)

conductor
(electricity) a material that allows electric current to flow through it easily

Conductors

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.

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 9.23, is a tool used to measure current, voltage and resistance.

Figure 9.22 High-voltage (typically 550 000 V) power lines distributing electricity most often use aluminium wires as their main conductor.

Figure 9.23 Digital multimeters can measure current, voltage and resistance.

Try this 9.5

Investigating voltage

Construct a simple circuit with one light globe and a voltmeter. Start with the power supply on 2 V and record the voltage drop across the globe. Increase the voltage to 4 V and then 6 V. What do you notice about the voltage drop as you increase the power supply's voltage? Try to explain your observations.

Did you know? 9.3

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 9.24 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.

insulator (electricity) a material that does not allow current to flow through easily

Quick check 9.5

1. **Define** 'resistance'.
2. **Explain** what a conductor and an insulator are and give an example of each.

Practical 9.2

Effects of resistance

Be careful
Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

Aim
To observe and compare the flow of electrical energy through objects with varied resistance and explore the relationship between voltage and resistance

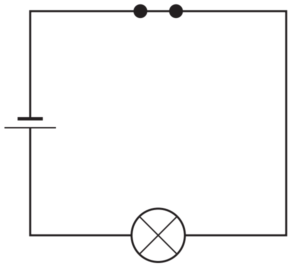
Materials

- DC power supply (6 V)
- 6 V light globes × 2
- 6 V globe holders × 2
- connecting leads (alligator clips)
- small piece of cylindrical plastic
- small piece of cylindrical carbon
- standard iron or steel nail
- ammeter
- voltmeter

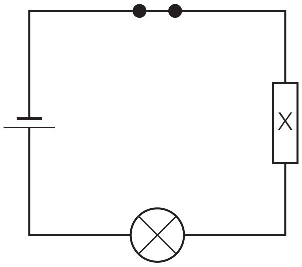
Method
In this experiment, you will be setting up various circuits as shown in the following diagrams. Draw each circuit diagram in the results section.

Record your observations of the relative brightness of globes in your results table.

1. Set up circuit 1. Record the brightness of the globe.

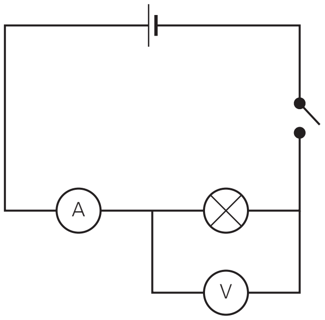


Circuit 1



Circuit 2

2. Set up circuit 2. Place the plastic, carbon and then the iron nail in turn at the position labelled **X**.
3. Record the brightness of the globe for each material and compare the brightness of the globe with that produced in circuit 1.
4. Set up circuit 3. Set your power source to 2 V. Connect the ammeter and voltmeter as shown on the right.
5. Record the brightness of the globe and the readings from the ammeter and voltmeter in your results table.
6. Repeat step 5 for 4 V and 6 V, recording the current and voltage in your results table for each voltage.



Circuit 3

Results
Table showing brightness, current and voltage measurements of different circuits

	Brightness of globe	Current (A)	Voltage (V)
Circuit 1			
Circuit 2 with nail			
Circuit 2 with plastic			
Circuit 2 with carbon			
Circuit 3 2 V			
Circuit 3 4 V			
Circuit 3 6 V			

continued →

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Discussion: Analysis

1. Describe how the brightness of the globe changed between circuits.
2. Explain the reason for the difference in globe brightness for the nail and the plastic.
3. Describe the relationship between the number of volts and amps for each of the conditions in circuit 3.

Conclusion

1. Draw a conclusion from this experiment about the relationship between voltage and resistance, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that _____________.

Practical 9.3

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

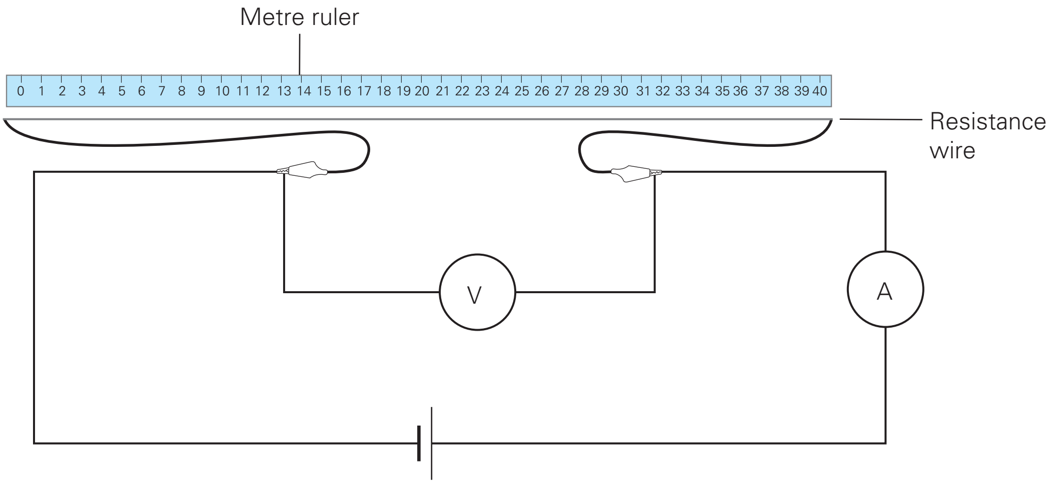
To investigate how the length of a wire affects its resistance

Materials

- DC power supply (6 V)
- connecting leads × 6
- resistance wire such as constantan or nichrome
- alligator clips
- ammeter
- voltmeter
- metre ruler

Method

1. Write a rationale about the factors that affect resistance.
2. Create a relevant and specific research question for this practical.
3. Identify the independent, dependent and controlled variables for this practical.
4. 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.
   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.



continued ...

5. Draw a suitable results table. (Hint: You should have four columns.)
6. Record the length of the wire between the alligator clips, and the readings on the ammeter and voltmeter in your results table.
7. 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

1. Record your results in your results table.
2. Calculate and record the resistance for each length of wire, using the Ohm's law equation.
3. Plot a graph of length of wire (metres) against resistance (Ω), including a straight line of best fit.

Discussion: Analysis

1. Identify any trends, patterns or relationships in your results.
2. Explain your results using your own scientific knowledge.

Discussion: Evaluation

1. Your line of best fit may not go through the origin. Explain where the extra resistance came from.

Conclusion

1. Draw a conclusion from this experiment about the effect of wire length on resistance, by copying and completing this statement in your science book.
   From this activity it can be claimed that __________. This is supported by the observations that _____________.

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 9.25. 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 9.26.

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.

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.

Figure 9.25 Fixed resistors have coloured bands that indicate their value.

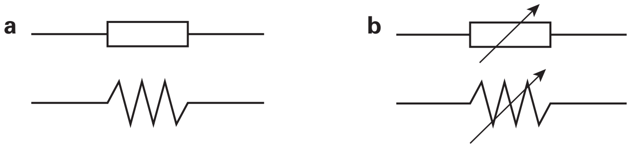


Figure 9.26 (a) The symbol for a fixed resistor is either a rectangle or a zigzag line. **(b)** The symbol for a variable resistor is the same, but with an arrow through it.

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Quick check 9.6

1. **Explain** how a variable resistor works and give an example of how it may be used in your home.

Practical 9.4

Current and resistance

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. The power supply is to be turned off when changing the circuit.

Aim

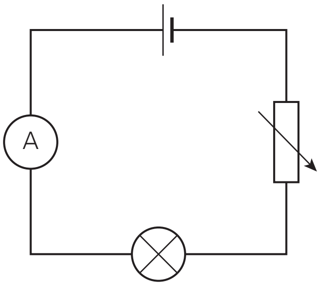
To investigate the relationship between current and resistance using a variable resistor

Materials

- 6 V power supply
- 6 V light globe
- variable resistor
- connecting wires and connectors × 4
- ammeter

Method

1. Set up the circuit as shown in the diagram on the right and set the power supply to 6 V.
2. Adjust the variable resistor so that the light globe is at its brightest. Record the current shown.
3. Adjust the variable resistor so that the light globe gets dimmer and dimmer, recording the current at various points until the light globe is at its dimmest.



Results

Table showing measure of current for different brightness levels

Brightness of globe	Current
Brightest	
Bright	
Dim	
Dimmest	

Discussion: Analysis

1. Describe what happens to the current in the circuit as the resistance of the variable resistor increases.
2. Describe what happens to the brightness of the globe as the resistance is increased.
3. Predict what is happening to the voltage across the globe as it gets dimmer.

Conclusion

1. Draw a conclusion from this experiment about the relationship between current and resistance, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that _____________.

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Explore! 9.2

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 9.27 The robotic vacuum cleaner has sensors that tell it where it has already cleaned.

Figure 9.28 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 9.2 review

Online quiz	Section questions	Teachers can assign tasks and track results

Go online to access the interactive section review and more!

Section 9.2 questions

Remembering

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.

Understanding

4. **Draw** the symbols for the following electrical components.
   a) Single cell
   b) Three cells in a row
   c) Open switch
   d) Resistor
   e) Globe
5. 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').
6. **Summarise** how a variable resistor works.

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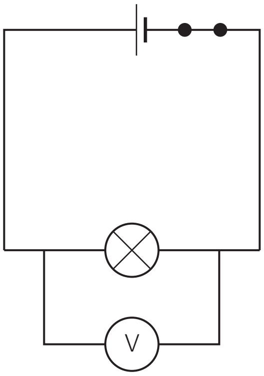
Applying

7. 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
8. Use your knowledge of light-dependent resistors to **propose** a household appliance that uses them.

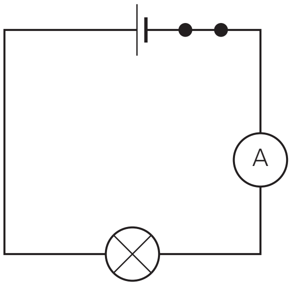
Analysing

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 in the diagram.
    b) **Identify** which side of the battery is positive in 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 source		

Evaluating

12. 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.
13. **Propose** three arguments for and three arguments against the widespread adoption and use of electric cars in Australia.

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9.3 More circuits and their applications

Learning goals

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

1. Draw series and parallel circuits.
2. Explore the safety aspects of household electricity.

WORKSHEET
More circuits and their applications

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 9.29).

series circuit
a circuit in which the batteries and other components are all connected one after the other

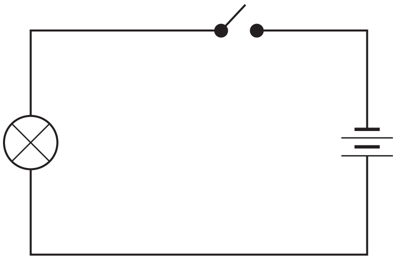

Figure 9.29 A series circuit diagram of a torch contains the symbols for a power source, light globe and switch.

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 9.30, 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.

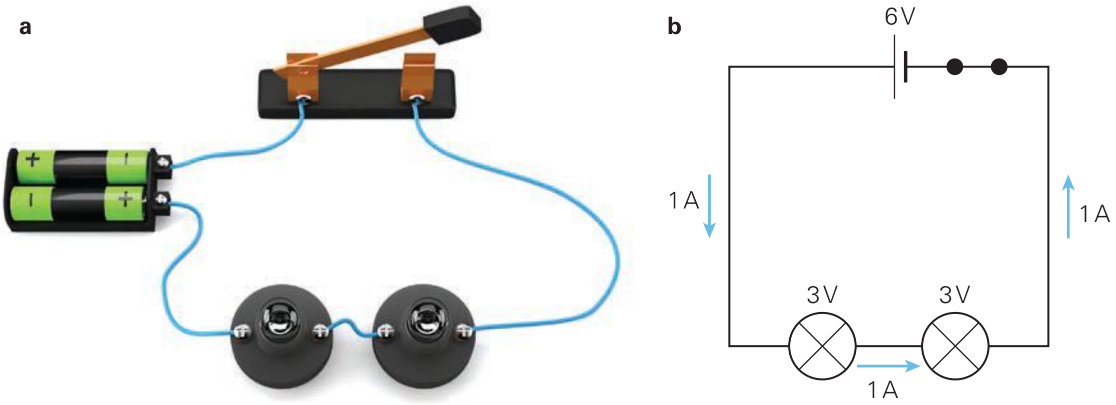

Figure 9.30 (a) A car headlight circuit modelled as a series circuit and **(b)** the matching circuit diagram with a 6 V power source and identical globes.

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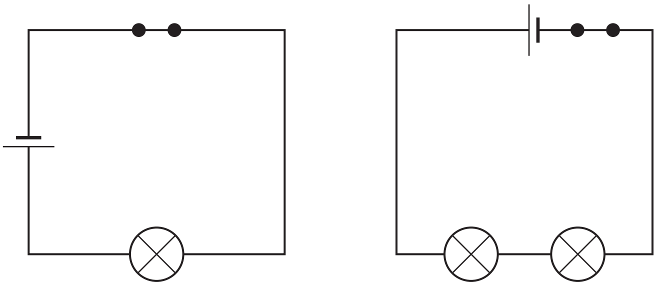
Try this 9.6

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

parallel circuit a circuit in which each component is connected in a separate conducting path

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 9.31.

In a parallel circuit, the current is split at each branching. For example, if the light globes in Figure 9.31 are identical, the current in each branch is half that of the power source. The voltage is the same across all the components.

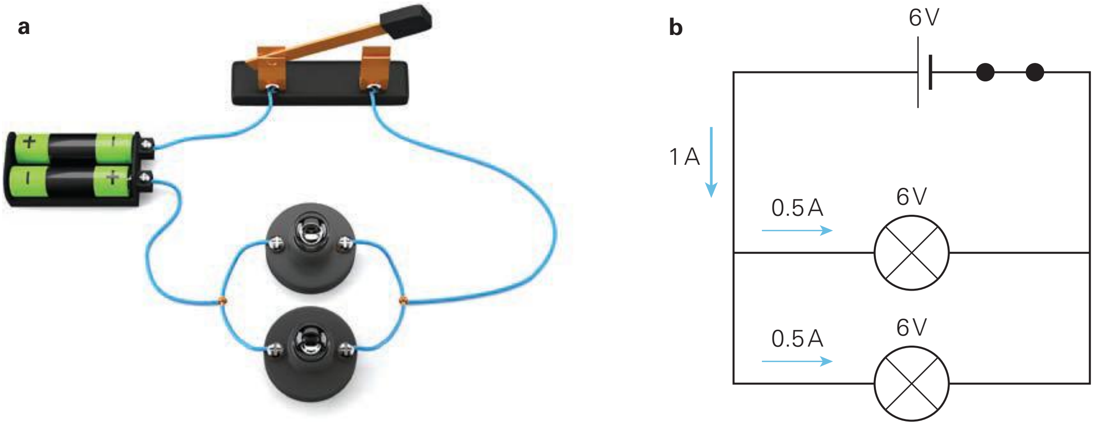


Figure 9.31 (a) A car headlight circuit modelled as a parallel circuit. **(b)** The matching circuit diagram; the blue arrows indicate current split.

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.

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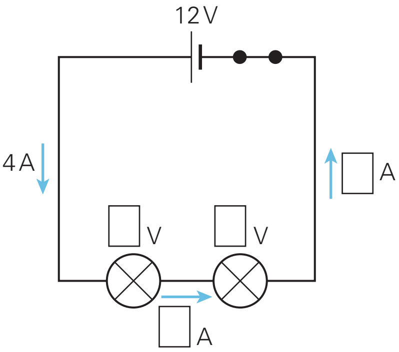
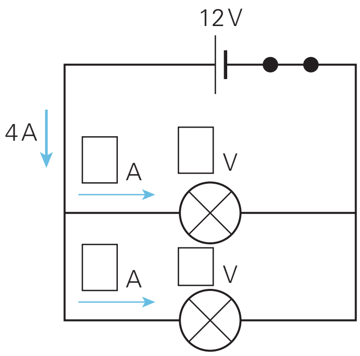
In a parallel circuit, each component is connected in a separate conducting path. This means that if one load component of the circuit is faulty, the other load components will still work. Most modern string lights are connected in parallel. If one of the 200 light globes fails, then the other 199 globes 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 9.32 Modern string lights are wired in a parallel circuit.

Quick check 9.7

1. **Describe** the differences between a series and a parallel circuit.
2. **Explain** why you would not wire your house in series configuration.
3. **Describe** how 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.





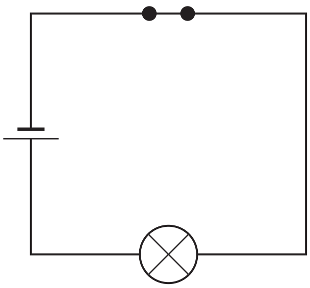
Try this 9.7

Parallel circuits

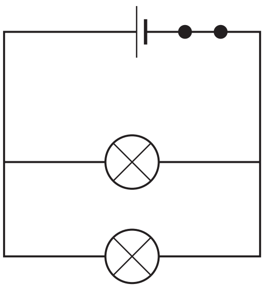
Two circuits have been set up for you by your teacher. They are shown here. Note the brightness of the globe in circuit 1.

Now look at circuit 2 where the two globes are connected in parallel.

WIDGET
Simple circuits



Circuit 1 – Single globe



Circuit 2 – Two globes in parallel

1. Do the globes in circuit 2 glow as brightly as the globes in circuit 1? Explain what you observe.
2. Predict what would happen if you disconnected the bottom globe in circuit 2.
3. Disconnect the lead. What happens to the brightness of the other globe? Explain what you observe.
4. What happens if you add another globe in parallel? Explain what you observe.
5. What happens if you add another globe in series with the bottom globe? Explain what you observe.

Practical 9.5

Series and parallel circuits

Aim

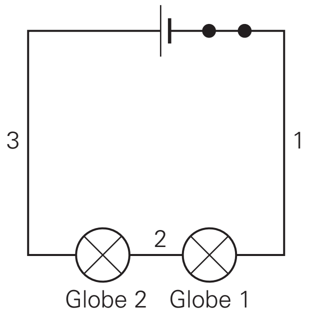
To observe and compare the values of current and voltage in series and parallel circuits

Materials

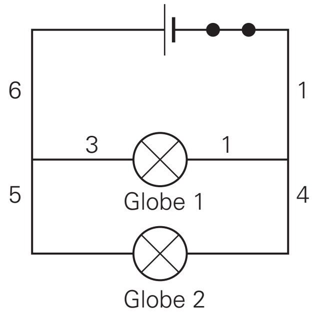
- DC power supply (6 V)
- 6 V light globes × 2 and 6 V globe holders × 2
- connecting leads (alligator clips)
- ammeter
- voltmeter

Be careful

Electric shocks may occur. Ensure the voltage output is not exceeded. Turn off the power supply when changing the circuit.



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.

Results

Copy and complete the following tables in your science book.

continued …

Current

Table showing current measurements

	Position	Current (A)
Series circuit	1	
	2	
	3	
Parallel circuit	1	
	2	
	3	
	4	
	5	
	6	

Voltage

Table showing voltage measurements

	Component	Voltage (V)
Series circuit	Power supply	
	Globe 1	
	Globe 2	
Parallel circuit	Power supply	
	Globe 1	
	Globe 2	

Discussion: Analysis

1. Explain the differences in your observations about the current values in the series and parallel circuits.
2. Explain the difference between your observations about the voltage values in the series and parallel circuits.

Conclusion

1. Draw a conclusion from this experiment about the difference in the values of current and voltage in series and parallel circuits, by copying and completing this statement in your science book.

   From this activity it can be claimed that __________. This is supported by the observations that _____________.

Household electricity

mains electricity the electricity that is supplied to homes

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**.

Figure 9.33 An Australian power point has three slots: active, neutral and earth.

Power points (sockets) in the home have three slots: active, neutral and earth (see Figure 9.33). 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.

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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 (see Figure 9.34). 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.

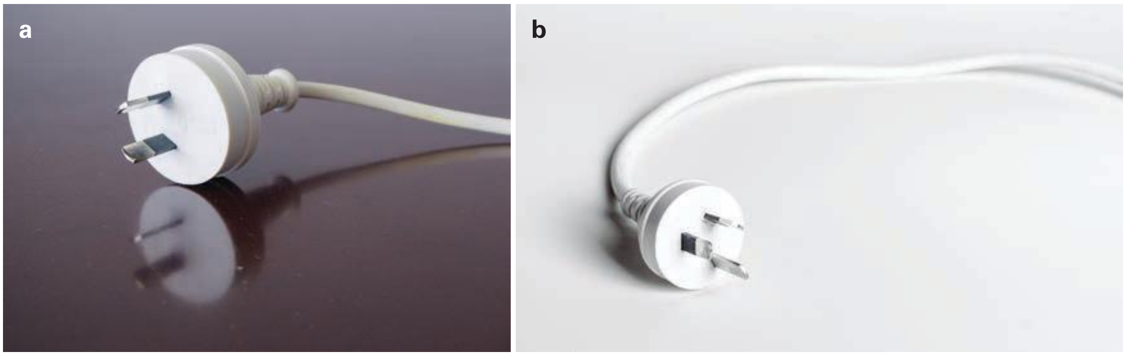

Figure 9.34 Power cords in Australia have either **(a)** a 2-pin plug or **(b)** a 3-pin plug.

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 (see Figure 9.35). This prevents the current going through the body of a person who might be touching the metal case of the toaster.

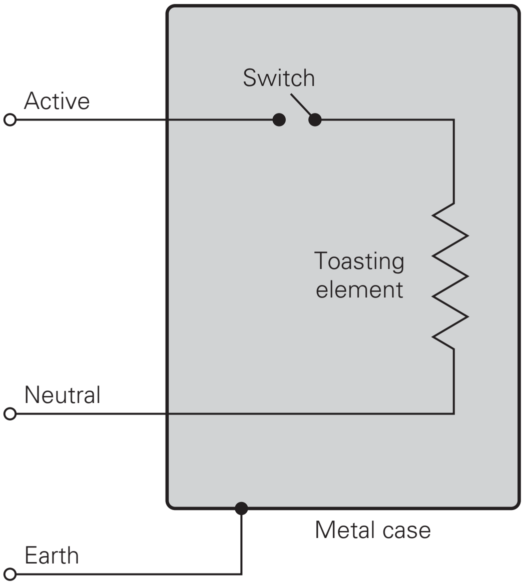

Figure 9.35 In an earthed appliance, like this toaster, any metal parts that can come into contact with the active part of the circuit and become 'live' automatically cause a large current to run to earth and blow a fuse or trip a circuit breaker. This is much better than having the current run through the user of the appliance!

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 9.36.

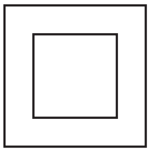

Figure 9.36 An appliance with this symbol on it is double insulated.

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? 9.4

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).

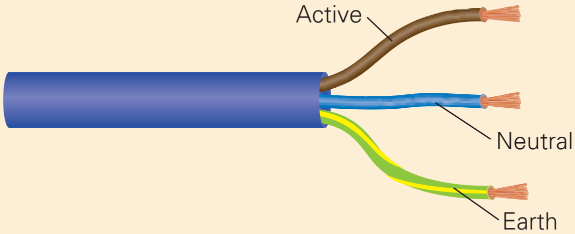

Figure 9.37 The modern colour code for electrical wires: brown for the active wire, blue for the neutral, and green and yellow for the earth.

Try this 9.8

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 a 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.
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?

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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 9.2 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

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

Figure 9.38 Electrical hazard symbols are placed where there is a risk of deadly electric shock.

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.

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 9.2 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 9.39 – notice the fuse on the right no longer provides an electrical connection.

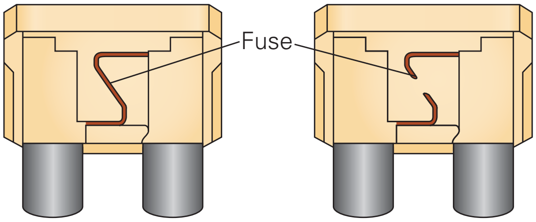

Figure 9.39 The wire inside a fuse will break if the current passing through it gets too high.

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In most modern houses, fuses have been replaced with circuit breakers. A **circuit breaker** (see Figure 9.40) 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 9.40 Circuit breakers protect electrical systems in houses and safety switches protect people against electric shock.

circuit breaker a device that carries out the same function as a fuse by breaking the circuit when the current flowing through it exceeds a certain threshold

short circuit when current is allowed to flow from one conductor to another with little or no resistance

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.

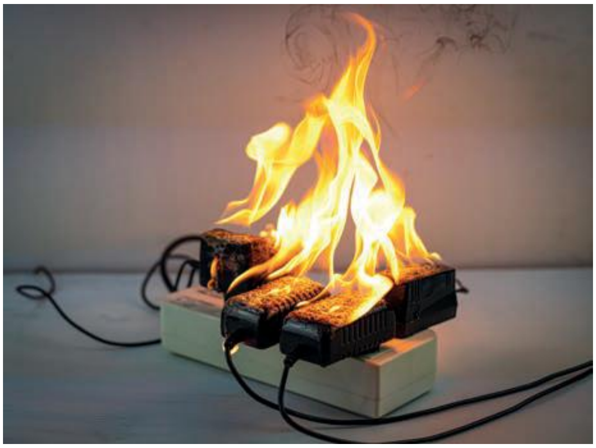

Figure 9.41 A short circuit can cause a fire.

Did you know? 9.5

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 9.42 Tasers are used by law enforcement officers.

Quick check 9.8

1. **Recall** the voltage of mains electricity in Australia.
2. **State** the purpose of the third pin of a power plug.
3. **Explain** why some appliances do not have an earth pin in the power plug.

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Section 9.3 review

Online quiz

Section questions

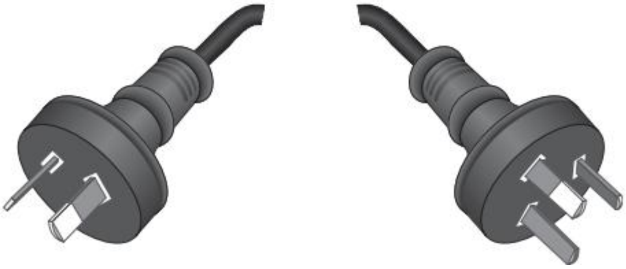
Teachers can assign tasks and track results

Section 9.3 questions

Remembering

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.



Understanding

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. **Explain** the function of a safety switch in an electrical circuit.

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Applying

9. 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.
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 9.43.

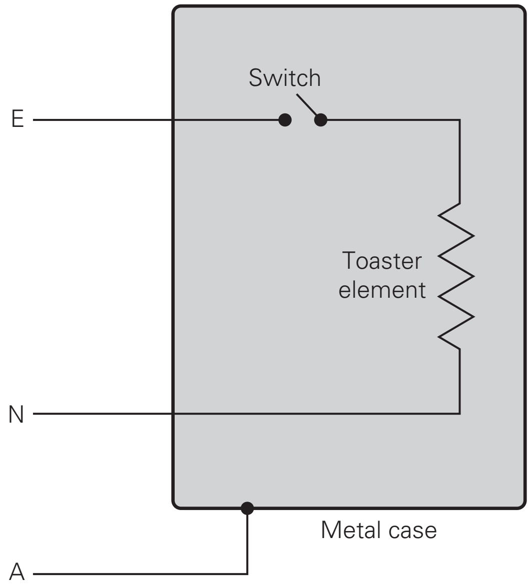
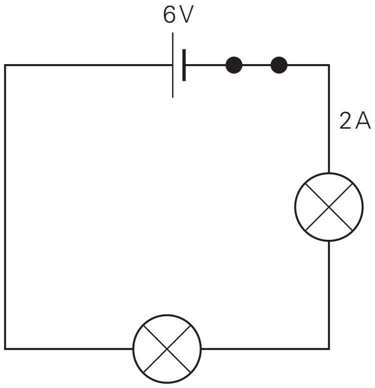


Figure 9.43 A circuit diagram of an incorrectly wired toaster

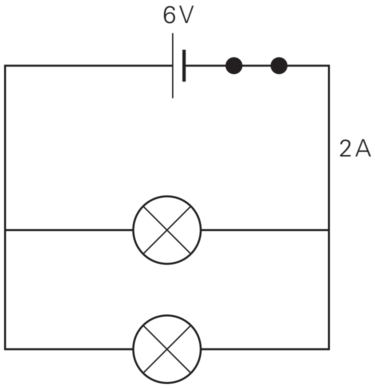
Analysing

12. A student constructs circuit 1 as shown. The circuit contains a 6 V battery and two identical globes. The current through the circuit is 2.0 A.
   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.



Circuit 1

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.
   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.



Circuit 2

Evaluating

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

Success criteria		Linked questions
9.1	I can define 'electricity', 'static electricity' and 'current electricity'.	2
9.2	I can construct circuit diagrams using correct symbols.	5
9.2	I can define 'voltage', current' and 'resistance'.	3, 4
9.3	I can distinguish between series and parallel circuits.	10, 11
9.3	I can describe the safety aspects of household electricity.	12

Go online to access the interactive chapter review!

Scorcher competition

Review questions

Data questions

Review questions

Remembering

1. **List** the three components that an electrical circuit needs.
2. **Distinguish** static electricity and current electricity.
3. For a certain electrical circuit, 20 coulomb of charge flows past a point in 5 seconds. **Calculate** the current in amperes.
4. **Define**:
   a) voltage
   b) current
   c) resistance
5. **Draw** these electrical components: open switch, closed switch, ammeter, voltmeter, battery, incandescent light globe, LED, resistor.

Understanding

6. **Describe** the energy transformations that occur in a working electrical circuit containing a battery and a light globe.
7. **Explain** why an ammeter and voltmeter are connected differently in a circuit.

Applying

8. **Explain** what a good electrical insulator is and give an example of where it may be used.
9. **Explain** why electrical wires made from gold or silver are not used for sending power from the power stations into households.

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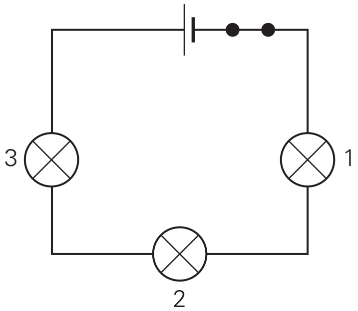
Analysing

10. 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.

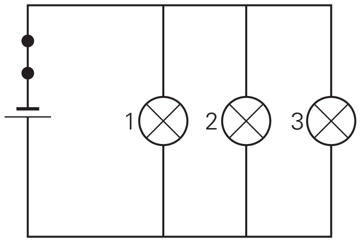
Globe broken	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
Globe 1			
Globe 2			
Globes 2 and 3			



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.

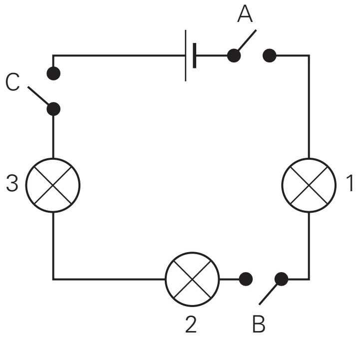
Globe broken	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
Globe 1			
Globe 2			
Globe 3			
Globes 2 and 3			



Circuit 2

11. 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.

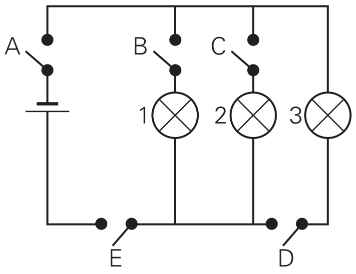
Switches turned on	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
A			
B, C			
A, B, C			



Circuit 3

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.

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			



Circuit 4

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Evaluating

12. **Propose** reasons for:
    a) household electrical wires being coated in plastic
    b) many household appliances being double insulated.

Data questions

You are a consultant from an energy company tasked with monitoring the energy usage of two key appliances in a home over 24 hours: a refrigerator and a washing machine. The homeowners would like you to analyse how these appliances consume electricity throughout the day and for you to suggest ways to improve energy efficiency.

The refrigerator runs continuously throughout the day, maintaining a constant temperature to keep food fresh, while the washing machine is used multiple times during the day for different laundry loads. Both appliances contribute to the household's energy consumption, and by understanding their usage patterns, you can recommend strategies for reducing energy costs.

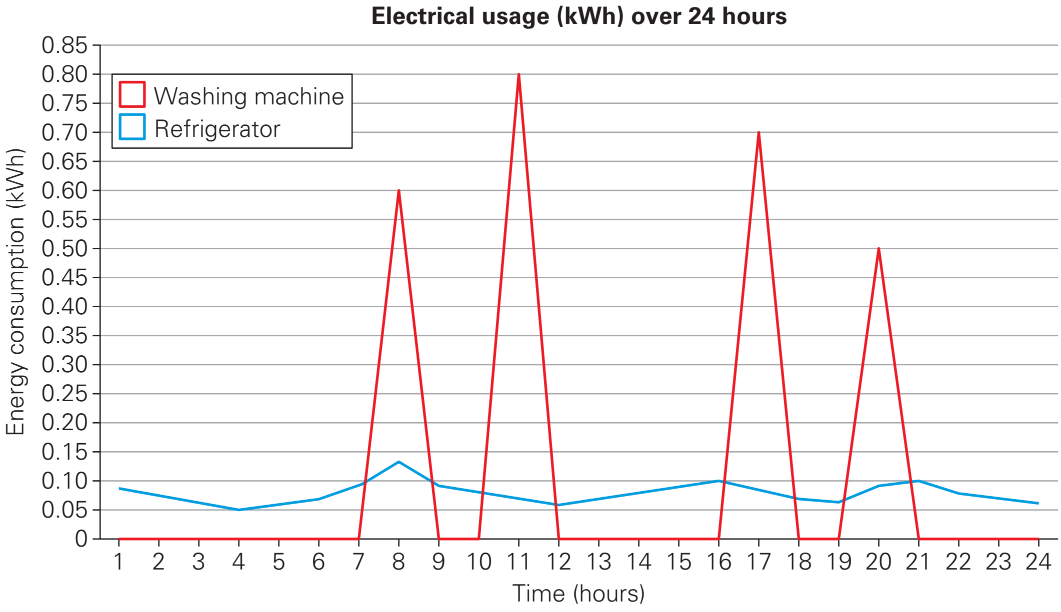


Figure 9.44 Energy usage of a refrigerator and a washing machine over a 24-hour period

Applying

1. **Identify** the hour during which the refrigerator's energy consumption is the highest. **Propose** an explanation for this increase in energy usage at that time.
2. **State** how many times the washing machine was used, and for how many hours it was running.
3. **Calculate** the total energy consumption of the washing machine throughout the day.

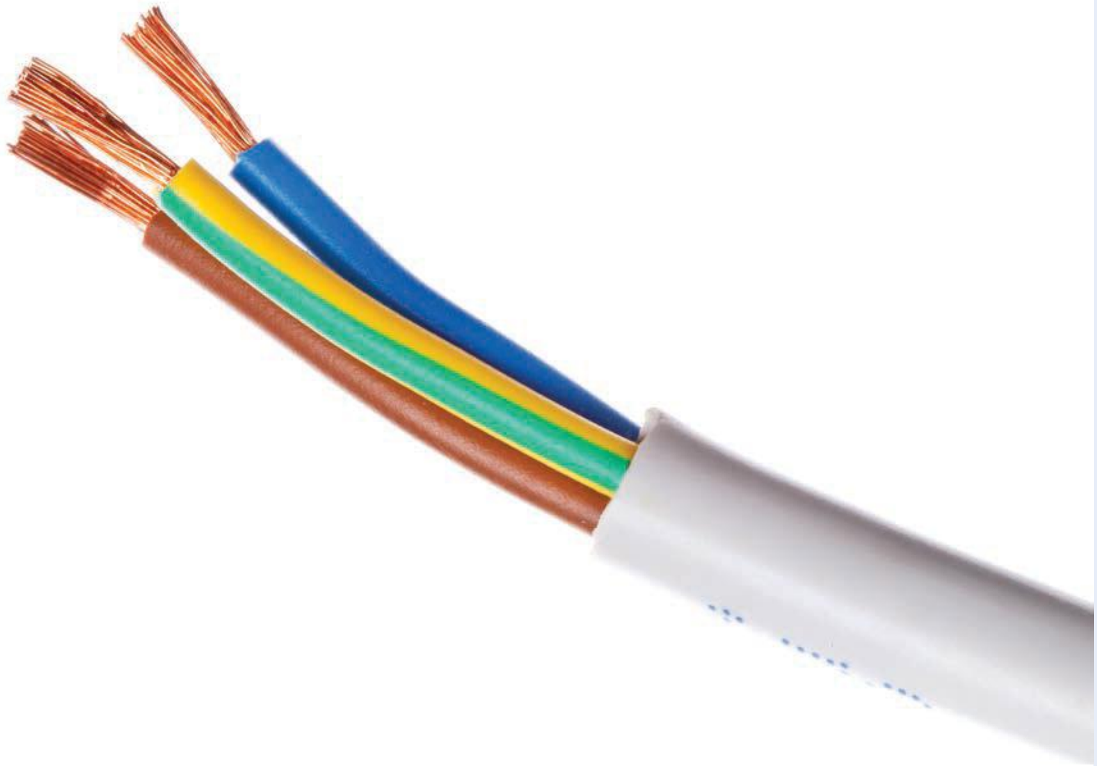
ISBN 978-1-009-60327-0 Shaw et al.

Analysing

4. **State** during which hours the washing machine uses the most electricity and propose an explanation for why that might be the case.
5. **Compare** the energy usage trends of the refrigerator and washing machine. Describe how their patterns of energy consumption differ and propose an explanation.
6. Using the data, **determine** the average energy usage per hour for both appliances.

Evaluating

7. Assume that the cost of electricity is 30 cents per kWh. **Calculate** the cost of running each appliance over the 24-hour period. State which appliance is more expensive to run, and by how much.
8. If the goal is to reduce the overall household energy consumption, **describe** the recommendations you could make for the use of the washing machine and refrigerator to lower energy costs. Consider changes to usage patterns.
9. Suppose you have access to a solar panel system that can provide up to 3 kWh of electricity during peak sunlight hours (from 10 a.m. to 4 p.m.). **Describe** how this renewable energy source could be used to reduce the electricity cost of running these appliances.



ISBN 978-1-009-60327-0 Shaw et al.

STEM activity: Can you see the renewables?

Background information

In this chapter, you learnt how circuits work and some applications for them in your household. Technology has significantly advanced over the past 30 years, and now circuits are becoming minute and more powerful to drive smaller devices. Have you ever thought about the amount of carbon emissions produced when you perform a search using your favourite search engine? Experts have estimated that a simple search consumes enough energy to release 0.2 g of carbon dioxide into the atmosphere. The number might seem small; however, imagine the emission from today's nearly 5 billion connected devices!

People and governments have recently started to invest in renewable and sustainable energy sources because our planet has gone through environmental change over centuries. Still, some people in our society need help in understanding that the energy resources of our planet are finite. Now more than ever, it is important that we all do our very best to change our current practices into more sustainable ones.

There are many ways to showcase this message to the world, and the most powerful ones all involve storytelling. Good stories have the power to bring us together, encourage us to understand and empathise with many causes. Recently, digital storytelling has been used by many professionals (including famous YouTubers) to tell/sell their ideas, opinions and/or products.

Figure 9.45 Even tablets and smartphones contribute to the carbon dioxide levels in the atmosphere.

DESIGN BRIEF

Design and create a 60-second infomercial promoting the use of renewable energy.

Activity instructions

In teams (maximum of four people per group), you will use the digital storytelling process (described in the following text) to create a short 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 (for example: videographer, researcher, movie editor) so everyone has the chance to develop and use different skills.

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Scenario

Your local council has just informed its residents that they wish to invest some capital to secure 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. On the other hand, 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.

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. Create a mind map of the advantages of renewable energy over non-renewable energy that should be communicated to your audience through the infomercial.

Design

2. Draw a story board to outline the content of your video. Write a script to go along with it, using information from your mind map.

Create

3. Film your video.

Evaluate and modify

4. Discuss with at least three of your colleagues the challenges you encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.

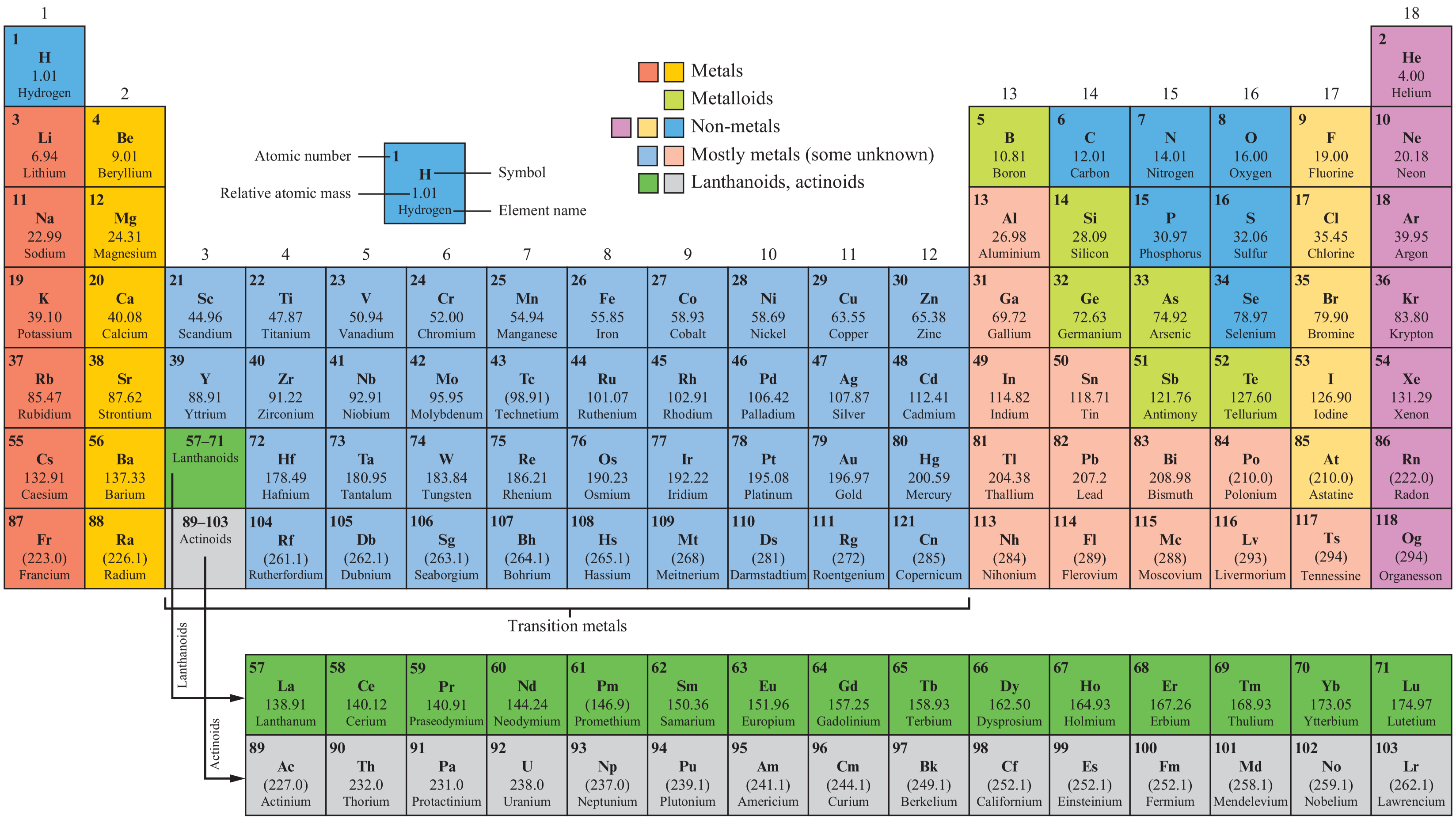
5. Have you finished your video? Congratulations! Now it is time to show it to someone in your family or someone in another year level and ask them for their opinion on it.

6. How effective is your infomercial? Based on the feedback from your family member, how will the target market respond?

7. Create a range of evaluative questions to use to gauge the success of your informercial. Show your infomercial to a target audience and use the question to test its effectiveness.

Appendix

The periodic table



Atomic number — 1
Symbol — **H**
Relative atomic mass — 1.01
Element name — Hydrogen

🟥 🟨 Metals
🟩 Metalloids
🟪 🟨 🟦 Non-metals
🟦 🟧 Mostly metals (some unknown)
🟩 ⬜ Lanthanoids, actinoids

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	121 **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

Transition metals

Lanthanoids															
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

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Glossary

accuracy how well a measuring instrument determines the variable it is measuring; it refers to how close a measurement is to the true value

alternating current a form of electricity in which the current reverses direction in regular cycles

alveoli the tiny sacs at the end of bronchioles in the lungs; the site of gas exchange with the capillaries

ammeter a device for measuring electric current

ampere the unit of electrical current, usually shortened to amp (A); 1 amp = 1 coulomb per second

anomalous a result that differs from the expectations suggested by scientific theory

anus the opening at the end of the digestive tract, through which solid waste leaves the body

aorta the largest vessel leaving the heart, from the left ventricle, carrying oxygenated blood to the body

artery a thick, muscular elastic vessel that carries blood away from the heart

asthenosphere the softer layer of rock under the lithosphere

atom the smallest particle that makes up all matter

atomic theory of matter all matter consists of indivisible particles called atoms

atrioventricular node a natural pacemaker that controls the heartbeat and is located in between the atria and the ventricles

atrium one of the two upper chambers of the heart, the left atrium and right atrium

bacteria very small prokaryotic organisms that have cell walls but lack membrane-bound organelles and a nucleus

bar graph (also column graph) a type of graph used to display the frequency of a qualitative variable, or a relationship between a qualitative independent variable and a quantitative dependent variable

battery a portable source of power; made up of two or more cells

bias when a source of information is influenced by personal opinion or judgement

biconcave concave on both sides

bile a substance that helps break down fats; it is produced in the liver and stored in the gall bladder

biodiscovery the collection and use of native biological material (e.g. plants and animals) for commercial applications

biological weathering the disintegration of rocks that is caused by living things

bioluminescence a chemical reaction that produces light in living things

biopiracy when naturally occurring, biological material is commercially exploited

bolus a lump of partially digested food

breccia sedimentary rock composed of angular broken pieces of rock larger than two millimetres

bronchi (sing. bronchus) the main airways in the lung; two primary bronchi branch off the trachea, one main left bronchus to the left lung and one main right bronchus to the right lung

bronchioles smaller tubes that branch off bronchi and lead to the alveoli

caecum a pouch that forms the first part of the large intestine

capillaries the smallest blood vessels, one cell thick, and the site of gas exchange with cells

carnivore a consumer (heterotroph) that feeds on animal matter

causation one event is caused by another event occurring

cell a single electrical energy source that produces a current

cell membrane the barrier that separates the inside of the cell from the external environment

cell wall a rigid structure that surrounds each plant cell, shaping and supporting the cell

cellular respiration a process that occurs inside mitochondria, where oxygen and glucose react to form carbon dioxide and water, producing useable energy

cementation the sticking together of sediment

chemical bond a strong force of attraction between two atoms

chemical change where one or more substances undergo a chemical reaction and a new substance, or substances, is formed; chemical properties change; mostly irreversible

chemical digestion a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

chemical formula a symbol for a compound that shows which elements, and how many atoms of each element, are present in one molecule or one basic unit of that compound

chemical potential energy the energy stored in the chemical bonds between atoms

chemical property a characteristic of a substance that can only be observed and measured by performing a chemical reaction or chemical change

chemical reaction a process or chemical change that transforms one set of substances (the reactants) into another set of substances (the products)

chemical weathering the process in which rocks are broken down and chemically altered via chemical reactions

chemiluminescence a chemical reaction that produces light

chloroplast a structure in a plant cell that contains chlorophyll and conducts photosynthesis

chyme a partially digested mass of food after it leaves the stomach

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 flowing through it exceeds a certain threshold

clasts small pieces of pre-existing rock that form a sedimentary rock

cleavage the tendency of a mineral or rock to break in a particular way because of its structure

colloid a mixture in which particles of one chemical substance will not dissolve but remain distributed throughout another chemical substance

combustion a reaction that involves the burning or exploding of a chemical substance in the presence of oxygen

compaction the process of particles becoming closely positioned together, using very little space

component a part of a circuit

compound chemical substance made up of two or more different types of atoms

conduction the transfer of thermal energy through collisions between particles

conductivity the ability of a substance to conduct or carry electricity or heat

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

conglomerate sedimentary rock composed of rounded rock fragments larger than two millimetres

constructive (divergent) a type of plate boundary that occurs when plates move away from one another

continental drift the theory of how the continents on Earth have moved over millions of years

continuous data quantitative (numerical) data points that have a value within a range; this type of data is usually measured against a scale that includes decimals or fractions, e.g. length in metres = 1.21, 1.7, 1.89 …

controlled variable a variable in an experiment that is kept constant so that it does not cause a change in the dependent variable

convection the transfer of thermal energy due to the movement of particles in a liquid or gas

convection currents the transfer of heat due to temperature differences between the upper and lower layers of Earth's mantle, causing movement of rocks within the mantle

core the inner part of Earth's structure

correlation a measurement of the relationship between two variables; how one changes relative to the other

corrosion the gradual and natural process of metals reacting with oxygen to form a new chemical substance; an example is rusting

coulomb the amount of charge transferred in 1 s with a current of 1 amp

craton the stable interior portion of a continent

crust the solid outer layer of Earth that supports all life on Earth

crystal a substance with a specific chemical composition, in which the atoms are arranged in an ordered way to form a geometric shape

crystallisation the formation of solid mineral crystals from a liquid, either by cooling or evaporation

cultural appropriation use of cultural knowledge, stories or tradition without acknowledgement or consent, often in ways that ignore their cultural meaning and disconnect them from the communities they belong to

current the flow of electric charge, which may continue in a steady manner for a period of time

cytoplasm the internal contents of a cell

cytosol the water-based mixture that fills a cell, containing different molecules; many chemical processes that happen within a cell occur in the cytosol

decomposition a reaction in which one substance breaks up into smaller ones

deep time the idea that Earth is very old

density a substance's mass per unit of volume

deoxygenated describes a substance that is low in oxygen

dependent variable the variable in an experiment that you measure (to see if the changes to the independent variable have caused it to change)

deposition the process that occurs when eroded particles stop moving and build up to form sedimentary rocks

destructive (convergent) a type of plate boundary that occurs when plates move towards one another

diaphragm a dome-shaped muscle that separates the chest and abdominal cavities; it contracts to draw air into the lungs

diatomic element an element that exists as a molecule consisting of two atoms of the same type

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differentiation the process by which stem cells become specialised

diffusion the movement of particles from an area of high concentration to an area of low concentration

direct current a form of electricity in which the current flows in one direction

discrete data quantitative (numerical) data points that tend to have whole numbers; this type of data is usually counted, e.g. number of pets = 0, 5, 1, 2

dissolution when water dissolves minerals in rocks

dissolution the process where individual molecules of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

DNA the material containing the code that allows a cell to produce copies of itself and regulates the functions within the cell

double helix a description of the structure of DNA where two strands wind around each other like a twisted ladder

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

ductility the ability of a substance to be drawn into a wire

duodenum the first section of the small intestine where many enzymes are secreted

earthed having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

elastic potential energy the energy stored when an elastic material is compressed or stretched

electrical energy energy carried by electricity moving in a wire; voltage is used to measure how much energy is carried by each unit of electricity

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 method of extracting a metal from its ore or purifying it using electricity

electromagnetic spectrum a way of organising electromagnetic waves according to their energy and wavelength

electrostatic charge a charge that stays on an object

element a chemical substance made up of only one type of atom

embryo a fertilised egg in the early stages of growth and differentiation

endoplasmic reticulum an organelle that is involved in making fats, carbohydrates and proteins

endothermic an absorption of heat energy in a chemical reaction characterised by a decrease in surrounding temperature

energy the capacity to do work; the total amount of energy is conserved in any process

energy transfer the movement of energy from one place or object to another

enzyme a protein that can speed up chemical reactions in living organisms

epicentre the location on Earth's surface directly above the focus of an earthquake

erosion the transport of rock fragments (that have resulted from weathering)

ethical relating to ethics, the field of considering what is right and wrong

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

eukaryotic a cell that possesses membrane-bound organelles and a nucleus

exothermic a release of heat energy in a chemical reaction characterised by an increase in surrounding temperature

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

extrapolation using existing data (such as a line of best fit) to make a less reliable prediction beyond the original dataset

extrusive describes igneous rocks formed on Earth's surface; also called volcanic rocks

filaments red, fleshy part of the gills with thousands of fine branches that take oxygen from water into the blood

focus the exact point under the surface of Earth where the earthquake occurs

fossil the remains, shape or trace of a bone, shell, microbe, plant or animal that has been preserved in rock for a very long time

function the job that an object does

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

gall bladder a small organ near the liver that stores bile and secretes it into the duodenum

galvanisation the process of coating iron or steel in zinc to prevent corrosion

generator a device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

geoid a model of Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

geology the study of Earth's dynamic structure and the processes through which our planet (and other planetary objects) have formed

geosphere all Earth’s geological materials including the magma, lava, rocks and minerals that make up the crust and layers beneath

Golgi body a structure in a cell involved in the modification, packaging and transport of proteins and lipids

GPS (Global Positioning System) a radio navigation system that allows land, sea and airborne users to determine their exact location, velocity and time

gravitational potential energy a type of potential energy; the energy an object has because of its height; GPE = mgh, where m is the mass of the object in kg, h its height in metres and g is acceleration due to Earth’s gravity, $9.8\ \text{m/s}^2$

guard cells cells on either side of a plant stoma that control gas exchange by opening and closing the stoma

haemoglobin a protein in red blood cells that binds to oxygen

heat thermal energy that is transmitted due to differences in temperature

herbivore a consumer (heterotroph) that feeds on plant matter

heterogeneous mixture describes a mixture that can be separated into its parts, and the parts retain their original properties; the mixture is not blended evenly

heterotroph any organism that obtains its nutrients by consuming other organisms

homogeneous mixture describes a mixture of two or more substances that are evenly distributed and do not separate out easily

hotspot a pocket of magma that sits just underneath the crust

igneous describes rocks that form from the cooling of magma (below Earth’s surface) or lava (above Earth’s surface)

ileum the third section of the small intestine, where further food breakdown and nutrient absorption occur

independent variable the variable in an experiment that you change or allow to change, so it causes change in the dependent variable (which you measure)

index fossil a lifeform that existed for a narrow and known period of geological time, which can be used for the purposes of relative dating

input energy the energy that a machine or device uses as its source of energy

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

interpolation using existing data (such as a line of best fit) to make a reliable prediction within the original dataset

intolerance an inability to eat a food without experiencing adverse effects

intrusive describes igneous rocks formed underground; also called plutonic rocks

investigable question a research question that can be answered by conducting a scientific experiment

irreversible incapable of going in the opposite direction

jejunum the second section of the small intestine, where food breakdown and nutrient absorption occur

joule the unit of energy or work done by a force of one newton over one metre

karst an area of land formed from rock such as limestone that is worn away by water to make caves and other formations

kinetic energy the energy of moving matter

lag time the time between the arrival of the P and S waves

large intestine the organ that is connected to the small intestine at one end and ends with the anus at the other

lattice a three-dimensional shape of atoms that pack together very tightly and form bonds that are extremely strong because the atoms bond to each other in multiple directions

lava molten rock from inside Earth (magma) that has reached the surface

Law of Conservation of Energy the law that states that energy cannot be created or destroyed

lenticels small slits on trunks or branches of trees that allow gas exchange

light energy a form of energy that travels as electromagnetic waves and can travel in a vacuum

line graph a type of graph used to display how a continuous quantitative variable changes over time, or in reference to the independent variable

lithosphere the solid outer layer of Earth consisting of the crust and the top layer of the upper mantle; it is split into giant slabs called tectonic plates

liver a large organ that has many functions, including the production of bile

load something that uses energy in a circuit

lustre the ability of a substance to become shiny when polished

macroscopic visible to the naked eye

magma hot fluid rock found beneath Earth’s surface

mains electricity the electricity that is supplied to homes

malleability the ability of a substance to be bent or flattened into a range of shapes

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mantle the layer of Earth underneath the crust that is made up of solid and semi-molten rock and surrounds the outer core

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

mechanical digestion a series of mechanical processes that break food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

median the middle value in a dataset that is arranged in order of size

membrane-bound organelle an organelle that is surrounded by an outer covering made of fat

metal a chemical substance that is shiny (lustrous), can conduct electricity and heat, is malleable and ductile, and is usually silvery/grey

metalloid a non-metallic substance that has some of the properties of both metals and non-metals

metamorphic describes rocks that are changed by being exposed to high temperature, pressure or both

meteorite a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground

microorganism an organism that is too small to be seen with the naked eye

microscopic anything that can only be seen clearly with the use of a microscope

mineral a naturally occurring chemical substance that is formed in the ground, with constant chemical composition, crystal structure and physical and chemical properties

mitochondrion a structure in a cell that converts the energy from food into the form needed by the cell during cellular respiration

mixture a substance made up of two or more different pure substances (compounds or elements) that are not chemically bonded together

mode the most commonly occurring value in a dataset

Mohs scale a scale from 1 to 10 that indicates the relative hardness of a mineral

molecule two or more atoms chemically bonded by strong covalent bonds

monatomic an element that exists as single atoms, all of one type

multicellular made of many cells

neuron a nerve cell

nominal data qualitative (categorical) data where the categories have no clear order, e.g. red, yellow, green

non-metal a chemical substance that is dull, cannot usually conduct electricity and is brittle

nuclear energy a non-renewable source of energy that uses the energy released by the nucleus of radioactive atoms

nucleus part of a cell that contains the genetic material

ohm the unit of electrical resistance (Ω)

omnivore a consumer (heterotroph) that eats a variety of plant and animal matter

opaque blocking light completely

ordinal data qualitative (categorical) data where the categories have an order, e.g. slow, moderate, fast

ore a rock that can be mined to obtain a valuable mineral or metal

organ a group of tissues working together to perform a function

organ rejection when an organ transplant recipient's immune system recognises the organ as foreign and attacks it

organ transplantation the process of removing a donor organ and then surgically implanting it into a recipient, to improve their organ function or replace a diseased organ

organelle a specialised structure in a cell that has a specific function or role

organism a living creature, such as a plant or an animal

origin the point (0, 0) where the *x*-axis and *y*-axis intercept when both axes start from zero

outlier an anomalous data point, likely the result of an error or mistake in data collection

output energy the energy that a machine or device provides or wastes

oxygenated describes a substance that contains oxygen

pancreas an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

Pangaea the supercontinent that has since broken into pieces and drifted apart

parallel circuit a circuit in which each component is connected in a separate conducting path

periodic table an organised list of all the known elements and their symbols

peristalsis a wave-like contraction of the muscles of the digestive tract that pushes the food along

pharynx the throat region where the nasal cavity and oral cavity meet, leading into the trachea

photosynthesis the process of creating sugar and oxygen from carbon dioxide and water in the presence of sunlight

photovoltaic able to produce electricity from light

physical change when the physical properties of a substance change in some way, but no new chemical substance is formed; it is mostly reversible

physical property a characteristic of a substance that can be observed and/or measured without changing it chemically.

physical weathering the process of breaking down rocks into smaller pieces or particles, without changing the chemical composition

plasma the yellow liquid component that makes up 55% of blood; it carries water, dissolved gases, hormones and other proteins

plate boundary the edge where two tectonic plates meet

plate tectonics the theory that Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

platelets tiny cell fragments that assist with blood clotting

polyatomic element an element that exists as a molecule containing more than two atoms of the same type

polymer a long molecule made of a chain of atoms in a pattern that repeats

porous a material that allows liquid or air to pass through it

potential difference the difference in electrical potential energy between the negative and positive terminals in an electric circuit

potential energy the energy stored in something because of its position, shape or composition; e.g. due to height above the ground, being stretched or compressed, or in chemical form

precipitate the solid that forms when two solutions are mixed and undergo a chemical change

precision how close measurements repeated under the same conditions are to each other

primary source (of information) a first-hand record or account

products the chemical substances that are present at the end of a chemical reaction

prokaryotic a cell that lacks membrane-bound organelles and a nucleus

protist a eukaryotic organism that is part of the kingdom Protista

pure substance a material that is made up of just one type of particle

pyroclastic consisting of or relating to small pieces of rock from a volcano

quarrying the removal of rock, sand and minerals from the surface of Earth without deep excavation

radiation the transfer of energy without requiring the presence of particles

radioactive having or producing the energy that comes from the breaking up of atomic nuclei

radioactivity energy released from the nucleus of an atom when the atom decays

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

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

reactants the chemical substances that are present at the beginning of a chemical reaction

rectum the second-last section of the large intestine; stores faeces

reflection seismology the use of shockwaves to investigate the structure of rocks underground

reliability the degree of consistency of your experimental measurements; a test is reliable if it gives the same result when it is repeated under the same conditions

resistance the degree to which a substance resists the flow of current; measured in ohms (Ω)

reversible capable of going in both directions

ribosome a structure in a cell that reads genetic information to assemble proteins

Richter scale a system used to measure the strength of an earthquake

ridge push a force that causes a plate to move away from the crest of an ocean ridge and into a subduction zone

rift valley an elongated depression in Earth's surface formed by the separation of tectonic plates

rock a naturally occurring substance composed of minerals forming Earth's outermost layers, formed as part of the rock cycle

rock cycle the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

rotational kinetic energy the energy an object has because it is rotating

saliva liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

sandstone sedimentary rock composed mainly of sand-sized silicate grains

Sankey diagram a flow chart that represents the flow of energy through a system

scatterplot a type of graph used to display the relationship between two quantitative variables

scientific notation a way of writing very large or very small numbers by putting one number before the decimal point, then multiplying by a power of 10

seafloor spreading a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

secondary source (of information) a second-hand account; a source that summarises, analyses or interprets primary sources

sedimentary describes rocks made from deposited materials that are the products of weathering and erosion

sediments sand, stones and other materials that slowly form a layer of rock

seismic wave a wave that moves through Earth during an earthquake

seismogram the pattern produced when seismic activity is recorded by a seismometer

seismometer an instrument that measures the intensity and duration of seismic waves during an earthquake

series circuit a circuit in which the batteries and other components are all connected one after the other

short circuit when current is allowed to flow from one conductor to another with little or no resistance

sinoatrial node a natural pacemaker that controls the heartbeat and is located in the wall of the right atrium

slab pull the pulling force exerted by a cold, dense oceanic plate plunging into the mantle due to its own weight

smelting the process of extracting a metal from rock by heating it in the presence of carbon

solar energy a renewable source of energy that converts the light energy from sunlight directly into another useable type of energy

solute a substance that dissolves in a solvent to form a solution

solution a liquid mixture in which the solute is dissolved and uniformly distributed within the solvent

solvent a liquid substance that dissolves a solute to form a solution

sound energy a form of travelling wave; sound consists of vibrations in the air

specialised cell a cell that has undergone structural changes that allow it to perform a specific task

specimen an object being observed under a microscope

sphincter a muscle that surrounds an opening in the body and can tighten to close it, e.g. at the bottom of the oesophagus, leading into the stomach

static discharge a sudden transfer of electrostatic charge

static electricity an imbalance of charge on objects

stem cell a cell that can develop into many different types of cells

stomata (sing. stoma) tiny pores (holes) in leaves that allow entry/exit of gases such as oxygen and carbon dioxide

stratigraphy a branch of geology that studies rock layers

streak test a test used to help identify a mineral by scratching a rock on a hard ceramic tile

structure a physical part of an object

subduction when the denser oceanic plate sinks underneath a less dense continental plate

subduction zone the area where a collision between two of Earth's tectonic plates causes one plate to sink into the mantle underneath the other plate

surface mining a method of mining that extracts a mineral from the surface, such as by digging an open pit

suspension a mixture in which one chemical substance will eventually settle out of the solvent

system a portion of the universe that is being analysed

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

tectonic plates giant slabs of rigid rock that float on the partially molten rock below Earth's surface and make up the lithosphere

temperature a measure of the degree of heat present in a substance; gives an indication of the average kinetic energy of the particles

thermal energy the energy contained within a material that is responsible for its temperature

tissue a group of cells performing the same function

tissue engineering the combined use of cells and engineering to improve or replace biological tissues

trachea the tube that carries air down to the lungs; also known as the windpipe

transform (conservative) a type of plate boundary that occurs when plates move parallel to one another

translucent allowing some light through, but no clear image can be seen through the substance

transparent allowing light to pass through, and a clear image can be seen through the substance

travelling wave a wave that can carry energy from one place to another

trend a pattern in a graph that shows the general direction/shape of the relationship between the dependent and independent variables

tsunami a great wave produced by an earthquake or volcanic eruption in the ocean

turbine a device that converts the kinetic energy of a fluid into useful work, e.g. a windmill

underground mining traditional method of mining by digging tunnels underground to extract ore

unicellular made of just one cell

vacuole a structure in a cell that stores water and nutrients

valid the experiment suitably addresses the research question and measures what it intends to measure

validity a measure of how closely the results of an experiment reflect what they should

valve a structure that prevents the backward flow of blood

variable a factor in an experiment with a value that varies or can be changed

vein a thin-walled vessel with valves that carries blood back to the heart

vena cava the large vessel that returns deoxygenated blood from the body to the heart, emptying into the right atrium

ventricle one of the two lower chambers of the heart, the left and right ventricles

villi finger-like structures in the digestive system that have a high surface area and rich blood supply for absorption of nutrients

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

voltage the potential difference between two points in an electric circuit; measured in volts (V)

voltmeter a device for measuring voltage between two points on an electric circuit

waste energy the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy and sound

wave energy the energy carried by a travelling wave (e.g. an ocean swell) or trapped in a standing wave (e.g. a guitar string)

xenotransplantation transplanting organs from one species into another

zygote a fertilised egg cell

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