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INCLUDED

Gemma Dale
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Victoria Shaw

8
Cambridge
science
for Queensland

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How to use this resource

Class activities in the print book

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

Did you know?

These are short facts that contain interesting information.

Quick check

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

Explore!

Students are encouraged to conduct research online to find and interpret 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

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

Hands-on activities

Try this

Classroom activities help explore concepts that are currently being covered.

Practical skills

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

Investigation

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

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End of chapter

Chapter review

Chapter checklist

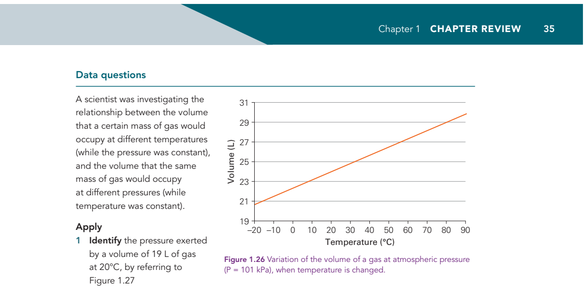
You can download this checklist from the Interactive Textbook to complete it.

1	**I can describe how a specialised cell's structure is related to its function.** e.g. Describe the structure of a red blood cell and how this helps its function.	
2	**I can recall the levels of organisation in an organism.** e.g. Organise the following words so they start with the smallest component and end with the largest: Organ, Cell, Organism, Organ system, Tissue.	
3	**I can describe the process of cellular respiration.** e.g. Recall the definition of cellular respiration.	
4	**I can identify the different parts of the respiratory system.** e.g. Describe the purpose of the diaphragm in the process of breathing.	
5	**I can describe how gas exchange occurs in plants.** e.g. Describe the role of stomata and guard cells.	
6	**I can describe how gas exchange occurs in fish** e.g. Describe how the structure of gills allows effective gas exchange.	
7	**I can identify the different parts of the heart.** e.g. Recall the route that blood takes through the heart, starting with the vena cava.	
8	**I can describe the structure and function of arteries, veins and capillaries.** e.g. Describe the structure of veins, and how this helps their function.	
9	**I can recall the different components of blood.** e.g. State the three components of blood.	
10	**I can recall the main nutrients that the human body requires.** e.g. State the main role of carbohydrates in the body.	
11	**I can identify the different parts of the digestive system.** e.g. Recall the route that food takes through the digestive system, starting with the mouth and ending with the anus.	
12	**I can recall the role of enzymes in the digestive system.** e.g. State the role of enzymes in the digestive system.	
13	**I can compare the digestive systems of carnivores and herbivores.** e.g. Describe how a carnivore's digestive system suits its diet.	
14	**I can describe different methods of organ repair and replacement.** e.g. Discuss some issues surrounding xenotransplantation.	

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

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

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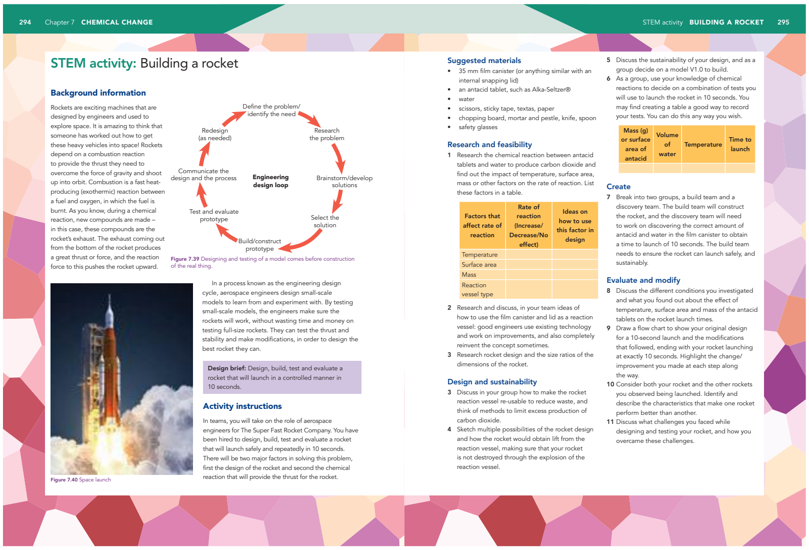
Data questions

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).

Apply

1 **Identify** the pressure exerted by a volume of 19 L of gas at 20°C, by referring to Figure 1.27

Figure 1.26 Variation of the volume of a gas at atmospheric pressure (P = 101 kPa), when temperature is changed.


294 Chapter 7 **CHEMICAL CHANGE**

STEM activity: Building a rocket

Background information

Rockets are exciting machines that are designed by engineers and used to explore space. It is amazing to think that someone has worked out how to get these heavy vehicles into space! Rockets depend on a combustion reaction to provide the thrust they need to overcome the force of gravity and shoot up into orbit. Combustion is a fast heat-producing (exothermic) reaction between a fuel and oxygen, in which the fuel is burnt. As you know, during a chemical reaction, new compounds are made – in this case, these compounds are the rocket's exhaust. The exhaust coming out from the bottom of the rocket produces a great thrust or force, and the reaction force to this pushes the rocket upward.

Figure 7.39 Designing and testing of a model comes before construction of the real thing.

Figure 7.40 Space launch

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 make sure 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 they can.

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.

STEM activity **BUILDING A ROCKET** 295

Suggested materials

- 35 mm film canister (or anything similar with an internal snapping lid)
- an antacid tablet, such as Alka-Seltzer®
- water
- scissors, sticky tape, textas, paper
- chopping board, mortar and pestle, knife, spoon
- safety glasses

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 film canister and lid as a reaction vessel: good engineers use existing technology and work on improvements, and also completely reinvent the concept sometimes.

3 Research rocket design and the size ratios of the dimensions of the rocket.

Design and sustainability

3 Discuss in your group how to make the rocket reaction vessel re-usable to reduce waste, and think of methods to limit excess production of carbon dioxide.

4 Sketch multiple possibilities of the rocket design and how the rocket would obtain lift from the reaction vessel, making sure that your rocket is not 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 of antacid	Volume of water	Temperature	Time to launch

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 need to work on discovering the correct amount of antacid and water in the film canister to obtain a time to launch of 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 the 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 change/improvement 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.

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

Links to the interactive textbook

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

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

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

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

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

Overview of the Interactive Textbook (ITB)

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

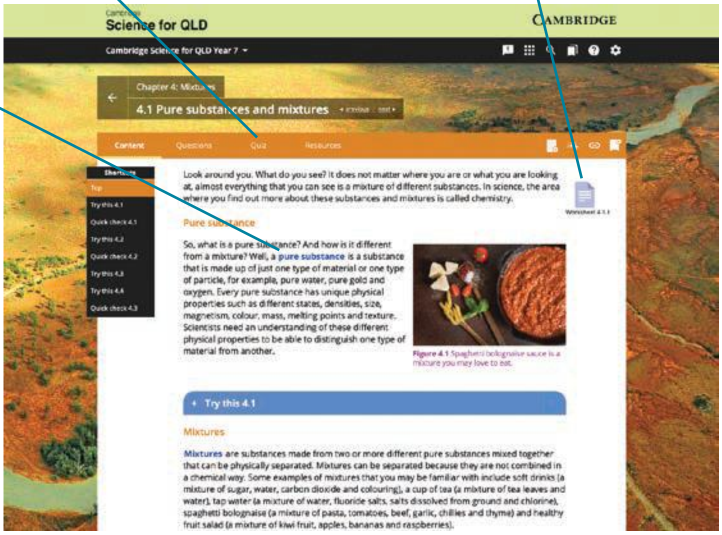
Definitions pop up for key terms in the text.

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

Worksheets are provided as downloadable Word documents.

Videos summarise, clarify or extend student knowledge.

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



Look around you. What do you see? It does not matter where you are or what you are looking at, almost everything that you can see is a mixture of different substances. In science, the area where you find out more about these substances and mixtures is called chemistry.

Pure substance

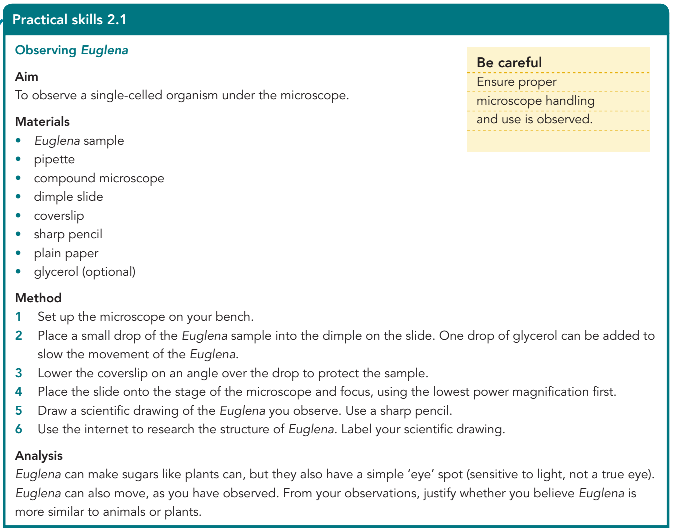
So, what is a pure substance? And how is it different from a mixture? Well, a pure substance is a substance that is made up of just one type of material or one type of particle, for example, pure water, pure gold and oxygen. Every pure substance has unique physical properties such as different states, densities, size, magnetism, colour, mass, melting points and texture. Scientists need an understanding of these different physical properties to be able to distinguish one type of material from another.

Figure 4.1 Spaghetti bolognaise sauce is a mixture you may love to eat.

Mixtures

Mixtures are substances made from two or more different pure substances mixed together that can be physically separated. Mixtures can be separated because they are not combined in a chemical way. Some examples of mixtures that you may be familiar with include soft drinks (a mixture of sugar, water, carbon dioxide and colouring), a cup of tea (a mixture of tea leaves and water), tap water (a mixture of water, fluoride salts, salts dissolved from ground and chlorine), spaghetti bolognaise (a mixture of pasta, tomatoes, beef, garlic, chillies and thyme) and healthy fruit salad (a mixture of kiwi fruit, apples, bananas and raspberries).

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



Practical skills 2.1

Observing *Euglena*

Be careful
Ensure proper microscope handling and use is observed.

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

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

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

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

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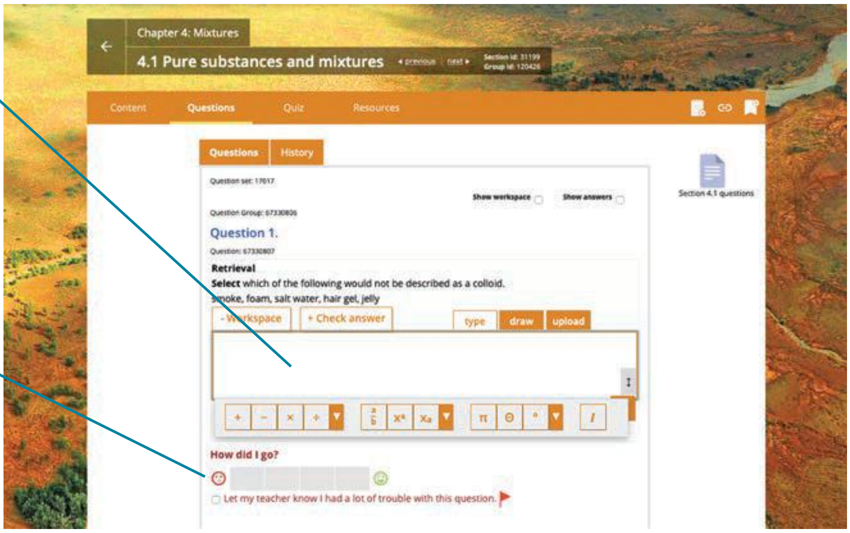
Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

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



Question set: 17017

Question Group: 67330806

Question 1.

Question: 67330807

Retrieval

Select which of the following would not be described as a colloid.

smoke, foam, salt water, hair gel, jelly

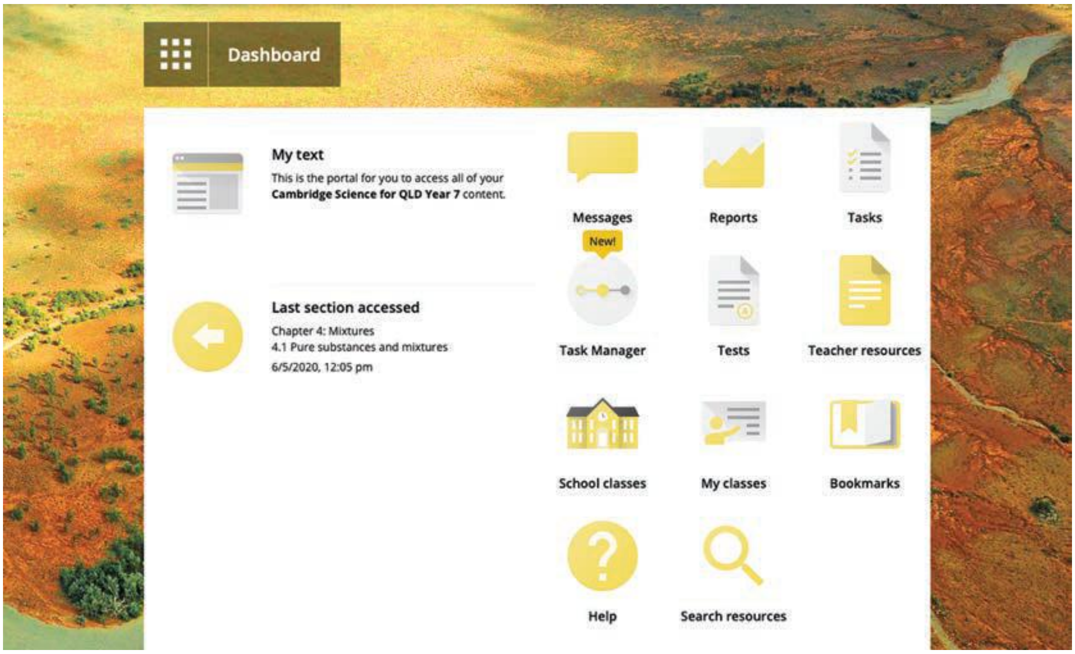
How did I go?

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

Overview of the Online Teaching Suite (OTS)

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

- **The Edjin learning management** system with class and student analytics and reports, and communication tools.
- Teacher's view of a **student's working and self-assessment**.
- **Chapter tests** and **worksheets** with answers as PDFs and editable Word documents.
- Editable **curriculum grids** and **teaching programs**.
- **Teacher notes** for Practical skills, Investigations and STEM activities are available as Word document downloads.



My text

This is the portal for you to access all of your **Cambridge Science for QLD Year 7** content.

Last section accessed

Chapter 4: Mixtures

4.1 Pure substances and mixtures

6/5/2020, 12:05 pm

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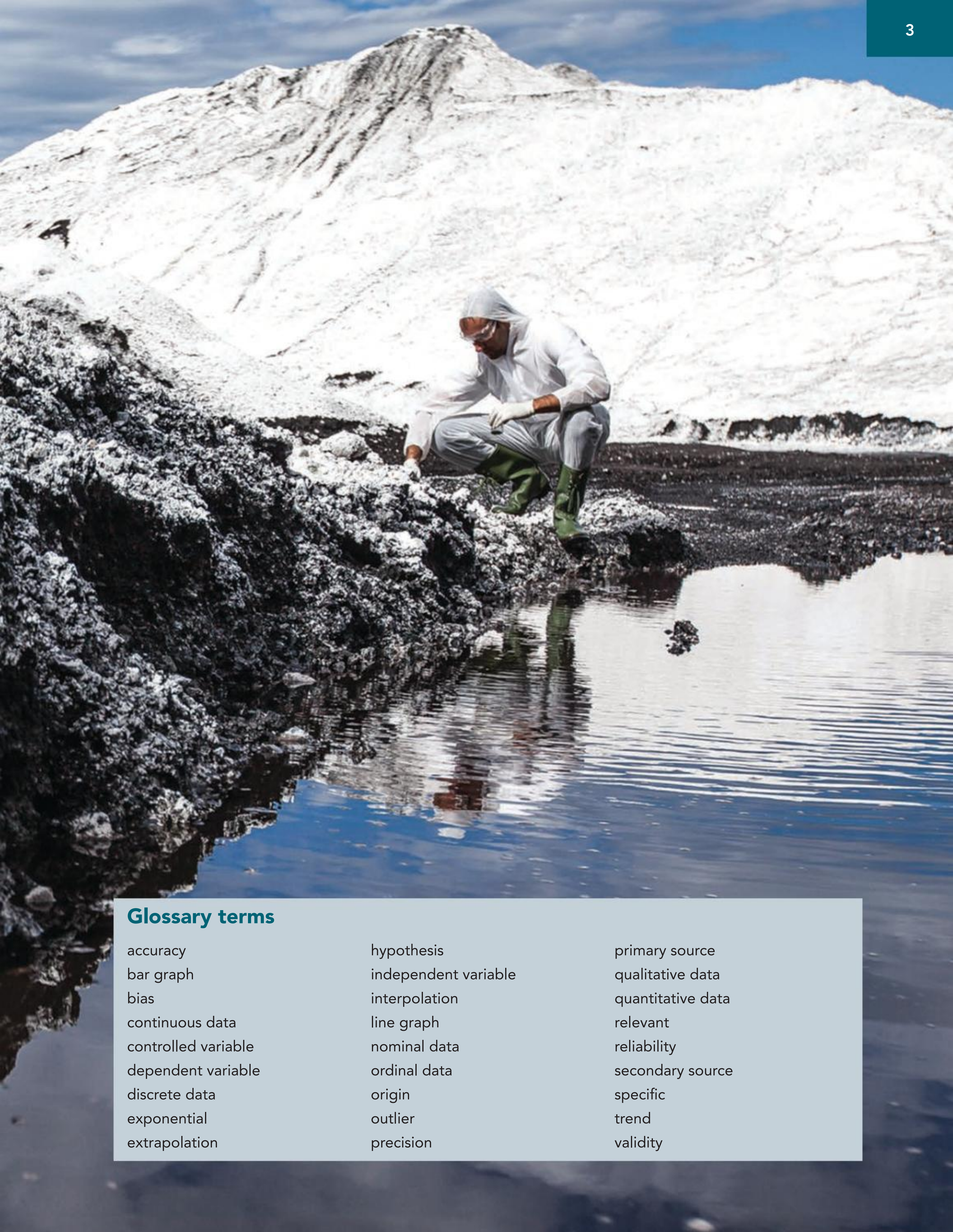
Chapter 1
Being scientific

Chapter introduction

By now, you know a bit about science as a discipline and the many different fields that scientists work within. In this chapter, you will be introduced to the scientific method, which is a type of framework for how science is practised. You will focus on carrying out research and analysing sources of data, learn how to record and process your own experimental data, and discover how to communicate your scientific findings to the world.



Glossary terms

accuracy
bar graph
bias
continuous data
controlled variable
dependent variable
discrete data
exponential
extrapolation
hypothesis
independent variable
interpolation
line graph
nominal data
ordinal data
origin
outlier
precision
primary source
qualitative data
quantitative data
relevant
reliability
secondary source
specific
trend
validity

1.1 The scientific method: questioning, predicting and conducting

WORKSHEET

The scientific method: review

Last year you looked at what science is, lab safety, how scientists gather data and how to use certain pieces of equipment. You were also briefly introduced to the scientific method.

Remember that the scientific method is a framework for how to plan, conduct and report on scientific research. The steps in the scientific method are shown here.

The scientific method

STEP 1: OBSERVE AND ASK QUESTIONS AND STATE VARIABLES
Define a good research question that can be tested.

↓

STEP 2: RATIONALE
Conduct some background research on the question. You will also assess the quality and reliability of your sources of information.

↓

STEP 3: CONSTRUCT A HYPOTHESIS
Construct a hypothesis. This is a testable prediction about the outcome of the experiment. It is an educated guess that is formulated from your research. You should also state your independent, dependent and controlled variables.

↓

STEP 4: METHODOLOGY
You will need to write a method that is easy to follow. It should include the materials and apparatus used, and the procedure in steps. You should also write a risk assessment.

↓

STEP 5: PROCESSING DATA
During the experiment, you will collect important data. It might be quantitative or qualitative data. You will display this 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: EVALUATION
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: CONCLUSION
This is an insightful interpretation of experimental evidence through a justified conclusion that is linked to the research question.

↓

STEP 9: REPORTING THE RESULTS
Scientists share their findings with the broader scientific community by writing a scientific report or presenting a scientific poster. Sometimes the conclusions raise more questions and can lead to further research.

Figure 1.1 The scientific method

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Asking research questions

Asking questions is the first step in the scientific process, as there needs to be a question asked before we can try to find an answer. You probably just google most questions you have, but the answers you find online are often the result of a lot of scientific research. A question to research can be about anything, such as: 'Why do people prefer red food over green food?' or 'Does listening to music help students focus in class?' Both these questions can lead to a possible experiment.

Brainstorming can be a great way to draw out all possible questions that might be tested.

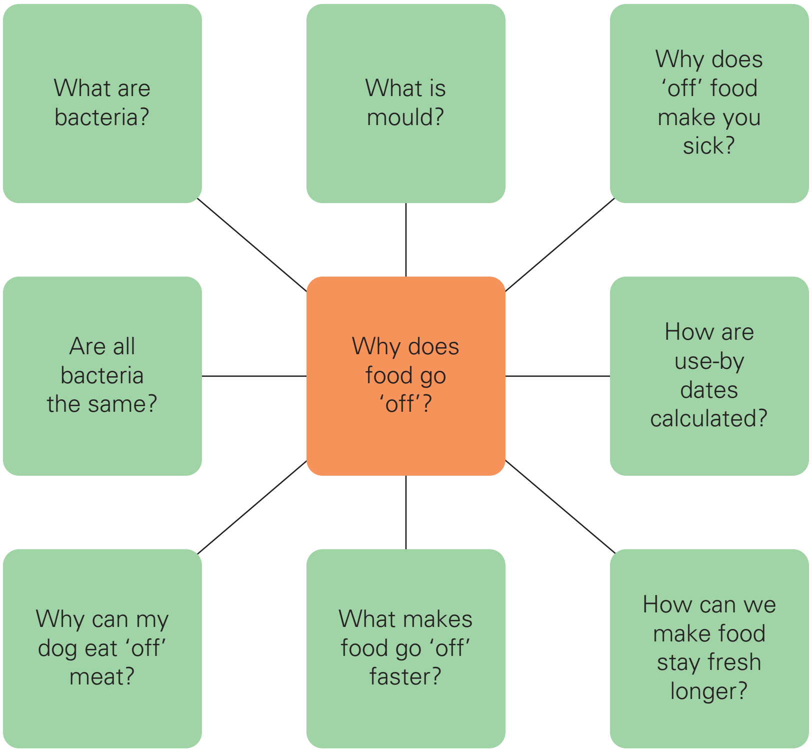


Figure 1.2 Brainstorming can help you develop questions.

Explore! 1.1

Think of a question you would love to know the answer to. The question could be anything at all. Use the following question starters to help you:

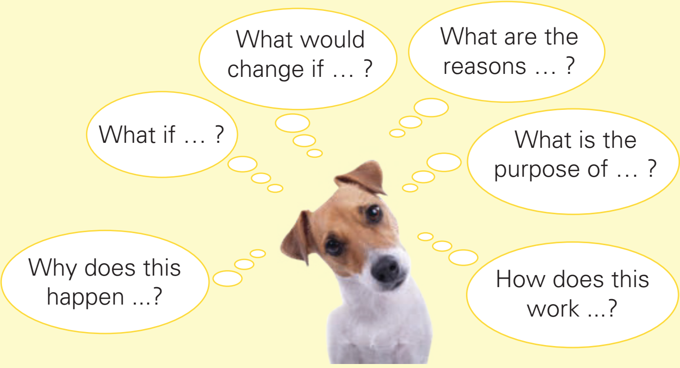


Figure 1.3 Begin by thinking of a question

Rationale

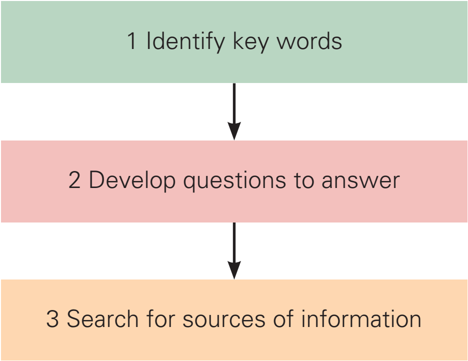
Now that you have a question to answer, do some research to find out what people already know about the question. For example, say you are investigating the red food question above. Our early ancestors associated certain food with specific colours: they would avoid blue, black, or purple foods, associating them with being toxic or spoiled. This may explain why many people don't like food being the colour blue.

However, in nature, the redder a food is, the higher the likelihood of it being nutritious, while green foods tend to be lower in calories (and therefore considered less delicious!). Red attracts attention, and increases blood flow and heart rate. When the blood flow is increased to the digestive system, it makes you hungry.

specific	clearly defined or identified
relevant	connected to the topic being investigated
primary source	a source of information that comes from your own findings or experiments
secondary source	a source of information that comes from someone else's research or findings

Think about your favourite fast food restaurant. What is the main colour that is used? Research some diet company logos, and you will find they use either blue or green.

When you are given a task to research, it can seem overwhelming. However, if you follow the steps below, it can make the whole process much easier.



1 Identify key words

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

Try this 1.1

Reading with a pen

While reading about your research question, keep a pen handy.

Underline key words or phrases.

Circle words or phrases you don't understand.

? Put this next to something that raises a question.

! Put this next to something that surprises you.

Write important thoughts in the margin or around the question.

For example:

How does palm oil farming in Indonesia affect young people? living in Australia?

2 Develop **specific** and **relevant** questions to answer

Questions you could investigate from the inquiry question shown in *Try this 1.1* are:

1 What is palm oil?
2 What is palm oil used for?
3 Who farms palm oil?
4 Where is Indonesia?
5 Why is palm oil farmed in Indonesia?
6 What is the age range of the 'young people' we are focusing on?
7 How can farming in another country affect Australia?
8 What are the effects of palm oil farming?
9 How do these effects relate to me?

3 Search for sources of information

Often when we have a question, other people have asked the same question and have conducted some form of research to find answers.

A **primary source** of information is one that comes from your own findings and experiments. A **secondary source** is when you search for other people's research and use their findings.

There are many types of resources that you can use to gather secondary data.

Using the internet

The internet is an amazing tool filled with lots of information. The problem is, there is so much information that sometimes it can be hard to find exactly what you are looking for. It can also be hard to decide whether the information you are reading is actually correct and free of **bias**. Information is biased if the writer has let their personal opinion or their own agenda influence their judgement. For example, if you search the website of a coffee company for information about the effects of caffeine, you are more likely to get information that is biased in favour of drinking coffee – there might be less information about the negative effects of caffeine and more about the positive effects.

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

Searching

When searching for information, there are techniques you can use to help refine your search. For example, if you were researching the question, 'What are the effects of palm oil farming?', you might use the techniques listed in Table 1.1.

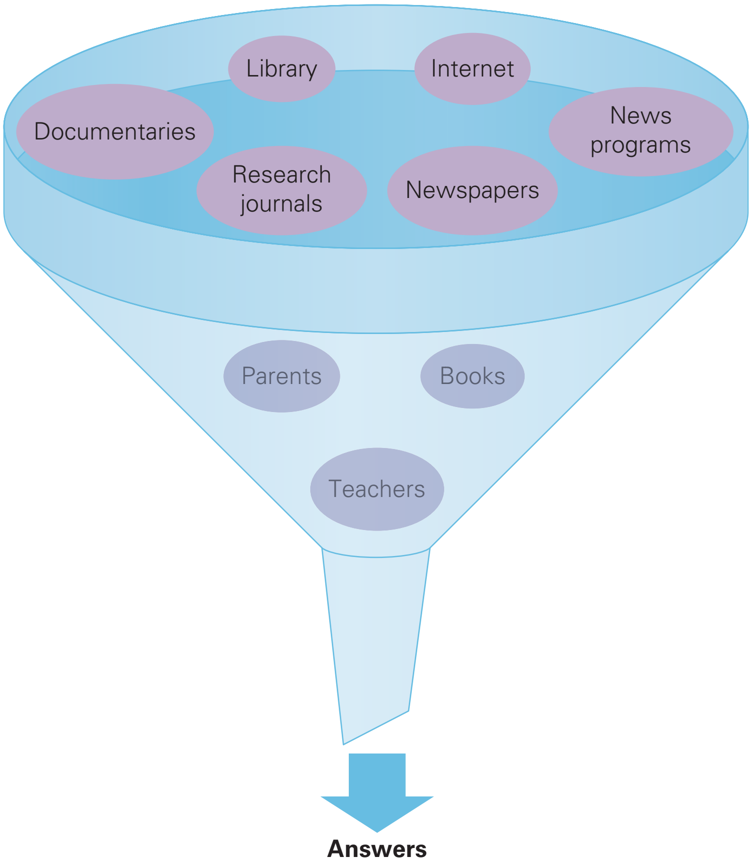


Figure 1.4 Resources for gathering secondary data

Search technique	How?	Example
Group words together	Use quotation marks to group search words together	"palm oil farming"
Search for titles or headings	Type: intitle: "search word"	intitle: "farming palm oil"
Search for a file type (see Table 1.2 below)	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 Worldbook Databases your school subscribes to

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

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Secondary sources

When you find some information, you can use the *CRAAP test* to check whether you should use that information. The CRAAP test takes into account the currency, relevance, authority, accuracy and purpose of the information.

When you use the CRAAP test, you give each of these factors a score of either 0, 1, 2 or 3. You then have to add all the scores up. Try to aim for total scores of at least 13. Table 1.3 explains how to apply the CRAAP test.

	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.

Table 1.3 The CRAAP test

	Description	Score			
		0	1	2	3
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, is written well and in a concise way.
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 research an inquiry question and use the CRAAP test to assess the usefulness of the resources you find.

1 Define the term 'adaptation'.
2 Outline one reason why it is important for animals to have adaptations.
3 Copy and complete the table below.

Australian animal characteristics	Animal 1	Animal 2
Common name		
Scientific name		
Where found in Australia		
Description of habitat		
Description of adaptation		
Type of adaption (behavioural, physiological, structural)		
Outline of how the adaptation allows the animal to survive in its habitat		

continued…

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...continued

4 Compile a sources list.
  a List the search terms you used for searches (at least three terms).
  b Name and score three of your sources.
  c Identify the best source of information you have accessed.
  d Compare the best source to the worst source.

Methodology

Variables

Next you will need to choose one factor you are going to change, and one factor you are going to measure. These are known as your *experimental variables*. The factor you change is the **independent variable** and the **dependent variable** is the one that changes depending on how you changed the independent variable. Everything else must stay the same, in order to ensure that your experiment tests what it sets out to test. All the variables you keep the same are known as **controlled variables**. If you fail to control these variables, they might affect the dependent variable, which would make it not a fair test and might cause you to draw false conclusions.

independent variable
the variable in an experiment that you manipulate, change or test

dependent variable
the variable in an experiment that you measure

controlled variable
a variable in an experiment that must be kept constant, so it does not affect the dependent variable

hypothesis
a prediction, or educated guess, about the effect that the independent variable will have on the dependent variable; a prediction of the outcome of an experiment

In the food experiment, the variables are as follows:

Independent variable: colour of food

Dependent variable: perception of calorie content or tastiness, or level of hunger stimulated

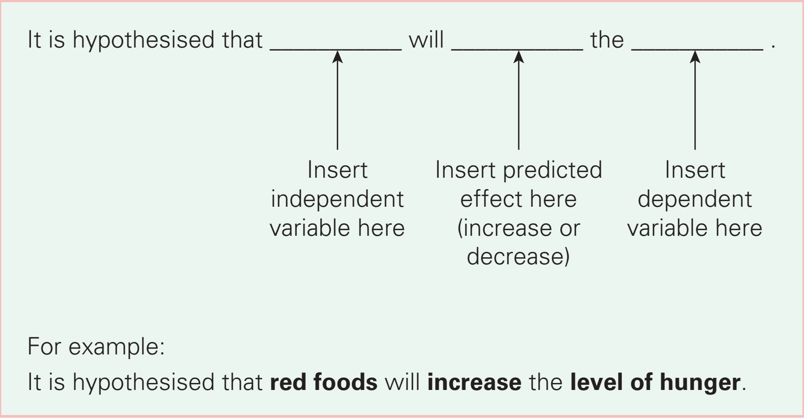
Controlled variables: time taken to look at food, portion size of food, plate that the food is placed on.

Writing a hypothesis

The variables in an experiment are used to make a prediction – this prediction is called the **hypothesis**. The hypothesis is a short statement about the expected effect of the *independent variable* on the *dependent variable*. You do not need to give a reason for your prediction. Two good ways to set out a hypothesis are shown in Figures 1.5 and 1.6.

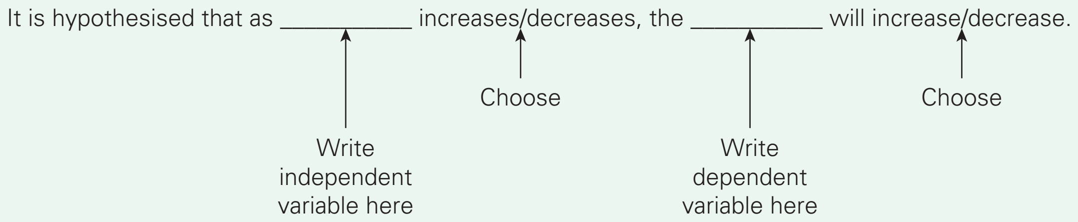
Points to remember when writing a hypothesis:

- A hypothesis is a prediction about the outcome of the experiment.
- It must be written as a statement that can be tested.
- Predict how the independent variable will affect the dependent variable.
- Do not use 'I think …'



For example:
It is hypothesised that **red foods** will **increase** the **level of hunger**.

Figure 1.5 Setting out a hypothesis: Example 1



For example:

It is hypothesised that as **temperature in the backyard** (°C) *increases*, the **time taken for clothes to dry** (seconds) will *decrease*.

Figure 1.6 Setting out a hypothesis: Example 2

Quick check 1.1

1. Sequence these steps in the order in which they should be done.
   1. Conduct experiment
   2. Record and process the results (data)
   3. Ask a research question
   4. Do background research
   5. Construct a hypothesis
   6. Analyse the data
   7. Evaluate the data and draw conclusions
2. Define these terms:
   - a Independent variable
   - b Dependent variable
   - c Controlled variables
3. Recall what a hypothesis must contain.

Writing a method

A method is a detailed description of the process involved in an experiment. It is a set of step-by-step instructions that will enable anybody to repeat the experiment exactly as you conducted it.

It is important to be as precise as possible, as this will allow you to identify any flaws in your process when you look at your results.

When you are writing a scientific method, think about how you would write the method for making a cake: the baker needs to know exactly how much flour, sugar, eggs and butter to add, in which order to add them, how long to cook the cake for and at what temperature, otherwise the cake could be a disaster.

Points to remember when writing a method:

1. Write the steps in order.
2. Start each step with a verb.
3. Include specific names and sizes of equipment used and quantities measured.
4. Outline what results will be measured and how this will be done.
5. Identify how the results will be presented.
6. Include the number of repeats that will be carried out. (Will means be calculated?)
7. Write in third person (no mention of you/I/we).

When you are writing your method, it is important to decide how many trials you will undertake. A reliable and fair experiment should have at least three trials, so that the mean can be calculated to minimise the uncertainties of measurements in the results.

You should also consider how many different levels or situations of the independent variable you want to test. For example, timing how long a substance takes to melt in the fridge, at room temperature, in direct sunlight and in a flame uses four different levels of 'temperature', which is the independent variable. This experiment is therefore said to have four experimental conditions.

Risk assessment

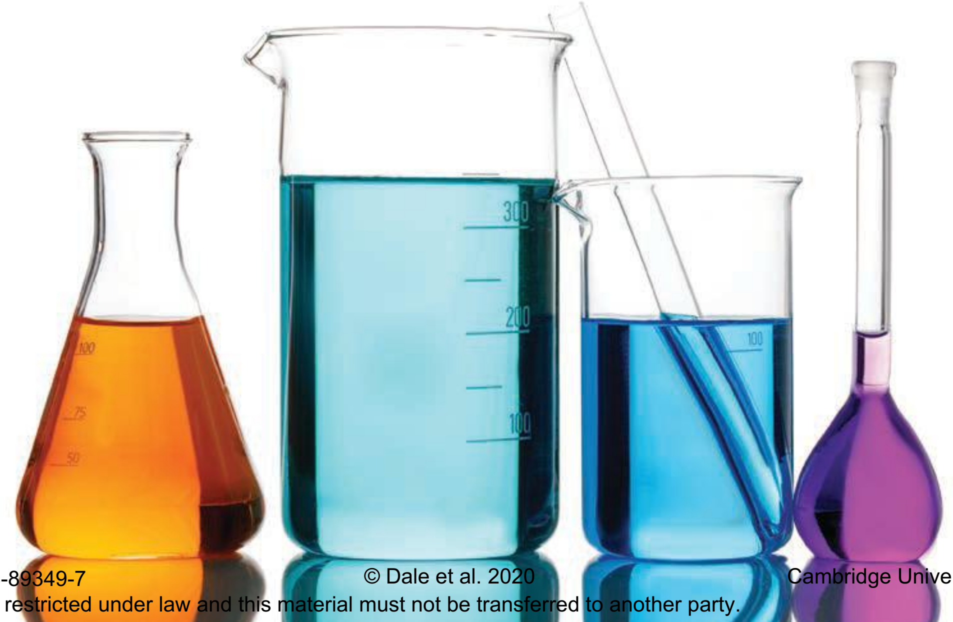
Even if you perform them carefully, all experiments carry an element of risk. Some can even be dangerous. Therefore, it is important that you write a risk assessment to show firstly, that you have considered the risks associated with the experiment, and secondly, that you know how to avoid or minimise these risks.

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 should a problem arise. 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	Move all glassware 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 how a risk assessment can be presented



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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 M)	 Corrosive, irritant	Corrosive to skin and eyes. The vapour may irritate the respiratory tract and lungs. It may also cause serious burns.
Moderate concentrations of hydrochloric acid (2.7 M – 6.8 M)	 Irritant	May cause irritation of eyes, skin and the respiratory tract.
Dilute hydrochloric acid (<2.7 M)	 Potential irritant, low hazard	May cause irritation of eyes and on 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 persons(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 An example of a simple SDS for hydrochloric acid. Usually companies will have a much more detailed and extensive SDS accompanying chemical products.

Try this 1.3

Writing a method to test the strength of shapes

Background

In this experiment, you will be measuring the strength under compression of different shapes of paper. You may choose any shapes you wish, but they all have to be the same height and made of the same materials (one sheet of A3 paper).

Aim

To measure the strength under compression of different shapes of paper

Materials

- 3 A3 sheets of paper
- 1 piece of cardboard
- several 50 g masses
- sticky tape
- scissors

Method

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

Independent variable	
Dependent variable	
Controlled variable	

2 Construct a hypothesis for your experiment. Predict how the independent variable will affect the dependent variable.

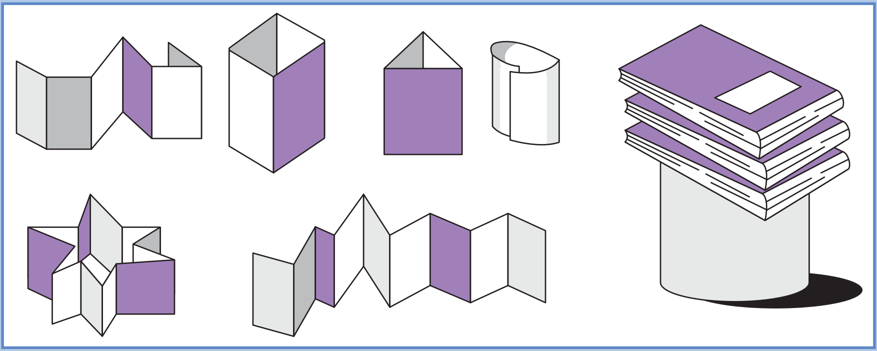

Figure 1.7 Some possible shapes to use (shown on left) and one way to test their strength (shown on right)

Results

Record your results in a table, using the table below as a guide.

Independent variable	Dependent variable			
	Trial 1	Trial 2	Trial 3	Mean

Analysis

1 Identify the strongest shape you tested.

2 Did anyone in the class have a stronger shape?

3 Suggest one more variable you controlled or should have controlled.

continued...

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…continued

Evaluation

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 regarding the strength of different shapes using data to support your statement.

Section 1.1 questions

QUIZ

Retrieval

1 **Define** the three types of experimental variables.

2 **Recall** three starters you could use to develop a question.

3 A student wants to see if writing all 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.

Comprehension

4 **Explain** why variables have to be controlled.

5 **Explain** the domains a CRAAP test assesses, by copying and completing the table.

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

6 **Explain** why a method that includes quantitative measurements should be carried out as accurately as possible.

Analysis

7 **Contrast** a primary source of data with a secondary source of data.

Knowledge utilisation

8 Erika says her scientific research satisfies the scientific method because she performed all the steps of the method. She carried out the following steps:

1. She asked a question.
2. She conducted an experiment.
3. She recorded her data.
4. She analysed her data and created some graphs.
5. She did some background research to explain her data.
6. She came up with a hypothesis.
7. She analysed the data and found that it supported her hypothesis (she drew a conclusion).
8. She published a report to communicate her findings.

Evaluate Erika's claim. Do you agree that she has followed the scientific method? Explain your answer.

1.2 The scientific method: recording, processing and analysing data

WORKSHEET

As you have already learned, the early steps of the scientific method involve asking a question, doing background research, constructing a hypothesis, and designing and conducting the experiment to test the hypothesis.

Hopefully, the experiment will yield some interesting data. You will need to:

- collect and record the data during the experiment
- process the data by calculating the mean, and then displaying your results in tables and graphs
- analyse the data by looking for patterns.

Displaying data in tables

It is a good idea to construct a table before the experiment begins, so you can record the data as you go.

All tables have:

- a title that describes what is in the table (not 'Results table').
- lines ruled in pencil (if on paper)
- column headings showing the unit that is measured.

Data for all trials should be included in the table, as well as means, differences or changes (if appropriate to the experiment). Units should only appear in the column headings.

Example of how to set up a table

An example of a table of data is shown in Figure 1.8. The title of this table is: 'How the mass of bicarb added to vinegar affects the height of bubbles produced over time.'

The values in a table should all be written to the same number of decimal places. In Figure 1.9, the table on the left is correct, but the table on the right is wrong, as the third value, 139, is not given to the same number of decimal places as the other data.

Once you have recorded your data in a table, it is good practice to write a short sentence summarising what the table shows.

For example, from the table in Figure 1.9, you could say:

'The results show that as time (s) increases, the volume of liquid (mL) also increases.'

Table: How the mass of bicarb added to vinegar affects the height of bubbles produced over time

The independent variable is placed in the left-hand column.

Independent variable: Mass of bicarb (g)	Dependent variable: Height of bubbles (mm)			
	Trial 1	Trial 2	Trial 3	Mean
1.0	89	91	90	90
2.0	105	104	106	105
3.0	139	141	140	140
4.0	162	165	159	162

The dependent variable is placed in the top row, and results for each trial are shown.

If multiple trials are recorded, then you should also include a column for the mean value.

Figure 1.8 How to set up a table of data

✓

Time (s)	Volume of liquid (mL)
1.0	89.1
2.0	105.2
3.0	139.0
4.0	162.5

✗

Time (s)	Volume of liquid (mL)
1.0	89.1
2.0	105.2
3.0	139
4.0	162.5

Figure 1.9 Data values in a column should all have the same number of decimal places.

Quick check 1.2

1 Identify the mistake in each of the following tables.

a

Time seconds	Temperature
0	40°C
60	50°C
120	60°C
180	70°C

b

Distance (km)	Time (s)
1	66.6
2	140.00
3	293.45
4	603.32

2 Construct a table to show the following data.

Max is making toffee. He is using a thermometer to measure the temperature of the sugar. He measures the temperature after 5 minutes and finds that the temperature of the sugar is 100°C. At 10 minutes it is 108°C, at 15 minutes it is 115°C and at 20 minutes it has reached 122°C.

3 Anna places a bottle of water in a freezer set at different temperatures and measures how long it takes the water to freeze at each temperature. She records her results in the table opposite.

Identify the mistake in the table.

Time to freeze (hr)	Freezer temperature (°C)
6	−2
4	−4
3	−6
2	−8

Calculating the mean

Worked example 1.1

A mean is one measure of central tendency; it is the typical value for that variable. Maher takes the following 5 temperatures from each corner and the middle of a pool at noon: 17°C, 15°C, 13°C, 16°C, 15°C. Calculate the average temperature of the pool.

Solution	Explanation
17°C + 14°C + 14°C + 16°C + 14°C = 75°C	The sum of the measurements is 75°C.
Average = $\frac{75°\text{C}}{5}$ = 15°C	Divide the sum by the number of measurements taken, which in this case is five.

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Try this 1.4

Testing paper planes

In this activity you will test how the size of a paper aeroplane affects the distance it can travel. You will record the data from multiple trials in an appropriate results table.

Materials

- A4 paper
- scissors
- measuring tape

Method

1. Define the following for your experiment: independent variable, dependent variable and controlled variables. Create a table of results for your experiment.
2. Construct a hypothesis for your experiment. Predict how the independent variable will affect the dependent variable.
3. Follow the steps shown in Figure 1.10 to produce a paper aeroplane.
4. Choose four different sizes of paper to make different sized paper aeroplanes. Planes made from bigger pieces of paper will have a bigger mass and a bigger wing span.
5. Throw the first aeroplane and measure the distance travelled until it hits the ground.
6. Record your measurement in the results table.
7. Repeat throwing this plane for two more trials, recording your result each time.
8. Repeat steps **5–7** for each of the four different planes.
9. Calculate the mean for each set of results.

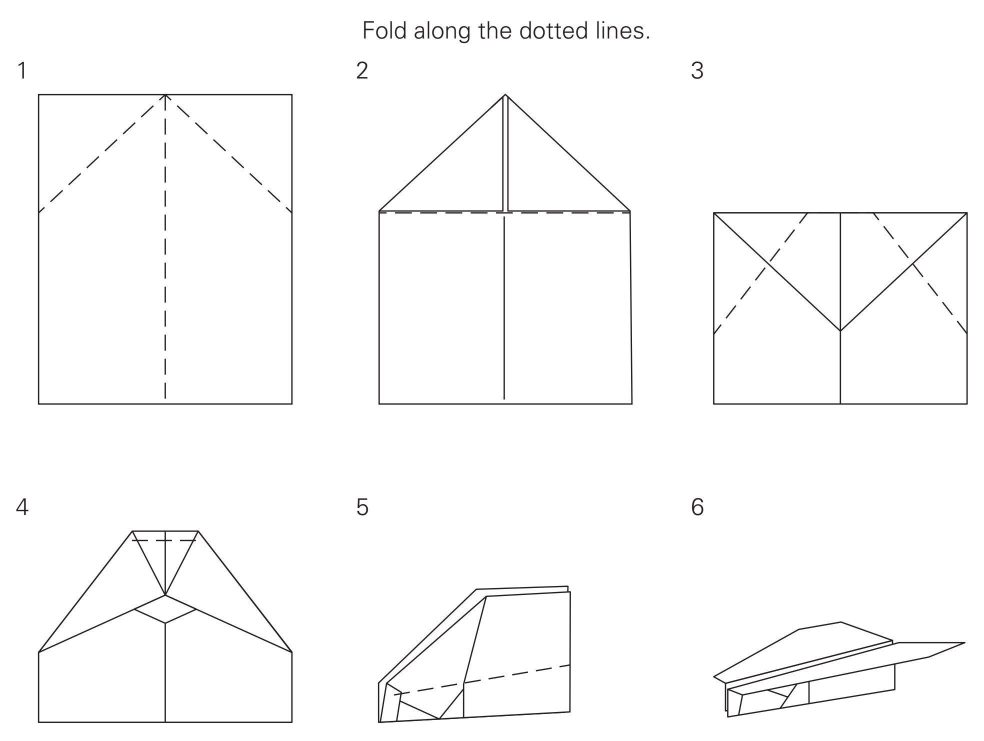

Figure 1.10 How to make the paper aeroplane

Analysis

Write a short summary of what your data shows.

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Evaluation

1. Identify other variables that you should have controlled during the experiment.
2. Identify one variable that you were not able to control, that could have affected your results (one potential source of error).
3. Suggest two other independent variables that you could change, other than the size of the aeroplane.
4. Explain the reason for conducting multiple trials and calculating the mean of your results.

Evaluating your data

Before you pack away the equipment, check your data to make sure you do not have any gaps or outliers. An **outlier** is a measurement that is very different from the data gathered in your other trials. If you see an outlier, perform that trial again, as the outlier could be the result of faulty procedure.

Displaying your data in graphs

Now that you have raw data from your experiment, it is important to display the data in a way that shows any possible patterns, trends or relationships that your experiment has uncovered.

The type of graph that is appropriate depends on the type of data you have collected. **Quantitative data** (numbers) is classified as either **continuous** or **discrete**. **Qualitative data** (descriptions or worded categories) is classified as either **ordinal** or **nominal**.

Quantitative data: continuous vs discrete

Quantitative data relates to numbers. Table 1.6 lists the differences between continuous and discrete quantitative data.

outlier
an extreme data value that is very different from the other data, and could be the result of faulty procedure

quantitative data
data values that are numerical in nature

continuous data
quantitative (numerical) data points that have a value within a range; this type of data is usually measured

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

qualitative data
data values that are worded/descriptive/categorical in nature

ordinal data
qualitative (categorical) data where the categories have an order, e.g. small, medium, large

nominal data
qualitative (categorical) data where the categories have no order, e.g. male, female

	Continuous data	Discrete data
Features	Usually measured	Usually counted
	Takes any value within a range, e.g. might have decimal places	Usually takes whole-number values
Examples	*Human height* If you measured the height (in metres) of every person in the classroom, the data might look like: 1.75, 1.77, 1.8, 1.835, 1.99 ... The data can be placed in a definitive order. *Other examples:* time, weight, temperature (measured with a thermometer or temperature probe)	*Number of plants* If you counted the number of plant seedlings that grew in an experiment, the data might look like: 1, 0, 5, 8, 17 ... It is impossible to have 1.39 plants. You can only have whole numbers. The data can be placed in a definitive order. *Other examples:* number of siblings, number of crystals formed after a chemical reaction

Table 1.6 The differences between continuous and discrete quantitative data

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Line graphs

A *scatter plot* is a way of displaying how one quantitative variable changes in response to another quantitative variable, by plotting points. When the points are connected, it is called a **line graph**. Line graphs are generally used with continuous data, as they show how the data points continue on from one another.

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

The lines at the side and bottom of a graph are called the *axes*. When you transfer data from a table, place the independent variable on the x-axis (horizontal axis). The dependent variable goes on the y-axis (vertical axis).

Table: The effect of time on car speed

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

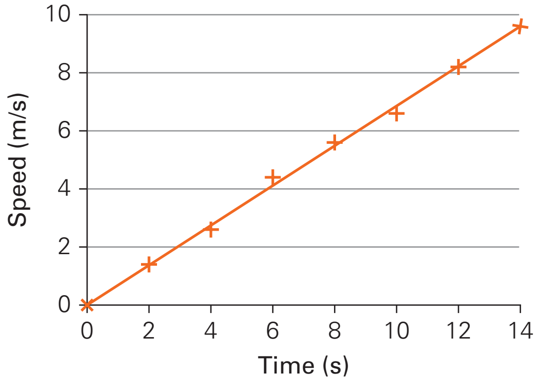

Figure: The effect of time on car speed

Figure 1.11 Table and figure showing the effect of time on car speed. Note that in the graph representation of this table, very small crosses have been used to mark the data points.

Practical skills 1.1

Pendulum 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

Materials

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

Planning

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

Independent variable	
Dependent variable	
Controlled variables	

continued…

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...continued

2 Construct a hypothesis for your experiment. Predict how the independent variable will affect the dependent variable.
3 Write a risk assessment for this experiment.

Method

1 Attach the weight to the bottom of the piece of string.
2 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 1.12.
3 Using the protractor, hold the string tight at 45 degrees and release the pendulum.
4 Start the stopwatch as soon as you release the pendulum and count three full swings (across and back), as shown in Figure 1.12.
5 When the pendulum returns for the third time, stop the stopwatch and divide the time by 3.
6 Record the time for one swing in the results table.

Results

Create a results table for your experiment.

Use the mean of each of your 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).

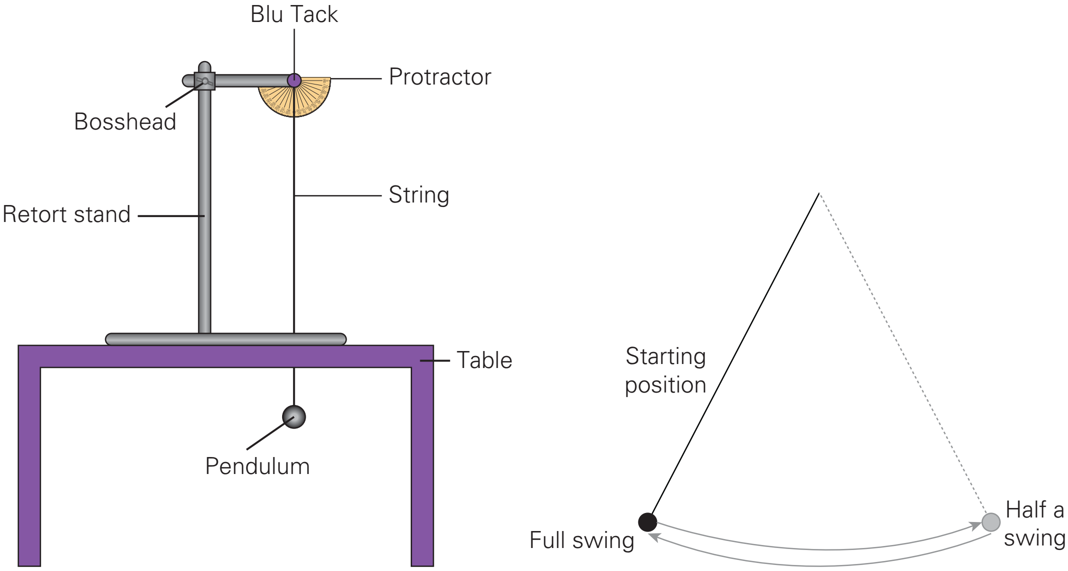

Figure 1.12 Experimental set-up. Left: setting up the pendulum. Right: timing the swing of the pendulum

Analysis

1 Identify any trends you see in your graph.
2 Explain whether your results supported or disproved your hypothesis.

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Qualitative data: ordinal vs nominal

Qualitative data involves categories, scales or descriptions. This type of data is in the form of words (rather than numbers). The differences between ordinal and nominal data are listed in Table 1.7.

	Ordinal data	Nominal data
Features	Categories have a natural order.	Categories do not have a natural order.
Examples	A chemical reaction is performed and the amount of product produced is described as 'low', 'medium' or 'high'. Five trials are completed and the data looks like: low, high, medium, low, low. These categories make sense if they are displayed in a certain order. *Other examples:* month of the year, size of the test tube (small, medium, large), the participant's response on a scale (strongly agree, agree, neutral, disagree, strongly disagree)	A survey is completed for background research and participants are asked to choose their favourite colour from a list. The data might look like: blue, pink, pink, yellow, green, blue. The categories could be displayed in any order. *Other examples:* gender (male or female), blood type (A, B, O, AB), eye colour (blue, brown, green)

Table 1.7 The differences between ordinal and nominal qualitative data

Bar graphs

bar graph
a type of graph used to display the frequency of a qualitative variable (category)

A **bar graph** (or column graph) is a way of displaying how a quantitative dependent variable (for example, heart rate) changes in response to a qualitative independent variable (for example, breed of animal). Categories are listed along the *x*-axis and numbers along the *y*-axis.

Bar graphs have spaces between the bars – the bars are not positioned next to each other.

An example is shown in Figure 1.13.

Table: Heart rates of different mammals

Animal	Heart rate (beats/min)
Camel	35
Horse	41
Human	70
Rabbit	210
Mouse	670
Rat	750

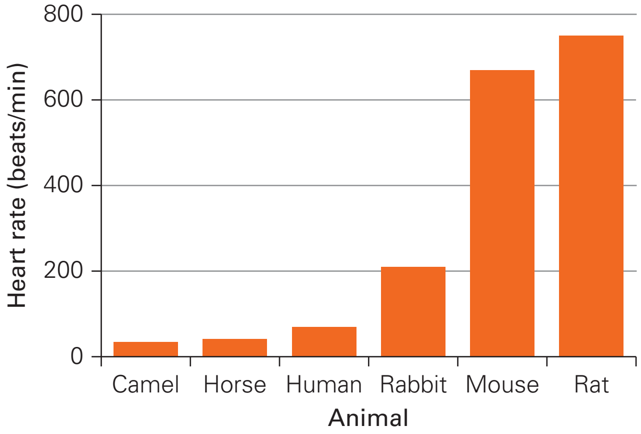

Figure: Heart rates of different animals

Figure 1.13 Data table and bar graph showing heart rates of different mammals.

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Guidelines for drawing graphs

- Always use a sharp, dark pencil.
- Usually the independent variable goes on the *x*-axis and the dependent variable on the *y*-axis. However, sometimes you may be asked to plot variables on specific axes in a way that contradicts this rule.
- Axes should be labelled with the quantity being measured and the units. The units should be in brackets after the quantity name – for example, time (s) or volume (L).
- Use the full width of the graph paper (if drawing on paper) and choose a scale that spreads the data points out over most of the grid. If you are measuring quantities where 0 does not mean 'no quantity' (for example, temperature), then you do not have to start the axes at zero. If the range of values does not go to zero (for example, 85–115), then don't start the axes at zero. In this example, you could start the axis at 80 and continue the numbers to 120. If the quantities on both axes go to zero, then the **origin** (where the axes meet) should be at (0, 0).
- The scale needs to increase evenly, preferably with each grid square used to represent multiples of 1, 2, 5 or 10. Do not have breaks in the scale – for example, you can't show 0 to 20 in intervals of 5 and then skip straight to 60.
- Data points can be marked with an 'x', not a dot, because dots (unless surrounded by a small circle) often disappear under a line of best fit. If you are plotting multiple sets of data on the same graph, use different-coloured points for each data set and add a legend.

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

Practical skills 1.2

Insulation of water

Background information

In this practical, you will gather data in order 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

Materials

- 4 × 250 mL beakers
- kettle
- thermometers
- foil
- cotton wool
- paper
- stopwatch
- elastic band

Planning

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		N/A

3 Construct a hypothesis for your experiment. Predict how the independent variable will affect the dependent variable.

continued…

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...continued

Method

1. Cover the sides of three beakers with either cotton wool, paper or foil, and use elastic bands to secure the covers in place. Leave one beaker without covering.
2. Place one thermometer in each of the beakers.
3. Boil the kettle and pour 100 mL of boiling water into each of the beakers. Start the stopwatch immediately.
4. Time for 5 minutes using the stopwatch, and then measure and record the temperature of the water in each beaker.
5. 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.

Results

Copy and complete the following table to record your results.

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

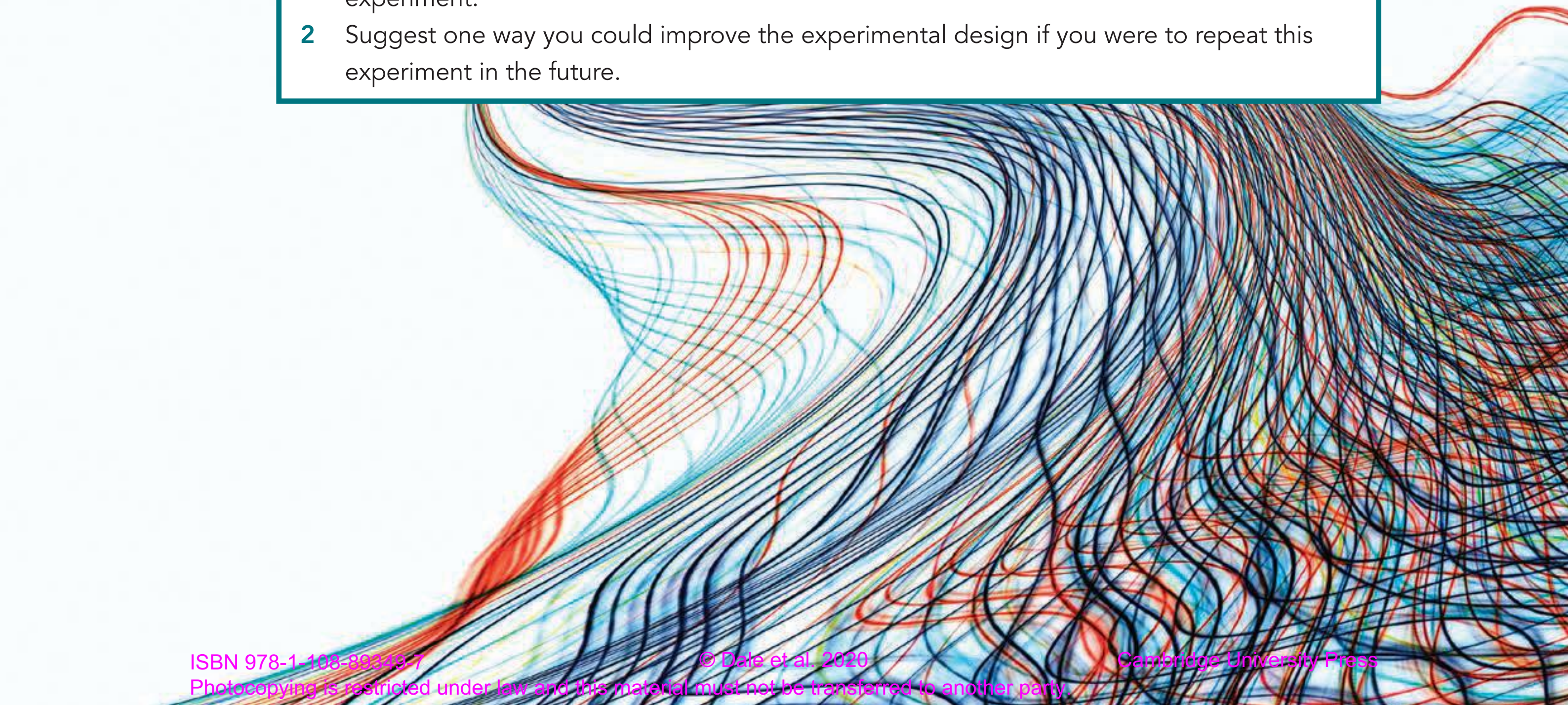
Create a bar graph for the mean data in your results table. Put the independent variable (insulating material) on the *x*-axis and the dependent variable (temperature after 5 minutes) on the *y*-axis.

Analysis

1. State whether your results supported or disproved your hypothesis and explain why.
2. Suggest a reason for using a beaker with no cover material.
3. Suggest a reason for putting your data into a bar graph, rather than just leaving it in a table.

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.



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Analysing data

Analysing data involves examining the tables and graphs and looking for patterns and relationships.

In Figure 1.14, the data show a steady increase. You would describe this by saying, 'As the age of the child (in years) increases, the size of clothing also increases'.

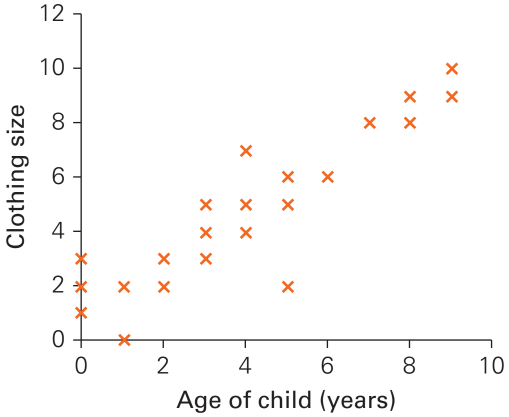

Figure 1.14 The effect of child age on clothing size

Describing patterns

We refer to patterns in graphs as **trends**. The graphs below show some common trends you might observe and describe.

In Figure 1.15, the data show a rapid increase that reaches a plateau (flat line) and then remains constant. You would describe this by saying, 'Initially during the first 60 months or so, as the number of months increases, the number of customers increases rapidly from 0 to 2000. Then, for the next 100 months, the number of customers remains fairly constant at around 2000'.

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

exponential
a population that grows at a rate proportional to its size

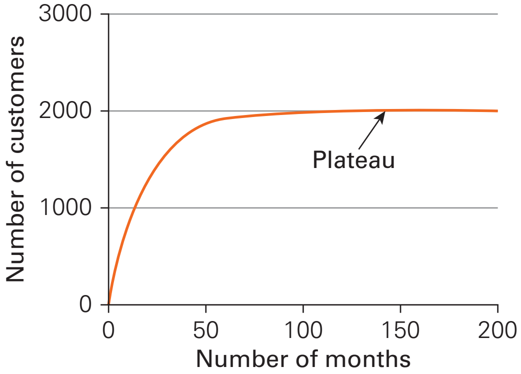

Figure 1.15 The total number of customers over months

The data in Figure 1.16 show an **exponential** increase. 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.

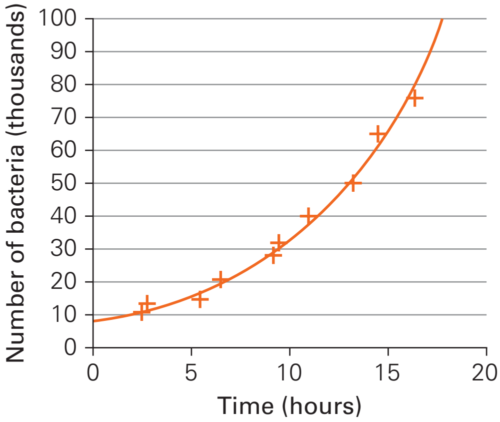

Figure 1.16 The effect of time on the number of bacteria

In Figure 1.17, the data do not show a clear pattern. There are seemingly random fluctuations over time.

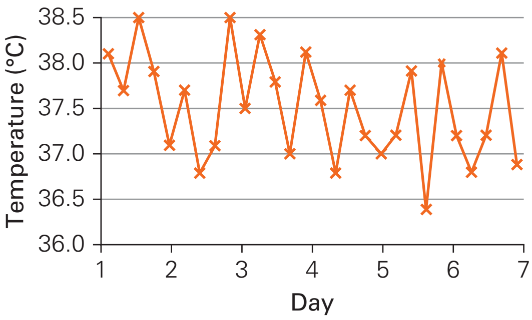

Figure 1.17 Temperature fluctuations over a seven day period

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Drawing a line of best fit

Once you have plotted your data, you may see a pattern (trend) in the results, such as a straight line or a curve. To highlight this pattern, we can use a curve or line of best fit. Connecting every data point suggests that there are absolutely no errors in the data, whereas a line of best fit approximates the relationship between the two variables. You can also use the line of best fit to predict missing measurements. If you make predictions inside the data set you originally collected, this prediction is called **interpolation**. This can be reliable in some circumstances, but not always. Care should be taken. If you predict outside the original data set, this prediction is called **extrapolation** and is less reliable.

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

extrapolation
using existing data (such as a line of best fit) outside the original data set to make a prediction

When drawing a line of best fit, make sure that there are as many points on one side of the line as on the other. You do not need to join each data point with the line. The line of best fit is like an 'average' that runs smoothly through the middle of the data points and makes the trend obvious.

A line of best fit:

- should be continuous
- can be straight, curved or any other shape that fits the data points. Do not try to draw a straight line of best fit over data that is clearly curved
- should not be forced through a (0, 0) origin if one is used on the graph
- should not be drawn beyond the range of the data points. It can, however, be linked back to the axes with a dotted or dashed line, as shown in Figure 1.18.

Figure 1.18 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 past the original data set. If you use the line in these regions (for example, to predict the reaction time for 0.1 M acid), then it is extrapolation and is less reliable.

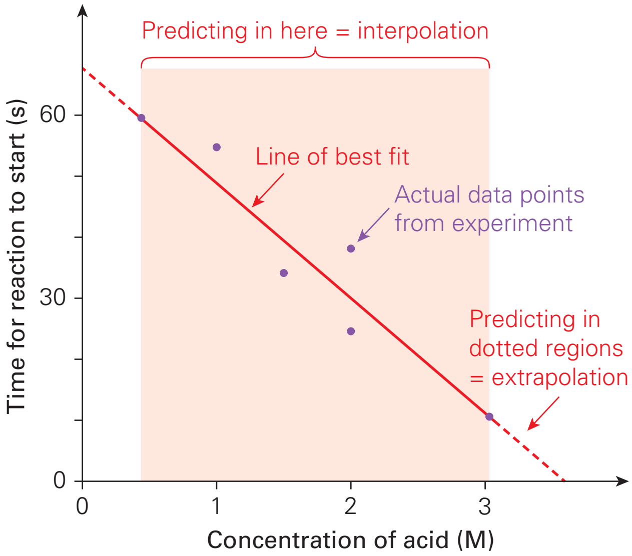

Figure 1.18 The effect of acid concentration on the time taken for a reaction to start

The line of best fit is not always a straight line. This graph in Figure 1.19 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.

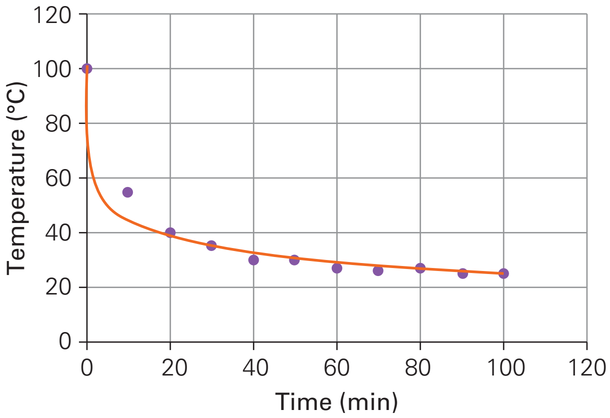

Figure 1.19 The effect of time on the temperature of 100 mL of water

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Try this 1.5

Balloon popping

Be careful

Safety glasses are a must for this practical.

Background information

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

Aim

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

Materials

- balloon
- string
- permanent marker
- ruler
- safety glasses

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 the balloon to indicate where you took the first measurement.
3. Use one breath to inflate the balloon. Without tying the balloon, measure 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, recording your results until the balloon pops.
5. Use your results to draw a line graph.

Results

Create a results table for this experiment.

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

Analysis

Identify one trend that you observed in your graph.

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

Draw a conclusion from this experiment. Justify your answer with data.

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Section 1.2 questions

QUIZ

Retrieval

1 **State** where units of measurement go, in a results table.
2 **Recall** four features of a correctly drawn results table.
3 **Recall** the term used when a measurement is repeated.

Comprehension

4 **Explain** what to look for when evaluating your data.
5 **Describe** where the independent and dependent variables should be placed in a table.
6 **Describe** where the independent and dependent variables should be placed on a graph.

Analysis

7 **Contrast** qualitative and quantitative data.
8 **Contrast** continuous and discrete data.
9 **Identify** two things wrong with the following table.

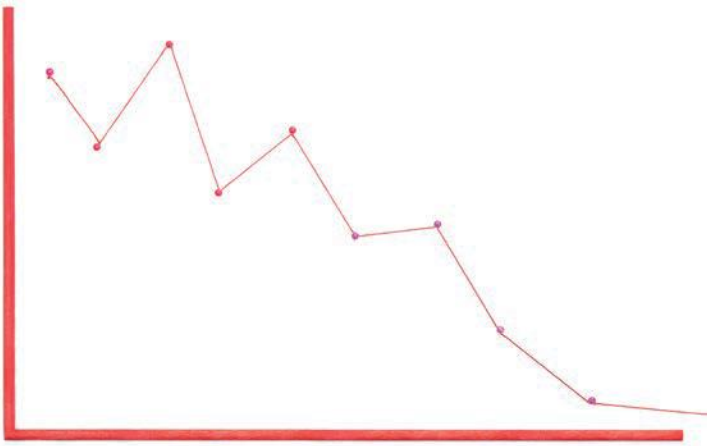
Height dropped	Bounce height (cm)			
	Trial 1	Trial 2	Trial 3	Mean
1 m	20	20	20	20
2 m	40.5	41	40	40.5
3 m	80	90	85	85

Knowledge utilisation

10 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 **Decide** on the type of graph that should be used to represent this data.
- b **Decide** which column would be used as the dependent variable.
- c **Propose** the independent variable in this experiment.



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1.3 The scientific method: evaluating and communicating

After you have conducted an experiment, recorded the data in a table and presented the data in a graph, it is time to explain what the data is showing. This is done in the analysis and conclusion sections of a scientific report. The reliability of your experiment is considered in the evaluation section.

Analysis

Once you have presented your data in a graph, you will need to analyse and interpret it. You need to state if there is any pattern, trend or relationship between the independent and dependent variable. This should be applicable to your research question. You can also include some scientific theory that you found out during your initial research to explain your results.

Evaluation

DOC WORKSHEET

The evaluation section of your scientific report is where you outline any problems you faced during the experiment and offer suggestions for improvements or extensions to the method.

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** and the **validity**, **precision** and **accuracy**. The Table 1.8 provides more detail on the difference between reliability and validity.

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
precision	how close repeated measurements are to each other
accuracy	how well a measuring instrument determines the variable it is measuring. It refers to how close a measurement is to the true value. You can increase the accuracy by choosing more appropriate equipment, or by ensuring it is properly calibrated.

	Reliability	Validity
What does it tell you?	The extent to which the results can be reproduced when the research is repeated under the same conditions.	The extent to which the results really measure what they are supposed to measure.
How is it assessed?	By checking the consistency of results across time, across different observers, and across parts of the test itself.	By checking how well the results correspond to established theories and other measures of the same concept.
How do they relate?	A reliable measurement is not always valid: the results might be reproducible, but they're not necessarily correct.	A valid measurement is generally reliable: if a test produces accurate results, they should be reproducible.

Table 1.8 The difference between reliability and validity

Here is an example.

Some students conducted an investigation into the effect of salt on the boiling point of water. They used a thermometer to measure the temperature at boiling point after salt had been added.

Description of the problem

The thermometer did not allow accurate readings, because the boiling point is found when the temperature stays the same for a period of time even though more heat is added. Depending on the type of thermometer and the size of the gradations, it may be difficult to see changes on a thermometer.

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 this occurred. This judgement could vary from person to person.

How it could be improved

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

Explanation of 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 bias or error.

Writing a conclusion

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

- what claim can be made from the experiment regarding the independent and dependent variables
- the evidence from your data that supports this claim
- an explanation of whether the data supports or disproves the hypothesis.

Remember, a hypothesis is never right or wrong. It is only supported or not supported which leads to more questions that need to be answered.

Here is an example.

Stuart conducts an experiment to see if taking his dog Jimmy for more walks reduces the number of socks Jimmy destroys.

Stuart's hypothesis is: 'It is hypothesised that the more walks Jimmy has per day, the fewer socks he will destroy.'

Stuart put his results into a graph and produced a line of best fit, shown in Figure 1.20.

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Figure 1.20 The effect of walks on the number of socks chewed

From the graph, Stuart developed the following conclusion:

'This experiment suggests that there is a relationship between the number of walks Jimmy has per day and the number of socks he destroys. The data shows that as the number of walks per day increased, there was a decreasing trend in the number of socks chewed, with five socks being chewed with one walk and no socks being chewed when there were six walks. This supports the hypothesis.'

Try this 1.6

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.
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.

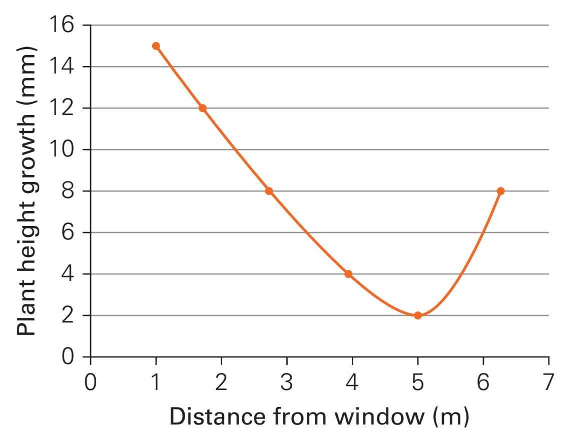

Figure 1.21 How the distance from a window affects plant height growth

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Section 1.3 questions

QUIZ

Retrieval

1 **Name** the part of a scientific report that states whether the hypothesis was supported.

2 **Name** the part of a scientific report where you can talk about problems you faced and changes you would make.

Comprehension

3 **Explain** how to draw a line of best fit.

4 **Explain** why graphs are used.

Analysis

5 **Identify** the general trend shown in the graph in Figure 1.22.

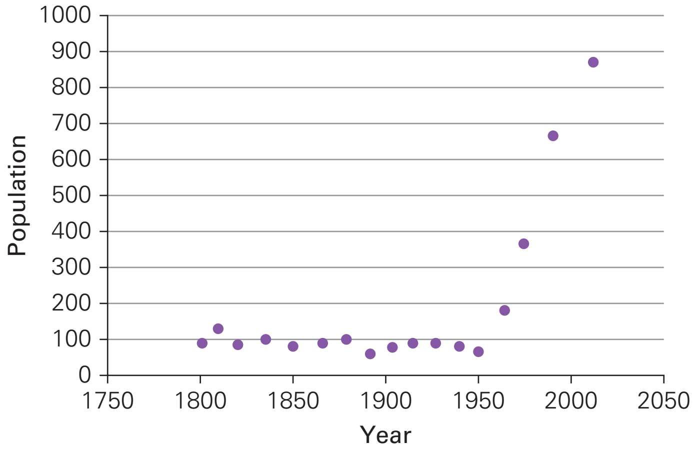

Figure 1.22 Change in population size over time

6 **Identify** the general trend in the graph shown in Figure 1.23.

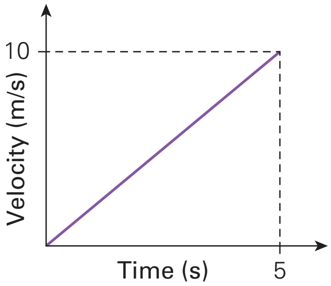

Figure 1.23 Change in velocity over time

Knowledge utilisation

7 Use this table of data to answer the questions below.

Time (s)	Temperature (°C)			
	Trial 1	Trial 2	Trial 3	Mean
60	80	83	82	
120	63	66	65	
180	30	32	65	

a **Calculate** the mean for the results in the table.

b **Determine** the outlier in the results.

c **Decide** on an appropriate type of graph for this data.

d **Construct** a graph for the data presented above.

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Chapter review

Chapter checklist

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

1	**I can define primary and secondary sources of information.** e.g. Contrast primary and secondary sources of information.	
2	**I can identify independent, dependent and controlled variables.** e.g. Explain the importance of controlled variables.	
3	**I can identify outliers in a dataset.** e.g. Define the term 'outlier'.	
4	**I can distinguish between quantitative and qualitative data.** e.g. State an example of quantitative data you could collect in your class.	
5	**I can distinguish between continuous and discrete data.** e.g. State an example of discrete data you could collect in your class.	
6	**I can distinguish between ordinal and nominal data.** e.g. State an example of ordinal data you could collect in your class.	
7	**I can select the most appropriate graph for a set of results.** e.g. Select the most appropriate graph for an experiment that collected data about the effect of different brands of shampoo on hair growth.	
8	**I can distinguish between interpolation and extrapolation.** e.g. Contrast interpolation and extrapolation.	

Review questions

Retrieval

SCORCHER

1 When conducting background research, **state** the difference between a primary source and a secondary source.
2 **Recall** what should be included in a hypothesis.
3 **Recall** what should be included in a conclusion.
4 The CRAAP test assesses the quality of a secondary source of information. **State** what the letters stand for.
5 **Define** the terms 'independent variable', 'dependent variable' and 'controlled variables'.

Comprehension

6 **Explain** how a well-constructed bar graph should look.

Analysis

7 **Classify** the type of data in each of the following data sets.
  a Age of students: 12, 13, 13, 14, 12, 18
  b Name of chemical compounds: copper chloride, lithium chloride, sodium chloride
  c Heat output: high, low, high, low, moderate, high
  d Time taken for a reaction to occur (seconds): 8.51, 3.29, 5.59, 1.24, 1.27
  e Location of a pot plant: full sunlight, partial sunlight, shade, darkroom

8 Several students were timed on how long each spent on chapter review questions, and then each exam score was recorded. The results were graphed and are shown in Figure 1.24.
  - 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.

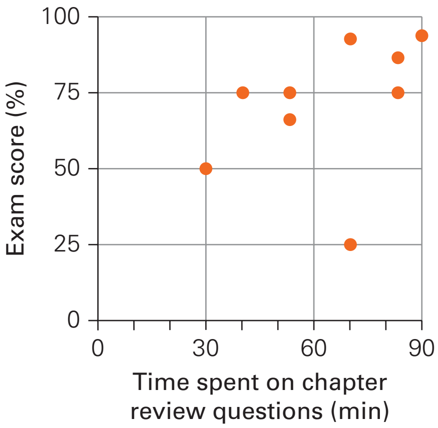

Figure 1.24 How time spent on chapter review questions affects exam scores

9 **Organise** these steps of the scientific method into the correct order:
  1. Do background research
  2. Construct a hypothesis
  3. Communicate your findings
  4. Record and process the data into tables and graphs
  5. Ask a question
  6. Conduct an experiment
  7. Analyse the data and look for patterns
  8. Evaluate the data and form conclusions

10 Inspect this table of experimental data, and **identify** two errors in how it has been constructed.

New growth in plant height (cm)	Amount of water provided to plant daily
0	0 mL
1	10 mL
3	20 mL
8	50 mL
1	100 mL

Knowledge utilisation

11 Estimate values using the scatter plot of data below.

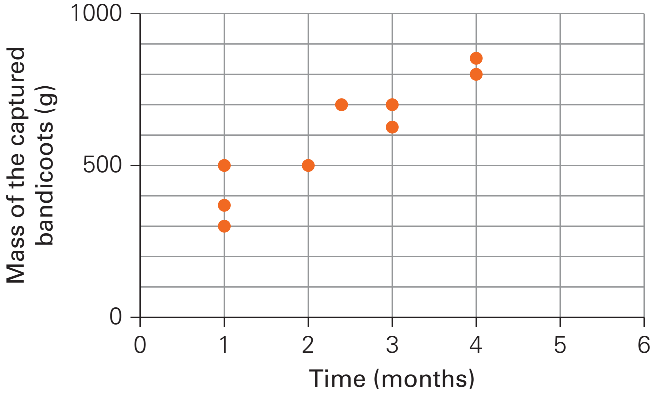

Figure 1.25 How time affects the mass of captured bandicoots

  - a **Determine** the masses of the two bandicoots captured after 3 months.
  - b **Identify** when a 500 gram 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 6 months.
  - d **Propose** a reason why there appears to be a trend of increasing mass with time.

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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).

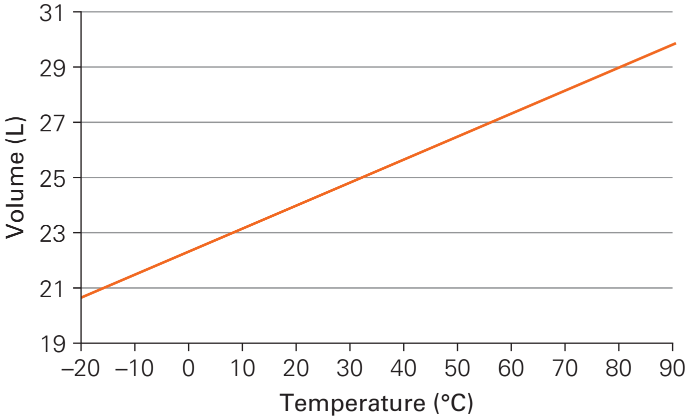

Figure 1.26 Variation of the volume of a gas at atmospheric pressure (P = 101 kPa), when temperature is changed.

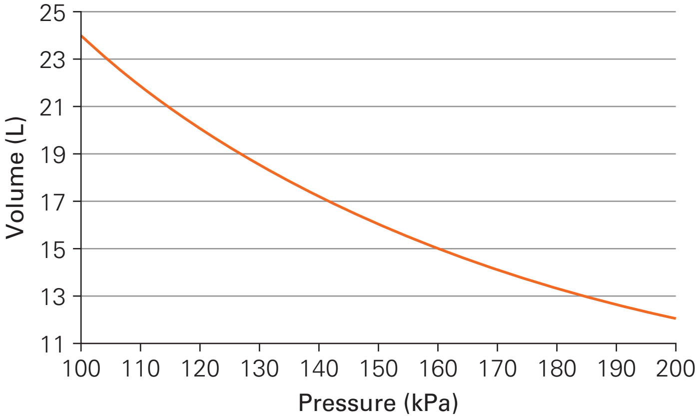

Figure 1.27 Variation of the volume of a gas at ambient temperature (T = 20°C), when pressure is changed.

Apply

1 **Identify** the pressure exerted by a volume of 19 L of gas at 20°C, by referring to Figure 1.27

2 **Identify** the dependent, independent or controlled character of each variable (volume, temperature, pressure) for the data presented in Figure 1.26.

3 **Identify** the volume occupied by a gas at 101 kPa pressure and a temperature of 10°C, by referring to Figure 1.26.

Analyse

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 1.26.

Interpret

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 pressure.

8 In Figure 1.26, **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 1.26 to **deduce** whether an increase in temperature at atmospheric pressure would affect the volume occupied by the gas.

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Chapter 2

Cells

Chapter introduction

Everything can be broken down into its smallest components. A house is made of timber, pipes and wires; cakes are made of flour, eggs and sugar; and all living organisms are made of cells. Cells are the basic building blocks of life, meaning that they are the smallest unit that can, potentially at least, carry out the processes that all living things do, such as moving, producing energy, sensing their environment, growth, repair, excretion and absorption of nutrients. In this chapter, you will explore the basic components of cells and the many types of cells that can be found in the natural world.

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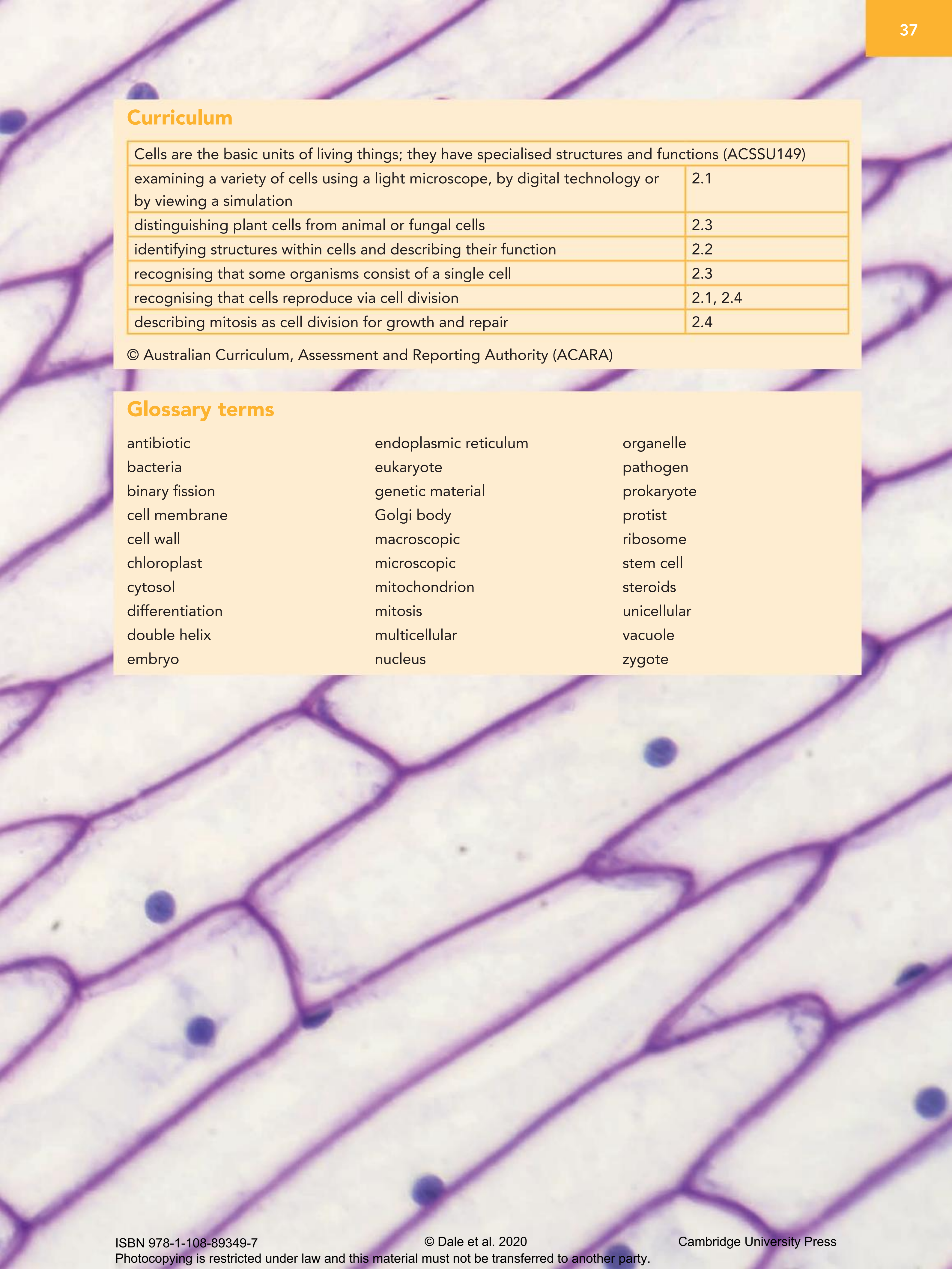

Curriculum

Cells are the basic units of living things; they have specialised structures and functions (ACSSU149)	
examining a variety of cells using a light microscope, by digital technology or by viewing a simulation	2.1
distinguishing plant cells from animal or fungal cells	2.3
identifying structures within cells and describing their function	2.2
recognising that some organisms consist of a single cell	2.3
recognising that cells reproduce via cell division	2.1, 2.4
describing mitosis as cell division for growth and repair	2.4

Glossary terms

- antibiotic
- bacteria
- binary fission
- cell membrane
- cell wall
- chloroplast
- cytosol
- differentiation
- double helix
- embryo
- endoplasmic reticulum
- eukaryote
- genetic material
- Golgi body
- macroscopic
- microscopic
- mitochondrion
- mitosis
- multicellular
- nucleus
- organelle
- pathogen
- prokaryote
- protist
- ribosome
- stem cell
- steroids
- unicellular
- vacuole
- zygote

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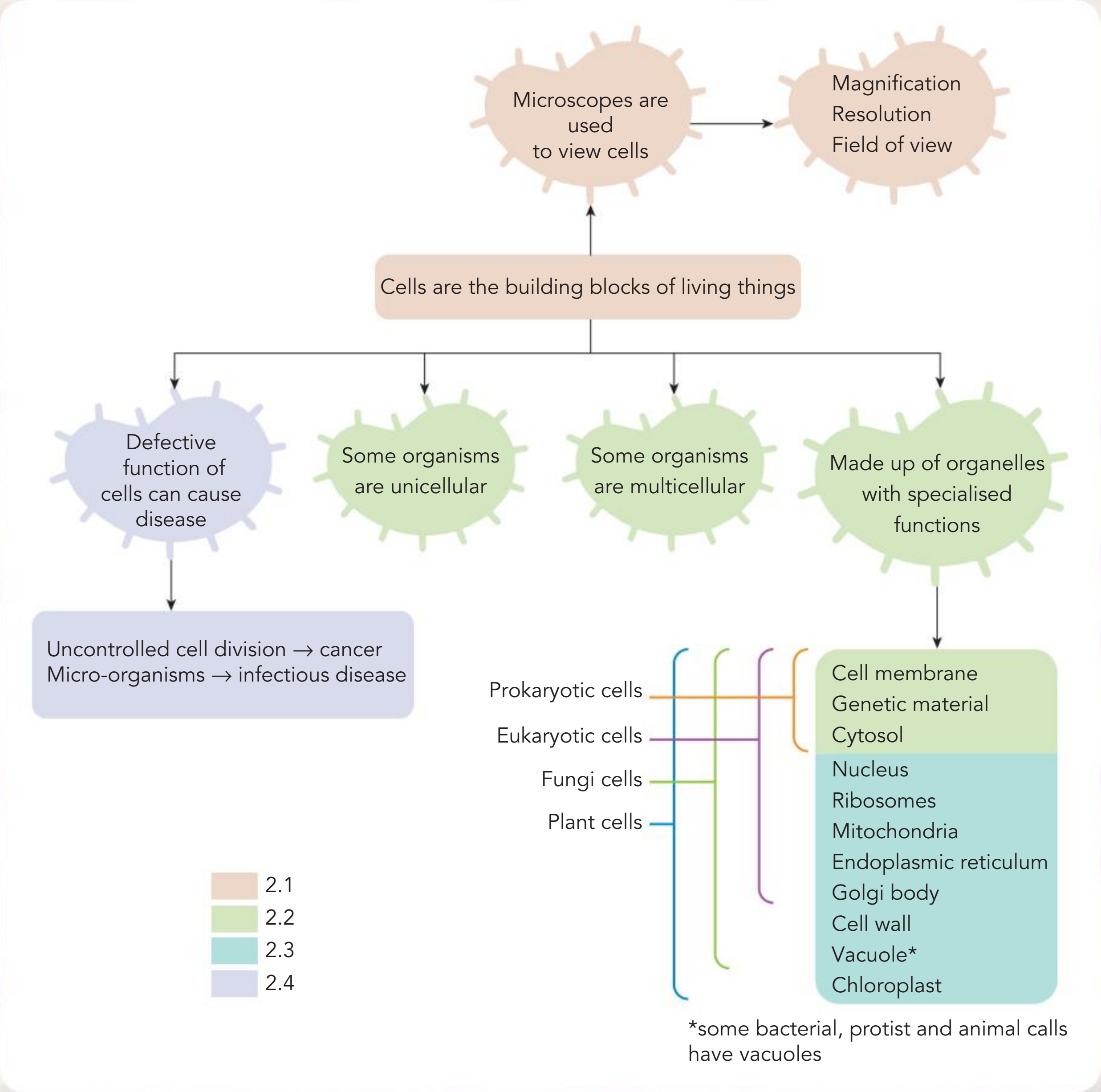
Concept map



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2.1 Microscopes and cells

The microscope

WORKSHEET

Throughout this chapter, you will explore the structure and function of cells. However, you would not have been able to learn this information without the invention of the microscope. It all began about 500 years ago, when scientists used hand-held magnifying glasses to view small **macroscopic** specimens – these were large enough to be visible to the naked eye. Scientists wished to view smaller and smaller specimens, and they soon found that using two lenses together enabled them to do so. This discovery led to the invention of the first light microscope. The light microscope that you use today in school is not very different from 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**.

macroscopic
visible to the naked eye

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

Did you know? 2.1

The scientist who first discovered single-celled organisms was Antonie van Leeuwenhoek. He called these organisms 'animalcules', meaning 'little animals'.

We now call these animalcules 'micro-organisms'.

Figure 2.1 Animalcules

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.

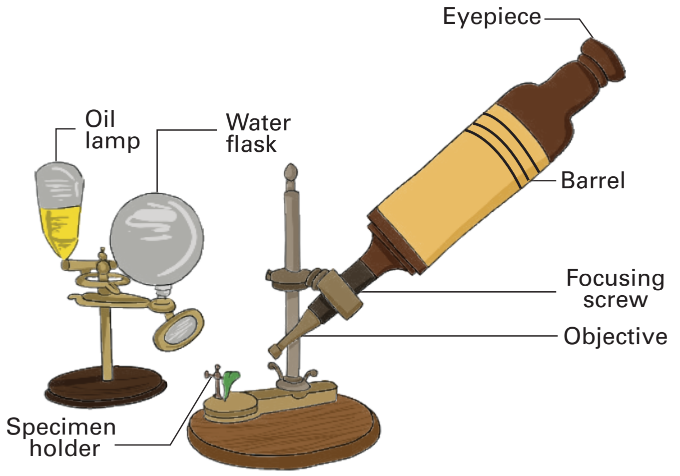

Figure 2.2 The Hooke microscope (circa 1660)

1. Find out about the role of the following scientists in the development of the microscope: Professor Pratibha Gai-Boyes, Professor Ed Boyes and Ian Wright; Robert Hooke and Antonie van Leeuwenhoek; Frits Zernike; Marvin Minsky; Ernst Ruska; and Gerd Binnig and Heinrich Rohrer.
2. Using A3 paper, draw an annotated timeline showing who developed what and when.

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Parts of a microscope

Although some microscopes are more advanced than others, most of those you use at school are light microscopes that have the same basic components. The microscopes you use 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 here is for use with one eye. Binocular microscopes can be used with both eyes.

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.

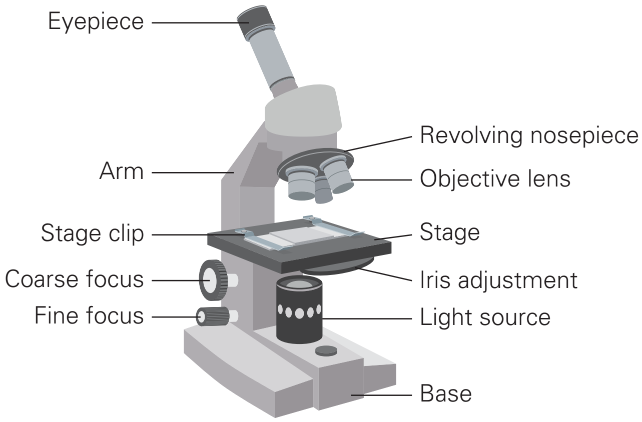


Figure 2.3 The parts of a monocular microscope

Microscope terms

When you use a microscope, you will often encounter special terms. Table 2.1 summarises some key terms.

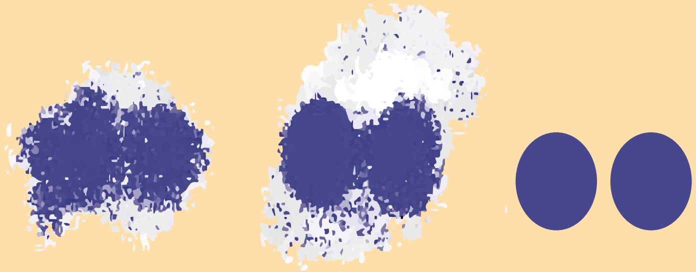
Term	Definition	Image
Magnification	How much the image of the specimen or object is increased in size (i.e. how much you are zooming in)	 Low magnification Medium magnification High magnification
Resolution	How detailed and clear the image is (i.e. how easy it is to tell two separate objects apart)	 Poor resolution Better resolution Best resolution
Field of view (FOV)	How much of the object you can see when you look through the eyepiece	 Human flea

Table 2.1 Some key terms used in microscopy

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Advances in technology

Binocular microscopes have an eyepiece for each eye. There are two types: simple binocular and stereoscopic. Simple binocular microscopes have one light path from the specimen, which is split and led to both eyepieces, so each eye has the same view. Therefore, the image looks flat (2D). Stereoscopic ('stereo') microscopes, which are much more expensive, lead two separate light paths from the specimen to each eye, so they have different views. The image has depth (3D). This is useful for manipulating or dissecting specimens, and the magnification does not have to be very large.

Light microscopes are limited in their usefulness. They can magnify a specimen up to 1500×, which 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 great detail.

In order to see things that are smaller than bacteria, scientists invented a different type of microscope, called 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, we 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
- scanning electron microscope (SEM) – the specimen to be viewed is not sliced, and the external surface can be viewed.

Unfortunately, electron microscopes are extremely expensive, and all specimens that are observed have to be prepared in a way that requires them to be killed first.

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

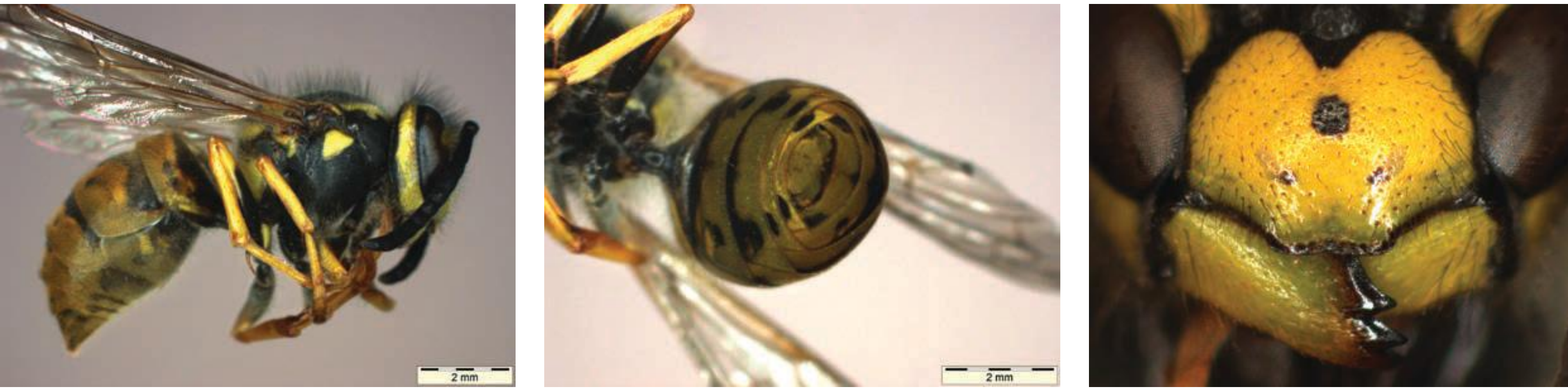

Figure 2.4 Stereo microscope images taken of a European wasp show its full body, its abdomen and its mandible.

Figure 2.5 Examples of specimens as seen through a TEM (left) and a SEM (right)

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Explore! 2.2

Types of microscopes

1. Do some research into the different types of microscopes that are used today: monocular microscope, stereo microscope and electron microscope.
2. 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					
Electron microscope					

Quick check 2.1

1. State the maximum magnification of the monocular microscope, the stereo microscope and the electron microscope.
2. State what micro-organisms 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.

Science as a human endeavour 2.1

Using your smartphone as a microscope

Most cameras on smartphones are not designed to produce high-resolution microscopic images. Researchers in the USA recently published their work on an attachment they had designed to place over the smartphone lens to increase the resolution and the visibility of tiny details of the images they take, down to a scale of approximately one-millionth of a metre. The new attachment uses artificial intelligence to create the level of resolution and colour required for laboratory analysis.

This attachment could help bring high-quality medical analysis into resource-poor regions, where people do not have access to expensive technologies. In addition, the attachment can be produced with a 3D printer, at less than $100 each.

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Practical skills 2.1

Using a microscope

Aim

To become proficient in 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.

Materials

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

Method

1. Cut one word out of a newspaper.
2. Attach the word 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.
5. Using the coarse focus knob, focus on the word.
6. Draw what you can see in the field of view at this lowest magnification. Record the magnification next to your drawing. In order to calculate the 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×.
7. Try moving the stage left and right, forwards and backwards, and note what you observe about the movement of the image.
8. Repeat steps **3–6** for each of the optical 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.

Analysis

1. Explain what happened to the word 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 word go in the same direction as the direction in which you moved the slide?
4. What did you notice about the orientation of the letters in the word? Were they 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 highest magnification objective lens.

Evaluation

Summarise the advantages and disadvantages of using a light microscope.

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Cell theory

Robert Hooke built a compound microscope that lit up the specimen he was viewing. Because of this invention, 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.

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.

nucleus
part of a cell that contains the genetic material

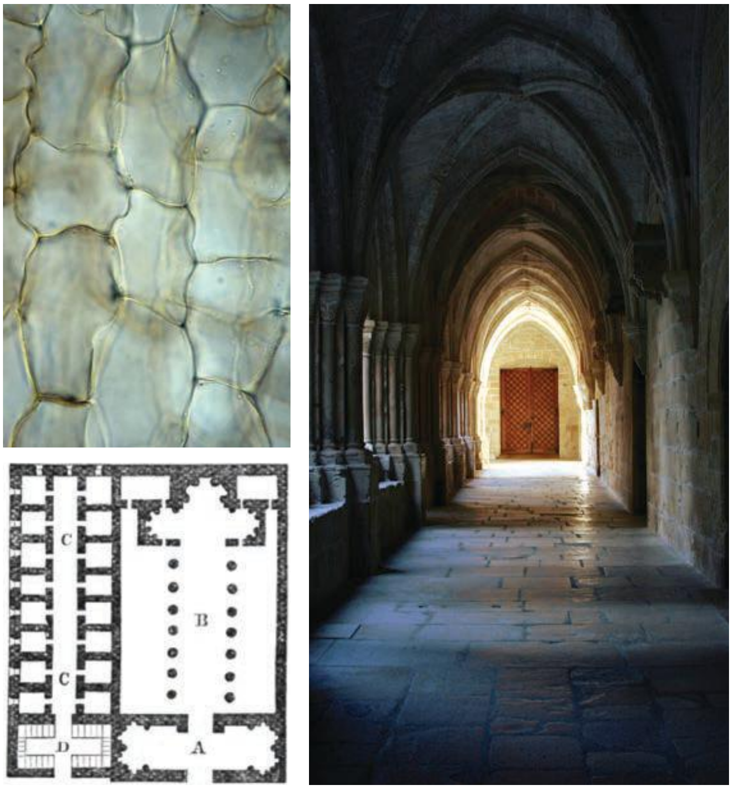


Figure 2.6 The cork cells (top left) Hooke observed looked like the monks' cells in the building plans (bottom left) of monasteries (right).

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

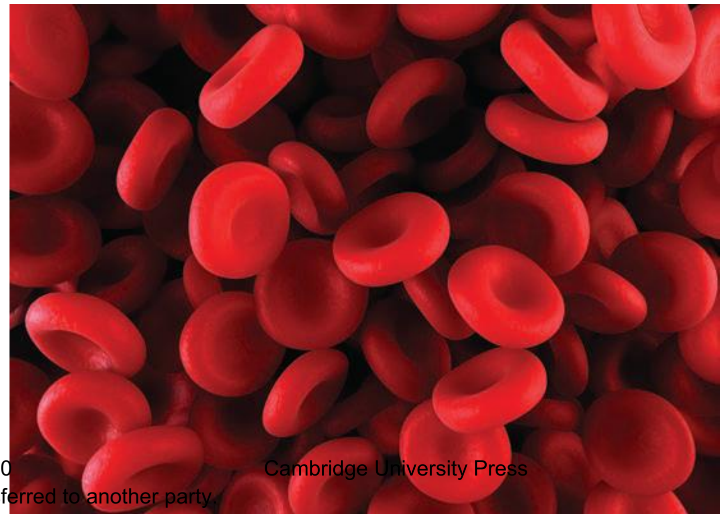
- Cells make up all living things.
- Cells are the basic building blocks of all living things.
- All new cells are produced from existing cells.
- All cells contain genetic information, which is passed from cell to cell during cell division.

Size of a cell

Cells are extremely small and most cells cannot be seen with the naked eye. That is why it was not until the invention of the microscope, around 350 years ago, that we even knew cells existed. If you take a look at your arm you can see skin and hair, but it is impossible to see the individual skin cells. They are described as being microscopic.

You may wonder why cells come in many sizes. The main reason is simple: their size and structure depends on their function. Red blood cells are biconcave and small, and carry oxygen in your blood to different parts of your body. When mature, they don't have a **nucleus**, and so there is more space to carry haemoglobin, a red pigment that holds oxygen. Being biconcave increases surface area, and their small size allows the red blood cells to squeeze through tiny blood vessels to deliver oxygen throughout your body.

Figure 2.7 Red blood cells



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Did you know? 2.2

Egg cells

Cells come in many shapes and sizes. The largest cells are eggs – an unfertilised egg is a single cell. Each egg holds the genetic information for the female of the species, and if fertilised, will eventually grow into a new individual. Egg cells are 'macro' cells. Macro means 'large-scale', and so they can be seen with the naked eye – that is, without a microscope.

Figure 2.8 The largest cells are eggs, and the largest of all is the ostrich egg.

Quick check 2.2

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

Try this 2.2

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).

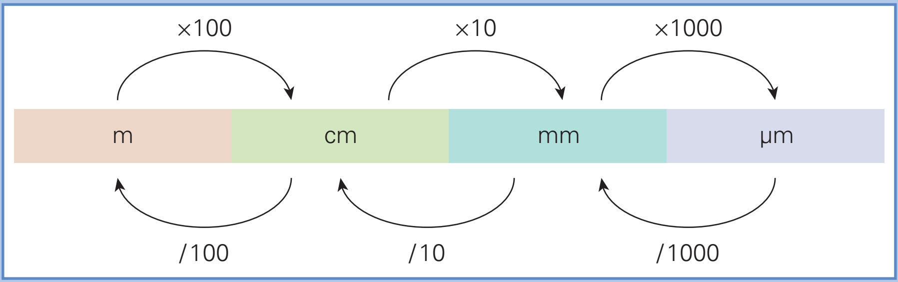

Figure 2.9 Conversions needed for different measurements

continued…

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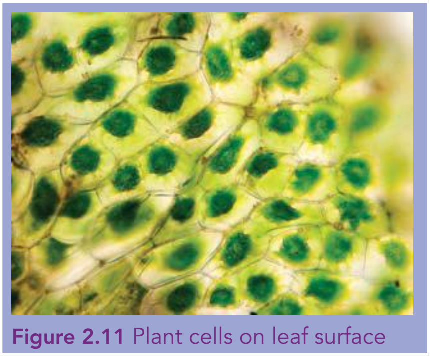
…continued

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 leaf surface		100
 **Figure 2.12** Sperm cells	0.05	

Section 2.1 questions

QUIZ

Retrieval

1 **Define** the term ‘microscopic’.

2 **Recall** the 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	

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

5 **Calculate** the magnification of the microscope when using the following objective lenses:

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

6 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.

7 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

8 **Demonstrate** how you would determine the size of a cell.

Comprehension

9 **Summarise** the structure and function of a red blood cell.

10 **Summarise** the advantages of using:

- a a monocular light microscope
- b a stereo light microscope.

11 **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.)

Analysis

12 **Distinguish** between a TEM and an SEM.

13 **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)

Knowledge utilisation

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

15 **Create** a detailed set of step-by-step instructions for a Year 7 student on how to use a microscope safely.

16 **Justify** the statement ‘the development of microscopes has changed our understanding of cells’.

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WORKSHEET

2.2 Organelles

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

genetic material
the material containing the code that allows the cell to produce copies of itself and to regulate the functions within the cell

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

All cells

Everything that we classify as living is 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**. 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**. 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 multicellular cells are specialised and much more complex.

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

- a **cell membrane**
- **genetic material**
- **cytosol**.

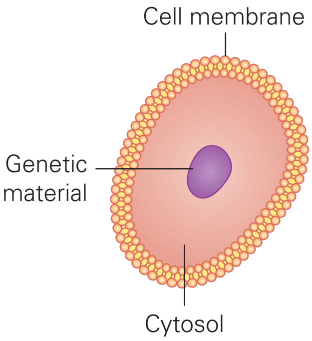

Figure 2.13 All cells, no matter how simple or complex, contain these three components.

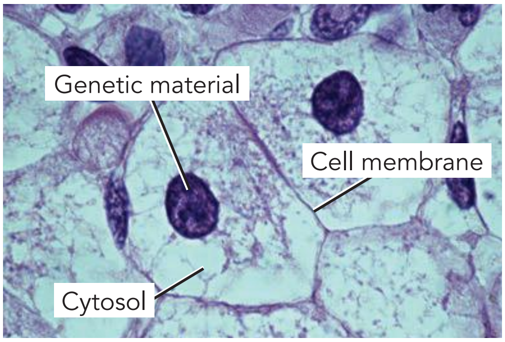

Figure 2.14 Shown here are human liver cells.

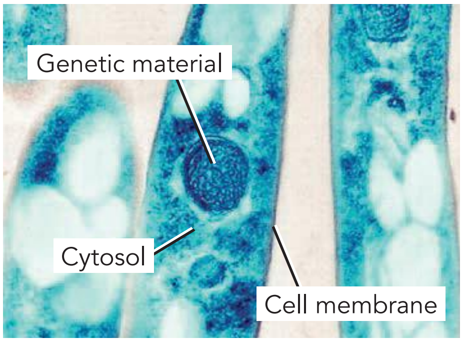

Figure 2.15 Shown here are *Bacillus anthracis* bacteria, which are unicellular organisms.

VIDEO What three components do all cells have in common?

Quick check 2.3

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

Organelles

Simple and complex cells

prokaryote
unicellular organisms that lack membrane-bound organelles and a nucleus

eukaryote
any cell or organism that possesses membrane-bound organelles and a nucleus

All cells can be grouped into two main categories: **prokaryote** (simple) and **eukaryote** (complex). Prokaryotes are unicellular organisms such as bacteria, while eukaryotes can be unicellular or multicellular. Examples of prokaryotes are animals, plants, fungi and protists. The two categories of cell type are based on the structures found inside each cell. All cells have a membrane, cytosol and genetic material, but eukaryotic cells are more complex and also have many membrane-bound structures, including a nucleus, that carry out specific functions. Prokaryotic cells do not have a nucleus or any membrane-bound structures.

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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 jobs.

organelle
a specialised structure in a cell, which has a specific function or job

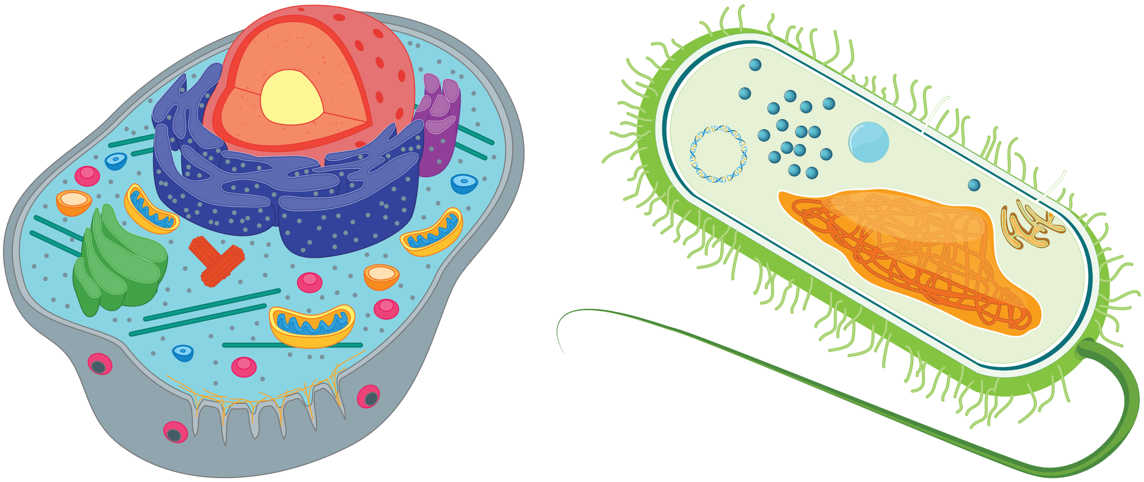

Figure 2.16 Eukaryotic cell (left) vs prokaryotic cell (right). Can you identify the cell membrane, genetic material and cytosol in each cell type?

Try this 2.3

Prokaryotes vs eukaryotes

For the following list of organisms, identify which are examples of prokaryotic cells and which are examples of eukaryotic cells.

Mushrooms	Archaea	Cyanobacteria	Tapeworms
Grass	Potatoes	Fruit flies	*Escherichia coli*

The cell city

Although all cells contain the structures described previously, only complex eukaryotic cells contain the specialised membrane-bound organelles that you are going to read about in this section. It is helpful to think of the cell as a city. A city has many needs, and each organelle caters for those needs. This idea is developed further in the STEM task for this chapter.

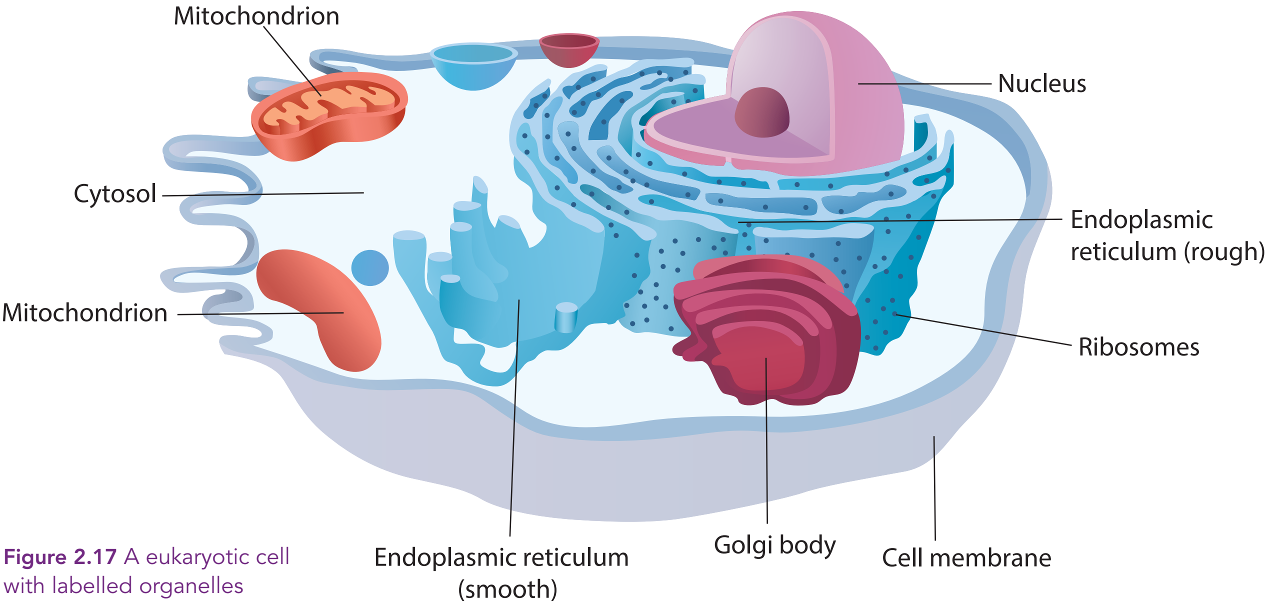

Figure 2.17 A eukaryotic cell with labelled organelles

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Nucleus

The nucleus is a large structure that holds the genetic material of a cell. It is like the brain of the cell and controls all of 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.

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

Figure 2.18 Top left: Graphic representation of a nucleus. Top right: an electron microscope image of a nucleus within a plant cell. Bottom: Parliament house - Canberra. The nucleus makes all the major decisions for the cell city.

Genetic material

The genetic material, or deoxyribonucleic acid (DNA), is found in every cell. DNA is 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 blueprints which the top level of government uses to keep everything running smoothly.

Figure 2.19 Top: Graphic representation of a DNA molecule. Bottom: Senators in discussion in the Federal Parliament of Australia.

Did you know? 2.3

The Moon and back!

We have trillions of cells in our body and each one contains DNA. 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!

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Cell membrane

The cell membrane is a thin double layer of molecules that separates the inside of the cell from its external environment, and controls what enters and leaves the cell. The cell membrane is like a protective border around the cell city, controlling who enters and leaves.

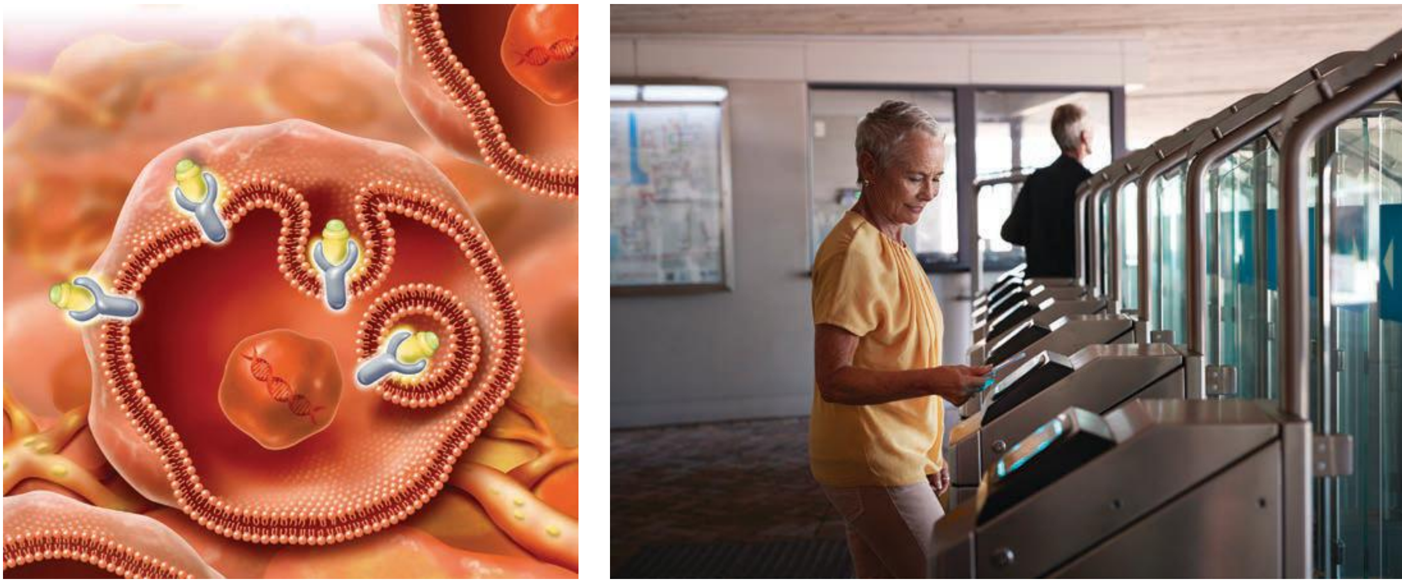

Figure 2.20 The cell membrane (shown at left) provides 'border security' for the cell.

Cytosol

Cytosol is a water-based mixture of organelles and small and large molecules that fills the cell. In eukaryotic cells, it refers to the liquid outside the organelles. Although it appears mostly transparent in a light microscope, it has a very complex structure, with regions that vary greatly in concentration and viscosity, 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 enzymes. Many nutrients and other materials may be stored in the cytosol.

Using the city analogy, we would say the cytosol makes the city to be like Atlantis, or a coral reef – it is an underwater city. The water fulfills the same functions for the cell city that the air does for us.

Ribosomes

Ribosomes are very small structures that 'read' the codes sent to them in the genetic material and use these to produce proteins that the cell needs to create structures and carry out different functions. Ribosomes would be the factories of the cell city, producing bricks, cars and different tools for the city to use.

ribosome
a structure in a cell that reads genetic information to produce protein from amino acids

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

Mitochondria

Mitochondria (singular: mitochondrion) are where sugars from food are turned into energy, in a process called *cellular respiration*. The output is a substance called ATP, the cell's source of energy. 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.

Endoplasmic reticulum

The **endoplasmic reticulum** (ER) is a large folded membrane attached to the nucleus. The name 'endoplasmic reticulum' might sound complicated but it is just a description of what it does: *endo* (inside), *plasmic* (cytoplasm), *reticulum* (network). There are two types of ER in the cell. When ribosomes are attached, the ER is rough, and it is involved in the synthesis and transport of proteins. If no ribosomes are attached, then it is smooth and is involved in the making of lipids and **steroids**. The ER is basically a highway that produces, then connects and delivers substances to different parts of the cell.

endoplasmic reticulum
a network of tubes within a cell that are involved in protein and lipid synthesis

steroids
compounds made by cells that are used in cell membrane stability and for cell signalling

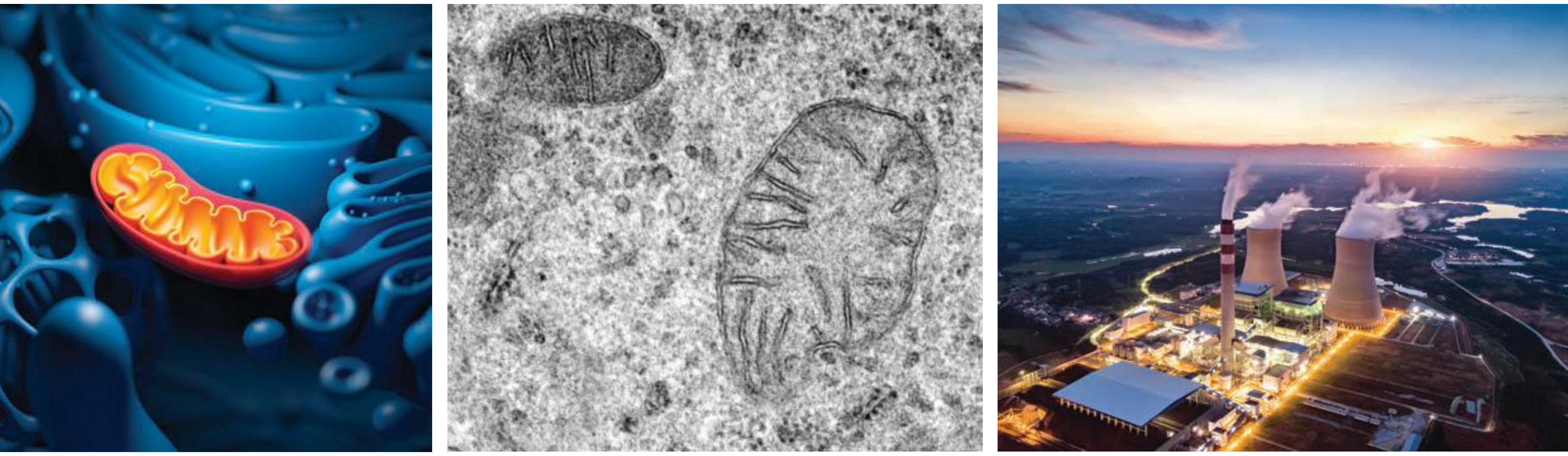

Figure 2.21 Left: Graphical representation of a mitochondrion. Middle: An electron microscope image of mitochondria. Right: The mitchondria produce energy from glucose, much like power stations can produce electricity from coal.

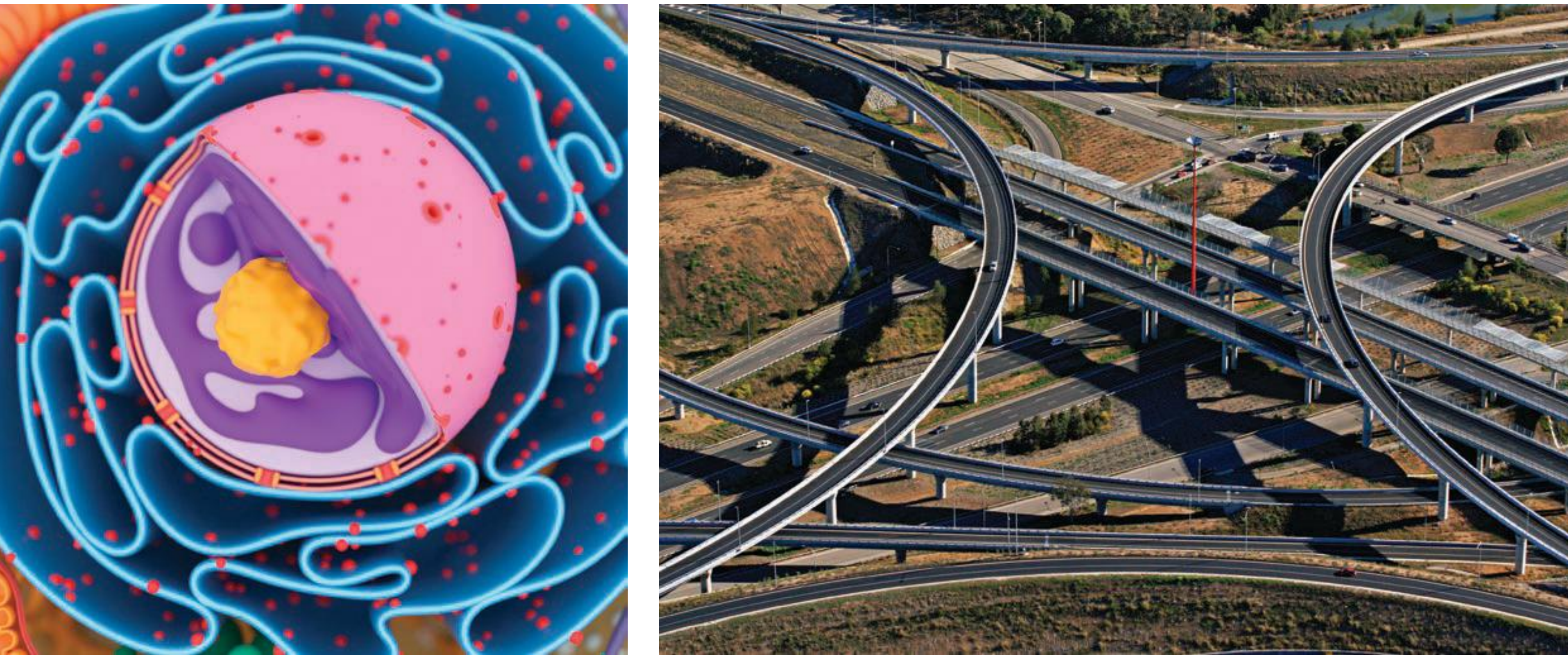

Figure 2.22 Left: Graphical representation of the endoplasmic reticulum around the outside of the nucleus. Right: The endoplasmic reticulum is the highway network of the cell city.

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Golgi body

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

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 (postal vans), and send them to where they are required.

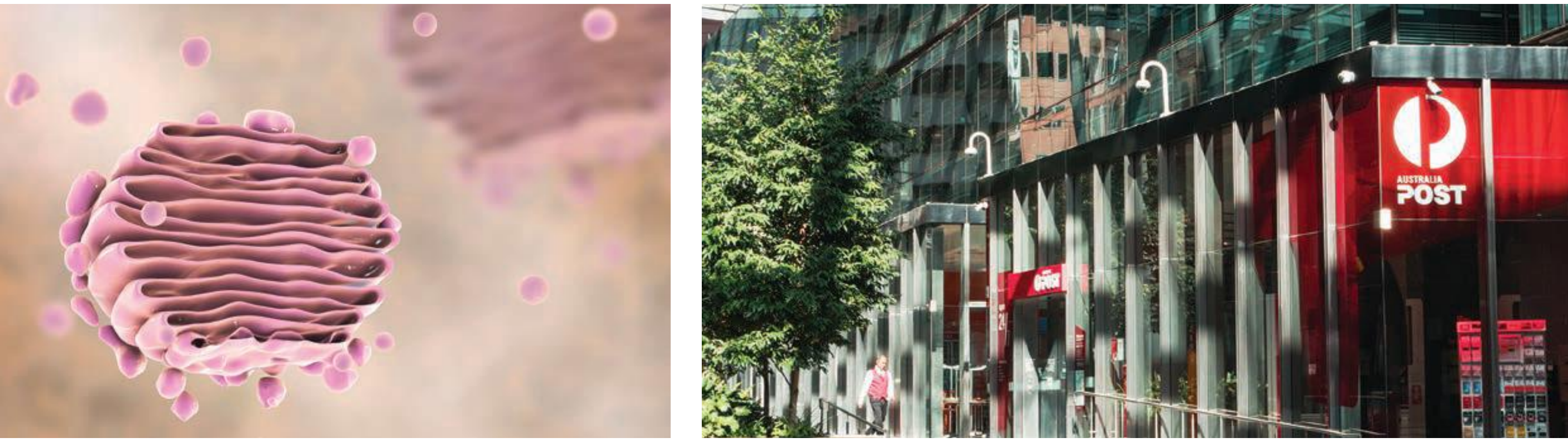

Figure 2.23 Left: Graphic representation of a Golgi body. Right: Golgi bodies act as the postal system of the cell city.

Try this 2.4

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 2.24 and label the following organelles: cell membrane, cytosol, nucleus (includes genetic material), ribosomes, smooth and rough endoplasmic reticulum, Golgi bodies, mitochondria.

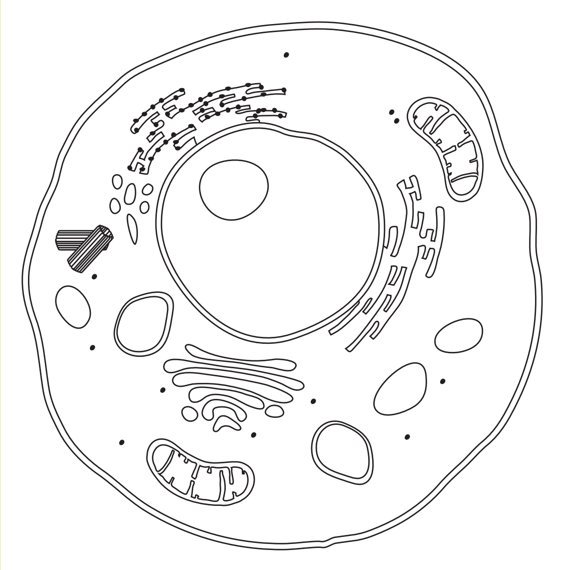

Figure 2.24 Diagram of a eukaryotic cell, ready for you to label it

VIDEO
What organelles do all eukaryotic cells contain?

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Explore! 2.3

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 2.25 A graphical representation of a microtubule

Science as a human endeavour 2.2

A new cell structure discovered

In 2019, scientists discovered a new organelle that helps to prevent cancer by ensuring genetic material is sorted correctly as cells divide. The discovery could improve future cancer treatments.

Section 2.2 questions

QUIZ

Retrieval

1 **State** three organelles found in all cells.
2 **State** three organelles found in all eukaryotic cells (not including the three from Question **1**).
3 What am I? **Identify** the correct organelle from the description.
  a I produce energy in the form of ATP for cells.
  b I am a barrier between the inside and the outside of cells, and I control who enters and leaves.
  c I am a water-based mixture that fills the cell, and many chemical processes happen within me.
  d I make proteins using the code in the genetic material of the cell.

Comprehension

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

Analysis

6 **Compare** the role of the rough endoplasmic reticulum and the Golgi body.
7 **Compare** the function of the cell membrane with that of the nucleus.
8 **Distinguish** between unicellular and multicellular, using examples.

Knowledge utilisation

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

2.3 Eukaryotic cells

All eukaryotic organisms have many of the same organelles as each other. 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 animals, plants, fungi and protists.

Figure 2.26 Plants and fungi living together

Animal cells

WORKSHEET

Animal cells contain all the organelles you learned about in the previous section. However, the numbers of organelles in a cell may vary, depending on what type of animal cell it is. Multicellular organisms like yourself are made up of many different types of specialised cells. Each of these different cell types has a specific job that allows your body to function properly. All the cells in your body start off as one cell, the **zygote** (fertilised egg). This cell divides into similar cells, which eventually differentiate into all the specialised cells around your body. A fertilised egg cell in the early stages of growth and differentiation is known as an **embryo**.

Cells that have the potential to turn into any other type of cell are called **stem cells**.

zygote	a fertilised egg cell
embryo	a fertilised egg cell in the early stages of growth and differentiation
stem cell	a cell that is able to develop into many different types of cells

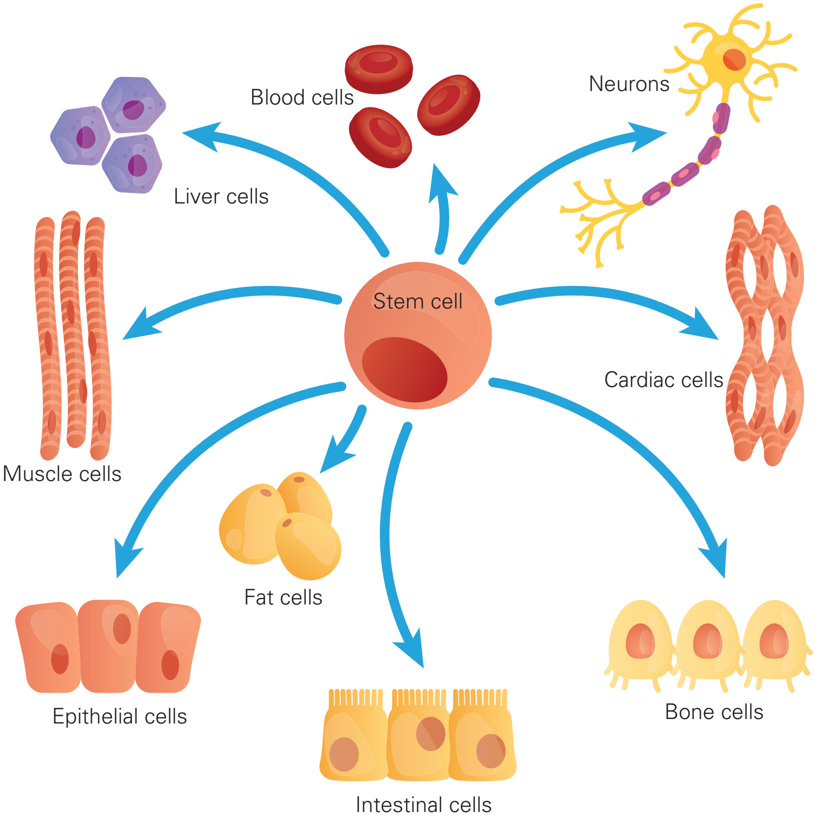

Figure 2.27 Embryonic stem cells can become many types of cells, in a process known as cell differentiation.

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differentiation
the process by which stem cells become specialised

The process by which stem cells become specialised is called **differentiation**. Once a stem cell has differentiated into a specialised cell, such as a nerve cell, it can only ever replicate into another cell of the same type.

Stem cells don't only exist in embryos. You still have 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.

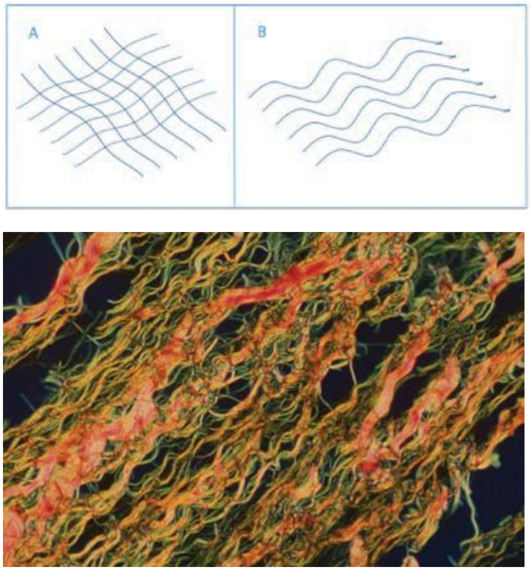


Figure 2.28 Top: Collagen fibre structure in normal tissue (A) and scar tissue (B). Bottom: Scar tissue.

Explore! 2.4

Stem cell therapy

Because stem cells are able to turn into any type 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 or regenerative medicine.

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

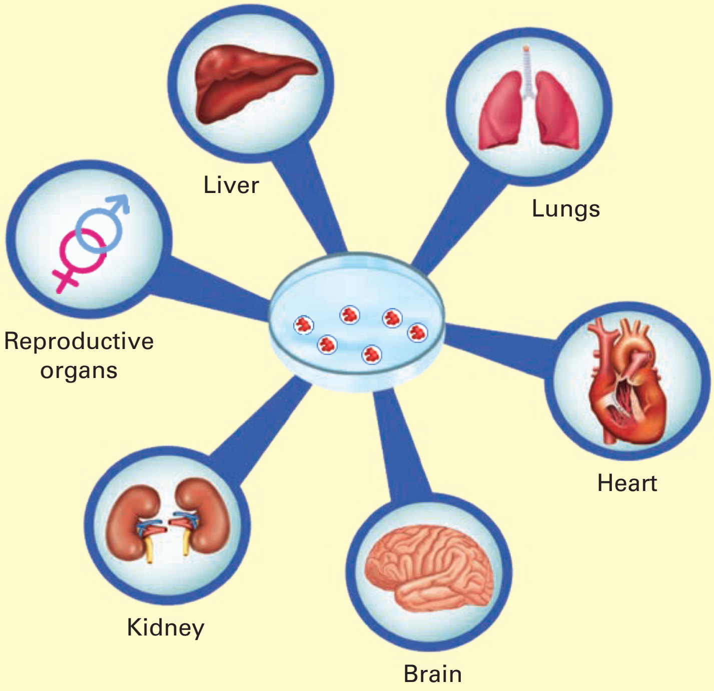


Figure 2.29 A stem cell can replicate and become any one of the 200+ types of cells in the body.

Science as a human endeavour 2.3

Exciting uses of stem cells

Late in 2018, the results of two exciting research projects were published by scientists in Europe. First, in Germany, scientists succeeded in generating beating heart muscle cells from stem cells. Their work may provide a new approach for the treatment of heart attacks. Second, in Sweden, scientists developed a faster method of generating functioning brain cells from embryonic stem cells. The new method reduces the time required to produce the cells from months to two weeks, and may help in the treatment of degenerative diseases of the nervous system, such as dementia.

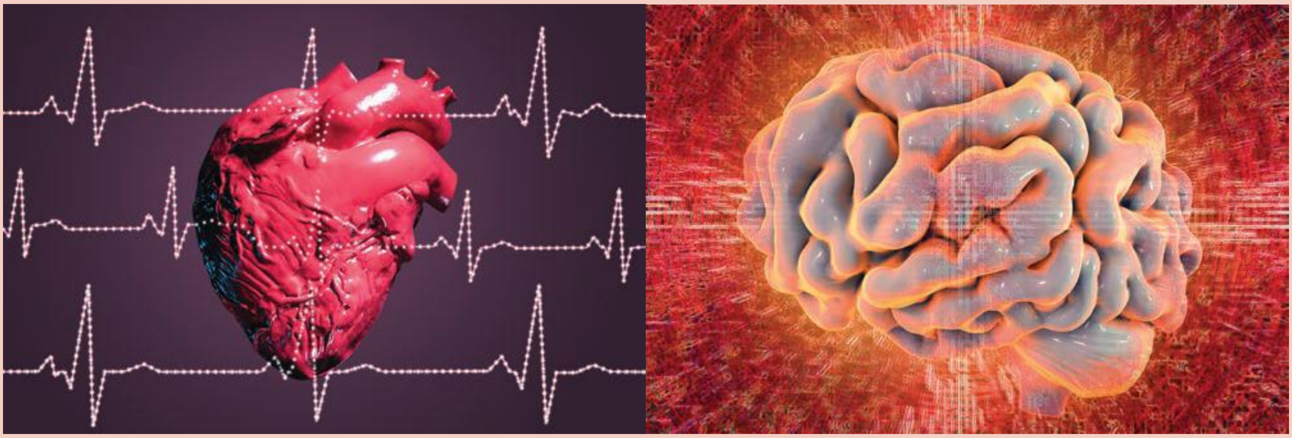
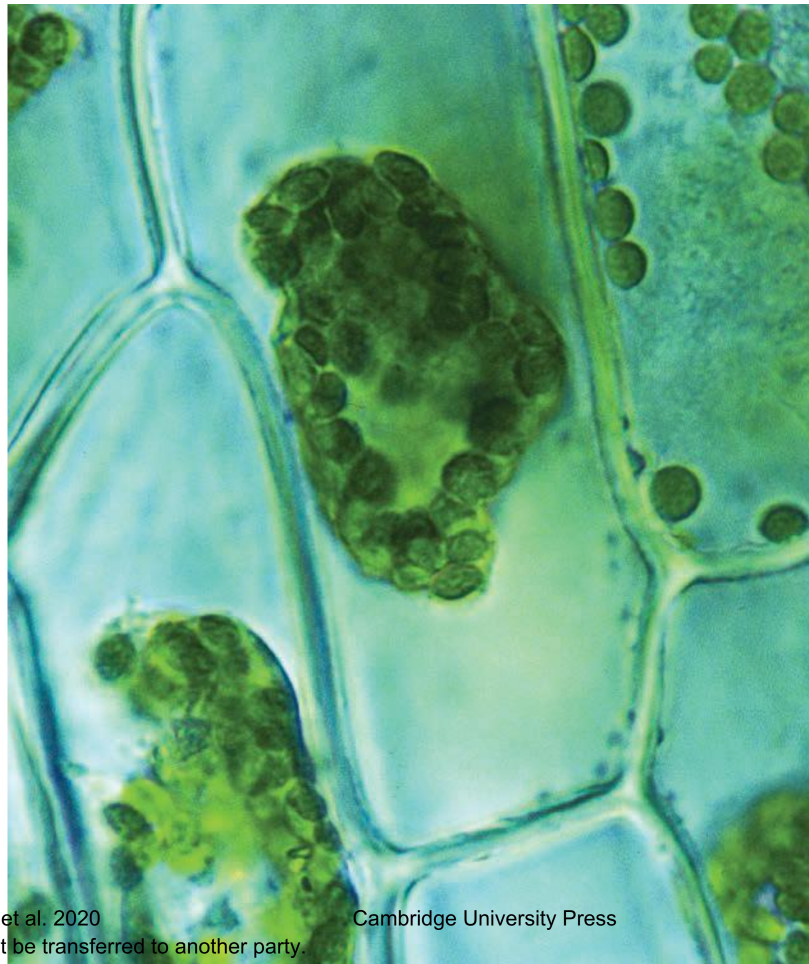


Figure 2.30 Stem cells may help in the treatment of heart and degenerative diseases of the nervous system.

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 their use in medicine.

Figure 2.31 Plant cells: the green blobs are chloroplasts. Also note the thick cell wall that surrounds each cell.



Plant cells

Plants are different from all other eukaryotic organisms in many ways. Most noticeably, they do not need to move in order to search for food, because they can make their own food in the process called *photosynthesis*. This difference means that plants have some organelles that animals and fungi lack. The special organelle in plants that carries out photosynthesis is called a **chloroplast**.

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

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Figure 2.32 Eucalyptus trees can only grow as tall as they do because of the rigid cell wall that surrounds each of their cells.

Chloroplasts contain a green pigment called *chlorophyll*, which captures the Sun's light and makes plants green. Chloroplasts are found in plant cells that are exposed to light (e.g. leaf cells) but not in cells of the roots.

Because plants do not need to move, they lack a skeleton and muscles, 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 provides shape and support for the plant. The cell wall is made of a substance called *cellulose*.

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

vacuole
a structure in a cell that stores water and nutrients

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, and if not watered will start to die. This is because the vacuoles in each cell are losing water, the cells become flaccid, and so the plant cannot hold its shape. 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 2.33 A thirsty plant: the vacuoles are no longer full of water and so they cannot help to support the plant in standing upright.

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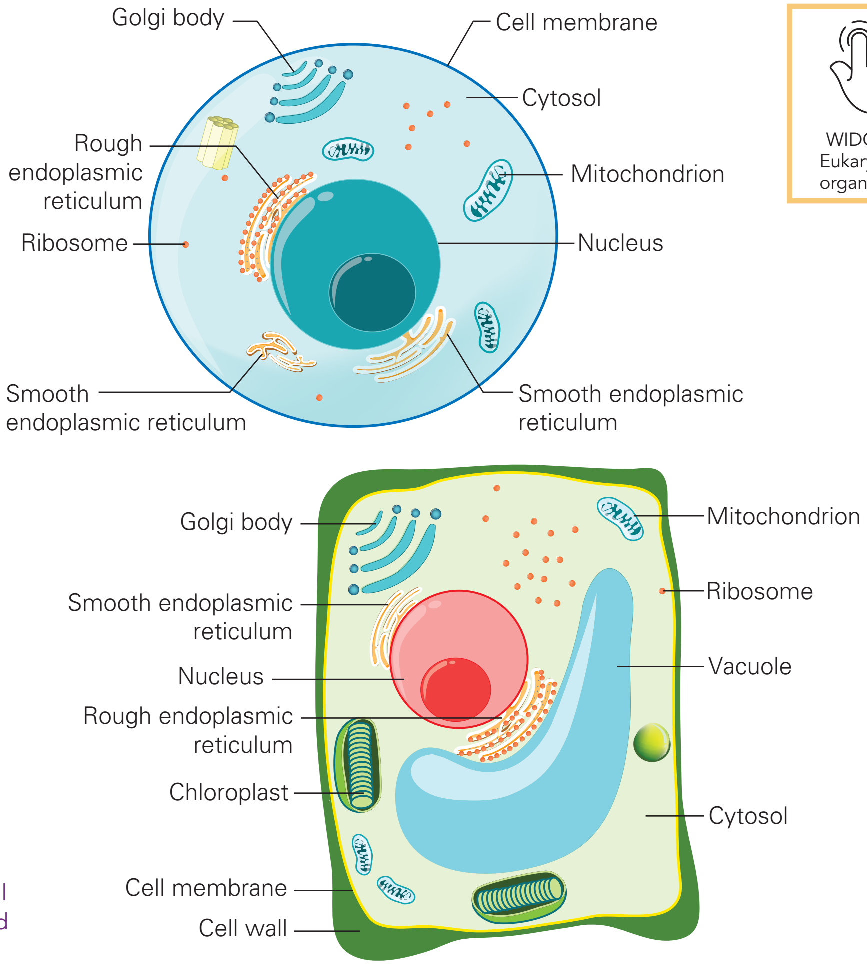
Distinguishing animal cells from plant cells

You have seen that animal cells and plant cells have many organelles in common, as they are both 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.

In addition, 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.



WIDGET
Eukaryotic organelles

Figure 2.34 Animal cell (top) and plant cell (bottom) showing the major structures and organelles

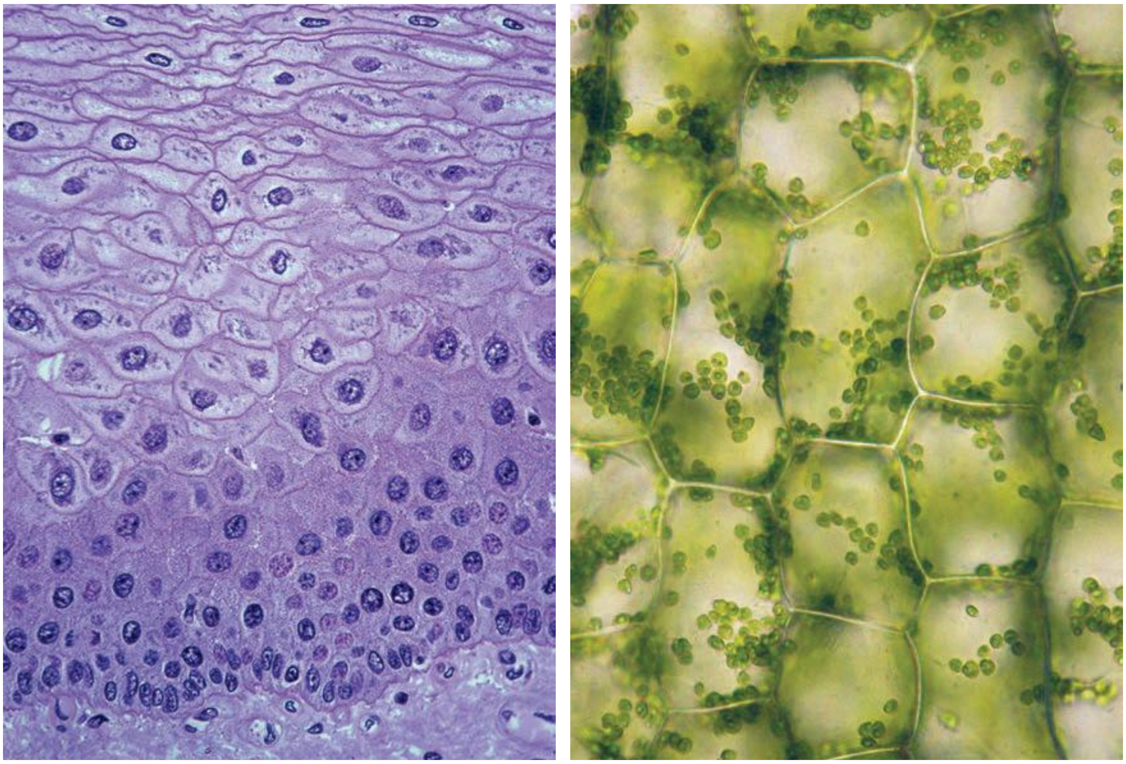


Figure 2.35 Left: Animal (oesophagus) cells at 100× magnification. Right: Plant cells at 100× magnification

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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 these 'extra' organelles.

Try this 2.5

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 2.36. 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. 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.

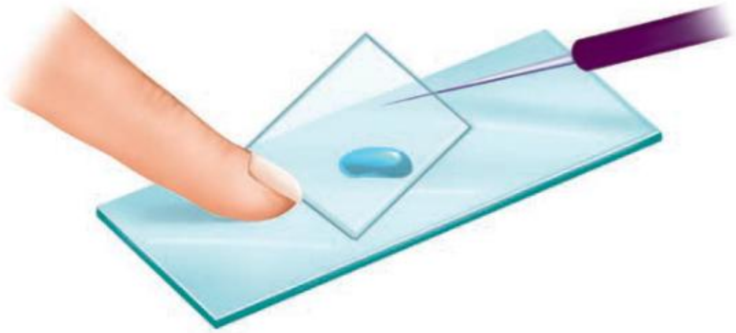
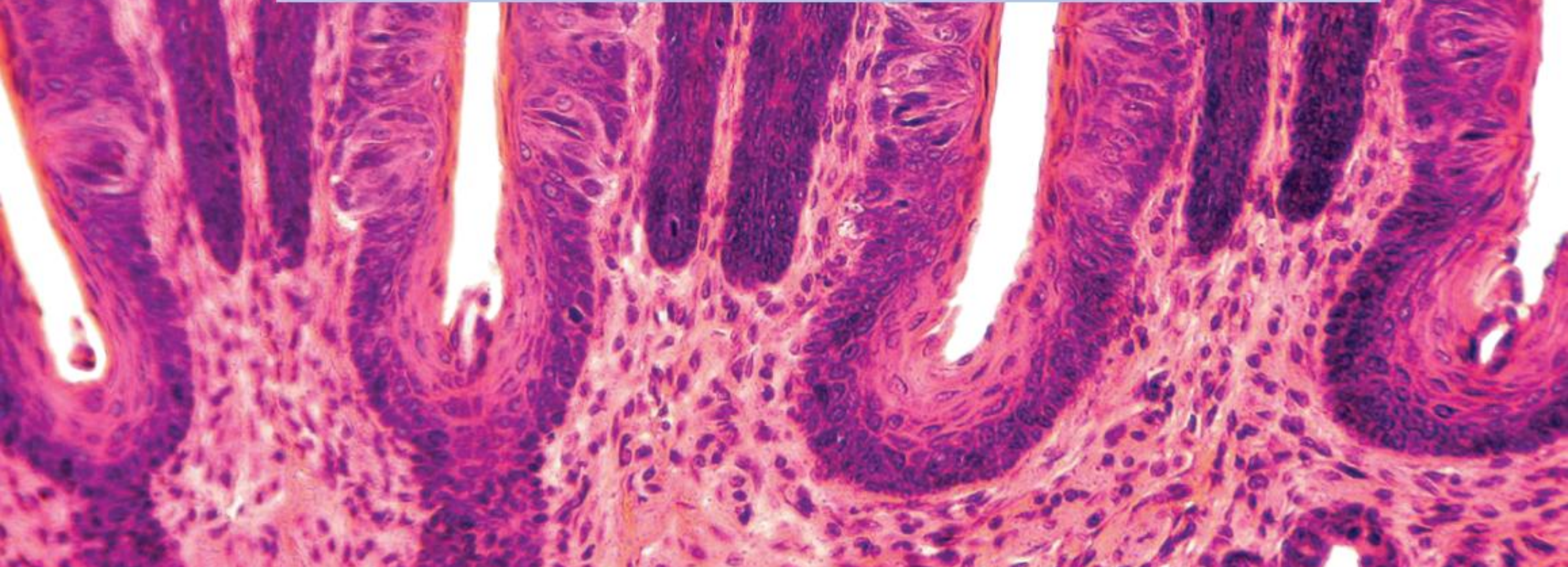


Figure 2.36 Lowering the cover slip slowly is very important when preparing a wet mount.



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Practical skills 2.2

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. No food items are to be consumed.

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 slides

Method

1 Prepare wet mounts:
   a Peel a translucent (see-through) piece of tissue from the onion.
   b Place the piece of onion tissue on a glass slide and 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: 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. Place on your first slide and focus using the coarse focus knob. Once focused, turn to the next objective lens. Use only the fine focus knob to focus now. Once focused, move to the highest magnification and again focus using the fine focus knob.

3 Draw a diagram: 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. Label all the organelles you can see, using a ruler and labels at the side of the diagram. Record the name of the specimen, the magnification the drawing was drawn at, and determine the cell size.

Results

Your results will be in the form of four plant cell diagrams and four animal cell diagrams.

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 Were the plant and animal cells all the same size? If there are differences, can you explain why?

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Try this 2.6

Making a model: 3D cell

Aim

Create a 3D 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 3D model of the cell.
4. Explain to the class and your teacher how your model represents all the parts of a cell.

Results

Plants		Animals	
Cell	**Material 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			

Analysis

Explain why models are used in science.

Evaluation

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

Fungi

Fungi are similar to both plants and animals, and most are multicellular, but they also have their own unique cell wall. Fungi are *heterotrophs*, like animals, which means they have to digest other organisms in order to gain nutrients. Fungal cells therefore don't have chloroplasts like plant cells do. Their cell wall is made of *chitin*, not cellulose.

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Did you know? 2.4

Fungi and beetles

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

Figure 2.37 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 in order to reproduce.

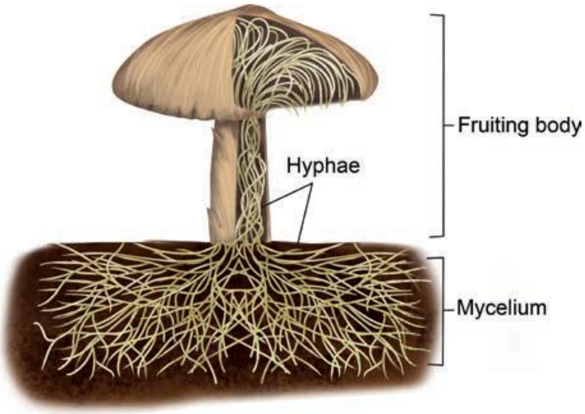

Figure 2.38 Diagram of a fungal cell

Figure 2.39 Fungi: (top) toadstool, (middle) chanterelle mushrooms, (bottom) puffball

Quick check 2.7

1 State whether fungi are prokaryotic or eukaryotic.
2 Name the organelle that fungal cells have that animal cells do not.
3 Contrast the cell wall of a plant with the cell wall of a fungus.
4 Explain the function of the cell wall.

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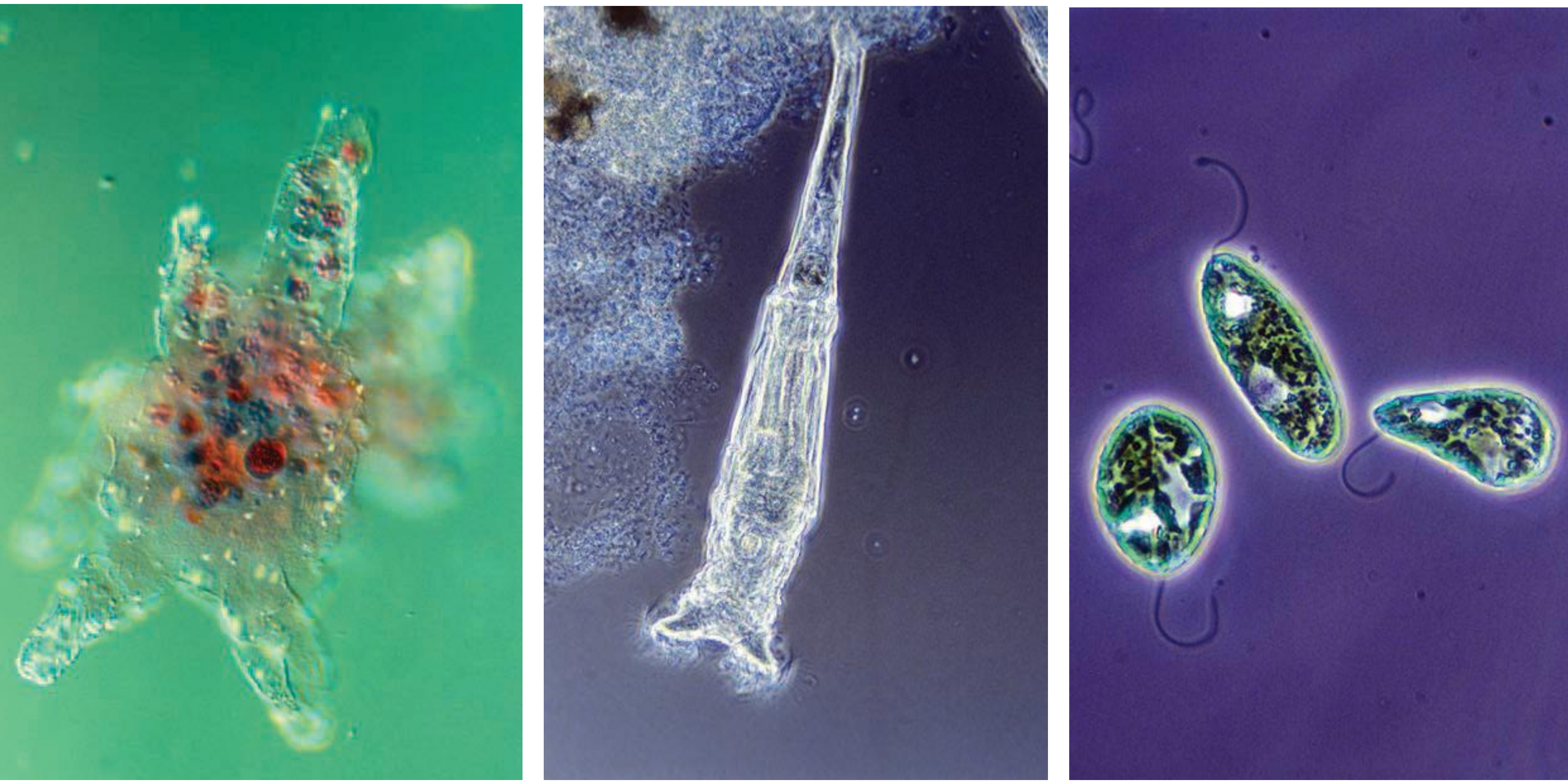

Figure 2.40 Protists: left amoeba (left); rotifer (middle); right *Euglena* (right)

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 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*, rotifers, amoebas and *Paramecia*. Each of these types of protists is slightly different in structure, depending on their function.

protist
a eukaryotic organism that is part of the kingdom Protista

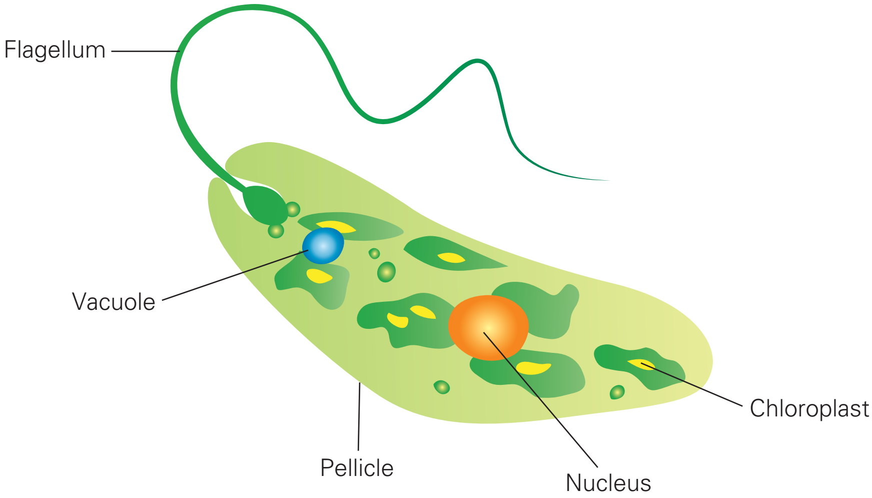

Figure 2.41 *Euglena* have chloroplasts which are typically considered a plant cell organelle, but they also have a flagellum which is more typical of an animal cell.

Section 2.3 questions

QUIZ

Retrieval

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** three 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 a **Name** the organelles labelled A to E in the eukaryotic cell shown in Figure 2.42.

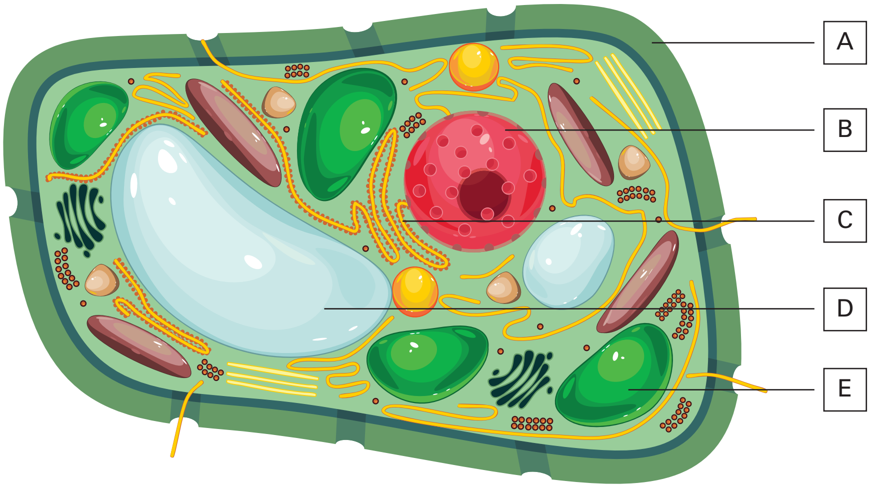

Figure 2.42 Eukaryotic cell

b **Identify** the type of cell is shown in Figure 2.42. Explain your answer.

7 **Identify** where you are most likely to find protists.

Comprehension

8 **Explain** why fungi are known as heterotrophs.

9 **Summarise** the steps you need to take when preparing a wet mount.

10 Stem cells are currently of massive interest to scientists. **Explain** why this is the case, using what you have learned about their use in therapy and other medicinal applications.

11 **Explain** how the shapes of various cells help them to carry out their function within the body. You may like to refer to red blood cells, sperm cells and muscle cells.

Analysis

12 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.

13 Yeast are unicellular eukaryotic cells, and belong to the Fungi kingdom. 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 1 minute.

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Temperature (°C)	Height of column of gas produced in the tube (mm)			
	Trial 1	Trial 2	Trial 3	Average
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 optimum temperature for yeast.
c **Infer** the effect that an even higher temperature, such as 100°C, would have on the yeast being tested.

Knowledge utilisation

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

2.4 Function and malfunction

DOC WORKSHEET

Cell division

At the start of this chapter you learned about cell theory. The development of cell theory was made possible by the invention of the microscope, which allowed scientists to observe and prove certain characteristics that all cells display. One of the most easily observable parts of cell theory is that 'all cells come from pre-existing cells'. This is referring to cell division, when one cell splits to form two new identical cells, called *daughter cells*. The scientific term for this process in eukaryotes is **mitosis**. In prokaryotes, it is known as **binary fission**.

mitosis
the type of cell division in which one cell divides into two cells that are exactly the same

binary fission
a mode of asexual reproduction by bacteria, where genetic information is copied and the cell splits in half

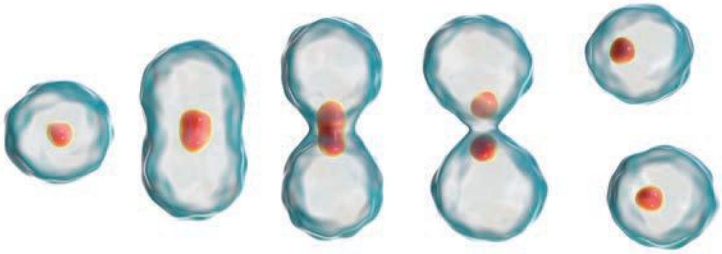
Figure 2.43 A simplified representation of mitosis: one cell forms two new identical daughter cells

Why do cells divide?

Mitosis happens for a number of reasons: repair, growth and reproduction.

Repair

If you cut your skin or break a bone, your body can close the wound or set the bone over time. This happens because millions of new cells are produced to replace the damaged cells. Some cells in your body, such as your red blood cells and skin cells, need to be replaced regularly.


Figure 2.44 A cut heals because mitosis occurs, creating new cells to replace the damaged ones.

Growth

In order to grow, your body needs to make more cells. You first started out as a single cell, which was a fertilised egg. By the time you become an adult, you will be made of around 37.2 trillion cells. A massive amount of cell growth occurs before you are born and in your first few years of life, but you will still be growing until your late teens. This means your bone cells need to

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reproduce in order for you to get taller, your muscle cells need to keep up with your bone cells, and your nerve cells need to grow in order to extend throughout your body.

Did you know? 2.5

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. No wonder mitosis happens a lot!

Reproduction

Unicellular organisms such as bacteria remain as one cell their entire life. They don't undergo cell division for growth and repair, because their whole body is just one cell. The only reason bacteria divide is for reproduction. This form of reproduction is known as *binary fission* and involves the bacterium splitting in half to produce an identical copy of itself. Because this process does not require a mate and is fairly simple, bacteria can reproduce around every 30 minutes. This means that, in one day, a single bacterial cell could become 140 737 488 355 328 cells.

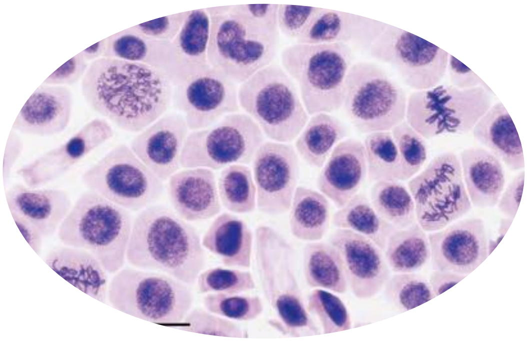

Figure 2.45 The ability to view cells under a microscope, such as the onion cells undergoing mitosis shown above, has helped us understand cell function and division.

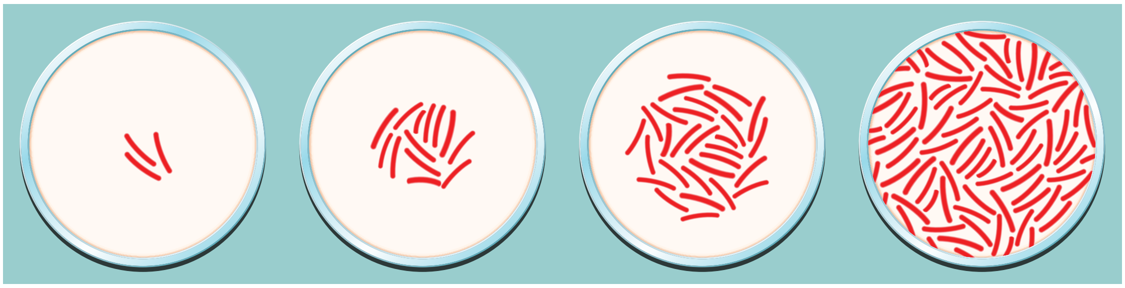

Figure 2.46 Bacteria, under the right conditions, can reproduce very quickly by binary fission.

Explore! 2.5

Cancer

Cancer is a disease of the body's cells. Cells normally grow and multiply in a controlled way, but if there is a change in someone's genetic code, this control can be lost. Cancer is the term used to describe uncontrolled cell division. Because cancerous cells can arise from almost any type of cell, there are about 100 different types of cancers.

1 Research and define the terms 'benign' and 'malignant'.

2 Select a type of cancer to investigate – for example, prostate, breast, bowel, skin, lung. Summarise the cause, prevention and treatment of the chosen cancer.

Figure 2.47 Doctor checking a mole for signs of skin cancer

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Science as a human endeavour 2.4

Cervical cancer

You may have seen in the news in 2019 that Australia is on track to be the first country in the world to eliminate cervical cancer. This prediction has been credited to the introduction, a decade ago, of the human papillomavirus (HPV) vaccination program for schoolchildren. The Cancer Council NSW has shown that if vaccination and screening levels are continued, rates of diagnosed cervical cancer will drop.

Quick check 2.8

1. Cell division is a normal process that occurs in your body. Recall the three reasons it occurs.
2. Explain why skin cells need to divide regularly.
3. State the name of the process that bacteria undergo to reproduce.
4. Describe a disease that results from a malfunction of the normal process of cell division.

Micro-organisms

Micro-organisms are organisms that are so small they can only be viewed using a microscope. Bacteria, some fungi and some protists are examples of such small organisms. As you know, most bacteria (such as those in your intestines) and fungi (such as the yeast used to make bread) are harmless and can actually benefit us in some way. However, some are dangerous. ‘Germ’ or ‘**pathogen**’ is the general term used to refer to a microorganism that can cause a disease or infection. When you go to the toilet, you probably wash your hands straight away. This is because you were taught from an early age that washing your hands kills germs. This might seem like common sense, but until about 150 years ago, people didn’t know that diseases came from micro-organisms and that the air is full of micro-organisms. Before this time, people believed that mould on bread appeared spontaneously – this theory is known as *spontaneous generation*.

pathogen
an organism that causes disease

A scientist known as Louis Pasteur was a microbiologist who used microscopes to study the microscopic world. He conducted a series of experiments proving that food went off because it was contaminated by micro-organisms in the air. His experiments in the 1860s led him to invent *pasteurisation*, which is the process of heating food or drink to a high enough temperature to kill any harmful micro-organisms, before sealing it. This greatly increases the shelf life of foods and prevents the spread of disease.

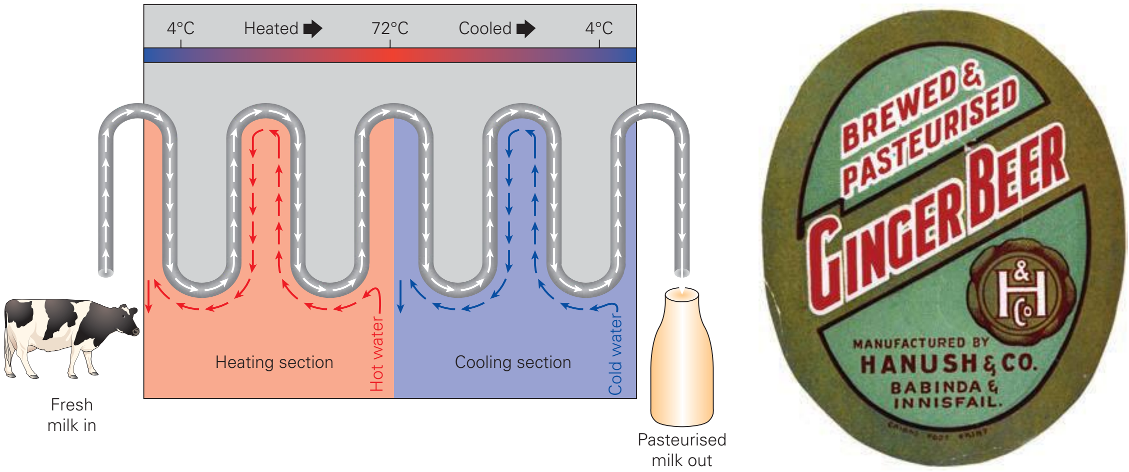

Figure 2.48 The process of pasteurisation (left) has been used for a long time, as can be seen in the label of ginger beer from Queensland in the 1940s (right).

Try this 2.7

Observing 'friendly' bacteria 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 how similar/different they are to eukaryotic cells like plant and animal cells.

Investigation 2.1

Modelling pasteurisation

Be careful

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

Aim

To test the effect of temperature on the growth of bacteria

Planning

1 Write a rationale about the factors that affect the growth of bacteria and methods that prevent this 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.

Materials

- probiotic drink
- 4 agar plates
- sterile swabs
- evaporation dish
- Bunsen burner
- tripod, heatproof mat, pipe clay triangle
- sticky tape
- disposable gloves

Method

Part 1: Boiled (100°C) probiotic

1 Place 10 mL of probiotic drink into the evaporation dish.
2 Heat to boiling point using a Bunsen burner.
3 When the mixture starts to boil, turn off the heat.
4 Dip the sterile swab into the heated mixture and spread the mixture over the agar sheet, as shown in Figure 2.49 and explained below.

   Swabbing technique

   When you use the sterile swab, gently rub the swab over the agar in tight lines to start with, and then slowly spread the lines apart as you move down the agar plate.
5 Place the lid on the plate and, with 2 to 4 pieces of sticky tape, tape down opposite edges of the plate.
6 Label the agar plate. Write your group name, date, and the independent variable. Keep your writing small, and write around the outside edge of the agar plate.
7 Place the agar plate in the incubator with the agar side up, at 30°C, for two days.

Figure 2.49 How to rub the swab over the agar

Part 2: 30°C probiotic

8 Dip a new sterile swab into the original probiotic mixture (unboiled).
9 Swab an agar plate as you did previously.

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...continued

10 Place the lid on the plate and, with 2 to 4 pieces of sticky tape, tape down opposite edges of the plate. Label the agar plate.

11 Place the agar plate in the incubator with the agar side up, at 30°C, for two days.

Part 3: Refrigerated (4°C) probiotic

12 Repeat steps **8–10** and place the agar plate in the refrigerator at 4°C for two days.

13 After two days, remove the agar plates from the incubator and refrigerator, and count the number of colonies that you can see on the agar plates. A colony should look like a slightly raised round dot on the agar plate.

Results

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

Analysis

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

Evaluation

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

Conclusion

Draw a conclusion from this experiment regarding the effect of temperature on bacterial growth, using data to support your statement.

Following on from Pasteur's experiments, other scientists used microscopes to help them link micro-organisms to disease. This led to the realisation that washing our hands, cleaning our homes and cooking food properly can limit the spread of disease.

Figure 2.50 Washing hands can prevent the spread of micro-organisms.

By following simple hygiene practices, humans are living much longer and healthier lives. Some ways in which you can prevent the spread of micro-organisms and prevent diseases from passing from one person to another are:

1. Cover your mouth and nose with a tissue or your elbow pit when you sneeze.
2. Wash your hands regularly, especially if you cough or sneeze into your hands.
3. Avoid touching your eyes, nose or mouth after touching contaminated surfaces such as hand rails or door handles.
4. Do not share drink bottles or cutlery with other people.
5. Quarantine – this is when a sick person is kept away from the healthy population, to prevent the illness from spreading. If your doctor has ever told you to stay home from school, that is a form of quarantine.

Disease

When someone says 'disease' it might seem obvious what they mean. However, a disease can be many things: it can be a viral, bacterial or fungal infection; it can be inherited from your parents; or it can be a condition that develops over time due to your environment. That is why we define a disease as any condition that negatively affects the normal functioning of any part of a living thing. Because this definition is very broad, we classify diseases into two categories: infectious and non-infectious.

Having a deeper understanding of cells allows us to understand and treat many diseases.

antibiotic
a medicine or chemical that can destroy harmful bacteria in the body or limit their growth

In the past, if you were very sick and had to go to the doctor, you may have been given **antibiotics**. Antibiotics kill most of the bacteria they come into contact with, but do not harm the cells of your body.

Figure 2.53 Antibiotics kill most of the bacteria they come into contact with.

Before the invention of modern antibiotics, there were limited ways to treat bacterial infections, so if you had a cut that was infected, you had two choices. You could either try the limited treatments, wait and

Figure 2.51 Always sneeze into a tissue.

Did you know? 2.6

Touching your face is one of the easiest ways to allow micro-organisms into your body. On average people touch their face around 2000 times per day. See how many times you touch your face in the next 20 minutes – it may shock you!

Figure 2.52 How many times do you touch your face?

Quick check 2.9

1. Define the following terms: pathogen, micro-organisms, pasteurisation.
2. Explain the link between the three terms in Question **1**.
3. Explain why it is better to sneeze into your elbow and not into your hands.

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Figure 2.54 Infected mouth ulcer

hope that the infection got better and did not spread, or you could cut that part of your body off, to prevent the infection from spreading to the rest of your body.

Alexander Fleming accidentally discovered the first antibiotic effective against a wide range of bacteria in 1928, when he was growing some bacteria in a laboratory. The bacteria became contaminated with a mould, and he noticed that the mould was killing the bacteria. This led to the discovery of the first antibiotic, called *penicillin*. Penicillin works by breaking down the cell wall of bacteria, which causes the cells to burst and die. For his work on developing penicillin and being the first to use it to treat an infection, the Australian scientist Howard Florey shared the Nobel Prize with Alexander Fleming and Ernst Boris Chain, a scientist who isolated and purified penicillin.

Figure 2.55 Shown here is a photo of Fleming's culture Petri dish

Figure 2.56 Testing antibiotics

In 1964, Dorothy Hodgkin won the Nobel Prize for being the first person to uncover the structure of penicillin using X-ray analysis. Her discovery allowed scientists to develop many other types of antibiotics. Some work in the same way as penicillin, and others slow or prevent the reproduction of bacteria, which gives the body's immune system a better chance to deal with the infection itself.

Figure 2.57 Sometimes rest is all your body needs to help heal itself.

It is important to remember that antibiotics only work on bacteria. If you are infected by a virus or some other type of microorganism, taking antibiotics will not cure you. In fact, taking antibiotics when you don't need them can kill the good bacteria in your body, and in the long term can lead to bacteria that are resistant to antibiotics.

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Science as a human endeavour 2.5

Fighting antibiotic-resistant bacteria

According to the World Health Organization, around 700 000 people die every year as a result of antibiotic resistance. Antibiotic-resistant bacteria cannot be killed using antibiotics and it is predicted that this issue will become the biggest global threat to human health in the next 15 years. However, in 2020, a new group of antibiotics that have a unique approach to attacking bacteria were discovered. This discovery could lead to the development of different antibiotics and help overcome antibiotic resistance.

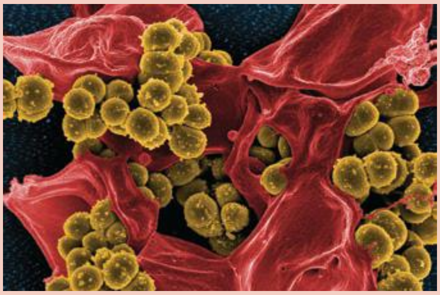

Figure 2.58 Antibiotic-resistant bacteria are a very real threat.

Quick check 2.10

1. State the definition of ‘disease’.
2. State the categories of disease.
3. Name a type of antibiotic.
4. Describe how antibiotics work.

Investigation 2.2

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 – this is a substance that can kill fungi. Soil is a good source of antifungal bacteria, and so your aim in this experiment is to test the effectiveness of different soil dilutions on the growth of fungi.

Aim

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

Planning

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.

Materials

- 4 dilutions of soil: 10% (1 g soil), 20% (2 g soil), 30% (3 g soil) and 40% (4 g soil) with water added up until the 10 mL mark for each dilution
- yeast solution (1 tablespoon yeast in 250 mL warm water)
- 1 agar plate per group
- sterile swab
- 4 plastic pipettes
- sticky tape
- disposable gloves

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Method

1. Draw a cross on the bottom of the agar plate, creating four quadrants.
2. Thoroughly swab the agar plate with the yeast solution, horizontally and then vertically, to get full coverage.
3. Using a pipette, place a few drops of each soil dilution in each quadrant and label the agar plate lid.
4. Allow time for the drops to be fully absorbed into the agar.
5. Cover the agar plate with the lid and with 2 to 4 pieces of sticky tape, tape down opposite edges of the plate. Label the outside edge of the plate on the agar side.
6. Place in an incubator at 30°C for two days.
7. 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.

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 bacterial growth.

Evaluation

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

Conclusion

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

Section 2.4 questions

QUIZ

Retrieval

1. **Define** the term ‘mitosis’.
2. **State** the three reasons that cells divide.
3. **Recall** why antibiotics are only useful in treating bacterial infections.

Comprehension

4. **Explain** how bacteria reproduce.
5. Sometimes cells are described as clones. **Explain** what this means.
6. **Describe** the difference between infectious and non-infectious diseases, using examples.
7. **Summarise** the process of pasteurisation, illustrating how it is beneficial to humans.
8. **Explain** in what way cancer relates to the control of cell division.
9. **Explain** how the development of different microscopes has led to our current understanding of cells.

Analysis

10. **Distinguish** between malignant and benign cancer.

Knowledge utilisation

11. **Propose** the reasons why you should never remove the sticky tape from your agar plates after carrying out an experiment investigating bacteria and its antifungal properties.
12. ‘Pasteurisation has led to improved human health.’ **Decide** on the truth of this statement.
13. **Develop** an experiment that investigates hand washing. Your aim is to determine the effectiveness of washing hands on preventing bacterial growth. You may like to begin by identifying your independent and dependent variables. Consider using agar plates for this task.

Chapter review

Chapter checklist

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

1	**I can use a microscope correctly.** e.g. Define the term 'resolution'.	
2	**I can distinguish between different types of microscopes.** e.g. Discuss the advantages of using electron microscopes.	
3	**I can recall modern cell theory.** e.g. Recall the main statements that describe modern cell theory.	
4	**I can compare prokaryotic and eukaryotic cells.** e.g. Describe how you would identify prokaryotic and eukaryotic cells.	
5	**I can compare animal, plant and fungi cells.** e.g. Use a Venn diagram to compare animal, plant and fungi cells.	
6	**I can describe the structure and function of different cell organelles.** e.g. Describe the structure and function of the Golgi body.	
7	**I can recall the purpose of mitosis.** e.g. State the three reasons why cells divide.	
8	**I can describe the effect of micro-organisms on human health.** e.g. Define pasteurisation.	

Review questions

SCORCHER

Retrieval

1 Of the four kingdoms – Animal, Plant, Fungi, Protist – **state** which consist of unicellular organisms and which consist of 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 a **Recall** the role of the following organelles in the cell.

Organelle	Role in the cell
Nucleus	
Cytosol	
Golgi body	
Ribosomes	

b Copy the cell diagram in Figure 2.59, and **identify** the organelles listed in part **a**.

c Is the cell shown in part **b** a plant cell or an animal cell? **Explain** how you know.

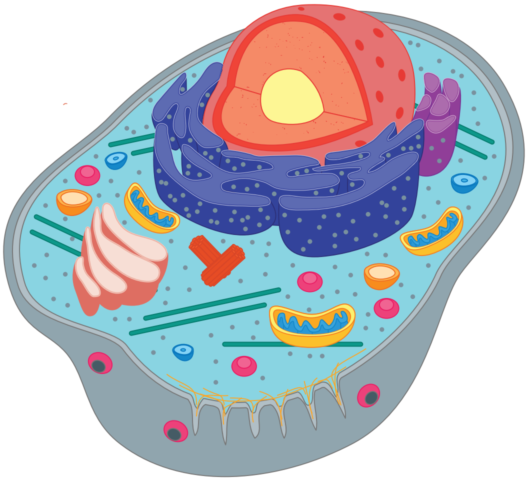

Figure 2.59 Eukaryotic cell

6 **Recall** the role of the mitochondria in cells and why they are so important.

7 **Identify** the type of cell that can turn into any other type of cell.

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8 **Identify** two disadvantages of the electron microscope.

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

10 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.

Comprehension

11 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.

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

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

Analysis

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 microscope with two hands to the bench
	Carry microscope with two hands back to the cupboard
	Turn off the power and let the lamp cool
	Using 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 cover and plug in the microscope
	Unplug the microscope, pack up and place on cover
	Use only the fine focus knob

14 **Classify** animals, plants and fungi as unicellular, multicellular or both.

15 **Contrast** the terms 'resolution' and 'magnification'.

16 Draw a Venn diagram to **compare** prokaryotic cells (such as bacteria) with eukaryotic cells (such as plant and animal cells).

Knowledge utilisation

17 **Create** a flow diagram to describe the process involved in a stem cell transplant for leukaemia.

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

Data questions

Eucaryotic organisms can achieve cell growth and repair through the process known as mitosis. The relative time required for each of the stages of cell duplication in a eukaryotic cell is shown in the pie chart below. The time taken for the mitosis phase (M) of cell division for different types of cells is given in the table.

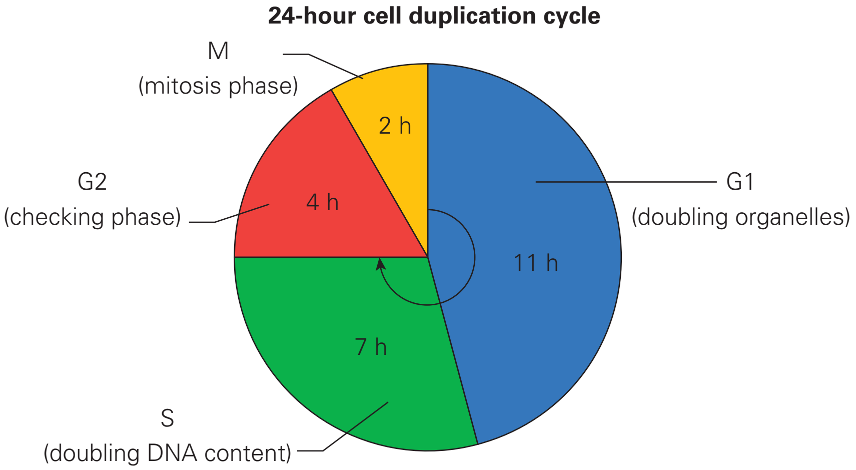

Figure 2.60 Relative duration of each of the four phases of a typical 24-hour cell division cycle in a eukaryotic cell.

Cell type		Temperature (°C)	M phase duration (min)
Plants	Grass	20	110
	Sunflower	20	85
	Pea	3	18 000
		10	4200
		20	110
		25	80
Animals	Rat	37	43
	Chicken	37	80
	Cockroach	35	140

Table 2.2 Duration of the mitosis phase (M phase) at different temperatures for different cell types

Apply

1. **Identify** which stage in the eukaryotic cell division cycle takes the longest time.
2. **Identify** which animal in Table 2.2 has the longest mitosis phase duration.
3. **Calculate** the percentage of time in the cell duplication cycle used for doubling organelles.

Analyse

4. **Identify** the relationship between the duration of the M phase in a pea cell and the temperature.
5. **Identify** how long a cell will take to duplicate all of its content if it follows the typical 24 h cycle.

Interpret

6. **Infer** why the M phase duration is given at different temperatures for plants and animals in Table 2.2.
7. **Predict** in what phase of cell duplication the content of DNA in the cell is the highest.
8. Refer to Table 2.2 and **deduce** whether or not it is possible to affirm that animals have longer mitosis phases than plants.
9. Based on the data provided, **predict** whether the mitosis phase of cell replication would be faster or slower for a grass cell at a temperature lower than 20 °C.

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STEM activity: Design a city

Background information

All living things, from humans to dogs, trees and bacteria, are made up of cells. Cells are the smallest unit of life and are so small that you cannot see most of them 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. For example, 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. Cells also reproduce via a process called mitosis, in which each cell divides and produces two identical cells. Unicellular organisms reproduce by mitosis, and multicellular organisms use mitosis for growth and repair.

Analogies are often used in science to explain, in simple terms, how processes work. An *analogy* is a comparison with something familiar. 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 or vlog/video

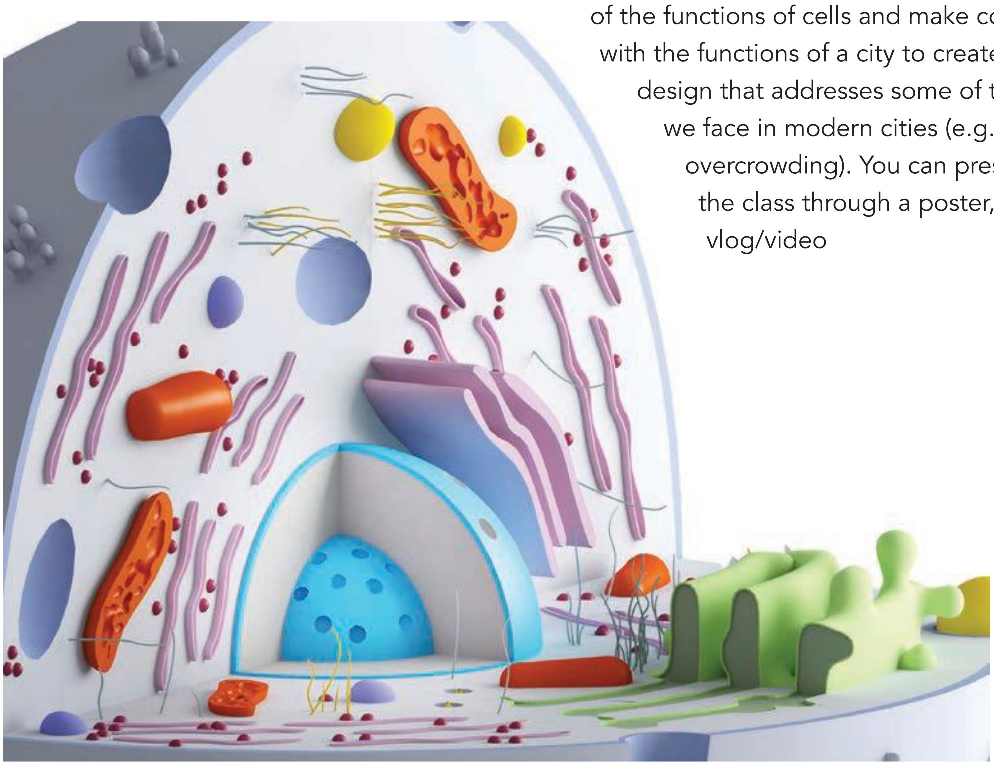

Figure 2.61 A cell can be compared to a city.

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Suggested materials/presentation format

- Poster
- PowerPoint
- Video

Research and feasibility

1 List all the major organelles and their functions. As a group, research the issues/resources that face a city such as Brisbane (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

You are a large and complex multicellular organism. You eat, move, sleep, think, breathe and fight disease every day, and you can only do this because of all the different types of cells and tissues in your body. 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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Curriculum

Multi-cellular organisms contain systems of organs carrying out specialised functions that enable them to survive and reproduce (ACSSU150).	
identifying the organs and overall function of a system of a multicellular organism in supporting the life processes	3.2, 3.4, 3.5, 4.3
describing the structure of each organ in a system and relating its function to the overall function of the system	3.2, 3.4, 3.5, 4.2
examining the specialised cells and tissues involved in structure and function of particular organs	3.1, 3.2, 3.3, 3.4, 3.5
comparing similar systems in different organisms such as digestive systems in herbivores and carnivores, respiratory systems in fish and mammals	3.3, 3.4, 3.6

Glossary terms

alveoli
anus
aorta
artery
atrioventricular node
atrium
biconcave
bile
bolus
bronchi
bronchioles
caecum
capillaries
carnivore
cellular respiration
chemical digestion
chyme
diaphragm
duodenum
enzyme
ethical
filaments
function
gall bladder
guard cells
haemoglobin
herbivore
heterotroph
ileum
intolerance
jejunum
large intestine
lenticels
liver
mechanical digestion
neuron
omnivore
organ
organism
organ rejection
organ transplantation
pancreas
peristalsis
pharynx
plasma
platelets
rectum
saliva
sinoatrial node
sphincter
stomata
structure
tissue
tissue engineering
trachea
vein
vena cava
ventricle
villi
xenotransplantation

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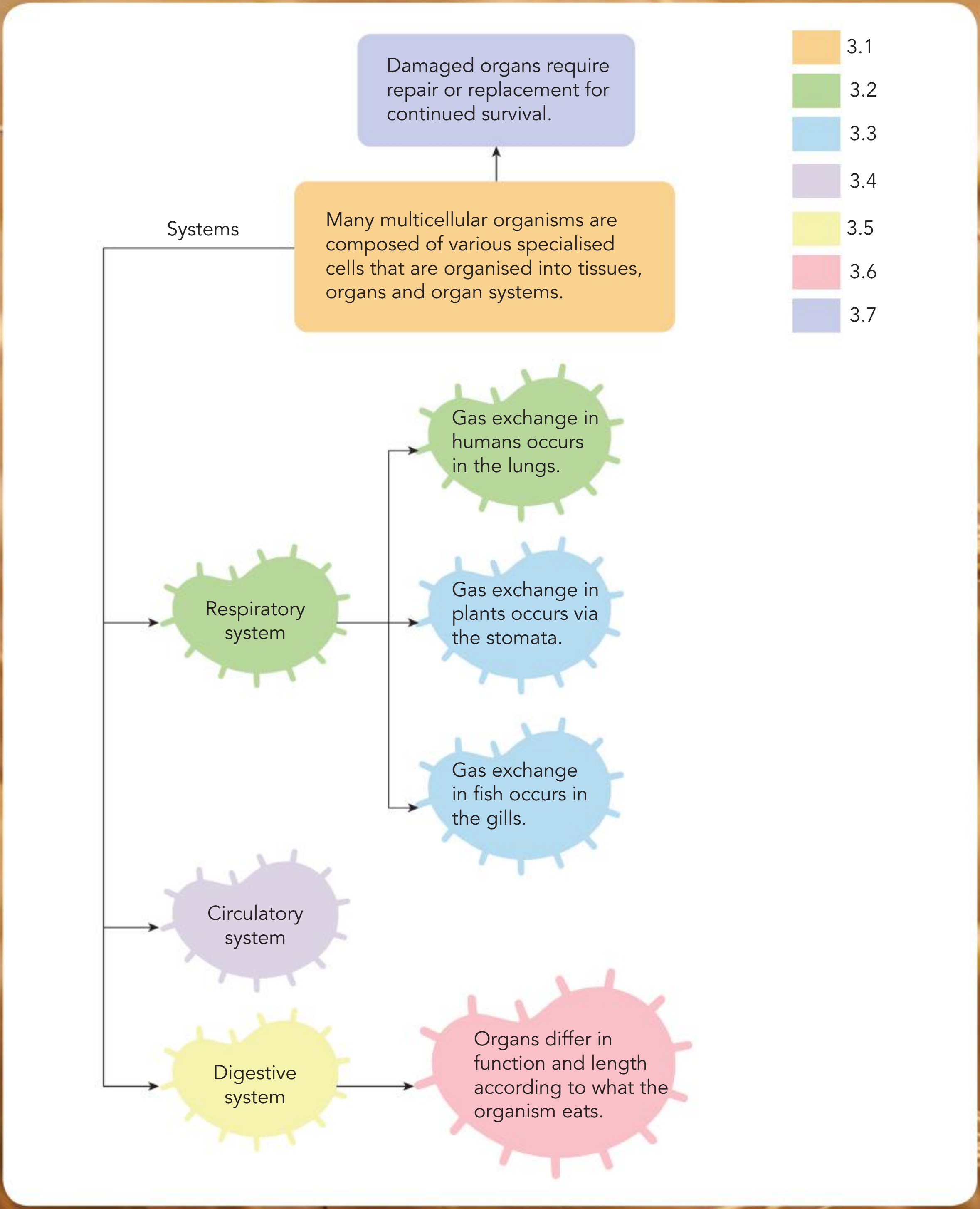
Concept map



Damaged organs require repair or replacement for continued survival.

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

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 function and length according to what the organism eats.

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3.1 Cells to systems

Specialised cells

Humans are animals, and our cells contain a nucleus, cell membrane, cytosol, mitochondria and all 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 an activity that the structure helps the object to complete.

All the cell types in your body begin as unspecialised stem cells. As the cells grow and develop, they **differentiate**, forming over 200 different types of cells that are you. These cells then replicate to produce more copies of each type of specific cell.

Neurons

Nerve cells or **neurons** allow all the parts of your body to work together, by transferring signals to and from your brain to each part of your body via the nervous system. Nerves are important because they allow us to interact with the world around us via our senses. Neurons are long, thin cells that connect to each other via 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 cell in your body is your sciatic nerve, which stretches from the bottom of your spine to your big toe.

Red blood cells

Red blood cells transport oxygen to all the cells in your body. These blood cells have to pass along tiny blood vessels and so they are flat and have a **biconcave** shape. When they reach maturity, they do not have a nucleus, which gives them extra room to carry oxygen around the body.

DOC WORKSHEET

structure
a physical part of an object

function
the job that an object does

differentiation
the process by which cells become specialised

neuron
a nerve cell

biconcave
concave on both sides

Figure 3.1 Neurons are shown on the left, and on the right is the main organ of the nervous system, the brain.

Figure 3.2 Red blood cells travelling through a blood vessel. Note their biconcave shape.

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As they do not have a nucleus, they cannot undergo cell division, and so all red blood cells are produced in the bone marrow. Your red blood cells are replaced every 120 days.

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. This means that the sperm cells have to be able to move. 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 which digest through the membrane of the egg cell, allowing the sperm nucleus to enter.

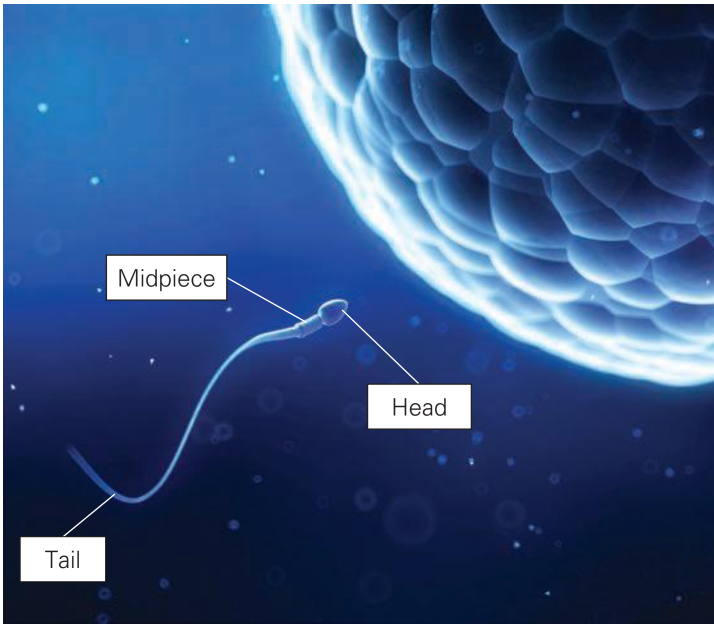

Figure 3.3 A sperm swimming towards an egg. Note its long whip-like tail.

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:
  a Neuron
  b Red blood cell
  c Sperm.

Practical skills 3.1

Specialised cells

Aim

To observe specialised cells under the microscope

Materials

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

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.

continued…

...continued

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.
13 Repeat steps **8–12** for each slide.

Results

Copy the following tables and use them to record your observations and measurements.

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				

Analysis

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

Evaluation

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

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Levels of organisation

Cells are organised into tissues, tissues into organs, and organs into organ systems. An example is shown in Figure 3.4.

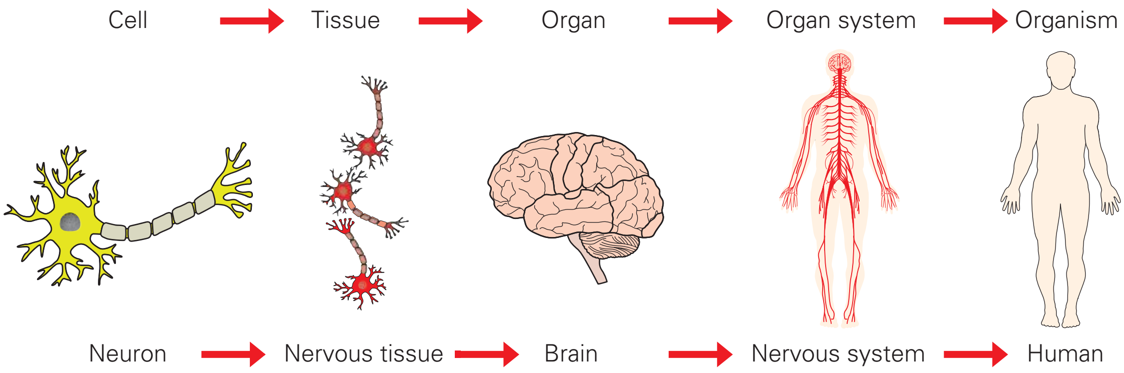

Figure 3.4 The nervous system is an example of cells being organised into an organ system.

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 and this cell 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, and are composed of many specialised types of individual cells that carry out specific functions. Because of this, the cells inside your body cannot gain nutrients and get rid of wastes without the help of other cells. This is where tissues, organs and organ systems come into play.

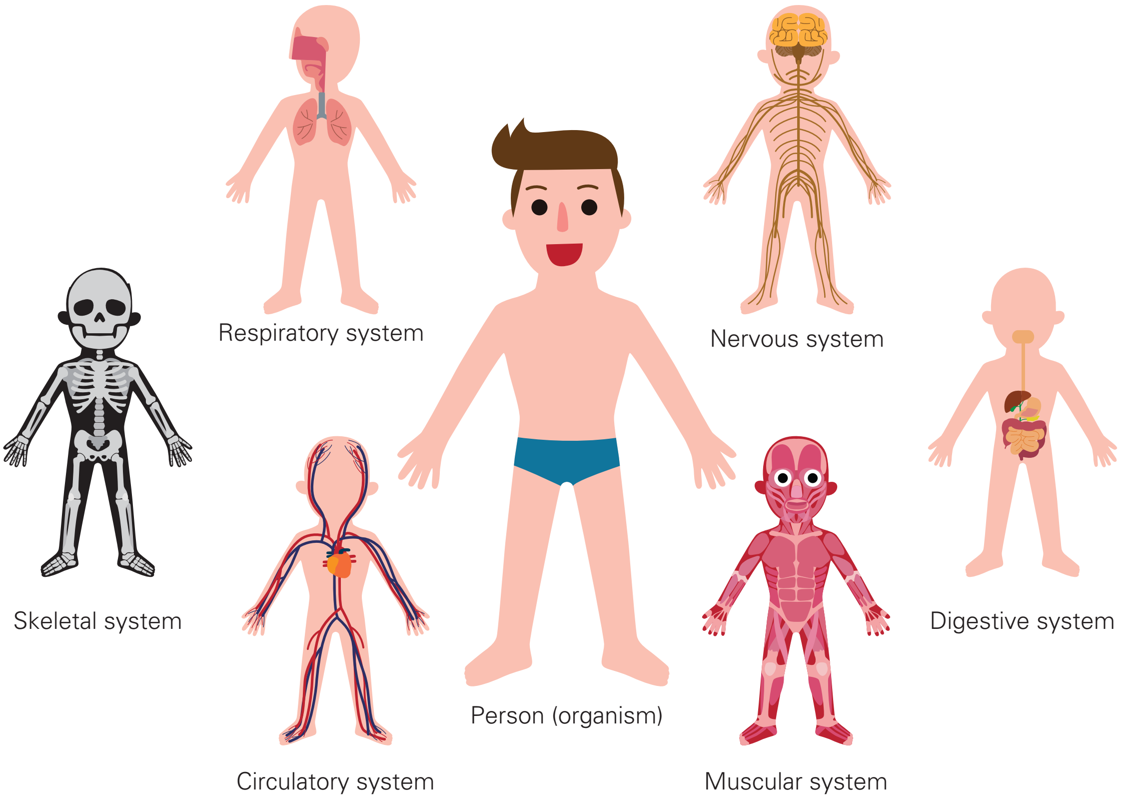

Figure 3.5 A multicellular organism, such as a human, is composed of many specialised cells, which are organised into tissues, organs and organ systems.

Tissues

When a group of cells of the same type work together in a body, we call them a **tissue**. One of the most obvious tissues in animals is muscle tissue. These groups of cells contract and relax in order 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 good supply of blood 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

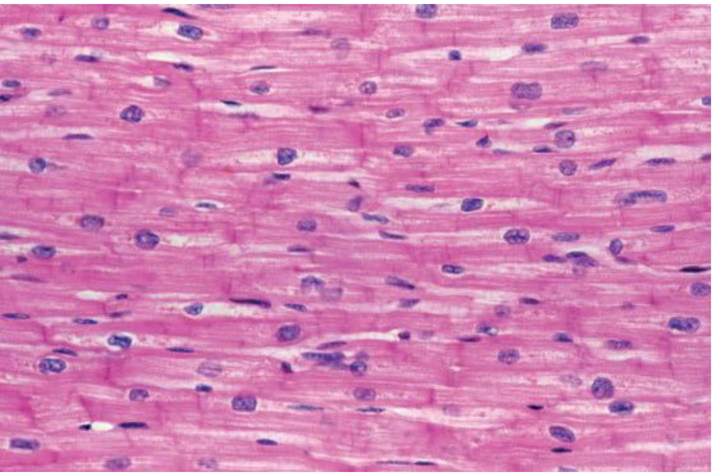

Figure 3.6 A high-magnification photograph of human cardiac (heart) muscle, seen through a light microscope. Each of the long, thin muscle cells has a purple nucleus. Note that a stain has been added to the tissue to make it more visible.

Organs

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 made up of different nerve tissues that make up the grey and white matter. There are also many blood vessels that flow through the brain.

organ
a group of tissues working together to perform a function

Figure 3.7 The human brain is a complex organ composed of neurons, blood vessels and other cells.

Did you know? 3.1

The largest organ in the human body is actually 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 onto your skin. The skin cells themselves are replaced every 10–30 days, which means that, on average, we each get through around 900 complete skins in a lifetime.

Science as a human endeavour 3.1

Practice makes perfect

In late 2017, a research team from the University of Minnesota used 3D printers to produce lifelike artificial organs for training surgeons to practise on. While the use of models and computer simulations in surgical training is not new, these fake organs are much more realistic, as they perfectly mimic the anatomical structure, look and feel of a patient's organ. It is even possible to embed soft sensors in them, to give the surgeons feedback about their technique, with the aim of minimising surgical errors and improving patient outcomes.

Organ systems

A group of different organs working together is called an organ system (or body system). The structures of the system each perform distinct processes or functions. Your digestive system is one of the most diverse organ systems in your body, with around twelve main organs, such as the mouth, stomach, liver, pancreas and intestines, along with many other smaller organs and glands that help to break down food and absorb nutrients into your bloodstream.

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

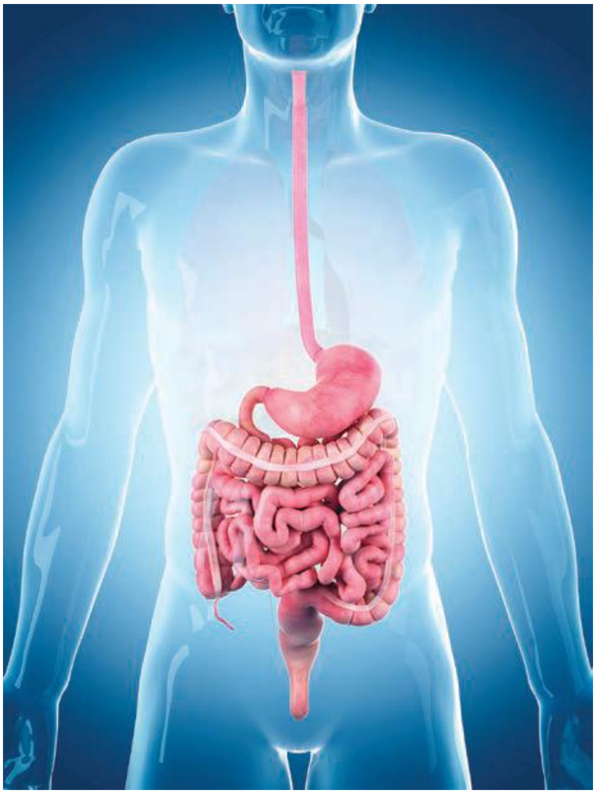

Figure 3.8 The human digestive system is essentially a long tube from the mouth to the anus. Many accessory glands assist in the digestive process.

Try this 3.1

How many human organ systems can you name? Brainstorm with a partner and make a list. A helpful starting point might be to think of organs in the body and then classify them according to what organ system they belong to.

Organisms

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 3.9 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 Name five components of the human digestive system.

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Explore! 3.1

Plants are complex

They 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.

Research one plant of your choice and list one example of each of the levels of organisation:

Cell: Tissue: Organ: Organ system: Organism:

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.

Section 3.1 questions

QUIZ

Retrieval

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 are correct.
   a An organ 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.

Comprehension

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.

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

Analysis

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, brain, muscle, blood.

Knowledge utilisation

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.

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3.2 The human respiratory system

WORKSHEET

Breathing vs 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 of carbon dioxide and water. If you stop breathing, you are preventing oxygen entering your body and therefore depriving your cells of oxygen, meaning ATP cannot be made.

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

Key idea
To summarise: breathing is a physical process, respiration is a chemical process.

Figure 3.10 When you breathe out on a cold day, you can see your warm breath start to condense in the cold air.

Did you know? 3.2

Freedivers

While you or I might be able to hold our breath under water for about 30 seconds, people who practise freediving can hold their breath for 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. In 2018, Croatian freediver Budimir Šobat held his breath under water for 24 minutes and 11 seconds, breaking the Guinness World Record by 8 seconds.

Figure 3.11 Freediving in the ocean

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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 transports the oxygen you breathe in and removes the carbon dioxide you breathe out.

Big breath in!

diaphragm
a dome-shaped muscle that separates the chest and abdominal cavities; it contracts to cause us to inhale

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, drawing air in through your mouth and nose decreasing the pressure in your lungs compared with the outside. 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.

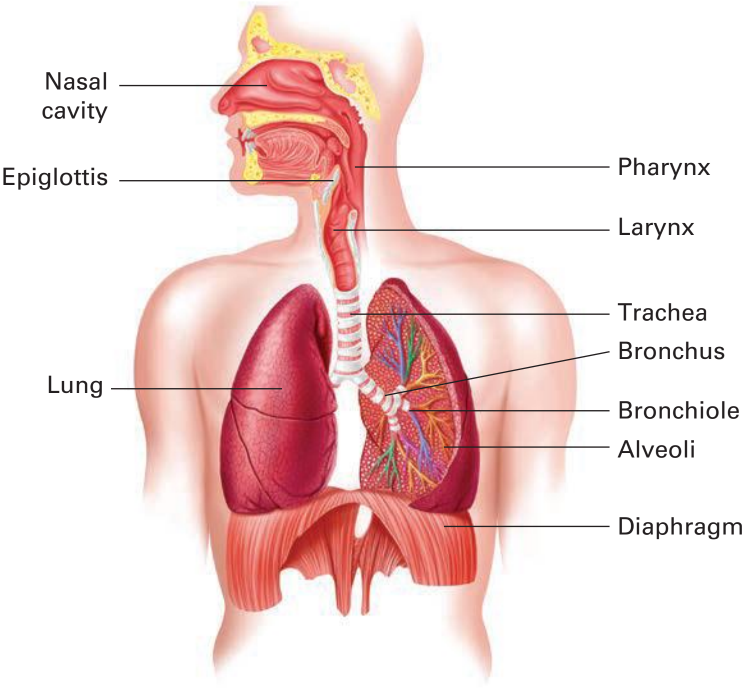

Figure 3.12 Structure of the human respiratory system

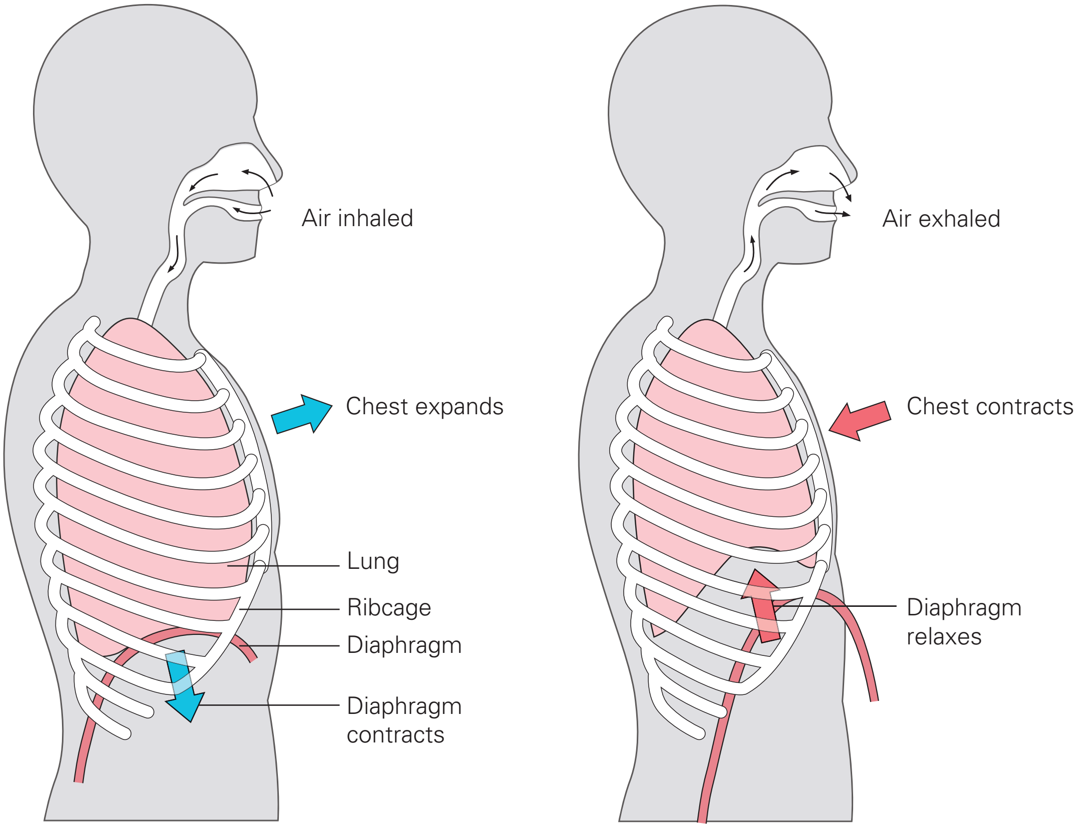

Figure 3.13 The movements of the chest during inhalation and exhalation

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Try this 3.3

Diaphragmatic breathing

Diaphragmatic breathing involves paying close attention as you breathe, in a slow and controlled way. It is commonly used during mindfulness activities and meditation. Let's have a try!

Step 1 Find a comfortable position where you are standing up straight against a wall, or seated in a chair with your feet flat on the floor. Close your eyes.

Step 2 Relax your shoulders. Place your hands over your stomach, around the level of the base of your ribs.

Step 3 Close your mouth and begin to breathe in and out slowly through your nose. Notice how, when you breathe in, your stomach seems to swell under your hands and your rib cage expands upwards and outwards. As you breathe out, you can feel the diaphragm relax and your ribs sink back in.

Step 4 Practise breathing in and out through your nose, in a slow and controlled way. Pay attention to the noise of your breath, and try to notice the sensation as the air enters and exits your nose. If you are aware of any tension you are holding in your body, for example in your shoulders, try and relax, and breathe out the tension with each exhalation.

Practising diaphragmatic breathing is a great way to refocus and allow yourself to be present in the moment. It can slow your heart rate, boost oxygen levels and even reduce blood pressure.

Mouth and nose

The two main openings to your respiratory system are your mouth and your nose. 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 also 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

bronchi
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

Trachea and bronchi

The trachea is a wide tube with thick protective rings of cartilage that keep it open. You can feel the rings if you feel your throat. Warm, moist air from the nose and mouth enters the lungs by travelling down the trachea. The structure of your lungs is very similar to a tree. The trunk of the tree is the trachea, and this large tube splits into two smaller tubes called **bronchi**, which are

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 sleep apnoea. Describe this condition.
4 What treatments are available to reduce snoring?

Figure 3.14 This drawing of the lungs shows the blue central trachea dividing into the left and right bronchi. The orange bronchi then branch into bronchioles.

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similar to branches and lead into the left and right lungs. The bronchi then branch into smaller and smaller tubes called **bronchioles**, which are similar to small twigs.

Alveoli

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. As the diaphragm and intercostal muscles relax, the carbon dioxide-rich air is exhaled out through your nose and mouth.

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

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

VIDEO
Describe what happens in an alveolus

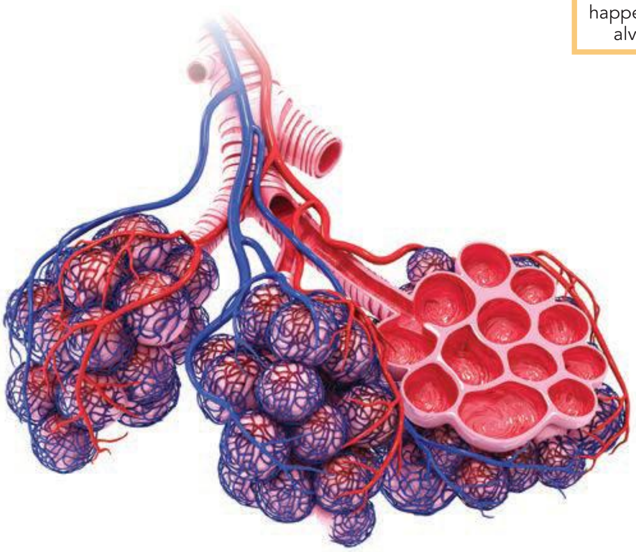

Figure 3.15 Gas exchange occurs between the alveoli and the capillaries. The oxygenated blood is returned to the heart, and the carbon dioxide-rich air is exhaled.

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
- 2 rubber bands
- 2 balloons
- 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 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 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.

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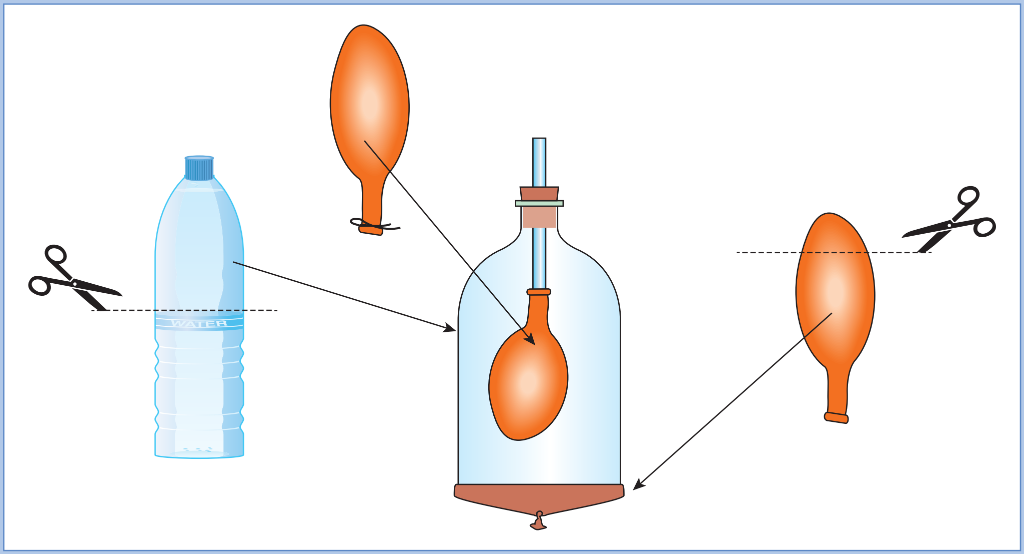

Figure 3.16 Experiment set-up. Breathing in: pressure in the lungs is lower than the atmosphere, so air flows in. Breathing out: pressure in the lungs is greater than the atmosphere, so air flows out.

Results

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.

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.

Science as a human endeavour 3.2

Asthma

Asthma is a chronic lung condition that involves inflammation of the airways, tightening of the bronchioles in response to certain triggers, and hypersecretion of mucus in the airways. People who suffer from mild asthma might feel slightly tight in the chest when they exercise or breathe in cold air, but some severe sufferers must take medications such as steroids every day to treat the inflammation.

A recent development has seen asthma patients benefitting from using an antibody that has previously been used to treat eczema (an inflammatory skin condition that causes dry, itchy rashes). The antibody appears to block a protein that causes some of the inflammation in the airways, and results in improved lung function in the participants and less reliance on steroid medications.

Figure 3.17 An asthma sufferer uses a reliever medication (an inhaler or puffer) to reduce the inflammation and open up their airways.

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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.
3. Sequence these terms in order so that they represent the direction of airflow during inhalation: alveoli, pharynx, nose/mouth, bronchus, trachea, bronchiole.
4. Explain how the diaphragm is involved in breathing in and out.

Did you know? 3.3

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

Deep in the lungs, the alveoli are the site of gas exchange in humans and other species that have lungs. But some members of the animal kingdom have developed 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 comes into contact with 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 alveoli in our lungs have all the features listed above, which makes them an extremely efficient gas exchange surface. Their surface area is so large that if you were to pop your alveoli open and spread them out flat, they would cover 18 table tennis tables. That is a lot of surface area for gas exchange, squeezed into your chest.

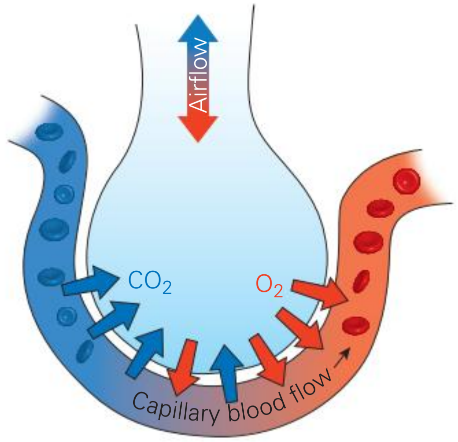

Figure 3.18 Gas exchange between the alveolus and the capillary. Note the direction of diffusion as oxygen enters the bloodstream and carbon dioxide leaves the bloodstream.

Quick check 3.4

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.

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Practical skills 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 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 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.

Air source	Bromothymol 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.

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.

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Explore! 3.3

Frog business

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 cold blooded. This means that their level of respiration can be lower, compared with warm-blooded animals, 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.

Figure 3.19 A frog keeping its nostrils above water to breathe

Figure 3.20 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.

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Section 3.2 questions

QUIZ

Retrieval

1 **Name** the gas that is absorbed into the body by the respiratory system.

2 **Name** the gas that is removed from the body by the respiratory system.

3 **State** the more biologically correct name for the 'windpipe'.

Comprehension

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:

Structure	Function
Alveolus	
Trachea	
Nose	
Bronchiole	

7 **Summarise** the movement of the diaphragm during inhalation and exhalation.

8 **Describe** how the structure of the alveoli facilitates gas exchange.

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.

Analysis

10 **Contrast** the term 'breathing' with the term 'respiration'.

11 The graph in Figure 3.21 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.

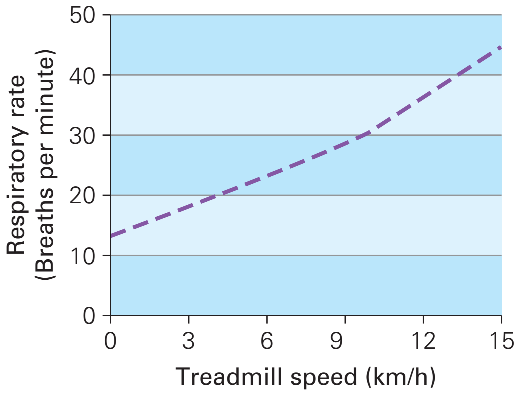

Figure 3.21 Respiratory rate vs treadmill speed

Knowledge utilisation

12 **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.

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 which then results in a chest infection. **Propose** a reason why a build-up of fluid in the lungs can be harmful, and why the person may experience shortness of breath.

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3.3 Other respiratory systems

Respiratory systems in plants

Gas exchange is important for all living organisms, including plants. Plants carry out cellular respiration as well as photosynthesis, and so they need organs that allow their internal structures to exchange gases with the environment. The main gas exchange organ in plants is the leaf. It is in the leaf that plants take up carbon dioxide (one of the reactants in photosynthesis) and release oxygen (a waste product of photosynthesis).

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** in the stomata enable them to open and close.

DOC WORKSHEET

The guard cells of stomata contain large vacuoles that, when filled with water, hold the stomata 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 pores 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).

stomata
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

Figure 3.22 Leaves are like lungs for a plant.

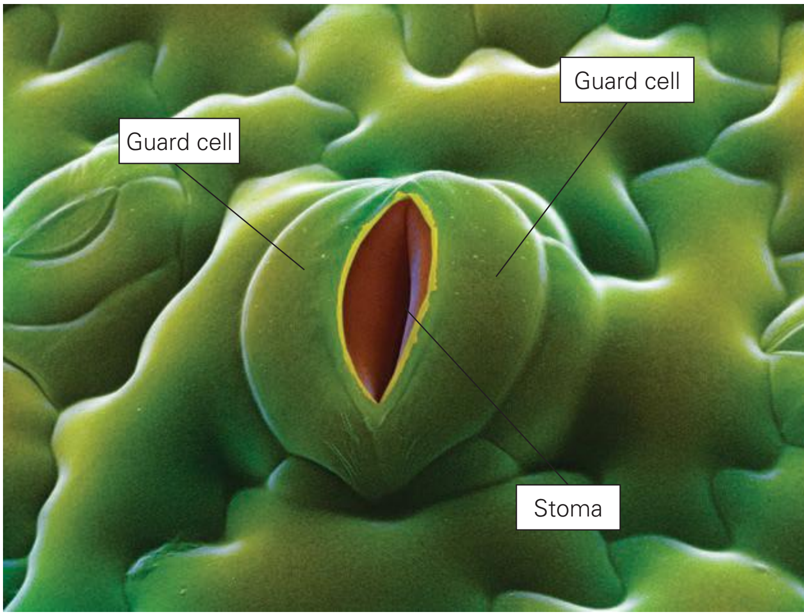

Figure 3.23 Swollen guard cells have forced open this stoma, allowing gases to enter and exit the leaf.

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Practical skills 3.3

Stomata lab

Aim

To observe plant stomata using a compound microscope, and estimate their size

Materials

- leaves
- compound microscope
- transparent ruler
- sticky tape
- glass slide
- transparent nail polish

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.

Method

Calculating FOV and estimating the size of the object

Refer to Practical skills 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

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

Plant	Sketch, magnification and diameter estimate

continued…

...continued

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.

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 similar to what happens in the stomata as they lose water. By closing the stomata, the plant is able to limit water evaporation and save water.

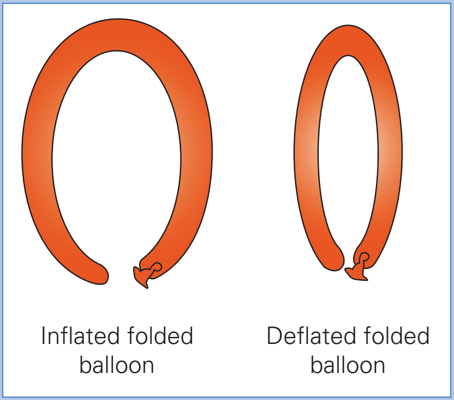

Figure 3.24

Science as a human endeavour 3.3

Thirsty plants

At present, agriculture consumes 90% of the world's fresh water to irrigate (water) crops. Scientists have found a way to genetically alter crops so that they are only able to partially open their stomata. This means the plants lose less water vapour when they open their stomata to gain the carbon dioxide they need to carry out photosynthesis. In a study conducted on tobacco plants, the modification improved crop water use by 25% but did not affect the yield of the crops – that is, the same amount of tobacco was produced. Tobacco plants are easier to genetically modify, but now the research team hope to apply their discoveries to food crops.

Although the stomata on leaves do a great job of providing gases for the leaves, other parts of the plant need to respire, using oxygen. 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. Lenticels allow the thick woody parts of the plant to exchange gases with the air.

lenticels
small slits on trunks or branches of trees that allow gas exchange

Figure 3.25 The small horizontal slits in this tree trunk are lenticels. You may have seen these on trees but not known what they are.

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Quick check 3.5

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 cannot function under water, and gills do not function on land. However, both these structures take in oxygen from the surroundings 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 3.26 The highly folded inside of fish gills maximises the surface area available for gas exchange.

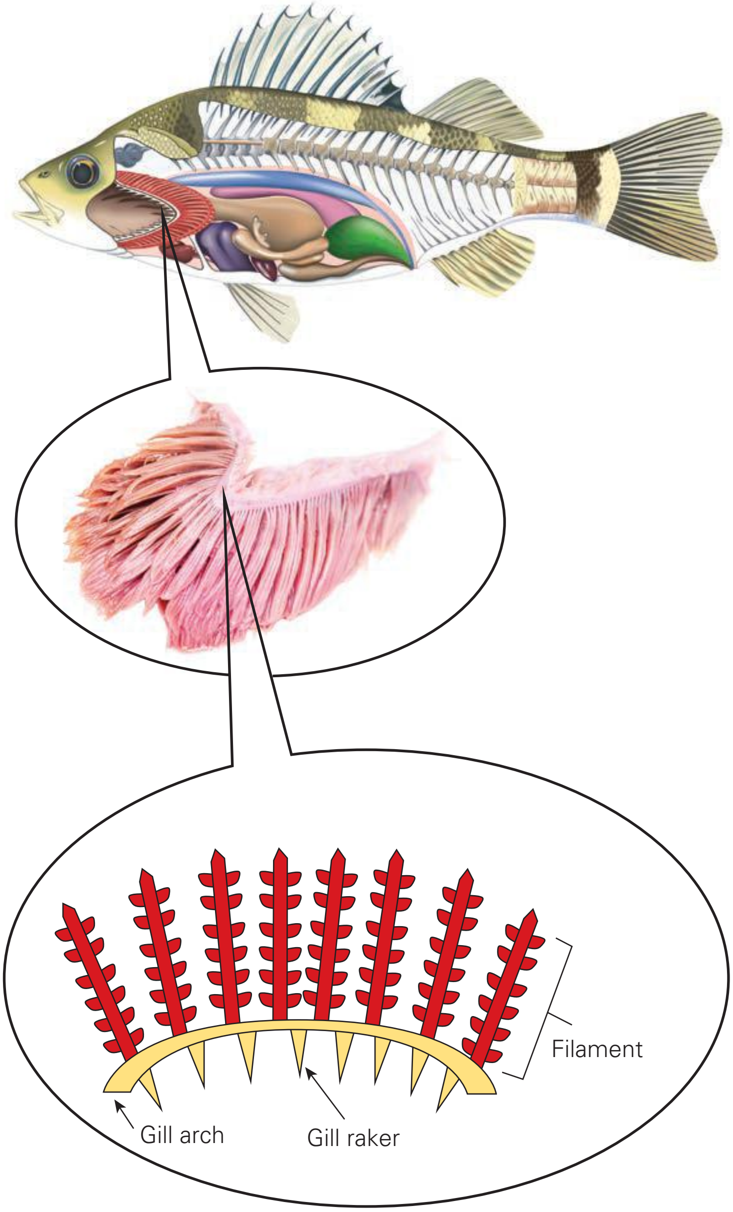

Figure 3.27 The complex structure of fish gills

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Explore! 3.4

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: the bigger the difference between the concentration of a gas in two areas, the faster diffusion occurs.

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? 3.4

Axolotls

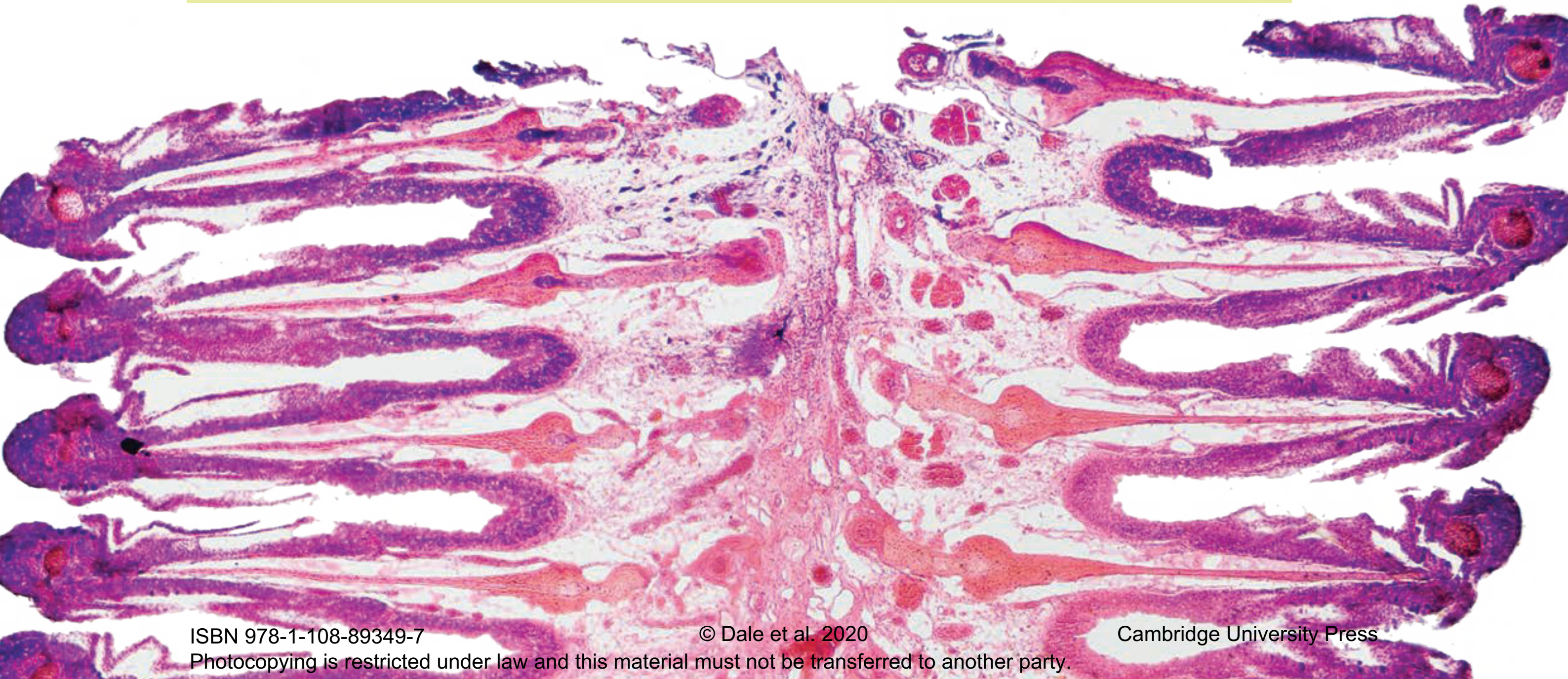
You may think axolotls have a super stylish headdress, but it actually has a very important job. It is their gills!

Unlike other salamander species, 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 to breathe underwater.

Figure 3.28 The gills of an axolotl stick out from the side of its head to maximise gas exchange with the surrounding water.

Quick check 3.6

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 skills 3.4

Fish dissection

Aim

To observe a fish dissection and view gills under a microscope

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.

Materials

- dissection microscope
- Petri dish
- ½ 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 3.29.

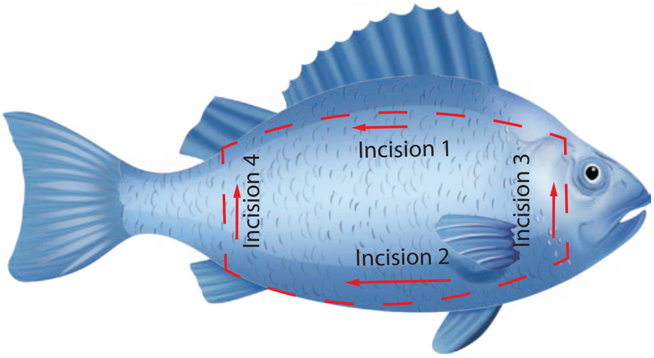

Figure 3.29 External incisions

This will expose the internal anatomy of the fish.

2 Your teacher will identify the structures shown in Figure 3.30.

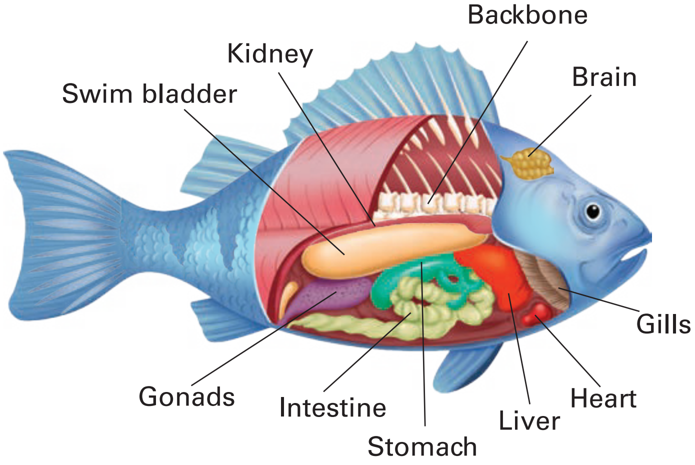

Figure 3.30 Internal organs of the fish

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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. 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.

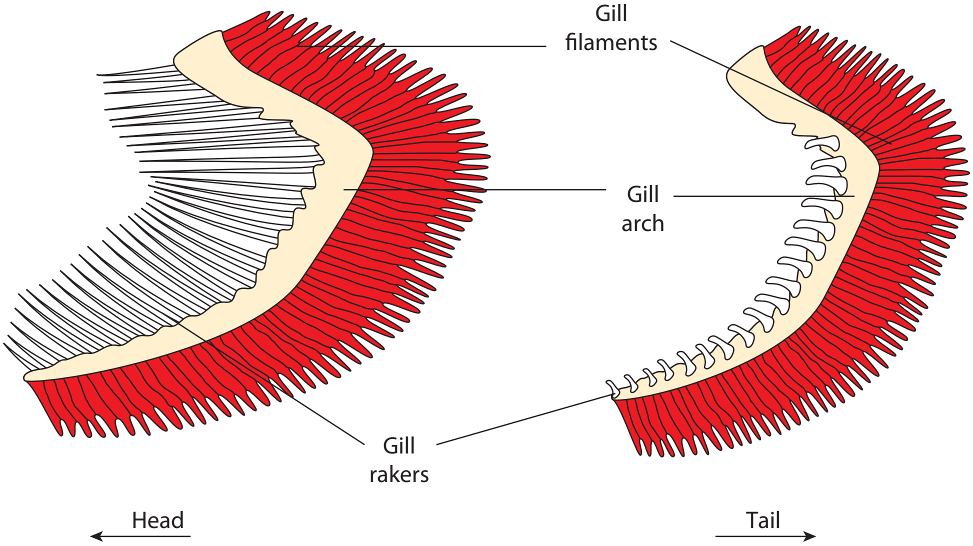

Figure 3.31 Observe the structures: *gill filaments* are the site of gas exchange; *gill rakers* are appendages along the front edge of the gill arch; *gill arches* support the gills.

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.
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.

Analysis

1 Name the organ involved in water 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.

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Science as a human endeavour 3.4

Super crab!

The invasive green shore crab has surprised researchers by demonstrating that it uses its gills not only for obtaining oxygen but also for getting nutrients. Because crabs have a hard shell, it was assumed that they obtained their nutrition by eating food and digesting it. However, crabs have been observed to absorb amino acids (which make up proteins) through their nine sets of specialised gills. This might explain why crabs are able to thrive in tough environmental conditions.

Figure 3.32 The green shore crab

Section 3.3 questions

QUIZ

Retrieval

1 **Define** the term ‘gas exchange’.
2 **State** three gas exchange structures found in nature.
3 **State** the location of stomata.

Comprehension

4 **Explain** how stomata open and close.
5 **Describe** the reason for lenticels on a tree.
6 **Summarise** how surface area is maximised in gills.

Analysis

7 **Contrast** the structure of the lungs with the structure of a tree.
8 **Contrast** the structure of human lungs with the structure of frog lungs.

Knowledge utilisation

9 **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

10 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

The partner of most of the organ systems in the body is the circulatory system. This is a transport system that moves oxygen, nutrients, hormones, immune cells, waste and heat throughout the body, in one continuous loop, for your entire life. Without the circulatory system, none of the other organ systems would be able to function.

Heart

DOC WORKSHEET

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 generates high pressure, which pushes blood out of your heart into the arteries. Blood is pushed towards the heart because valves in the veins prevent back-flow, and it continues moving because of muscles around the veins applying pressure.

Science as a human endeavour 3.5

Printed heart

In 2019, scientists in Israel announced that they had 3D-printed an entire heart, using a bio-ink gel made from cells. The thumb-sized heart was printed in just three hours and contained the atria and ventricles of a normal heart. The scientists are now working on how to make it beat and circulate blood, but this development could potentially be used in the future to 3D-print organ replacements for humans.

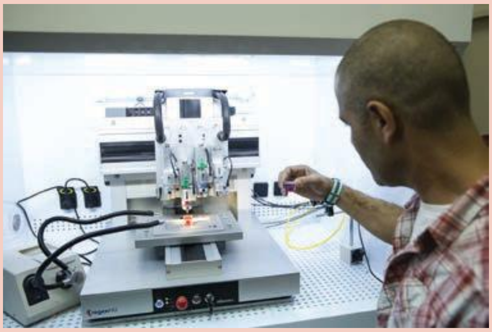

Figure 3.33 3D printing of a human heart

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 soft side of your wrist, slightly off centre towards the thumb). Count the number of beats you feel in 15 seconds, using the stopwatch, and then multiply by 4 to find your heart rate in beats per minute (bpm).

Test your pulse under the following conditions, then copy and complete the table.

Test condition	Heart rate (bpm)
Lying down	
Sitting	
After jogging for 3 minutes	

Figure 3.34 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.

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atrium
one of the two upper chambers of the heart, the left atrium and right atrium

ventricle
one of the lower two 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

Once in your heart, blood is ready for recirculation. Your heart 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** (v-shaped bottom part 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 natural pacemakers, called the **sinoatrial node**, located in the wall of the right atrium, and the **atrioventricular node**, located between the atria and the ventricles. The nodes send an electrical signal throughout the heart, causing it to contract.

The human circulatory system is like a double pump: the left side sends blood out to the body, and the right side sends blood to the lungs. Let's follow the path of a red blood cell through the circulatory system, using Figure 3.36 on the following page.

VIDEO
Describe how the heart chambers contract

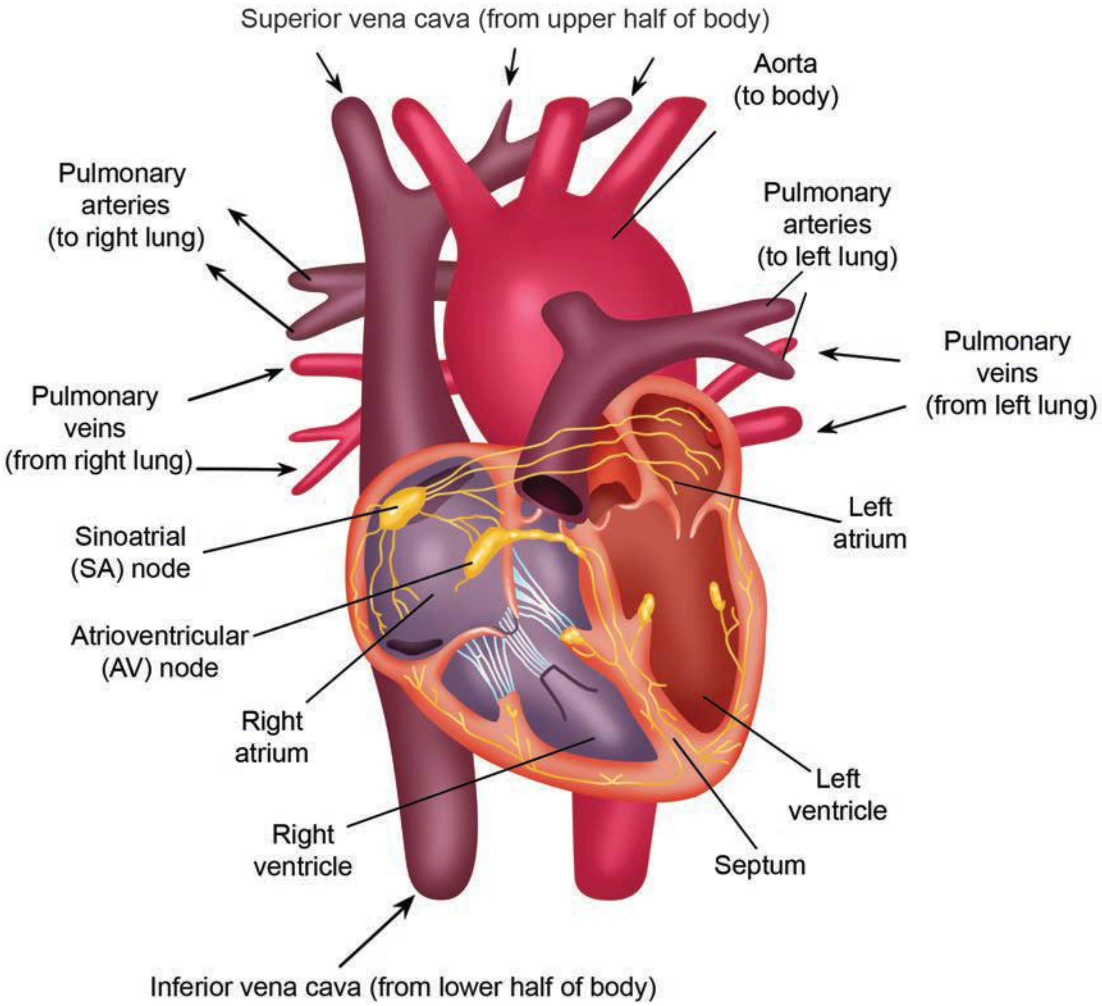

Figure 3.35 The human heart and its major vessels, chambers and valves. The heart is labelled as it sits in your chest, but it is drawn as if it were visible to someone facing you. This is why the left ventricle is located on the right-hand side of the diagram.

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Did you know? 3.5

Red or blue?

When you look at your wrist, you might be tempted to think that your veins are blue. The light passing through our skin makes our veins look blue, but this is just an illusion! Veins look blue because blue and red light have different wavelengths and penetrate your skin with different levels of success. Red light travels easily through your skin and is absorbed by the red pigment (haemoglobin) in your red blood cells. However, blue light is largely scattered when it hits your skin and is reflected back to your eye as blue light.

Blue veins are particularly noticeable on very pale skin, and may have caused the expression "blue blood" when talking about royals. In the 18th century, 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 actually still red, just a darker shade. Some diagrams use blue to indicate areas of the circulatory system containing deoxygenated blood, but this is just a colour choice. Your blood is always red.

Blood returning to the heart from the body enters the heart though the **vena cava** and goes into the right atrium. This blood has low levels of oxygen and high levels of carbon dioxide, and so in the diagram it is coloured dark red.

vena cava
the large vessel that returns deoxygenated blood to the heart, emptying into the right atrium

aorta
the largest vessel leaving the heart, from the left ventricle, carrying oxygenated blood to the body

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.

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. Notice that, in Figure 3.36, the blood coming from the lungs is now coloured bright red.

The oxygenated blood then returns from the lungs through the pulmonary veins into the left atrium, where it passes into the left ventricle and is then pumped out via the **aorta** to all the different parts of the body, delivering oxygen to the cells and picking up the waste carbon dioxide.

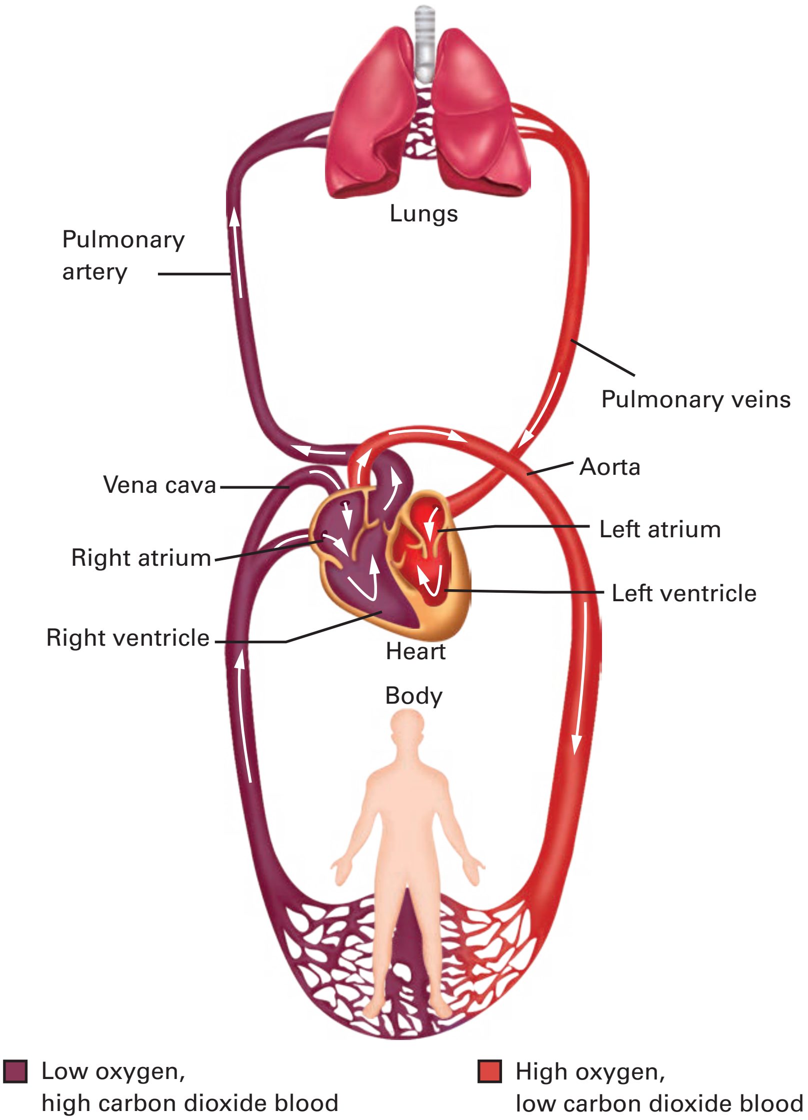

Figure 3.36 Blood flows in the following loop: right atrium → right ventricle → pulmonary artery → lungs → pulmonary vein → left atrium → left ventricle → aorta → body tissues → vena cava → right atrium … and the loop starts again.

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Quick check 3.7

1. Name the four chambers of the heart.
2. Name the two structures that make up the heart's natural pacemaker.
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

Practical skills 3.5

Sheep heart dissection

Aim

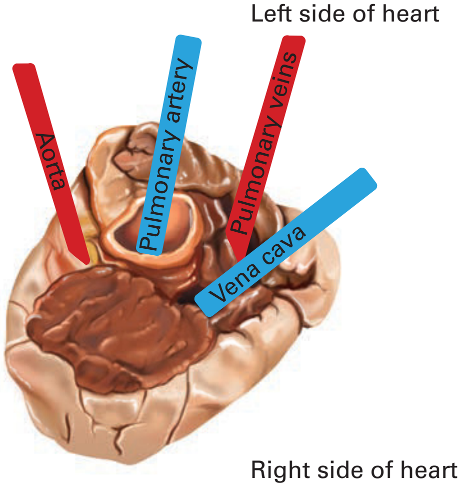
To identify the path of blood flow through the heart and become familiar with the structures

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 chamber as the vena cava)
    - pulmonary vein – place a red pipe cleaner here (representing oxygenated blood, note that this connects to the same chamber 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.



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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 atrium.

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.

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.

Science as a human endeavour 3.6

Mapping the heart

The electrical signals generated in your heart usually keep it beating in a way that allows the atria to fill, then the ventricles to fill, and then the blood to exit via the major vessels. But occasionally, the electrical signals go haywire. In some cases, the heart can go into a rapid, dangerous arrhythmia. In a recent study, scientists created 3D simulations of a patient's heart, to allow them to tailor medical treatment. A 3D simulation can allow cardiac surgeons to identify the exact location of the electrical problem, and destroy the tiny areas of heart muscle that are causing the problem, to prevent the heart from going into a fatal arrhythmia.

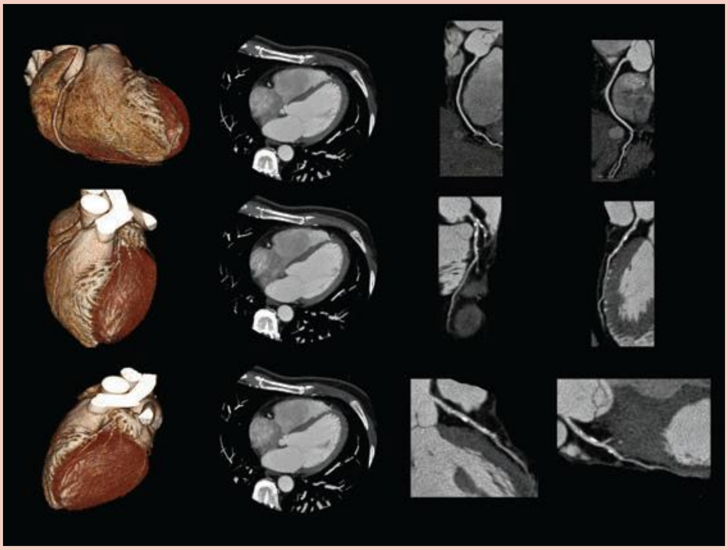

Figure 3.37 A CT scan of a patient's heart

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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 usually 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 have to be thick, muscular and strong to withstand the great pressure being pushed upon them.

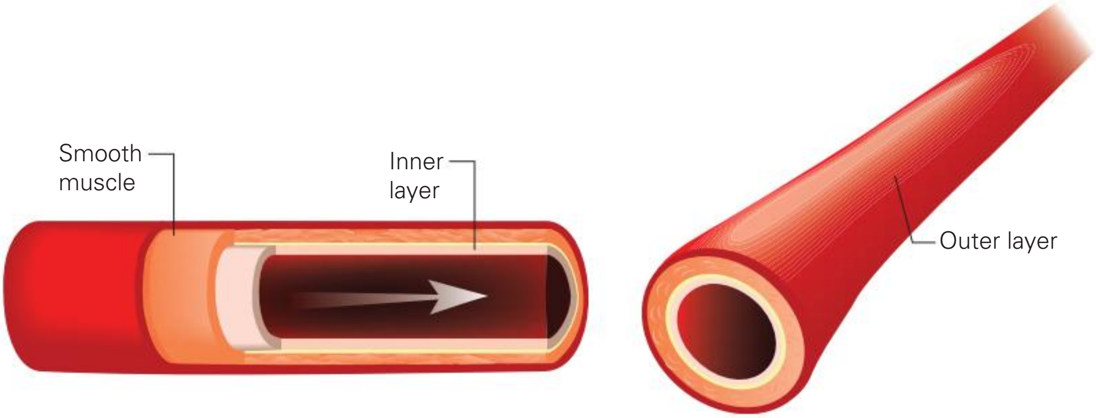

Figure 3.38 The structure of an artery

Capillaries

As the blood travels away from the heart, it enters smaller and smaller blood vessels, eventually leading to 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.

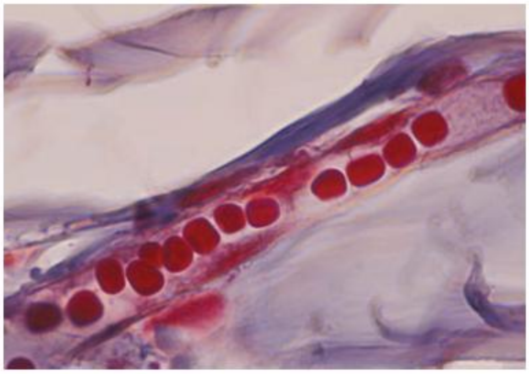

Figure 3.39 A capillary is only slightly wider in diameter than a red blood cell.

Veins

vein
a thin-walled vessel with valves that carries blood back to the heart

As the 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. However, the veins need to prevent blood from flowing backwards, and so they have special valves that prevent this from happening.

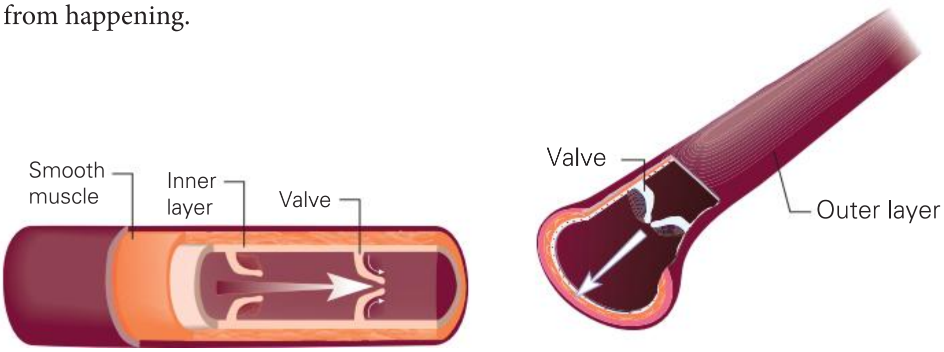

Figure 3.40 The structure of a vein

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Quick check 3.8

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.

Explore! 3.5

Circulatory system technologies

There are a number of surgical procedures and devices that can assist people who have malfunctioning hearts. Choose one or more of the following to research, and answer the questions below.

- coronary artery stents
- 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?

Did you know? 3.6

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.

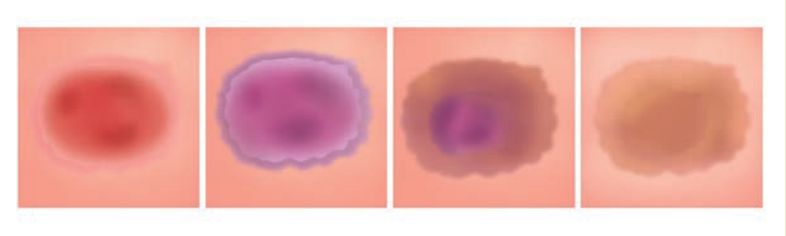

Figure 3.41 from left to right, a stage 1 bruise is red; a stage 2 bruise is purple. At stage 3 it becomes blue, and at stage 4 it becomes more yellow.

Try this 3.8

Examining vessel types

Your teacher can provide some prepared slides showing cross-sections of arteries, veins and capillaries. Observe these vessel types under the microscope, and try to identify all the features discussed in this section.

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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.

Most of your blood is made up of a liquid called **plasma**. Plasma is a yellowish liquid, made up mainly of water, that contains all the dissolved nutrients and hormones that are travelling to the tissues around your body.

plasma
the yellow liquid component that makes up 55% of blood; carries water, dissolved gases and hormones

haemoglobin
the red pigment in blood that binds to oxygen, allowing red blood cells to carry oxygen

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 that can carry oxygen molecules. The biconcave shape provides a greater surface area for gas exchange and also allows the cells to be extremely flexible so that they can fit through small capillaries easily.

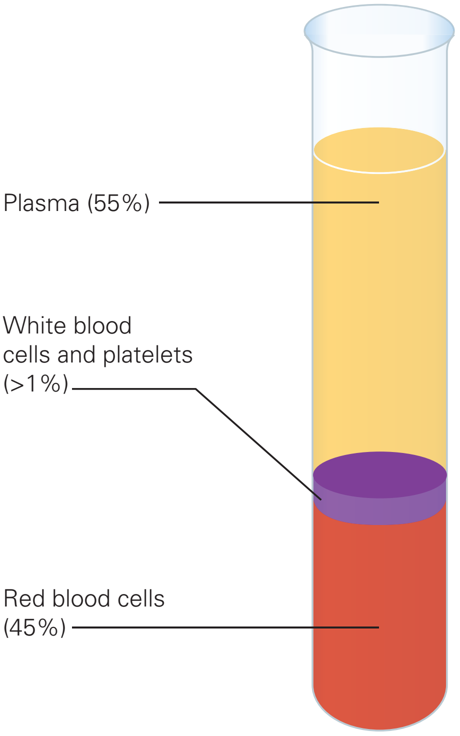

Figure 3.42 The components of blood, separated into layers using a centrifuge

Figure 3.43 Red blood cells

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 using special chemicals known as antibodies to destroy the invaders.

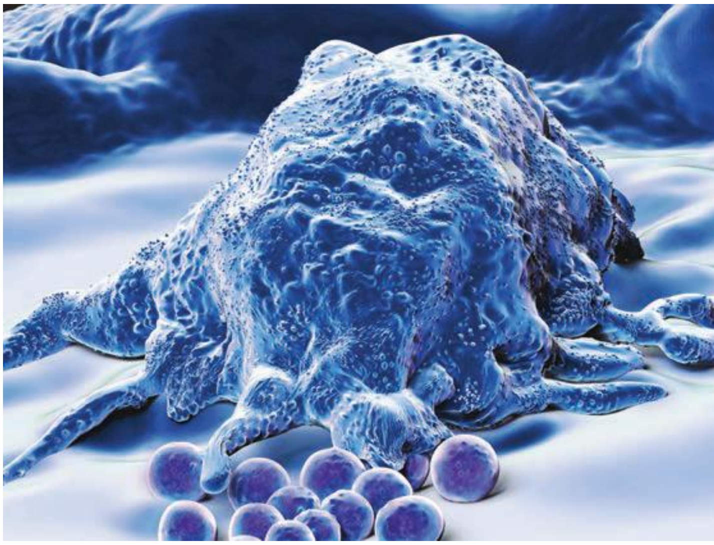

Figure 3.44 A large white blood cell (called a macrophage) engulfing and destroying bacteria

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Another component of your blood is the **platelets**. These tiny cells help blood to clot and help scabs form. Platelets are much smaller than red blood cells. If platelets come into contact with any punctures along the blood vessels, they become activated and change shape. This allows them to seal the puncture. 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 cells that assist with blood clotting

Figure 3.45 Platelets help a scab to form over a wound

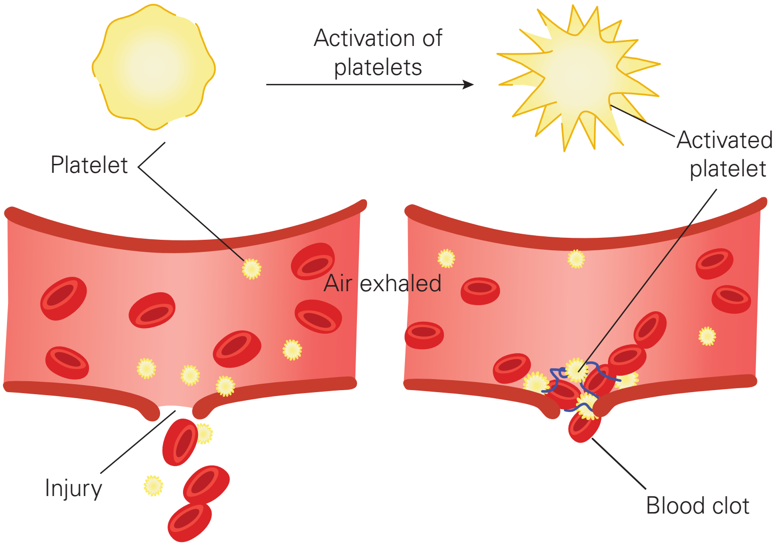

Figure 3.46 Platelets in the blood, sealing a hole in a blood vessel

Did you know? 3.7

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 3.9

1. On average, recall how much blood is in your body.
2. Name the three components of the human circulatory system.
3. Name three types of cells found in the blood, and state their approximate percentage composition in the blood.
4. Recall what is contained in the plasma.

Section 3.4 questions

QUIZ

Retrieval

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.

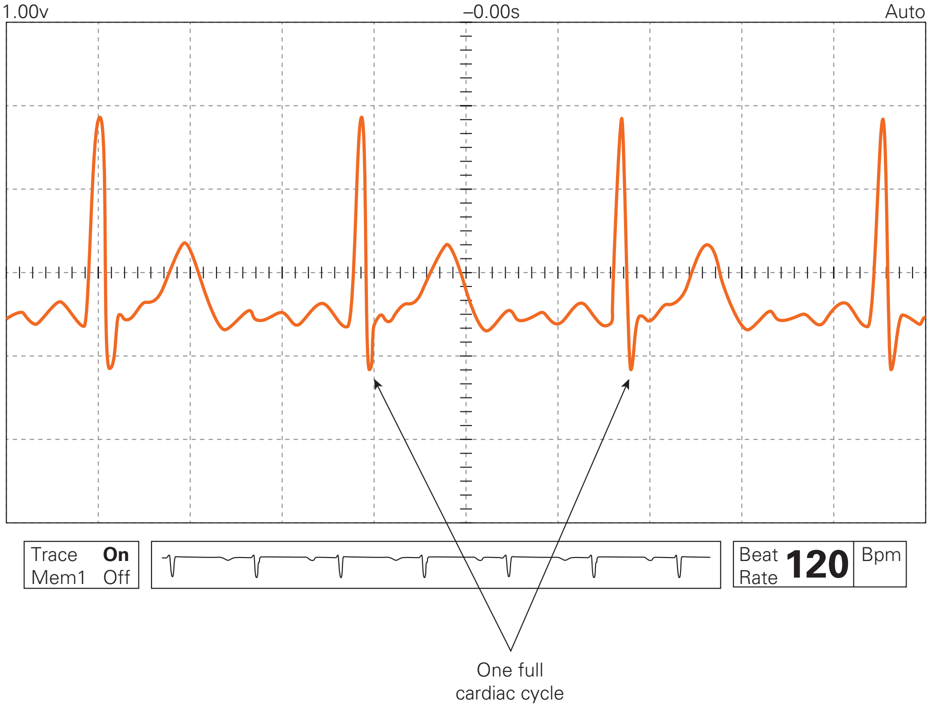

Figure 3.47 ECG printout of a person's heartbeat

5 **Identify** the point in your circulatory system where your blood pressure would be highest.
6 **Identify** the point in your circulatory system where your blood pressure would be lowest.
7 The image in Figure 3.47 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 (heart beat + refilling stage). If the person's heart rate is 120 beats per minute, **calculate** how much time this full cycle takes.

Comprehension

8 **Explain** how heart muscle is different from a muscle in your arm.
9 **Explain** the function of a platelet.
10 **Explain** how the structure of a capillary allows it to exchange nutrients and gases with cells.

Analysis

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.

Knowledge utilisation

12 **Construct** a flow chart showing the path of an oxygen molecule, from when it diffuses from the alveoli into the 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.

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3.5 The human digestive system

The nutrients we need

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 living organisms. The main 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. 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 also 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 have to consume them in the food we eat.

DOC WORKSHEET

heterotroph
any organism that obtains its nutrients by consuming other organisms

Did you know? 3.8

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.

You would get most of your vitamin C from red, yellow and orange fruits and vegetables. But where do carnivores get their vitamin C from? Dogs and many other animals can actually synthesise their own vitamin C inside their bodies. This adaptation could come in handy if you do not like eating your vegetables!

Figure 3.48 All citrus fruits have a high level of vitamin C.

Quick check 3.10

1 Recall the simplest carbohydrate.
2 Recall what you might also know lipids as.
3 Name some sources of protein.

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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
a series of mechanical processes that breaks 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

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, and bile acting to emulsify (break up) fats.

Chemical digestion involves chemical changes that occur when enzymes break the food down into its most basic chemical components.

The human digestive system is essentially a long tube from your mouth to your anus! Let us take a closer look at the structure and function of this vital organ system.

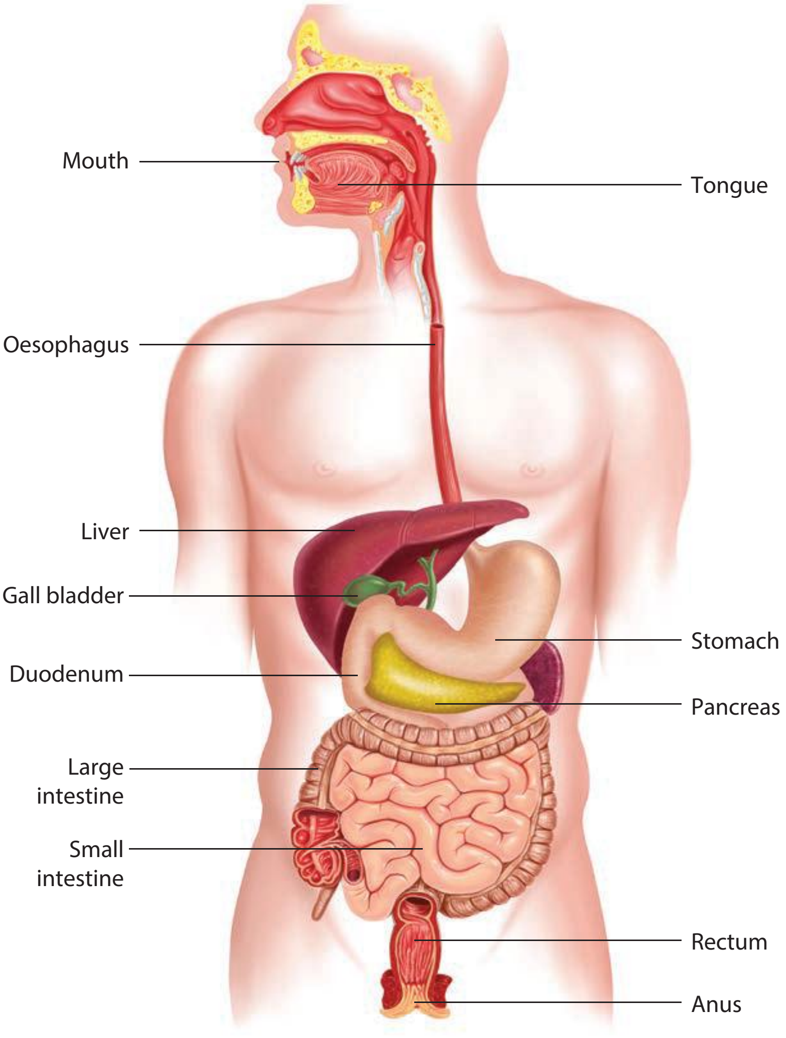

Figure 3.49 The human digestive system

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Mouth and tongue

The mouth has many specialised structures that start the digestive process. First, your teeth snip, tear, chomp and grind the food, breaking it down 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**.

bolus
a lump of partially digested food

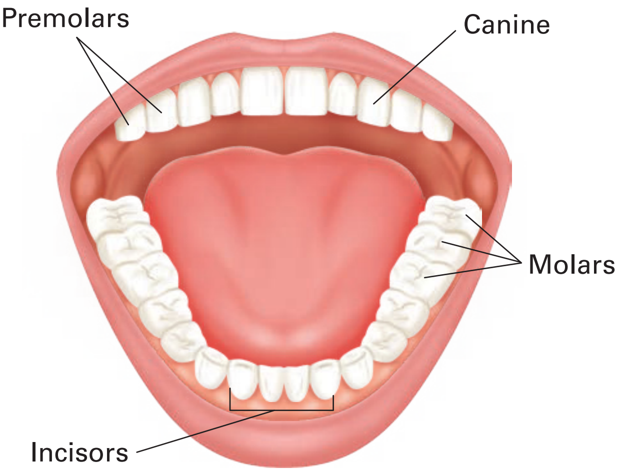

Figure 3.50 The different kinds of adult teeth: incisors for cutting, canines for tearing, and molars for grinding

Did you know? 3.9

The average person's tongue is around 8.5 cm long and has 2000–4000 taste buds on it. A quarter of the population have 4000 taste buds and have 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 3.51 An average human tongue (left); an average sun bear tongue (right)

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 help speed up chemical reactions

Saliva lubricates the food to make its movement through your body smoother. It also contains special chemicals, 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 maltose in your mouth. Many more enzymes are found along the digestive tract, and each is designed to break down a particular food type.

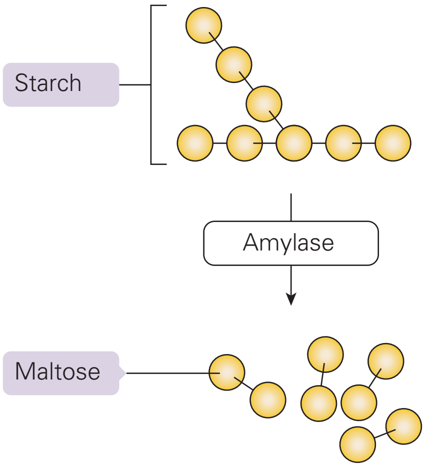

Figure 3.52 Amylase breaks the bonds in starch to form smaller maltose molecules.

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Try this 3.9

Thanks, enzymes!
Ask your parent/guardian if you can try this at home. 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 sub-units.

VIDEO
Describe peristalsis

Oesophagus

When you swallow food, a wave-like contraction of 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. Peristalsis is so effective that you could actually eat upside down and the food would still be pushed against gravity, up your oesophagus!

peristalsis
a wave-like contraction of the muscles of the digestive tract that pushes the food along

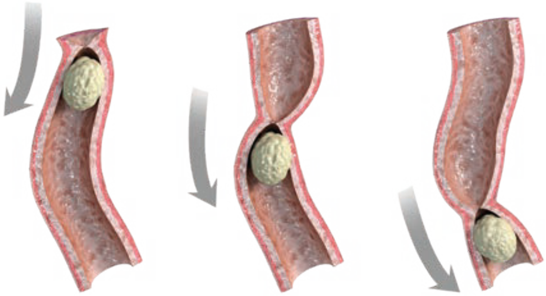

Figure 3.53 Peristalsis moves food down the oesophagus.

Try this 3.10

Modelling peristalsis
Find a 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 3.11

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’.

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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 – these are known as the gastric juices. The sphincter at the opening of the stomach is very important, as it prevents these enzymes and acids from entering the oesophagus and burning the tube, causing a symptom called indigestion or '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

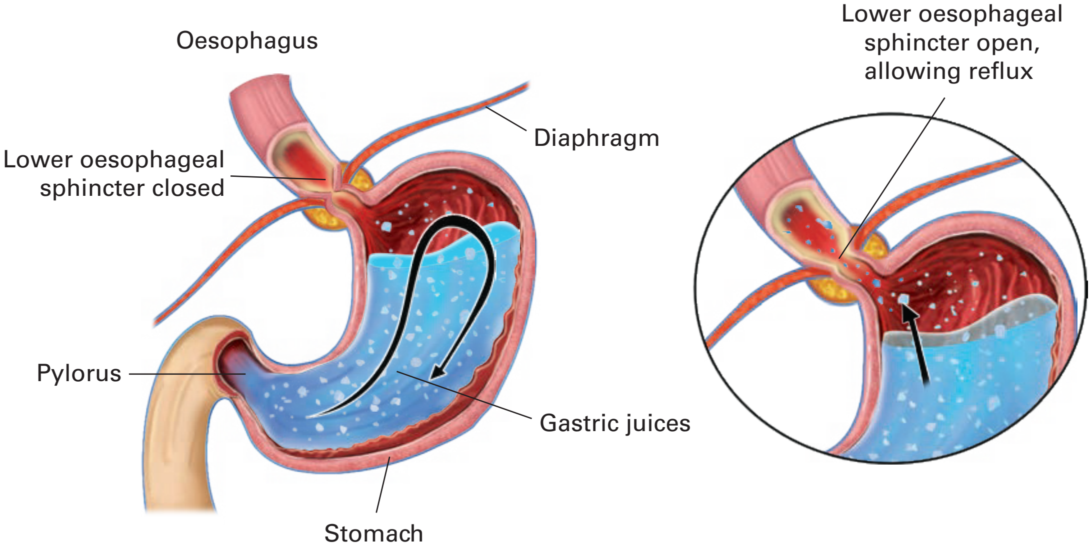

Figure 3.54 When the oesophageal sphincter fails to close, gastric juices can irritate the bottom of the oesophagus.

Try this 3.11

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 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 2–6 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 protein enzymes to work at. The stomach wall is a mucosal membrane, which produces mucus to protect the stomach tissue from the strong acid.

Enzymes act to *catalyse* (speed up) chemical reactions. The main enzyme in your gastric juices is called *pepsin* and its role is to begin

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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.

chyme
a partially digested mass of food after it leaves the stomach

The stomach absorbs some substances into the bloodstream, such as water, medicines and alcohol. The digested bolus is now called **chyme** and it leaves the stomach by passing through the pyloric sphincter into the small intestine.

Figure 3.55 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.

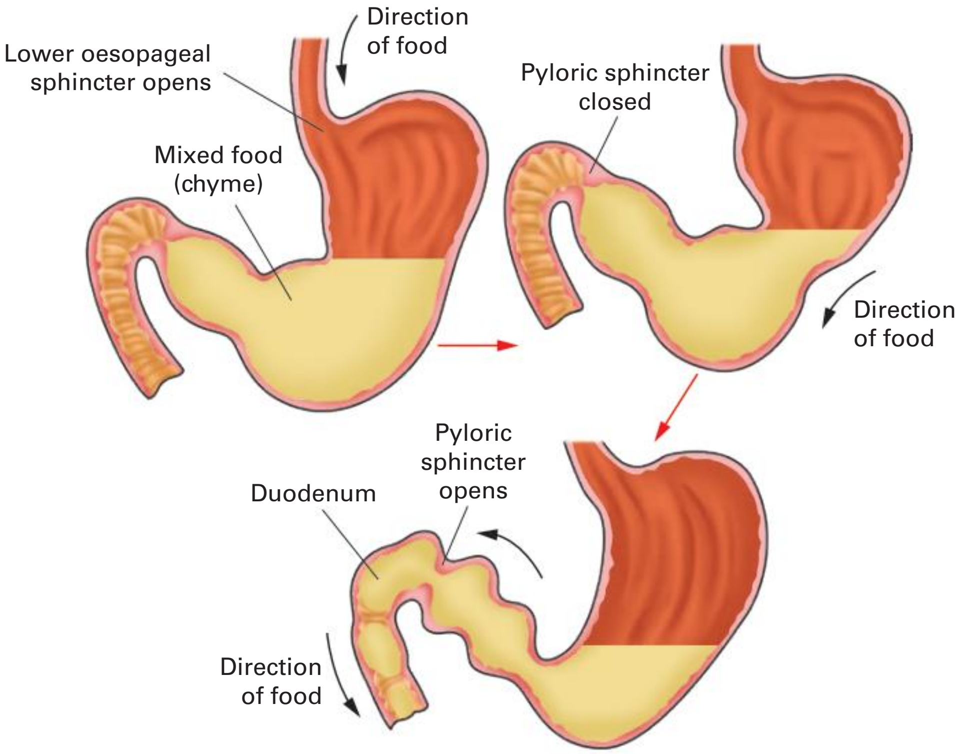

Figure 3.56 The pyloric sphincter controls the flow of chyme out of the stomach and into a region of the small intestine called the duodenum.

Quick check 3.12

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.

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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 an average of 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 is still propelling the chyme forwards and continues all the way along the digestive tract.

The **liver** produces **bile**, which helps to break down fats or lipids mechanically. 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 little globs that can be easily moved and broken down further. Bile has the second job of neutralising the harmful 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 high flow of blood, which increases the efficiency of nutrient absorption into the bloodstream.

The end section of the small intestine is the ileum. The main function of this portion of the intestines is to finish off any absorption of nutrients, and to compact the remaining digested food and pass it through into the large intestine.

duodenum
the first section of the small intestine

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 metabolic and secretory functions, including the production of bile

bile
a substance produced in the liver and stored in the gall bladder, which helps emulsify fats

gall bladder
a small gland 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

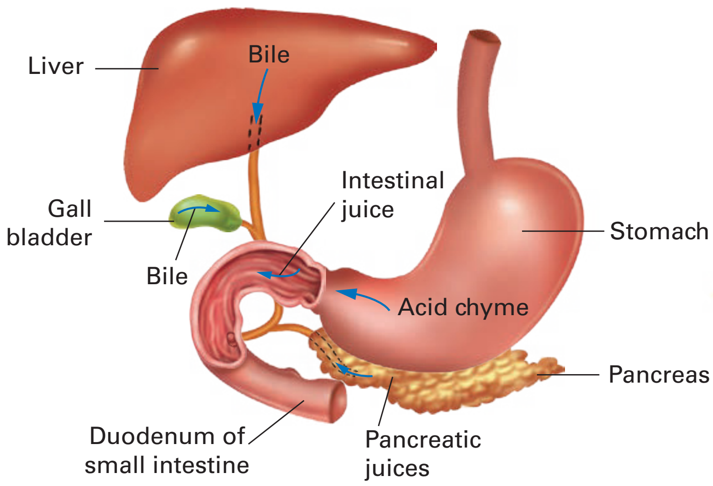

Figure 3.57 The liver, gall bladder and pancreas all contribute to the digestion of food and are connected to the duodenum.

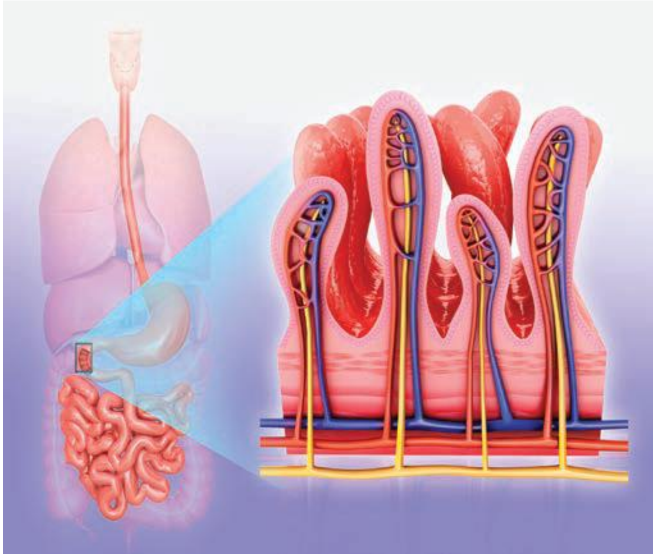

Figure 3.58 Finger-like villi in the intestines are specialised for absorption of nutrients.

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Large intestine

large intestine
the organ that is connected to the small intestine at one end and 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

The **large intestine** is 1–2 metres long and has five parts: caecum, appendix, colon, rectum and anus. Its function is to absorb most of the water from the material left over from digestion. The large intestine also has large numbers of friendly 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 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 (see Did you know? 3.10). As waste enters the large intestine and passes through the colon, water leaves the waste, resulting in a solid mass called faeces. 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**.

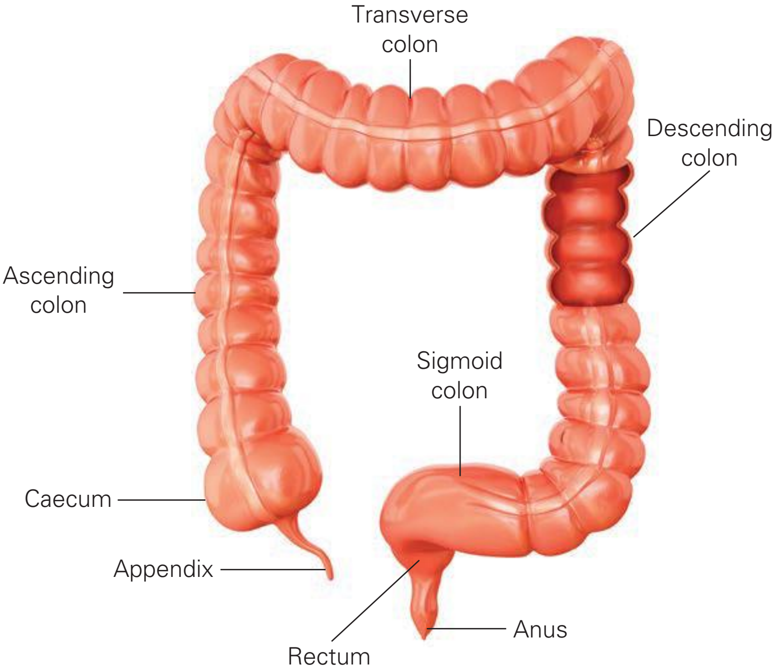

Figure 3.59 The five sections of the large intestine

Did you know? 3.10

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, recent research in Canada suggests that the average person is more likely to have a 1:1 ratio of bacteria and human cells. Most of these bacterial cells are 'friendly bacteria' found in our digestive system that help our body break down and digest nutrients from the food we eat. It is thought that the appendix could be a safe haven for good bacteria that can repopulate the gut after sickness and diarrhoea. So next time you eat a meal, think about all the bacteria hard at work in your digestive system, helping you break it down.

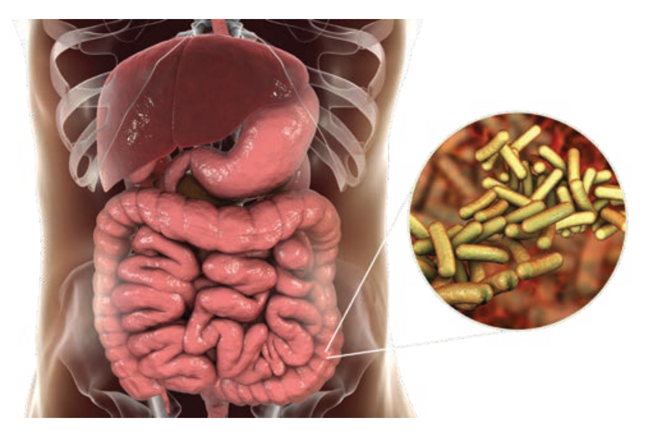

Figure 3.60 Most bacteria in your body are in the intestine.

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Quick check 3.13

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 absorption of nutrients.
4. Organise the following sections of the large intestine in the correct order that faeces pass through: rectum, colon, anus, caecum, appendix.

Did you know? 3.11

Is your stomach rumbling?

Ever heard those gurgling stomach noises when you are hungry? Well, they are actually the sounds of hyperactive peristalsis in the intestines, and are named *borborygmi*. When the muscles in your stomach and small intestines 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.

Digestion gone wrong

Food poisoning

Your body is very smart – it can detect hazardous substances in the food you eat. Sometimes food can be contaminated with toxins or micro-organisms that could do harm to your body. If your body senses the presence of these harmful substances, it signals your digestive system to empty fast. 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 from a much worse fate.

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 undergoing 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 carbohydrate into 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 can all drink milk as babies. This means that the enzyme called lactase, which breaks down lactose, is found in everybody when we are young. 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 of Asian, African, Indigenous and South American backgrounds are more likely to develop lactose intolerance at a young age.

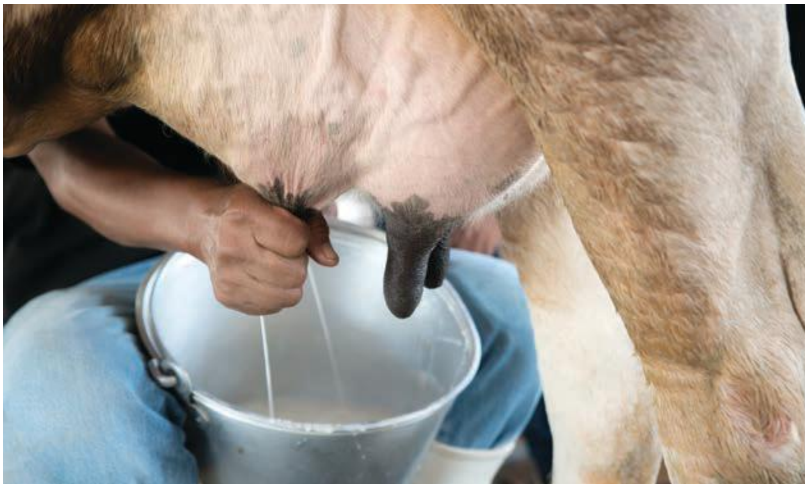

Figure 3.61 All mammals produce milk, but not all adult humans can digest it.

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- 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.

Explore! 3.6

Coeliac disease

People are becoming more aware of foods that contain gluten, and many people have started to follow gluten-free diets. 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.

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 a coeliac sufferer's body responds to gluten.

Science as a human endeavour 3.7

Seeing you from the inside

Imagine swallowing a pill-sized camera that captures images over the next 24 hours as it makes its way through your digestive system. Well, this technology is not new, and it gives doctors a unique view of what is going on inside your oesophagus, stomach and intestines. But there is a lot that a camera can't do: it can't deliver drugs, it can't grab a foreign object and remove it, and it can't perform a biopsy (slice off a tiny piece of tissue for analysis). This is why medical researchers are working with engineers to design tiny robots that can be put to work in your digestive tract. These robots need motors, sensors and smooth outer surfaces so that they can pass through your digestive organs without damaging them, before finally being excreted just like any other waste product.

Figure 3.62 An artist's impression of a tiny robotic device crawling through an intestine

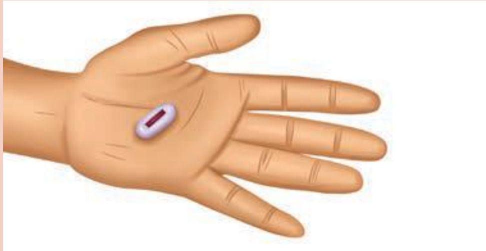

Figure 3.63 An illustration showing the scale of a robot frozen inside some ice, which the patient swallows. Once warmed up in the digestive tract, the robot unfolds into the shape on the left.

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Section 3.5 questions

QUIZ

Retrieval

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.

Comprehension

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.

8 A friend who is coming to your house for dinner suffers from coeliac disease and lactose intolerance. **Describe** a meal you could cook that would be suitable for this friend.

Analysis

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 emulsify fats	

Knowledge utilisation

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 large intestine 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.

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3.6 Other digestive systems

WORKSHEET

Have you ever had food poisoning? If so, it was probably from that time when you ate undercooked chicken or you finished the slightly questionable leftovers from several nights ago and ended up spending the following day on the toilet. Well, that was because the food that you ingested had too many bacteria on it for your body to deal with. But why does that happen to you, when some scavenger animals can eat half-rotten corpses and not get sick?

carnivore
a consumer (heterotroph) that feeds on animal matter

omnivore
an organism that eats a variety of plant and animal matter

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 have learned to cook our food, which vastly reduces the amount of harmful bacteria our digestive system has to contend with. **Carnivore** and scavenger species such as vultures have several traits that have evolved which allow them to eat food containing large amounts of bacteria that could kill a human.

Figure 3.64 Vulture eating a rotting corpse

Digestive system length

The digestive system is shorter in a carnivore than in a herbivore or an **omnivore**. Because animal cells do not have a cell wall (cell walls contain cellulose which is hard to digest), they are easier to digest and so it takes less time for them to pass through the consumer's digestive system. Because the food spends less time in the body of the carnivore, any harmful bacteria on the food have less chance to grow and cause illness.

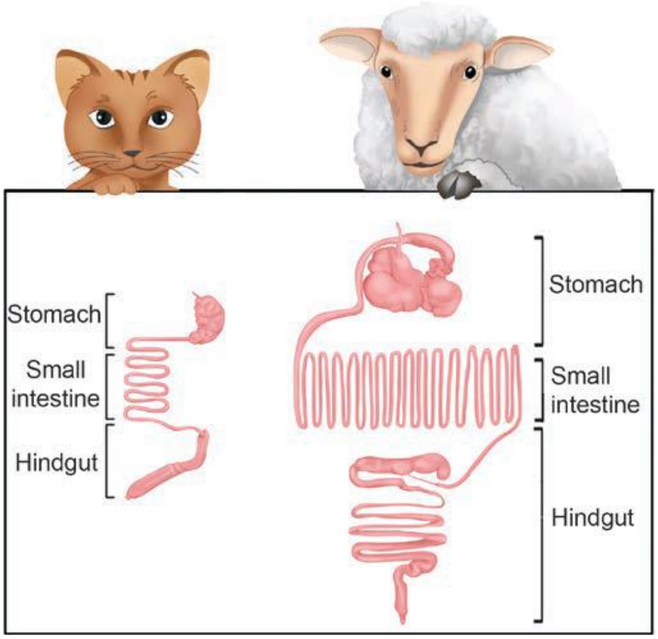

Figure 3.65 Cat (carnivore) and sheep (herbivore) digestive systems

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Stomach acid

The stomach acid in humans is around 1.5 to 3.5 on the pH scale. This is quite strong and allows our bodies to kill many harmful micro-organisms, 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 3.66 Make sure you check the use-by date of meat.

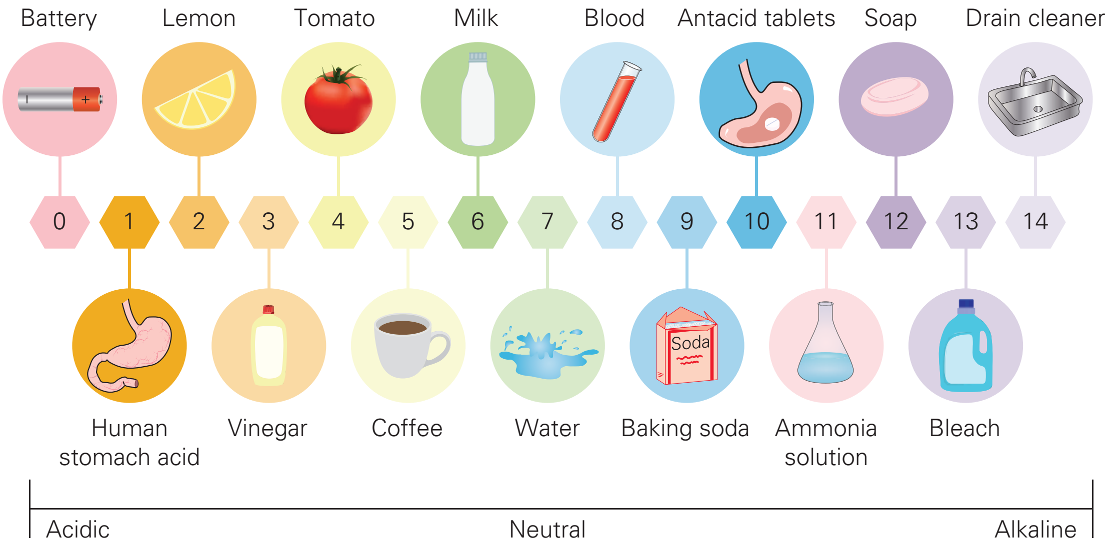

Figure 3.67 The pH scale

Did you know? 3.12

Bird vomit

As a defence mechanism when threatened, vultures and other birds, such as some seagulls, can projectile vomit onto predators. As you know, vomit smells bad at the best of times but just imagine how it would smell if you had been eating rotting flesh! If you add to that the corrosive levels of acid in the stomach, vomit makes a very effective warning system.

Figure 3.68 Vultures and many gulls use vomiting as a defence technique.

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Quick check 3.14

1 Explain how vultures defend themselves from predators.
2 Contrast a vulture's stomach acid with a human's.
3 State who has a shorter digestive tract: carnivores or herbivores.

Explore! 3.7

Carnivorous plants

Not all plants rely solely 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

Figure 3.69 A Venus fly trap and an unsuspecting fly

2 Sundew

Figure 3.70 A sundew wrapping around an insect

3 Pitcher plant

Figure 3.71 A pitcher plant, and its possible prey

Herbivores

Eucalyptus leaves are toxic for humans. In fact, if you ever tried to eat some you could find yourself struggling to breathe, losing your balance and feeling very dizzy. Leaves are also made of cellulose, which is not easy for humans (or carnivores) to digest and obtain any nutrients from. So it is surprising that eucalyptus leaves are the koala's primary source of nutrition.

herbivore
a consumer (heterotroph) that feeds on plant matter

Koalas are **herbivores**, and so they have many 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 cell walls can be digested. In herbivores, the caecum contains millions of friendly bacteria that are specialised to break down certain plant materials (such as eucalyptus leaves).

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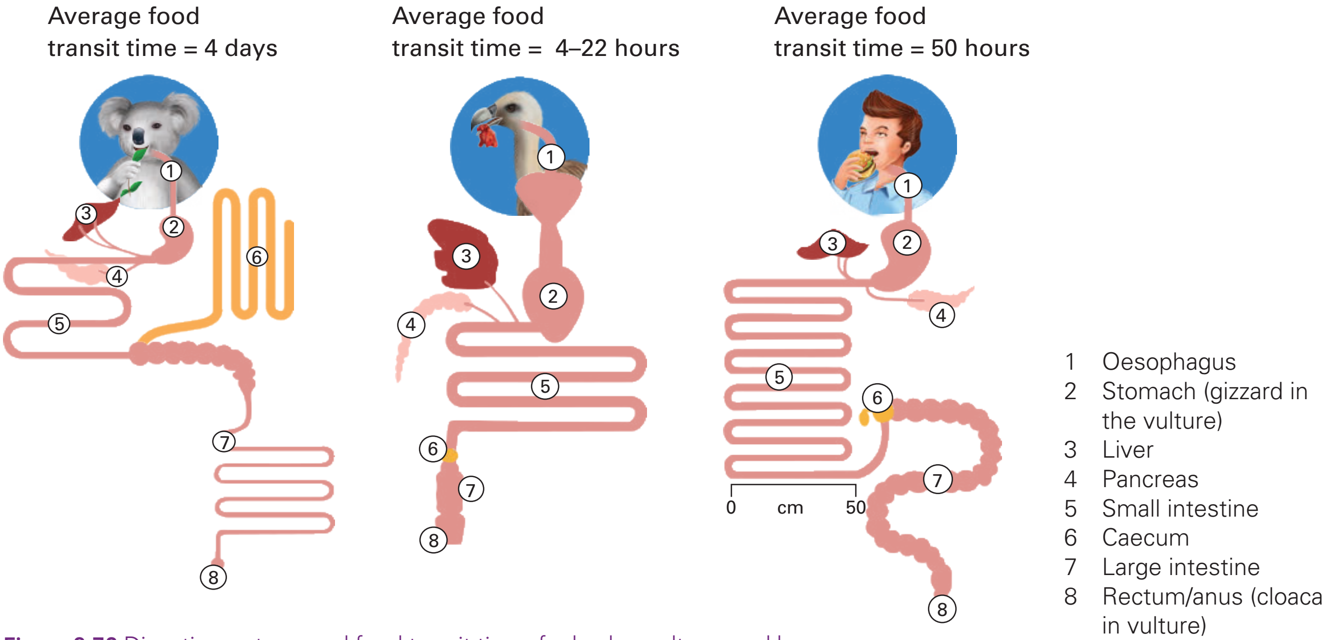


Figure 3.72 Digestive systems and food transit times for koalas, vultures and humans

Koalas get most of their water from the leaves they eat, and so they do not often need to climb down from the tree they are living in.

Eucalyptus leaves are very low in nutrients and so, even with a 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 are absorbed from the food.

Did you know? 3.13

Eating Mum's faeces

Baby koalas are not born with the special friendly bacteria they need to digest eucalyptus leaves. They need to eat their mothers' faeces (called pap) in order to start their own colony of bacteria in their caecum.

Figure 3.73 A mother and baby koala

Science as a human endeavour 3.8

Cows and the climate

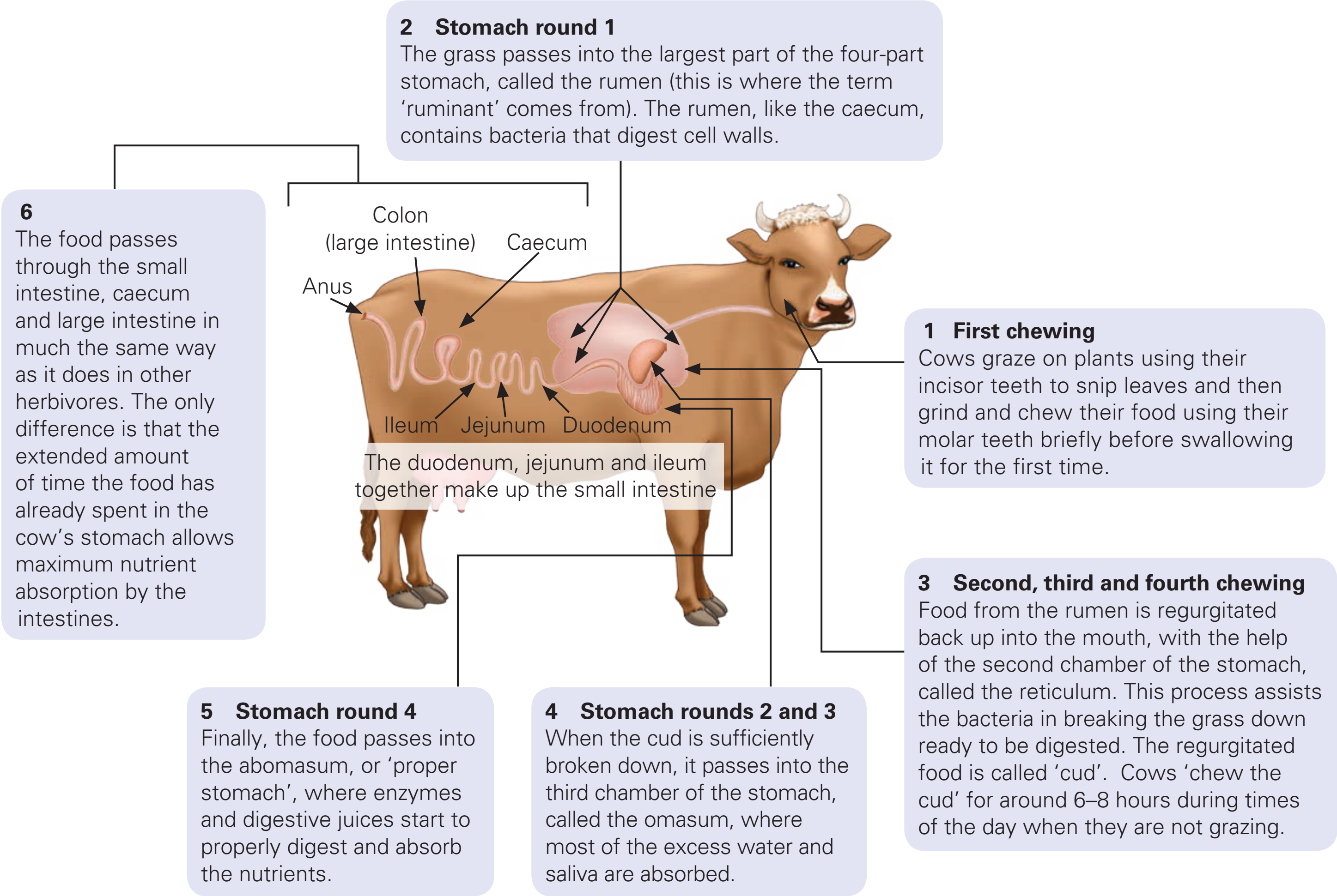
Cows burp a lot of methane gas, which is a naturally occurring product of fermentation in their rumen. The micro-organisms that colonise their digestive tract assist in breaking down the plant matter, producing methane as a waste product. Unfortunately, methane is also a potent greenhouse gas – cows account for about 25% of the methane produced in the USA.

A recent study has experimented with supplementing the diets of dairy cows with a chemical compound that inhibits micro-organisms from producing methane. It showed a 30% reduction in methane, and the cows actually gained more weight without eating any extra feed, meaning they were extracting more energy. The feed supplement is in the early stages of development, but could be a helpful tool in the fight against climate change.

WIDGET
The mammalian digestive system

Ruminants

If you've ever seen a cow, it was probably chewing. 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, deal with being a herbivore in a unique way. Figure 3.74 shows the path of food through a ruminant.



The duodenum, jejunum and ileum together make up the small intestine

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.

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.

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.

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.

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.

6
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.

Figure 3.74 The passage of food through a cow's stomach

Quick check 3.15

1. Summarise the role of the caecum.
2. Define the term 'friendly bacteria'.
3. Distinguish between the length of a carnivore and a herbivore digestive tract.
4. Describe the way a ruminant digests plant matter.

Try this 3.12

Digestive flow charts

Construct three flow charts on a poster showing the digestive tracts of a carnivore (not a human), 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.

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Section 3.6 questions

QUIZ

Retrieval

1 **Recall** the four 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 leaves are composed of, 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 **Recall** one way that the vulture uses its stomach acid other than for digestion.

6 **Identify** the product in the stomach that kills bacteria.

7 **Identify** two ways in which a vulture's digestive system is different from a human's digestive system.

Comprehension

8 **Explain** how a carnivore can eat meat containing harmful bacteria without becoming sick, while humans cannot.

9 **Describe** how baby koalas gain their friendly bacteria.

Analysis

10 Copy and complete the table, to **contrast** the digestive system of a koala with that of a human.

Human	Koala

11 Use the images in Figure 3.75 to answer the following questions.

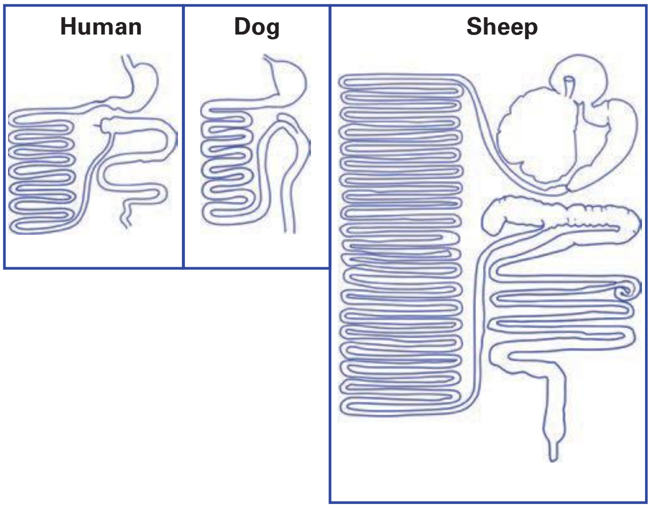

Figure 3.75 Digestive systems of a human, a dog and a sheep

a **Contrast** the digestive system of a dog and a sheep.

b **Identify** which two of the animals in Figure 3.75 probably have a similar diet.

Knowledge utilisation

12 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 repair and replacement

DOC WORKSHEET

Each of the organ systems in your body relies on the specialised function of many different organs working together to keep you healthy. But what happens when one of these organs is damaged, infected or cannot do its job properly? If one organ in a system cannot function at full capacity, it results in a chain reaction that can cause people to become very ill and have to go to hospital.

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.

In order 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 a foreign invader 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.

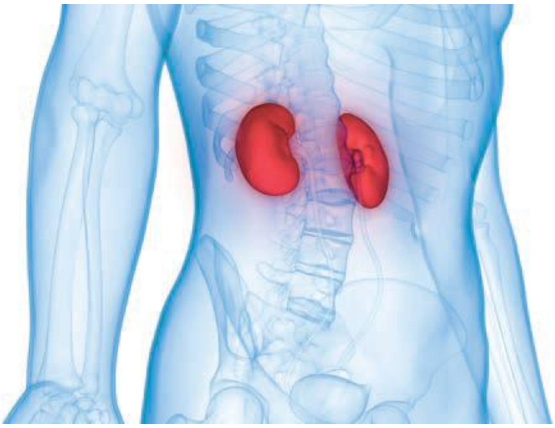

Figure 3.76 Most of us have two healthy kidneys. If they are damaged through disease, one option is a kidney transplant.

Organ donation is sometimes possible when a person dies, and has previously indicated that they would like to donate their organs. This amazing gift 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 2019, 1683 Australian lives were transformed by 548 deceased and 239 living organ donors and their families.

Figure 3.77 A surgeon performing a kidney transplant

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Not many deaths occur in a way that allows organ donation. For example, the person must pass away in a hospital, and very strict procedures must be followed to ensure the health of the organs being donated. 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.

Quick check 3.16

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! 3.8

Kidney transplants

A kidney transplant is a life-prolonging surgery but it does not provide a cure for end-stage kidney disease. The recipient must be medically suitable, and an available matching organ needs to be found. Conduct some research into kidney transplants in Australia and answer the questions below. The 'Kidney Health Australia' website is a great resource.

1 What are the steps involved in transplanting a kidney?
2 Where is the donor kidney positioned in the recipient's body?
3 What influences the success of the organ transplant? Give some statistics in your answer and discuss the anti-rejection drugs the person will need to take.

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 new technique is **xenotransplantation**. This is the process of transplanting organs from a different species than the recipient.

Doctors have been transplanting porcine (pig) heart valves into humans since 1965. Now scientists are trying to find a way to transplant entire pig organs. Pig organs are a similar size and shape to human organs. There are two main biological challenges that scientists face with this procedure.

- The biological markers on pigs' cells and organs do not match those in humans, and so the human recipient's body would reject the organ.
- There are viruses in pigs' genetic material that could infect and harm humans who receive a pig organ.

xenotransplantation transplanting organs from one species into another

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The first challenge that scientists are focusing on is to remove the viruses from the genetic material of pigs. This can be done using technology known as CRISPR, where an enzyme is used to cut out the parts of the genetic material of pigs that contain the viruses. CRISPR acts like a cut-and-paste tool, where the harmful parts of the genetic material are cut out and then a non-harmful section of genetic material is pasted in its place.

Scientists have used the CRISPR process to produce several healthy genetically modified pigs that do not contain the harmful viruses. Scientists now have to overcome the problem of the markers on pig organs that cause human bodies to identify the organs as foreign.

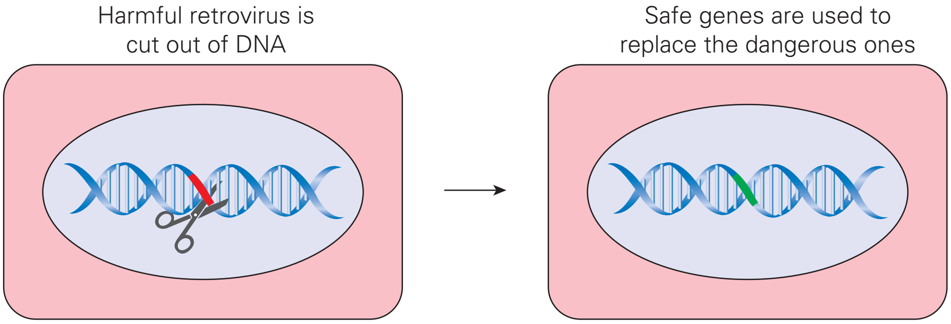

Figure 3.78 In the CRISPR process, the virus is cut out, and harmless genetic material is pasted in.

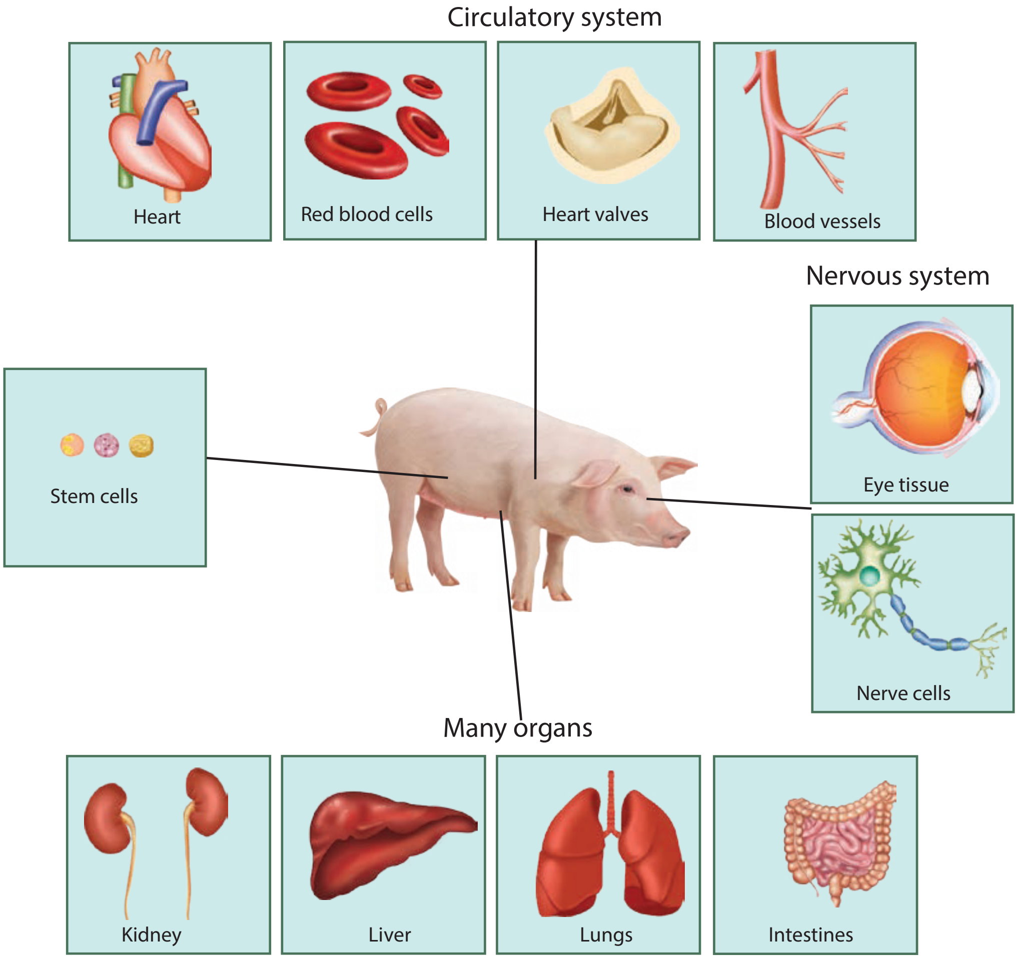

Figure 3.79 All the possible transplanted tissues and organs we could get from pigs

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Science as a human endeavour 3.9

Robots making organs?

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 induced 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.

In 2018, researchers at the University of Washington successfully put robots to work in making trays of kidney organoids in the lab. The automated system completes a researcher's daily work in around 20 minutes and makes fewer mistakes. The robotic system has also been programmed to analyse the genetic material in the organoids, and has led to new discoveries about the kidneys' blood supply and kidney disease.

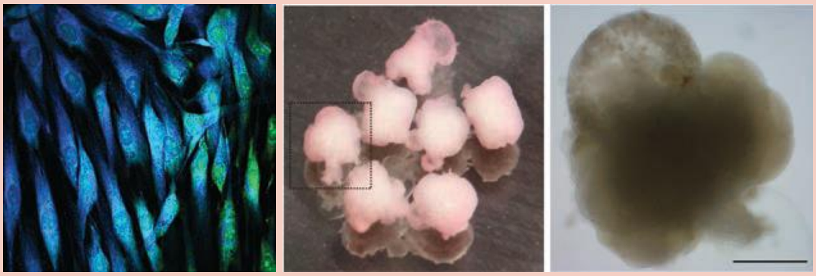

Figure 3.80 Mini brain organoids grown from stem cells. Left: Fibroblast cells (shown here) are used to produce stem cells. Middle and right: The stem cells are grown in culture and induced to form brain tissue, or 'mini brains'.

Organ regeneration

The liver is the largest organ in your body. 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. Another toxin that your body naturally produces is hydrogen peroxide – the same chemical that people use to bleach their hair. Obviously, having too much of this substance dissolved in the blood could cause major damage throughout the body.

The liver usually does a great job of turning hydrogen peroxide into the harmless substances water and oxygen. However, too much salt in the blood can reduce the liver's ability to break down hydrogen peroxide. Salt comes directly from our diet, and people who eat fast food or processed foods regularly consume high levels of salt and so are at risk of reducing their liver's ability to function. 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 3.81 Hot chips are delicious, but you need to be careful how much salt you eat.

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tissue engineering the combined use of cells and engineering to improve or replace biological tissues

As you learned earlier in this chapter, 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 tissue found in the patient. This process is called **tissue engineering** and it is a fast-growing area of research. The liver is the only human organ that can not only repair itself but can regrow dead or damaged areas. This means that healthy living organ donors can donate part of their liver and 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.

Quick check 3.17

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

During this experiment you will add hydrogen peroxide to blended cow's liver. If the hydrogen peroxide is broken down, then oxygen bubbles will be produced. You will add different amounts of salt solution to test the effect of salt on liver function.

Be careful

Safety glasses and gloves must be worn.

Planning

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.

Materials

- 4 large test tubes
- 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
- test tube rack
- disposable gloves
- marker
- stopwatch

Method

1. Place the test tubes in a rack and label them 0%, 10%, 20%, 30%, 40%.
2. Add 3 mL of liver solution and 3 mL of the first salt solution and allow them to combine for 3 minutes.

continued...

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...continued

3 Mark the level of the solution with a marker.
4 Add 2 mL of hydrogen peroxide to the test tube and time until the bubbles stop being produced.
5 When the bubbles stop being produced, record the time in the results table.
6 Repeat steps **4–5** after combining liver solution and a different salt solution in each of the remaining tubes.

Result

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

Analysis

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

Evaluation

1 Identify any limitations in your investigation.
2 Using your results, suggest a range in the 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

Draw a conclusion from this experiment regarding the effect of salt on liver function, using data to support your statement.

Ethics

When we discuss organ transplants, we often have to 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 3.82 Judges make decisions based on law, but ethics may also be a consideration in the decision-making process.

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Ethics of organ transplants

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 have to 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).

There are 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 two-way table showing the possible advantages and disadvantages (risks) for both an organ donor and a recipient.

Explore! 3.9

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?

Section 3.7 questions

QUIZ

Retrieval

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 organ inside a human.
5 **Define** 'organ donor'.
6 **Define** 'organ transplant'.
7 **Identify** one organ that can regenerate.
8 **Identify** how Australian rules keep organ donation fair.

Comprehension

9 **Explain** why transplanted organs may be rejected.
10 **Summarise** how too much salt can be harmful to a person.

Analysis

11 **Distinguish** between ethics and laws.
12 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 3.83 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?)

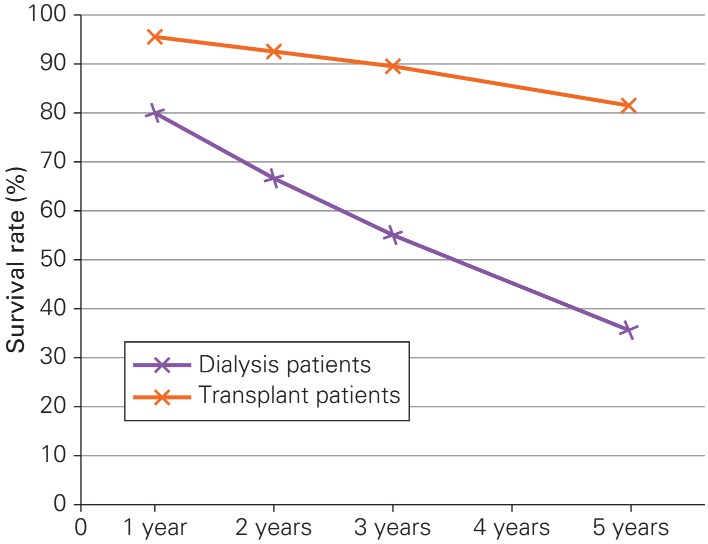

Figure 3.83 Survival rate of patients on dialysis vs patients who have received a kidney transplant

Knowledge utilisation

13 **Justify** why liver regeneration would be more beneficial than a liver transplant.

Chapter review

Chapter checklist

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

1	**I can describe how a specialised cell's structure is related to its function.** e.g. Describe the structure of a red blood cell and how this helps its function.	
2	**I can recall the levels of organisation in an organism.** e.g. Organise the following words so they start with the smallest component and end with the largest: organ, cell, organism, organ system, tissue.	
3	**I can describe the process of cellular respiration.** e.g. Recall the definition of cellular respiration.	
4	**I can identify the different parts of the respiratory system.** e.g. Describe the purpose of the diaphragm in the process of breathing.	
5	**I can describe how gas exchange occurs in plants.** e.g. Describe the role of stomata and guard cells.	
6	**I can describe how gas exchange occurs in fish.** e.g. Describe how the structure of gills allows effective gas exchange.	
7	**I can identify the different parts of the heart.** e.g. Recall the route that blood takes through the heart, starting with the vena cava.	
8	**I can describe the structure and function of arteries, veins and capillaries.** e.g. Describe the structure of veins, and how this helps their function.	
9	**I can recall the different components of blood.** e.g. State the three components of blood.	
10	**I can recall the main nutrients that the human body requires.** e.g. State the main role of carbohydrates in the body.	
11	**I can identify the different parts of the digestive system.** e.g. Recall the route that food takes through the digestive system, starting with the mouth and ending with the anus.	
12	**I can recall the role of enzymes in the digestive system.** e.g. State the role of enzymes in the digestive system.	
13	**I can compare the digestive systems of carnivores and herbivores.** e.g. Describe how a carnivore's digestive system suits its diet.	
14	**I can describe different methods of organ repair and replacement.** e.g. Discuss some issues surrounding xenotransplantation.	

Review questions

SCORCHER

Retrieval

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 role of the small intestine and the large intestine in humans.

4 **Define** 'xenotransplantation'.

5 **Identify** the correct word for each of the numbers in the following diagrams: 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.

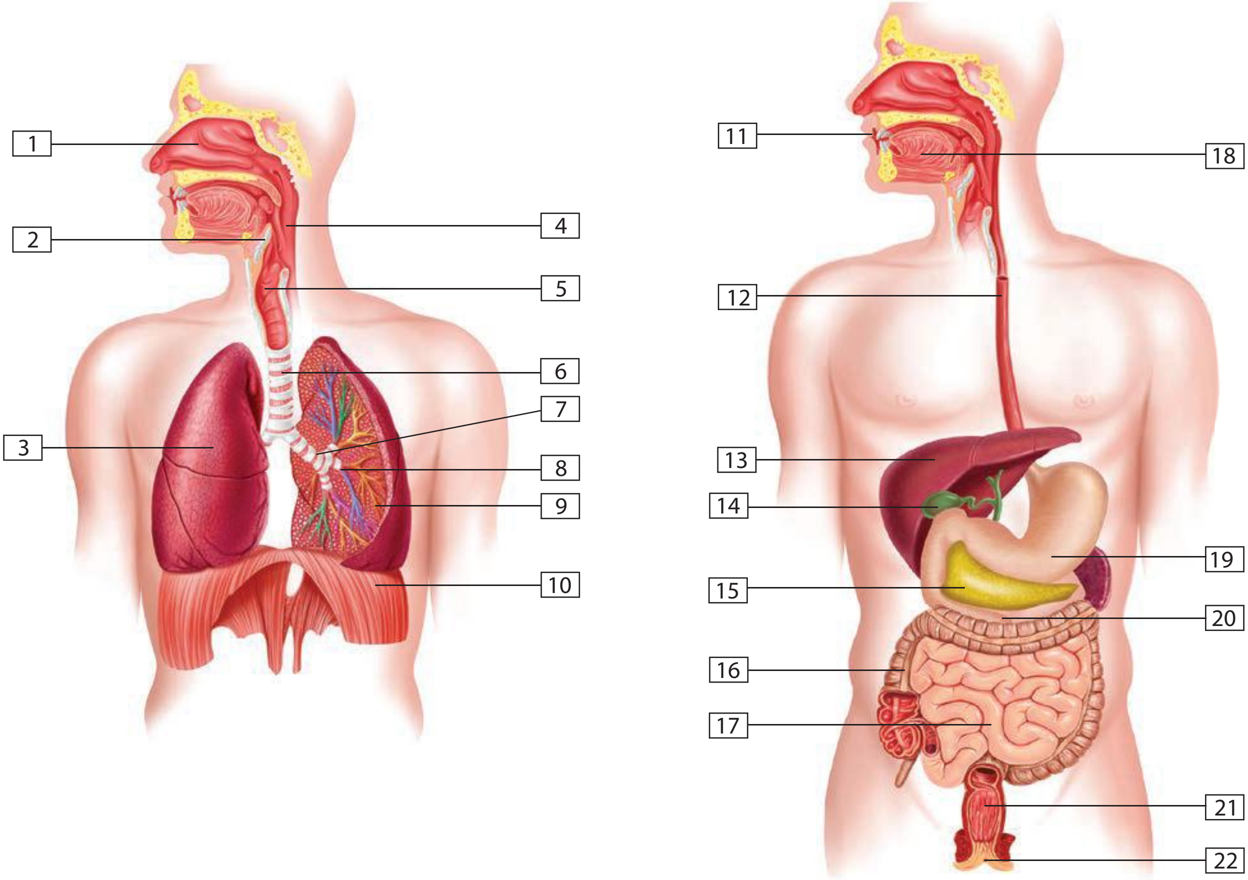

Figure 3.84 Human respiratory (left) and digestive systems (right)

Comprehension

6 **Describe** the contents of blood.

7 **Explain** the role of enzymes in the digestive system, using examples.

8 **Explain** the function of the liver.

9 **Explain** what is meant by a 'living donor'.

10 **Summarise** three essential features of gills if they are to efficiently exchange gases and act as lungs for fish.

11 **Explain** why it could be harmful to treat a koala with antibiotics for an infection.

Analysis

12 **Sequence** these terms in order of increasing size/complexity: organ, organism, tissue, cell, organ system.

13 **Contrast** the digestive systems of a carnivore and a herbivore.

14 Examine this statement: 'Lactose intolerance should be referred to as lactase deficiency'. **Consider** why this is the case.

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15 **Distinguish** between mechanical digestion and chemical digestion.

16 **Contrast** the contents of the blood as it leaves your heart to when it returns to the heart.

17 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		

18 Complete the table to **compare** the structure and function of villi and alveoli.

	Villi	Both	Alveoli
Structure			
Function			

19 Forced vital capacity (FVC) is a measure of how much air a person can blow out in one exhalation. The graph in Figure 3.85 shows the normal values for men (in red) and women (in purple) according to their age. Use the graph to answer the following questions.

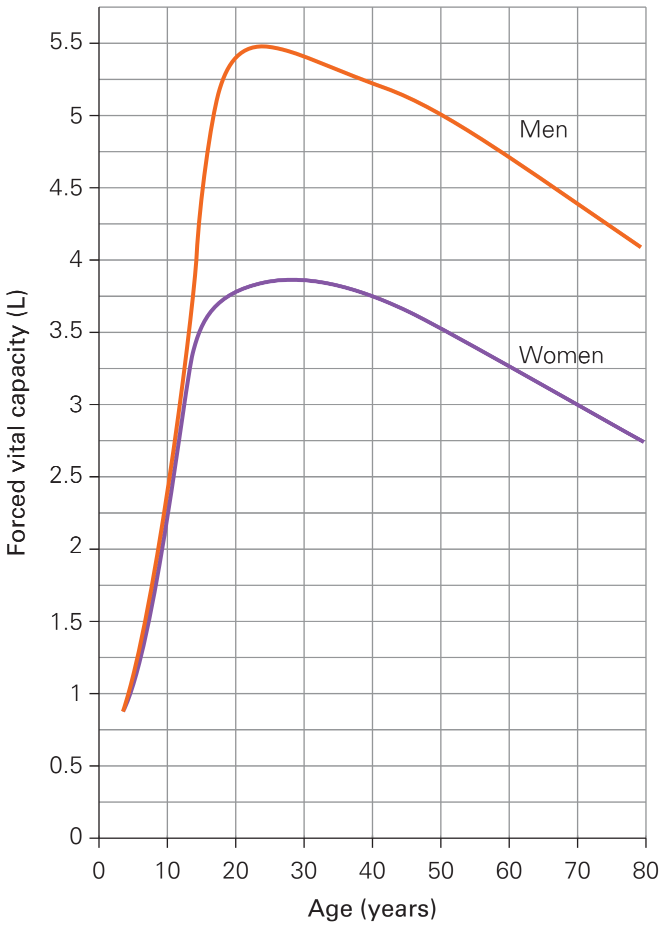

Figure 3.85 Forced vital capacity versus age, for men and women

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 larger FVC than females.

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Knowledge utilisation

20 Other than breaking down food, **propose** another function of stomach acid.

21 **Construct** a flow chart or a story that depicts the path taken by a single molecule of oxygen, from when it enters the mouth, 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.

22 **Propose** two reasons why most frogs need to remain near water.

23 **Construct** a Venn diagram to compare the gas exchange structures of fish, frogs and humans.

24 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. 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 3.86. The relationship between maximum heart rate (HR_{max}) and age of the athlete is shown in Figure 3.87 on the following page.

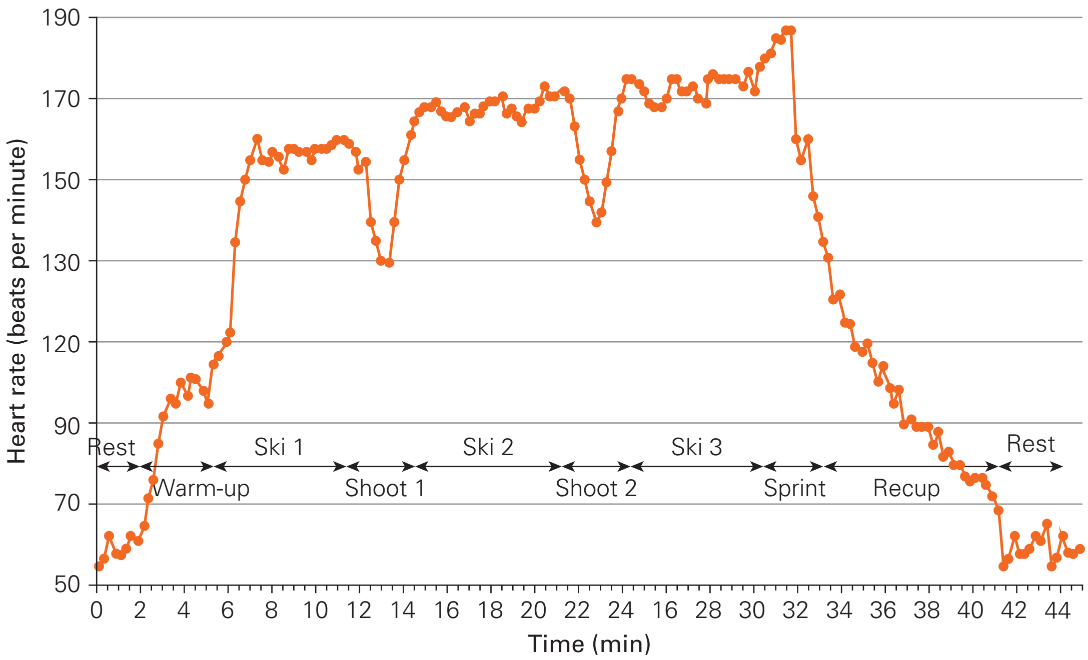

Figure 3.86 Heart rate of an athlete during a biathlon race including warm-up, three ski phases, two shootings, a final sprint and a recuperation phase.

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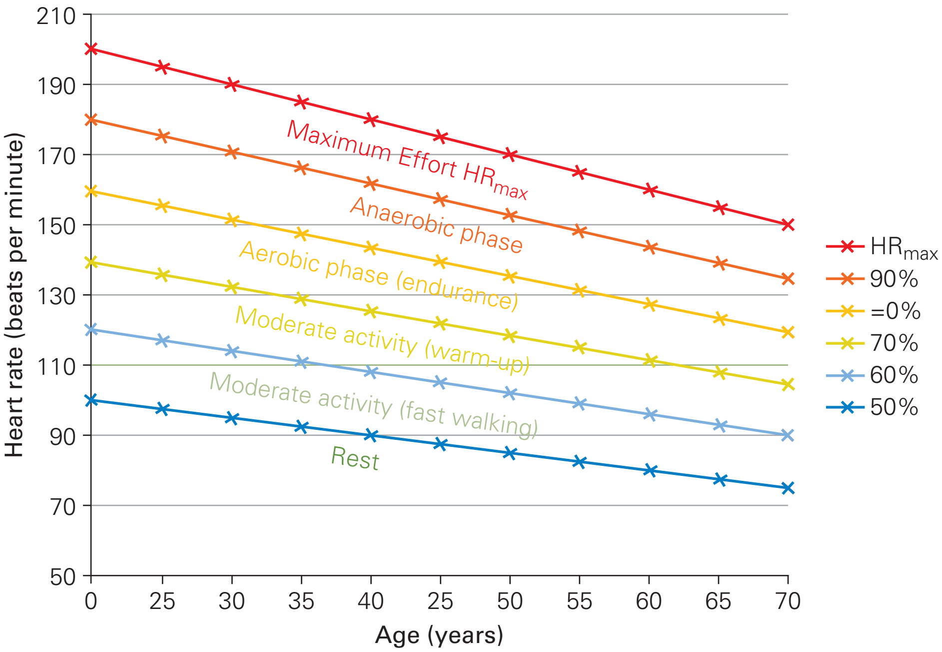

Figure 3.87 Activity intensity linked to the average human heart rate as a function of its age. (Following the commonly accepted relation HR_{max} = 220 – age)

Apply

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 3.86, **identify** the potential age of the athlete knowing his HR_{max} is 190, and that HR_{max} = 220 – age.

Analyse

5 **Identify** the relationship between the heart rate during the successive ski periods and the fatigue of the athlete across the race.

6 **Contrast** the heart rate between 24 and 30 minutes (third ski phase), and between 30 and 32 minutes (final sprint).

Interpret

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 an incredible organ. It 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 3.88 and 3.89.

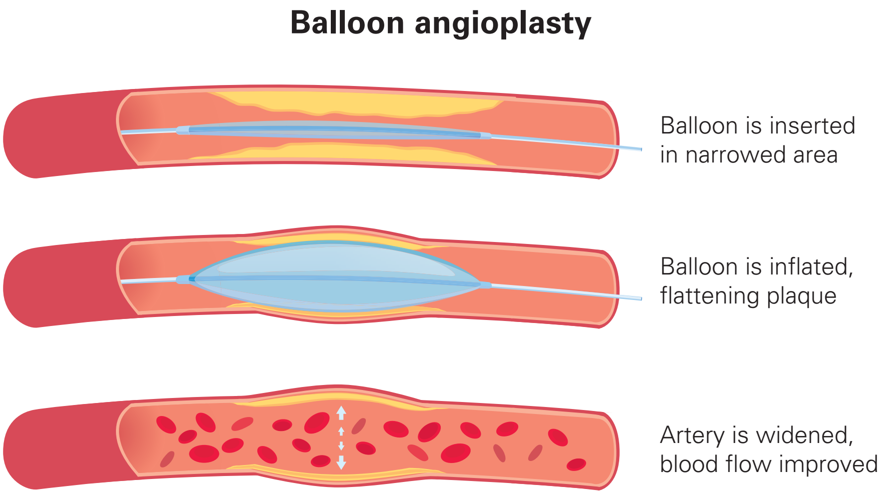

Figure 3.88 In angioplasty, a small 'balloon' is inflated inside the artery, which pushes the plaque aside and widens the vessel.

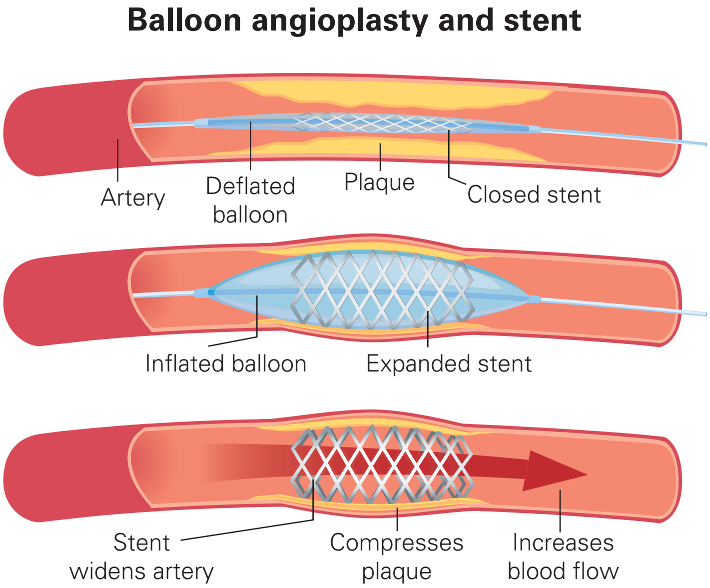

Figure 3.89 Many people also have a stent inserted inside the artery after the artery has been widened by angioplasty. A stent is a small tube made of plastic or metal that is inserted into the artery to prevent it narrowing again.

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It is important to note that neither of these methods actually cleans the plaque away. This is because blood vessels are fragile, and cleaning the plaque would cause it to dislodge, which is dangerous because it might then completely block a narrower blood vessel, causing a heart attack.

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 3.90).

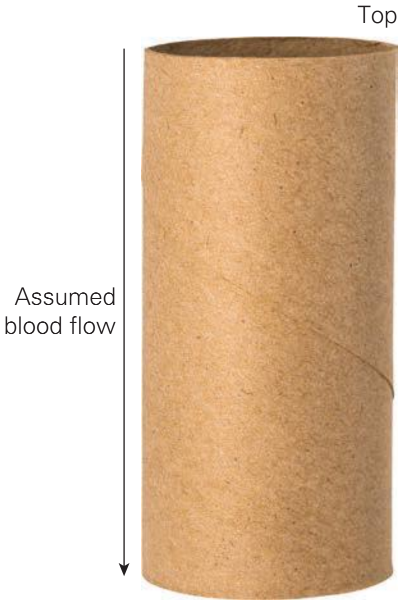

Figure 3.90 A model of an artery

Suggested materials

- model of a blocked artery, created using a tube or a toilet roll tube and Play-Doh
- paperclips
- string
- popsicle sticks
- cloth
- glue
- tape
- cardboard
- paper

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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 to pass 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/solutions 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 first agreed 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 cleaning 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.

Evaluation and modification

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
Reproduction

Chapter introduction

Reproduction is the means by which populations continue to survive on Earth. If a species fails to reproduce, it will become extinct. In this chapter, you will explore the different modes of reproduction, and the structures and mechanisms behind them. Humans have become adept at extending our lifespan, thanks to scientific discoveries and modern medicine. Technology such as IVF (in vitro fertilisation) now allows us to assist people who are finding it difficult to become pregnant. We also manipulate how some other organisms reproduce – examples are agricultural techniques for food crops and animals, and breeding programs for endangered animals.

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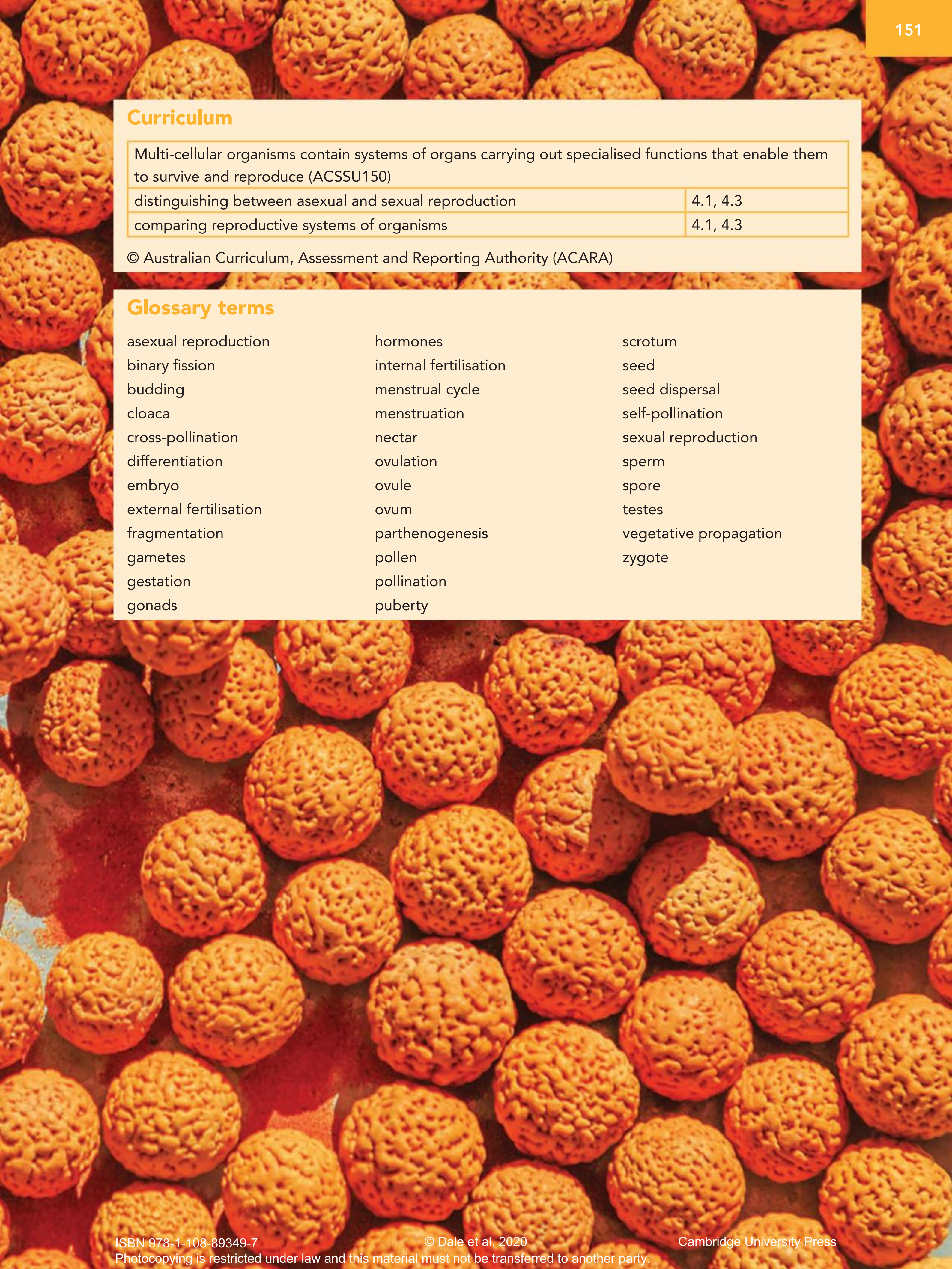

Curriculum

Multi-cellular organisms contain systems of organs carrying out specialised functions that enable them to survive and reproduce (ACSSU150)	
distinguishing between asexual and sexual reproduction	4.1, 4.3
comparing reproductive systems of organisms	4.1, 4.3

Glossary terms

- asexual reproduction
- binary fission
- budding
- cloaca
- cross-pollination
- differentiation
- embryo
- external fertilisation
- fragmentation
- gametes
- gestation
- gonads
- hormones
- internal fertilisation
- menstrual cycle
- menstruation
- nectar
- ovulation
- ovule
- ovum
- parthenogenesis
- pollen
- pollination
- puberty
- scrotum
- seed
- seed dispersal
- self-pollination
- sexual reproduction
- sperm
- spore
- testes
- vegetative propagation
- zygote

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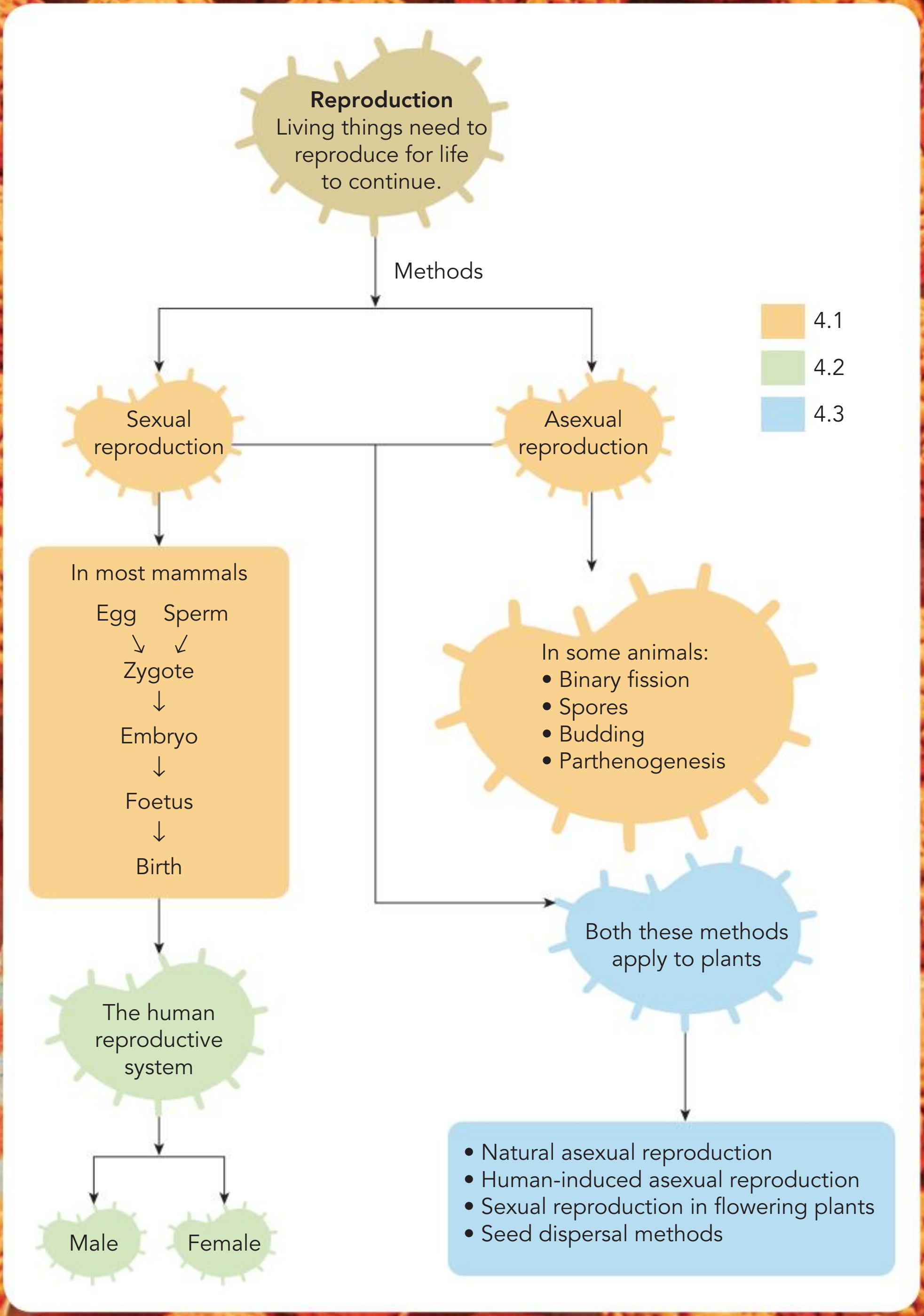
Concept map



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4.1 Asexual and sexual reproduction in animals

WORKSHEET

Every living thing on the planet will eventually die. Therefore, in order for life to continue, organisms need to produce more of their own kind through the process of reproduction.

There are two main types of reproduction: asexual and sexual.

Asexual reproduction occurs when organisms make an exact copy of themselves. There is no need for a second parent.

Sexual reproduction involves the genetic input of two parents, and tends to result in offspring with lots of variation. Humans reproduce via sexual reproduction. This means that, while siblings might look similar, they are rarely identical.

The male gonads are the testes and the female gonads are the ovaries.

When an egg cell and a sperm cell meet, they combine to form a fertilised egg, called a **zygote**. This cell has the correct amount of genetic material and it can begin to replicate by mitosis, which you may remember from Chapter 2, in which eukaryotic cells make copies of themselves. As this new cell replicates and becomes many cells, it grows and the cells take on special functions. The zygote will eventually develop into the **embryo** of the organism.

asexual reproduction	a method of reproduction in which there is one parent organism and all offspring are genetically identical
sexual reproduction	a method of reproduction in which there are two parent organisms and genetic variation in the offspring
gametes	the sex cells (eggs and sperm), each of which contains half the genetic material required to make an organism
gonads	the reproductive organs, where gametes are produced; testes for males and ovaries for females
zygote	a fertilised egg cell
embryo	a fertilised egg cell in the early stages of growth and differentiation; in humans, this would be from between two and eight weeks after fertilisation

Sexual reproduction

Sexual reproduction requires two organisms of the same species to each contribute a special cell that combines with the other to produce a new, unique offspring.

Sexual reproduction requires a sperm cell from the male and an egg cell from the female to combine. These cells each contain half the genetic information needed to form a new organism of the same species. We call these cells **gametes** and they form in the **gonads** of males and females.

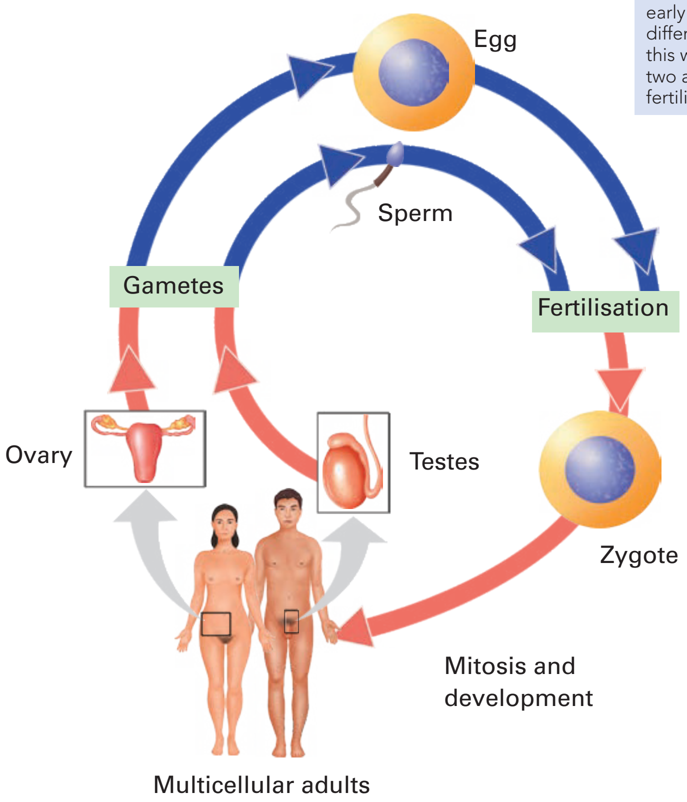


Figure 4.1 The human reproductive cycle

VIDEO
Contrast asexual and sexual reproduction

Quick check 4.1

1 Define the following key terms: asexual reproduction, sexual reproduction, gametes, gonads, zygote, embryo.
2 Recall the number of parents involved in asexual and sexual reproduction.
3 Name the female and male gonads, and name the female and male gametes.

Did you know? 4.1

Courtship

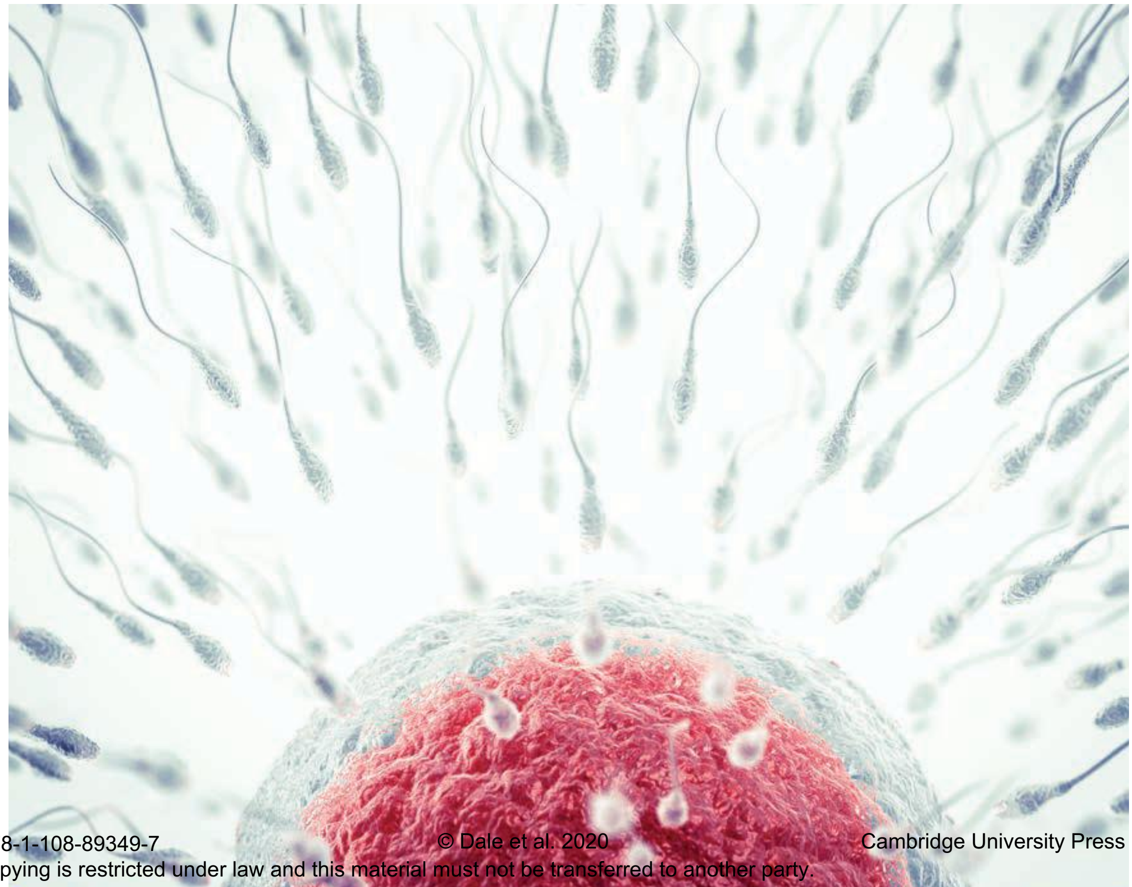

Figure 4.2 A male peacock, starting his performance

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

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

The male peacock puts on an impressive display to attract prospective females. He has a vibrant train of feathers in iridescent colours. If the peahen is suitably impressed, she will crouch on the ground. The peacock then advances, emits a 'hoot' and makes a short dash towards the peahen.

Figure 4.3 Many sperm cells will try, but only one will manage to fertilise an egg cell.



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Fertilisation methods

In mammals, fertilisation takes place within the body of the female – this is known as **internal fertilisation**. This method of fertilisation is important for animals that live on land, as it protects the gametes and zygote from drying out. In most mammals, development of the embryo is also internal, which protects the embryo from any threats in the outside world.

Although other land animals such as reptiles and birds also have internal fertilisation, the development of their young happens externally, in waterproof eggs.

External fertilisation takes place outside the parent animals and usually requires the animals to be aquatic or semi-aquatic, such as amphibians. This is because the eggs and sperm are expelled from the organisms' bodies and unite in water.

Figure 4.4 Internal fertilisation allows reproduction on land without gametes drying out.

Figure 4.5 Internal fertilisation in most reptiles is followed by external embryo development

Figure 4.6 A school of fish and a cloud of gametes that have been released in external fertilisation

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

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

Because the eggs and sperm are released outside the body, it is harder for them to meet, and the fertilised eggs have little protection. This means that organisms that reproduce in this manner have to produce lots of eggs and sperm cells, and release them all at the same time and reasonably close to each other.

Some potential problems with this method of fertilisation:

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

Quick check 4.2

1. Define the following key terms: internal fertilisation, external fertilisation.
2. State the type of fertilisation that occurs in mammals.
3. Describe some advantages of internal fertilisation and some disadvantages of external fertilisation.

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Gestation

Gestation is the term used to describe how long an embryo takes to develop inside the mother to the point where it can survive outside her body. In humans, the gestation period is called 'pregnancy' and usually takes about 280 days (nine months). This time varies between mammals.

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

differentiation
the process by which stem cells become specialised

Figure 4.7 A heavily pregnant dog. Dogs have a gestation period of approximately 63 days.

Stages of embryonic development in humans

In humans, the time from fertilisation to birth is around 40 weeks.

Egg to zygote

The unfertilised egg is released from the ovary and travels along the fallopian tube towards the uterus (see Figure 4.8). There is a 12–24 hour window in which the egg can unite with a sperm cell and become fertilised after it has been released. When fertilised, it is referred to as a zygote.

Zygote to embryo

The zygote undergoes cell division and splits into two cells, then these cells divide, and so on, forming a ball of cells. Over five days, the ball of cells moves along the fallopian tube and then implants into the wall of the uterus. The cells continue to divide and begin to specialise, and make up what is now referred to as an embryo.

Embryonic stage

The embryo continues to divide repeatedly, and the cells **differentiate** to become everything from neurons to liver cells to skin cells. The embryonic stage continues from week two to week eight. In humans, during this critical period, the developing embryo is susceptible to the effects of alcohol, diseases and drugs, which can lead to birth defects

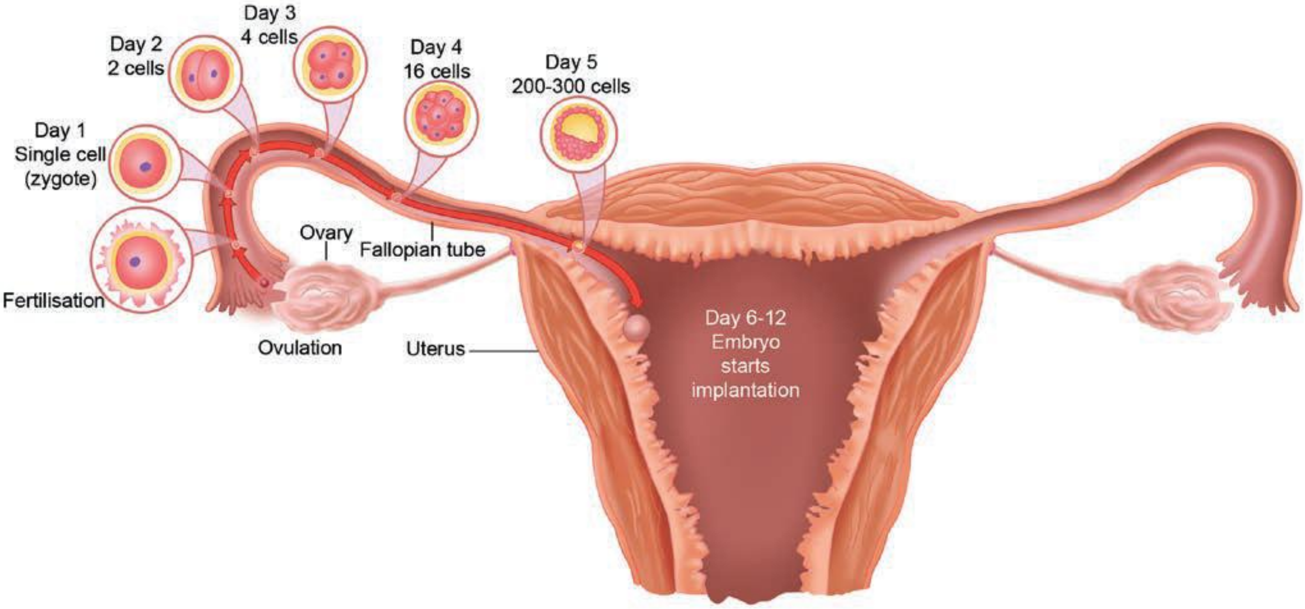

Figure 4.8 The female reproductive system

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such as limb abnormalities or problems with brain development. By the eighth week, all major organs are present but not fully developed.

Foetal stage

The foetal stage lasts from around week eight to birth. This is a time of rapid growth, and the organs become fully developed and functional. Alcohol, disease and drugs can still have an impact during the foetal stage of development.

Figure 4.9 A model showing a foetus that is nearly full term and ready to be born

VIDEO
Microscopic view of an IVF procedure

Explore! 4.1

Investigating gestation and development

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

Animal	Gestation period	Time until they can walk/move	Time relying on parent for food	Average life span
Human	280 days			
Pig				
Elephant				
Choose your own animal				

Science as a human endeavour 4.1

Reproductive technologies

Some people have difficulty conceiving (becoming pregnant) naturally, due to age or certain medical conditions. If a person or animal is unable to produce gametes, they are termed 'sterile'. Humans have developed sophisticated reproductive technologies such as IVF (in vitro fertilisation) to assist pregnancy. In 1944, a lab technician called Miriam Menkin managed to combine gametes in a Petri dish, but it wasn't until 1978 that the first successful human IVF birth occurred. Since then, the practice has become increasingly common, with more than eight million babies being born from IVF treatment.

Figure 4.10 American bison living in Colorado are at risk of becoming an endangered species. IVF technology may be a way to rectify this.

Some features of the IVF method:

- The female might take extra hormones to encourage release of multiple eggs (egg release is called ovulation).
- Eggs are harvested surgically.
- An egg is fertilised by a sperm in a laboratory.
- The fertilised egg is incubated and allowed to begin cell replication. When it has reached a size of around four cells (after approximately 36–48 hours), it is implanted back into the woman's uterus.

Reproductive technology also has implications for conservation efforts. For example, bison numbers in Colorado, USA, are so low that these animals are at risk of becoming endangered. In 2018, four bison calves and their mothers were released into a northern Colorado herd, including a 10-month-old calf named IVF. IVF technology is now being used in the conservation efforts of approximately 10 endangered species, including the Puerto Rican crested toad and northern white rhino.

Quick check 4.3

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

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

Birth

When a baby is ready to be born, the woman goes into labour – which, as the name suggests, can be hard work, lasting anywhere from a few hours to days. The cervix dilates and the uterus contracts, pushing the baby out of the vagina. The baby is usually born head first. However, situations such as a breech birth, where the baby's feet come out first, can result in a medical emergency and the baby may need to be removed surgically. This is done by making an incision across the woman's abdomen, called a caesarean section (C-section).

Development

Most mammals develop internally in the uterus of the mother and are born looking relatively similar to an adult organism. Internally developing organisms, including humans, receive nutrition directly from the mother, via the umbilical cord. Marsupials, such as kangaroos, are unique because the young are born in an extremely under-developed state, exiting the vagina when they are the same size as a jellybean! They must then climb up the mother's front and into her pouch where they continue to develop.

Figure 4.11 A baby joey. After being born, the joey wiggles its way into its mother's pouch to feed.

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Baby birds, reptiles, amphibians and insects tend to develop externally – outside the mother. They develop inside an egg and hatch once they are sufficiently equipped to survive in the world.

Parenting

Since birth, you have been looked after by adults. However, not all organisms care for their young. Insects, fish and some other simple organisms do not look after their young at all after they have laid their eggs. For example, moths lay their eggs on the under-surface of leaves, in order to hide them from the line of sight of predators and to provide them with a food source when they eventually emerge as a caterpillar. However, the female moths do not remain to protect them.

Figure 4.12 Caterpillars hatching under a leaf

Animals that do not look after their young often produce large numbers of eggs, resulting in an increased chance that some of the offspring will survive predation, disease and competition and develop to adulthood.

More advanced animals such as birds, mammals and even some frogs look after their fertilised eggs and their newborn offspring, which increases their chance of survival.

Figure 4.13 A kangaroo mother provides a safe environment for her offspring.

Did you know? 4.2

The male midwife toad

The male midwife toad is a dedicated father. He carries around the fertilised eggs, which he wraps around his back legs after mating. After about three weeks, when the eggs are ready to hatch, he will find an appropriate body of water where he will allow the tadpoles to emerge from their eggs and begin their independent life.

Figure 4.14 A male midwife toad, carrying fertilised eggs

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Asexual reproduction

Some organisms reproduce asexually, without the input of a partner. This method of reproduction is useful for organisms that are isolated from other members of their species or cannot move easily. Asexual reproduction can also be useful because it is fast and does not require time and energy to find a mate. The offspring produced are clones, genetically identical to the parent. If the parent is well adapted to the environment, this is a good thing. However, if environmental conditions change or a disease is introduced that the organisms are susceptible to, it can lead to the extinction of a whole species.

In asexual reproduction, one cell becomes two, and there are many different ways this can occur. There are several types of asexual reproduction, and include: binary fission, fragmentation, spore formation, budding and parthenogenesis.

binary fission
a mode of asexual reproduction by bacteria, where genetic information is copied and the cell splits in half

fragmentation
a mode of asexual reproduction where organisms can be cut in half and regrow into two genetically identical organisms

spore
an asexual reproductive cell produced by organisms such as fungi and ferns

Binary fission

Bacteria and some simple unicellular organisms, such as the amoeba, reproduce by splitting in half. This process is known as **binary fission**. The genetic material is copied, and then the cell constricts and splits down the centre, resulting in two identical daughter cells. This is similar to mitosis that occurs in eukaryotic organisms.

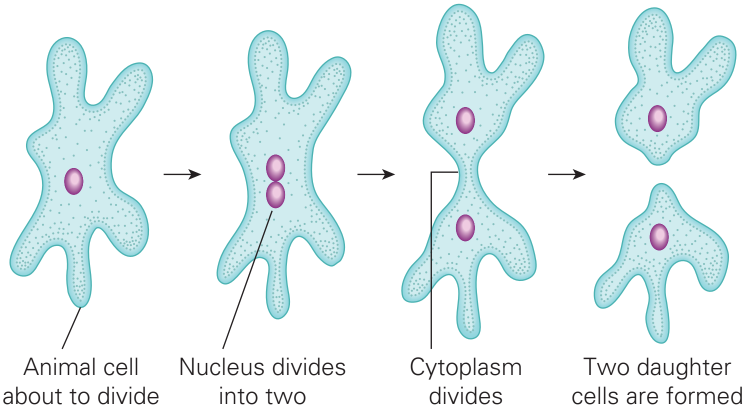

Figure 4.15 Binary fission in an amoeba (a unicellular organism)

Fragmentation

Some multicellular organisms, such as flatworms and sea stars, also reproduce asexually by **fragmentation**. If you cut a flatworm in half, both ends can regenerate and it will become two flatworms.

Figure 4.16 Fragmentation in a flatworm

Spore formation

Fungi and some plants, such as ferns, produce single-celled **spores** that are released into the environment. These spores are carried by the wind and land in a new location, where some develop into a genetically identical version of the parent organism. The spore is actually a clump of unspecialised cells surrounded by a protective coating. Note that spores can be formed by sexual or asexual reproduction.

Figure 4.17 Common puffball fungus releasing spores

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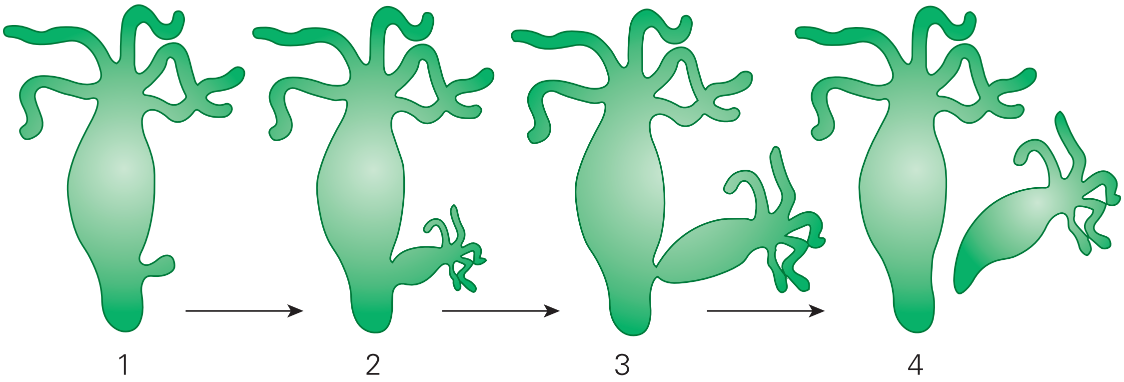

Figure 4.18 Budding in a hydra

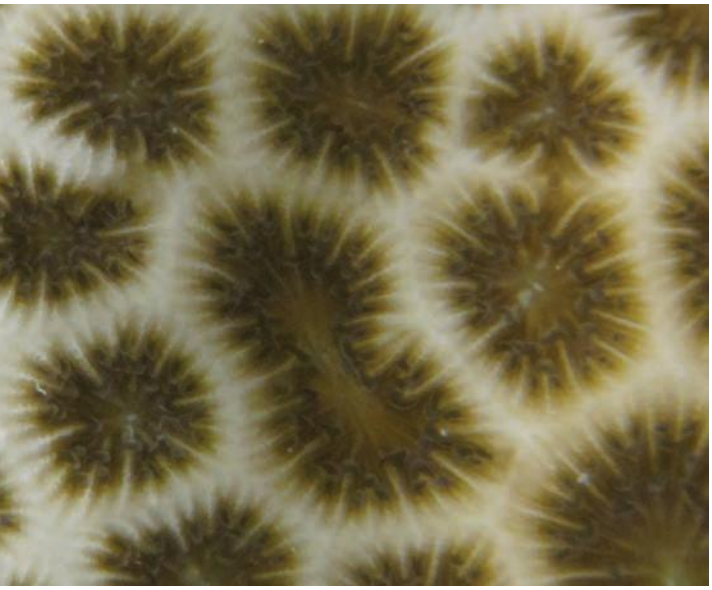

Figure 4.19 Corals reproduce asexually by fragmentation or budding. In the centre a *Leptastrea purpurea* coral polyp has produced a large bud which will split off.

Figure 4.20 In some species, such as stick insects, the females can reproduce by parthenogenesis.

Budding

Yeasts and simple aquatic animals, such as coral or hydra, reproduce asexually by **budding**. A genetically identical daughter offspring grows and develops on the side of the parent organism, before dropping off and continuing to live independently.

Parthenogenesis

Parthenogenesis comes from the Greek words for 'virgin birth' and is a form of asexual reproduction where an egg develops into an embryo without being fertilised. It is relatively common in a number of invertebrate species, but less so in vertebrates. Organisms such as bees and certain lizards lay unfertilised eggs which hatch to produced genetically identical copies of the mother. The resulting population is female because growth and development of embryos occurs with all genes inherited from the mother.

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

parthenogenesis
a mode of asexual reproduction where females give birth to unfertilised eggs that hatch to produce offspring that are genetically identical to the mother

Quick check 4.4

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

Try this 4.1

Asexual vs sexual reproduction

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

Section 4.1 questions

QUIZ

Retrieval

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

Comprehension

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

Analysis

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

Knowledge utilisation

11 **Construct** a short timeline of the human gestation period. Ensure you include the terms egg, zygote, embryo and foetus.
12 Many courtship displays demonstrate a male individual's strength through physical feats, or their health through the vibrancy of their colourings. **Discuss** why this would be useful information for the female.
13 **Propose** why organisms produced by asexual reproduction are sometimes called clones.
14 A brand new species of lizard is discovered, and a zoologist captures a female of the species. One year later, the lizard lays eggs that hatch into many female lizards. **Determine** the method of reproduction she has utilised.

4.2 The human reproductive system

As discussed previously, humans reproduce sexually via internal fertilisation, and have highly specialised body systems to support this process. Both females and males share some structural similarities: both possess gonads, which are the site of gamete production, although many of the other structures are different.

The female reproductive system

When a female is born, she has between 1 and 2 million eggs in her ovaries, in tiny sacs called follicles. Most of these eggs will be lost by the time she reaches puberty. Once she reaches puberty, one egg (**ovum**) is released into the fallopian tube each month, through a process called **ovulation**. If this egg is not fertilised, then the uterine lining is shed (along with the egg) and the woman experiences **menstruation** (a menstrual period).

WORKSHEET

ovum
egg, or female gamete

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

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

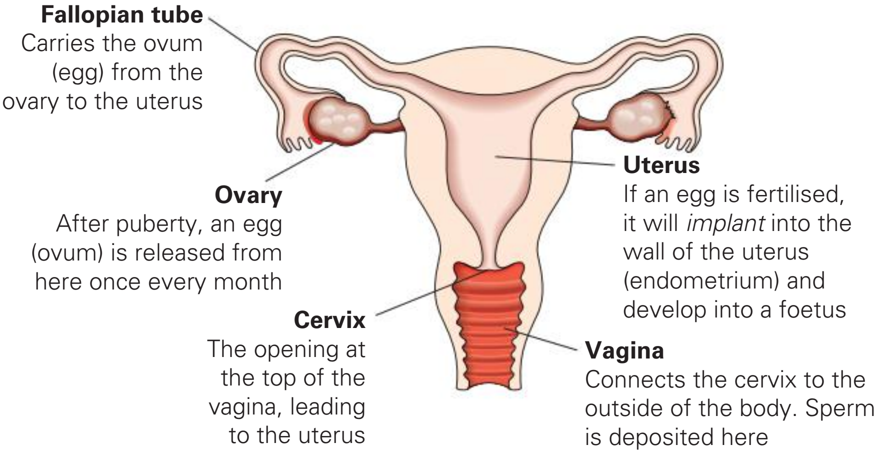

Figure 4.21 The female reproductive system

Did you know? 4.3

More than one uterus

Animals such as rabbits have a branched uterus, which allows for the development of multiple foetuses at the same time, even up to 14! However, this is not the only factor in the rabbit's rapid rate of reproduction. They also have a gestation period of 28–31 days, which means a single female could give birth to 168 live young per year! This is why it is illegal to possess a rabbit in Queensland without proper authorisation. Due to their quick rate of reproduction, rabbits are considered a risk to agriculture and native flora and fauna.

Figure 4.22 Rabbits are excellent breeders.

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The male reproductive system

puberty
the time of transition from juvenile form to adult form

sperm
the male reproductive cell, or gamete

testes
the male reproductive gland that produces sperm

scrotum
a sac that encloses the testes

Gamete production in males is a little different: once a male reaches **puberty**, he starts to produce **sperm** in his **testes**. The testes are suspended from the body in a sac called the **scrotum**, which is around three degrees cooler than core body temperature as sperm production is best at this temperature.

Sperm are around 0.05 mm long and are well adapted for swimming through the mucus of the vagina and the uterus to reach the egg. Each sperm has a long whiplike tail that beats in a corkscrew motion to propel the sperm forwards. They also have many mitochondria in their midpiece to provide energy for swimming, and a sac of enzymes in their head to digest through the egg membrane. Unlike eggs, sperm are produced in huge quantities throughout a male's life.

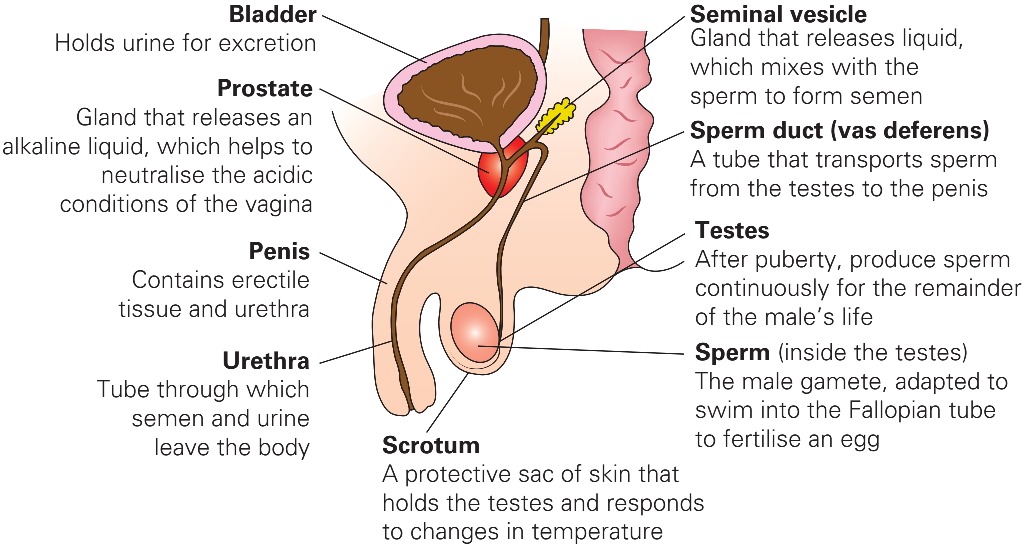

Figure 4.23 The male reproductive system

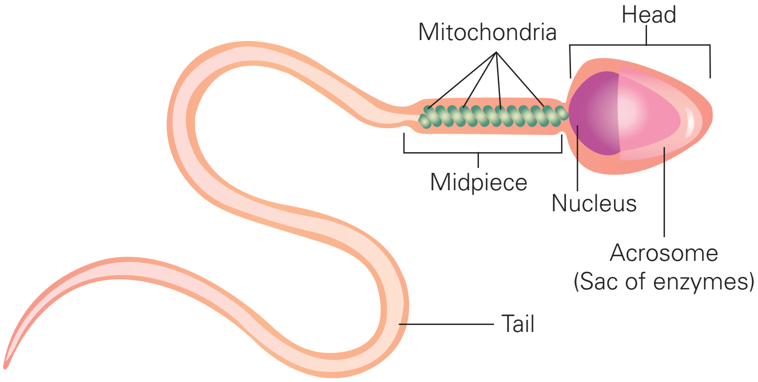

Figure 4.24 Sperm with its adaptations

Quick check 4.5

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

Try this 4.2

Model/diagram

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

Puberty

All animals develop from a juvenile form into their adult form early in their lives. This process involves many **hormones** that stimulate growth and changes in their bodies. This process of change is called puberty.

Goats, chickens, sheep and cows all go through puberty within their first year of life. In humans, puberty comes later. Girls go through puberty at around the age of 9–14 years, and boys go through puberty at around 12–16 years. This is why girls are often taller than boys in Years 7 and 8. However, puberty happens at different times for everyone and this is perfectly normal.

When humans go through puberty, they grow rapidly, start getting hair around their genitalia and become sexually mature, meaning that they can produce offspring. The main hormones involved in puberty are testosterone, follicle-stimulating hormone (FSH), luteinising hormone (LH), growth hormone, oestrogen and progesterone. Growth hormone and LH make you grow taller and stimulate hair follicles around the body to produce more hair, most noticeably on the face, legs, groin and armpits. FSH triggers eggs to develop in the ovaries of females and LH will then trigger ovulation.

Figure 4.25 Hair development is common during puberty.

Explore! 4.2

Puberty

Some of the changes you experience during puberty have already been mentioned, but what else happens?

1. Draw outlines of a female and a male on two separate pieces of paper.
2. Do some research and annotate your diagrams with the changes that occur during puberty and where they occur. If you can explain what causes the change, include that too.

In males, testosterone causes the testes to enlarge and produce sperm, the voice deepens and muscle size increases. Increased testosterone levels can also lead to more oil production on the skin and an increase in sweating. Both these attributes can lead to an increase in acne and body odour.

hormone
a chemical produced by cells that controls and regulates different processes in the body

Figure 4.26 Some unpleasant side effects of puberty: body odour and acne

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

In females, oestrogen and progesterone stimulate the eggs in the ovaries to develop and breast tissue to grow. Females might also notice that their hips widen and they begin to develop more fat around this area. These hormones prompt the **menstrual cycle** to begin.

The menstrual cycle

Hormones control a woman's menstrual cycle, which usually lasts around 28 days.

1. The pituitary gland in the brain releases FSH.
2. FSH causes one of the eggs in the ovary to mature. It also stimulates the ovaries to make oestrogen.
3. Oestrogen stimulates the pituitary gland to release LH.
4. LH triggers the release of an egg (ovulation).
5. Oestrogen also inhibits any more production of FSH (stopping other eggs maturing). It also repairs the uterine lining (endometrium).
6. Once the egg has been released, progesterone is produced by the empty follicle (called the corpus luteum or a yellow body). This maintains the uterus lining and inhibits LH.
    a. If a woman becomes pregnant, the follicle continues to produce progesterone and a placenta is formed.
    b. If pregnancy does not occur, then the corpus luteum stops secreting progesterone and decays into the corpus albicans. This causes the progesterone and oestrogen levels to drop towards the end of the menstrual cycle, the uterine lining breaks down and menstruation occurs.

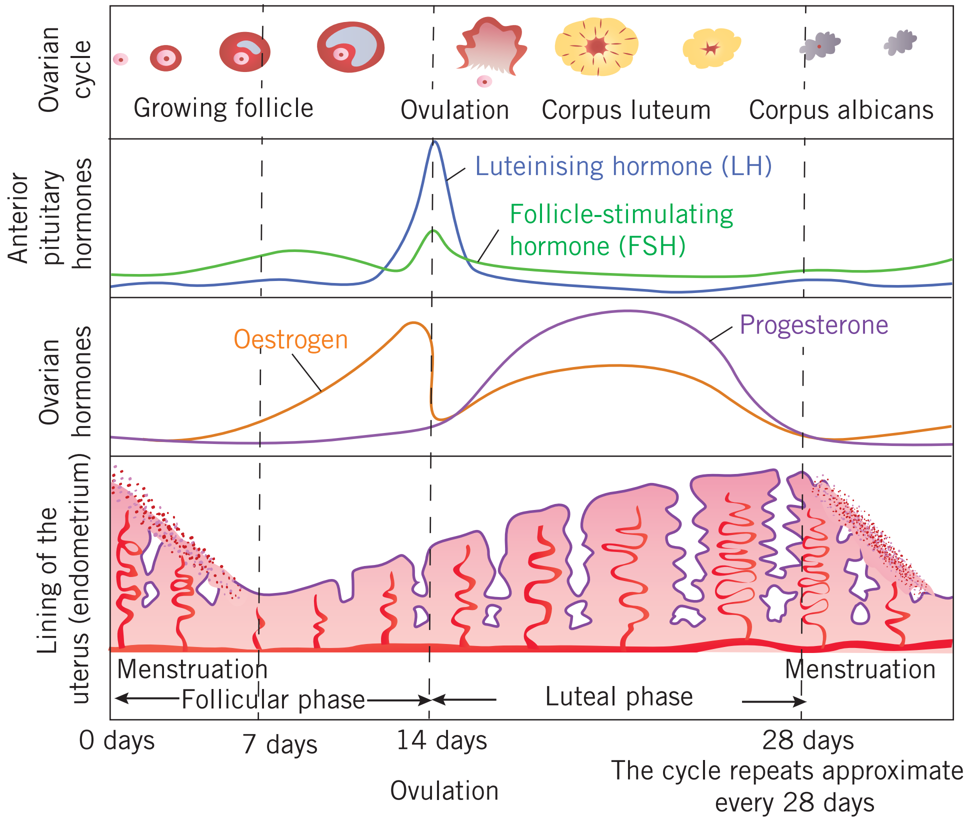

Figure 4.27 The link between the different hormones in the female reproductive system and the action of the follicles. After the follicle releases an egg, it is known as the corpus luteum.

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Did you know? 4.4

Cloaca – one hole does it all!

Humans have an anus to defecate out of, a urethra to urinate out of and, if you are a female, a vagina to push babies out of. But not all animals are like that. In fact, it is much more common to have one hole that does all of the above. This organ is called the **cloaca** and it is found in amphibians, reptiles, birds, some fish and even monotremes. This is why it can sometimes be tricky to distinguish between the sexes of certain animals. For example, birds mate by pressing their cloacas together in a process known as a 'cloacal kiss', where muscular undulations move the sperm from the male to the female.

Figure 4.28 A turtle laying an egg through its cloaca

Figure 4.29 Echidnas also have a cloaca

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

Quick check 4.6

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

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Science as a human endeavour 4.2

Early puberty caused by plastic

Figure 4.30 Wherever possible, use BPA-free plastics. If you can't, ensure you wash all food products before use.

The chemical called bisphenol A (BPA), used since the 1960s, is found in plastic containers, water bottles, inside tin cans used for storing food, and in cash register receipts. BPA is an endocrine-disrupting chemical (EDC), as it has been found to copy the action of the female sex hormone oestrogen. BPA can affect human reproduction and puberty, and has been linked to early puberty, low sperm counts and infertility in men, as well as breast and prostate cancer. Consequently, many BPA-containing products are banned in Australia. This is another good reason why you should minimise your use of plastics, especially those that are in contact with food.

Section 4.2 questions

QUIZ

Retrieval

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

Comprehension

6 **Describe** the cloaca.

Analysis

7 Referring to the graph of the menstrual cycle in Figure 4.27, answer the following questions.
  a **Identify** the hormones that peak just before ovulation (when the egg is released).
  b **Identify** the hormone that is at its greatest concentration when the uterine wall is at its thickest.
8 **Classify** the following structures as belonging to the female reproductive system, the male reproductive system or both systems: fallopian tube, penis, gonads, prostate gland, bladder, scrotum, ovary, vas deferens, cervix.

Knowledge utilisation

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

4.3 Plant reproduction

Plants can reproduce both asexually and sexually.

Sexual reproduction in plants, as in animals, involves gametes carrying out fertilisation, producing a zygote and embryo. Their reproduction systems are quite varied, and not all have flowers, fruits and seeds. But they do mean that the plant has to divert many resources to the production of a new unique offspring. This method of reproduction increases the genetic diversity of a population; however, it can take quite a long time, as it is usually dependent on the cycle of the seasons.

In order to take advantage of favourable conditions which may arise at other times, such as heavy rainfall, high levels of sunlight, regeneration after fire or sudden access to new space, most plants can reproduce asexually, which is a relatively fast process that requires less energy. However, asexual reproduction produces offspring that lack genetic diversity.

DOC WORKSHEET

Figure 4.31 Plants are a very diverse kingdom, including non-flowering plants such as A) moss, B) ferns, C) conifers and D) the flowering plants.

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Asexual reproduction in plants

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

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

Natural methods and human-induced methods of asexual reproduction are summarised in Tables 4.1 and 4.2.

Natural methods

Vegetative propagation method	Definition	Examples	Image
Bulb	• Underground stem for food storage • Food is stored in large leaves • Each bulb develops into a new plant	Onions, hyacinths, daffodils	 **Figure 4.32** An onion bulb with leaves and roots
Runner	• A stem that grows on top of and across the ground, from an existing stem • New plants grow from the runners	Strawberries, some grasses	 **Figure 4.33** Strawberry leaves and runner
Tuber	• Underground stem that contains stored food • The eyes of a potato can develop into new plants	Potatoes, sweet potatoes	 **Figure 4.34** A potato with eyes beginning to sprout
Rhizome	• Long modified stem that grows horizontally under the ground • New plants grow from the rhizome	Long grasses, ferns, irises, ginger, asparagus	 **Figure 4.35** Ginger rhizome with sprout

Table 4.1 Natural methods of asexual reproduction in plants

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Human-induced methods

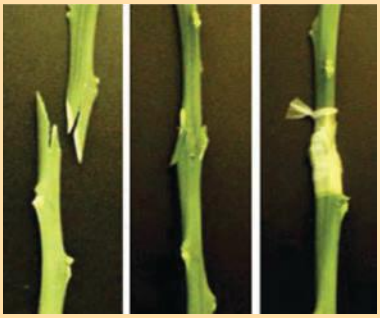
Vegetative propagation method	Definition	Examples	Image
Cutting	• Taking pieces of a root or stem • Each piece grows into a new plant	Bananas, roses, sugar cane	 **Figure 4.36** Some cuttings grow roots when placed in water
Grafting	Taking part of a plant and connecting it to another plant, combining the two plants	Citrus, grapes, apples, roses	 **Figure 4.37** The two pieces of stem (left) are tied in place and will eventually grow into one stem.

Table 4.2 Human-induced methods of asexual reproduction in plants

Figure 4.38 Some trees can have multiple fruits grafted onto the same tree. For example, plums, nectarines and peaches can be grafted together.

Figure 4.39 Growing new plants from cuttings is a way of making clones.

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Practical skills 4.1

Asexual reproduction in plants

Aim

To model the process of asexual reproduction, using potato tubers

Materials

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

Method

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

Results

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

Remember:

- Place the independent variable on the *x*-axis.
- Place the dependent variable on the *y*-axis.
- Label both axes.
- Write a title.
- Use over 75% of your graph paper.
- Use equal spaces between each number plotted.

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

Analysis

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

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Quick check 4.7

1 Define the terms 'asexual reproduction' and 'sexual reproduction'.
2 State two advantages of asexual reproduction in plants.
3 Define 'rhizome'.
4 Name one plant that can be grown from a cutting.

Sexual reproduction in plants

If you sit near a patch of flowers on a summer day, you may see a bee or a butterfly paying them a visit. Many flowers rely on these insects to help them reproduce by sexual reproduction. The flower is the sexual organ of the plant. The **pollen** it produces is the male gamete (similar to sperm) and the female gamete is inside the **ovule**. The parts of a flower are shown in Figure 4.45.

Pollination is the fertilisation process in which the pollen from one flower reaches the ovule of another flower. Bees and other insects are attracted to brightly coloured and scented flowers, in addition to the sweet **nectar** they produce, and pick up pollen while they are feeding. When the bee moves to the next flower, some of the pollen on the bee sticks to the stigma of the new flower, and the pollen grain then grows down the style to the ovule. This is where fertilisation occurs and seeds develop.

pollen
the male gamete in flowering plants

ovule
a structure in a flowering plant where the female gamete is produced and where seeds develop; also used to mean the female gamete

pollination
the process by which pollen sticks to the female structures of a plant and fertilises the ovule

nectar
a sweet liquid produced by flowers to attract pollinators

WIDGET
Sexual and asexual reproduction

Figure 4.40 A bee with large yellow pollen sacs on its legs

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Explore! 4.3

Pollination

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

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

1 Draw up a table with two columns. In the first column, list the four methods of moving pollen from one flower to another. Then research the types of flowers that use each method of pollination. In the second column, summarise what you have found out about the characteristics (shape/colour/size) of the flowers, their stamens and pistils.

2 What are the advantages and disadvantages of self-pollination? Do some research to find out how plants prevent self-pollination occurring.

self-pollination pollination that occurs by pollen from the same flower or from another flower on the same plant

cross-pollination pollination that occurs by pollen from another flower or plant

Figure 4.41 These flowers are pollinated by different methods. Can you identify what those methods are?

Did you know? 4.5

Palynology

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

Figure 4.42 There are many types of pollen in the air.

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Humans are attracted to flowers because of their beautiful and varied colours and scents, but the colourings that we see are just the tip of the iceberg. Many insects can see further into the electromagnetic spectrum than we can. If you view flowers under ultraviolet light, you will see that many have patterns that resemble a bullseye target or a landing strip. These patterns are designed to tell the insects exactly where they need to go to get the nectar.

Figure 4.43 Flowers with (left) a bullseye pattern and (right) a landing strip pattern

Quick check 4.8

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

Figure 4.44 Conifers, such as pine trees, have separate male (left) and female (right) cones on the same tree, they do not have flowers. They are wind-pollinated, male cones release pollen to the wind. When ready the female cones open and the pollen is blown inside to fertilise the female gametes which develop into seeds. To reduce self-pollination, female cones are on the higher branches and male cones on the lower branches.

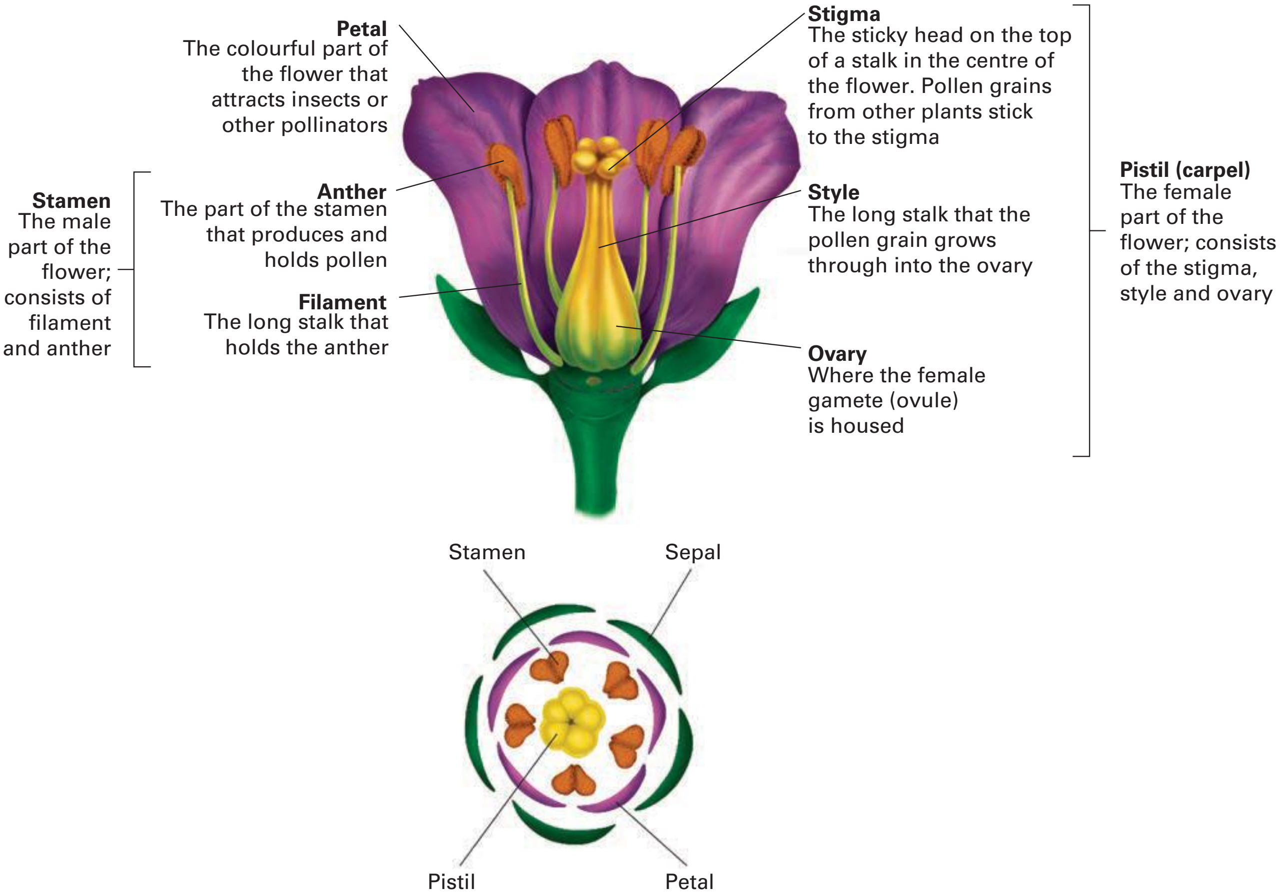

Figure 4.45 Top: A vertical section showing the reproductive parts of a flower. Bottom, left: a cross-section of the reproductive parts**.** Bottom, right: a lily showing stamens, style and and stigma.

Practical skills 4.2

Flower dissection

Be careful

Take extreme care when handling the razor blade.

Aim

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

Materials

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

Method

1. Refer to Figure 4.45 to help you to identify the parts of your flower. Draw a diagram of your first flower. Note the number of petals and sepals, and label these on your diagram.
2. Holding the flower carefully with tweezers on the chopping board, cut the flower in half vertically. This means you should now be looking at a vertical section of the flower, similar to the top picture in Figure 4.45.
3. Draw a diagram of the flower, and label all the parts of the flower you can recognise. Add 'M' next to the male parts of the flower and 'F' next to the female parts of the flower.
4. Gently remove the sepals and petals, by pulling them down towards the stem. Use a microscope to look at the tip of the petal at low magnification. Record your observations of the petal's texture in your results.

continued…

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…continued

5. Remove the flower's stamens, by breaking or gently cutting them off the stem. Examine the pollen with your microscope. Record your observations of the pollen's shape and texture in your results.
6. Gently remove all parts except the pistil, so that it remains alone on the stem. Carefully cut the pistil in half lengthwise, and use your hand lens to look at the inside of it. Record your observations of the style, ovary and ovules in your results.
7. Repeat steps **1–6** with the other flowers.

Results

Your results should consist of:

- Labelled diagrams of the whole flower and vertical section of the flower
- Observations made during the dissection.

Analysis

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

Science as a human endeavour 4.3

Healthy bees need diversity

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

Imagine that you were only allowed to eat one type of food. That would become boring and you probably would not be very healthy. Australian and German researchers have discovered that a diversified plant environment helps bees maintain stable populations. The bees' quality of life is highest in gardens and biodiverse forests, and lowest in mono-crop areas. As plant biodiversity declines, bees produce less offspring, and eventually bee colonies shrink in size. This means we need to protect our biodiverse environments in order to help prevent the extinction of bees.

Did you know? 4.6

The blue-banded bee

In 2017, residents living near the Merri Creek in Melbourne worked together to raise money to improve the quality of the habitat of the native blue-banded bee, as the area had lost the diversity of wildflowers that the bee needs for nectar. Blue-banded bees cannot travel very far and so their home needs to offer all their requirements for a healthy existence. The special thing about blue-banded bees is that they can perform a special type of pollination, called 'buzz pollination'. Some flowers hide their pollen inside tiny capsules, but a blue-banded bee can grasp a flower and shake it so much that the pollen shoots out of the capsules. The bee can then collect the pollen and carry it from flower to flower, pollinating the flowers.

Figure 4.46 The blue-banded bee

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VIDEO Australian plants and seed dispersal

Seed dispersal

In conifers and flowering plants, after fertilisation the embryo develops inside a seed or nut. **Seeds** may be in a fleshy structure that developed from the ovary after flowering. You know this as fruit! In every day language, when you use the word 'fruit', you will probably be thinking of something edible that is sweet or sour, such as apples, lemons, grapes or nectarines. However, in plant science, 'fruit' means the seed-containing structure which in flowering plants develops from the ovary, and this includes bean pods, wheat grains or corn kernels.

seed
a plant embryo enclosed in a protective coating

seed dispersal
the spread of seeds away from the parent plant

In pine trees and other conifers, the woody female cones protect their seeds. When the seeds are fully developed, the cones open and release the seeds.

Figure 4.47 Peaches produce a large seed surrounded by tasty flesh.

Figure 4.48 Pine cone ready to drop its seeds

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

Exploding!

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

Figure 4.49 Exploding seed pod

Hitching a ride on the outside

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

Figure 4.50 Burrs caught on a dog's fur

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Figure 4.51 Animals ingest seeds in fruit and then defecate the seeds in a new location.

Hitching a ride on the inside

As you know, fruit not only protects the seeds, but also can be very tasty. Some plants make their fruit extra sweet to encourage animals to eat the seeds. The seeds have a tough coat so that they won't be digested. When they eventually pass intact through the animal, they are in a brand new spot, where they may begin to grow.

Shooting the breeze

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

Floating away

A coconut is one giant seed. It is hollow and so it can float. This is how coconuts are able to move between islands and across oceans.

Figure 4.52 Dandelion seeds leaving a dandelion clock after getting caught in the breeze

Figure 4.53 A floating coconut

Quick check 4.9

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

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Investigation 4.1

Seed germination

Aim

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

Planning

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

Materials

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

Results

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

Analysis

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

Evaluation

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

Conclusion

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

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Science as a human endeavour 4.4

Technology and farming

There is continuous development in modern farming techniques. Technologies are applied in order to improve crop yields and sustainability. Two such examples are hybrid seeds and cloning.

Hybrid seeds are produced by companies through selective breeding. Two plants with favourable characteristics are bred together. For example, a strawberry plant that is drought tolerant may be cross-pollinated with a strawberry plant that produces a large amount of fruit. Hybrid seeds are common in commercial farming, especially to increase crop yields.

Figure 4.54 In 2014, several prefectures in Japan developed a new hybrid of strawberry capable of year-round production; they named the hybrid 'Yotsuboshi'.

Cloning technology is also used in farming. All over the world, wine growers are reporting that their grapes are ripening earlier due to hotter temperatures. Growers are having to respond by:

- irrigating their vines
- more effectively managing the grape canopies for shading, and
- moving their vine plantings to cooler parts of their properties.

However, as temperatures continue to increase, growers may have to consider growing grape varieties that are more drought and heat tolerant. One way of doing this is by cloning grape varieties that are well known for their tolerance to hot conditions and planting them in areas that are predicted to get hotter.

Figure 4.55 Grapes are cloned by taking a cutting from an existing grape vine and then grafting it onto another vine or encouraging the cutting to grow roots.

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Section 4.3 questions

QUIZ

Retrieval

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

Comprehension

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

Analysis

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

Knowledge utilisation

9 Evan lived in England for 15 years and never experienced hay fever. Hay fever is caused by pollen irritating the nasal passageways. Since moving to Australia, Evan has had hay fever every summer. **Propose** a reason for this.

10 A new volcanic island has formed in the middle of the Pacific Ocean. **Predict** the first type of plants that will grow on the island, and justify your answer, based on its method of seed dispersal.

Figure 4.56 An isolated island, which was formed by a volcanic eruption

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Chapter review

Chapter checklist

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

1	**I can distinguish between asexual and sexual reproduction.** e.g. State the advantages of sexual reproduction.	
2	**I can define the following key terms: asexual reproduction, sexual reproduction, gametes, gonads, zygote, embryo.** e.g. Define the term zygote.	
3	**I can distinguish between internal and external fertilisation.** e.g. Recall the disadvantages of external fertilisation.	
4	**I can recall the main stages of gestation.** e.g. Recall when an embryo becomes a foetus.	
5	**I can describe the main types of asexual reproduction in animals.** e.g. Describe fragmentation.	
6	**I can identify different parts of the male and female reproductive systems.** e.g. State the role of the fallopian tube.	
7	**I can describe how hormones affect the menstrual cycle.** e.g. Recall the hormone that triggers ovulation.	
8	**I can recall some methods of vegetative propagation in plants.** e.g. State an example of vegetative propagation.	
9	**I can describe sexual reproduction in plants.** e.g. Define pollination.	
10	**I can describe some methods of seed dispersal.** e.g. Discuss the methods by which plants can effectively disperse their seeds.	

Review questions

Retrieval

SCORCHER

1 **Recall** the mode of asexual reproduction used by:
  - a an amoeba
  - b a flatworm
  - c a strawberry plant
  - d ginger

2 **State** the function of the following structures in the human reproductive system:
  - a ovary
  - b scrotum
  - c fallopian tube
  - d prostate
  - e uterus.

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3. **Name** the parts of a flower that have the following function:
   - a attracts pollinators
   - b the site of seed development
   - c produces the male gametes
   - d produces the female gametes
   - e site where the male gamete sticks to the female part of the plant.
4. **State** the two methods of fertilisation in animals, and for each method give an example of one animal that uses it.

Comprehension

5. **Explain** why internal fertilisation exists in some animals rather than external fertilisation.
6. **Explain** four different ways that seeds might be dispersed.

Analysis

7. **Contrast** sexual and asexual reproduction to show the advantages and disadvantages of each method.
8. **Distinguish** between external and internal development of offspring, naming an example organism for each.
9. **Compare** the changes in male and female bodies during puberty by using a Venn diagram.

Knowledge utilisation

10. If a female reptile reproduces via parthenogenesis due a lack of male mates in the area, what can you **predict** about her offspring?
11. **Construct** a comic strip or diagram to model how sexual reproduction occurs in a flowering plant. Ensure the reproductive organs are labelled appropriately.
12. **Construct** a timeline of the human gestation period, indicating the names of the structure at each stage and approximate timeframes.
13. A biologist is investigating a species of frog that lives in an environment that is changing rapidly. **Propose** a reason why sexual reproduction would be better for this species of frog.
14. Certain orchids have flowers that closely resemble the shape of a female wasp. **Justify** a reason for this adaptation.

Mark Brundrett

Figure 4.57 *Drakea*, or hammer orchids, are pollinated by specific species of thynnid wasp, so their flowers have adapted to look like the females of those wasp species.

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Data questions

Meera wanted to find out the effect of substance A and substance B on hydra budding. She conducted an experiment for 6 days with 3 identical samples of hydra. She gave the same amount of food to each sample every day. She also daily added 1 drop of substance A to sample A, and 1 drop of substance B to sample B. The control was given no added substances.
The following graph shows her results.

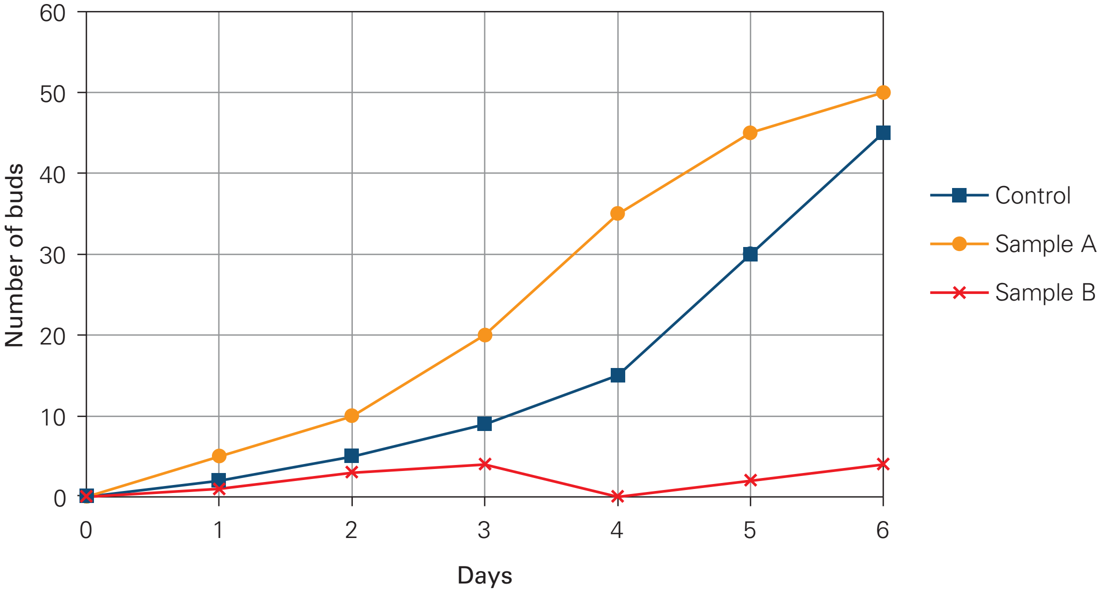

Figure 4.58 The number of hydra buds in the samples each day

Apply

1 **Identify** the sample that had the highest number of buds at the end of the 6 days.
2 **Identify** the sample that had at least one day with no buds.
3 **Determine** how many days it took for each sample to reach more than 10.

Analyse

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

Interpret

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

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STEM activity: Artificial bees to save the planet

Background information

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

Figure 4.59 *Tetragonula carbonaria*, also known as the sugarbag bee, is considered a 'safe' bee.

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

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

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

Activity instructions

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

Research and feasibility

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

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Design and sustainability

4 As individuals, sketch your own ideas, and then present to the group and discuss your key connections between how bees distribute pollen and your prototype. Discuss the best of each person's sketch.

5 As a group, sketch a design and annotate its key features, incorporating sustainable ideas. This means making sure that your prototype can be reused easily. Discuss in your group the size of your prototype, and the materials or manufacturing that would be required.

Create

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

Evaluation and modification

7 Present your prototype design to the class in a one-minute presentation of your scale diagram.

8 Discuss with the class your ideas of design and sustainability for the prototype.

9 Evaluate the issues arising from a man-made solution to an environmental problem.

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Chapter 5
States of matter

Chapter introduction

This chapter will introduce you to the amazingly minute world of particles and the idea that everything in our universe is made up of them – yes everything! You will focus on the three states of matter (solids, liquids and gases) and investigate how the particle model can explain not only their changes in state but also the properties they exhibit.

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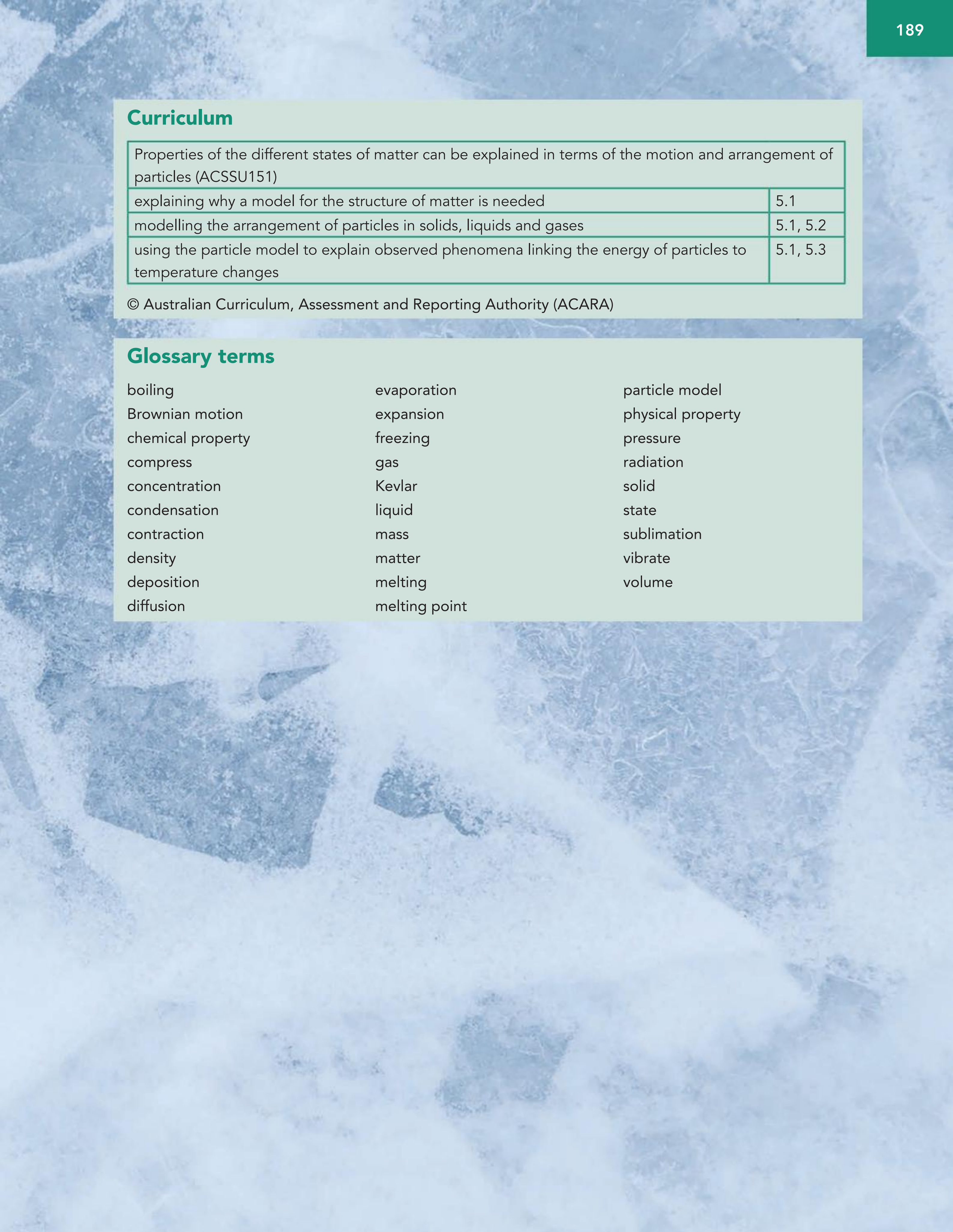

Curriculum

Properties of the different states of matter can be explained in terms of the motion and arrangement of particles (ACSSU151)	
explaining why a model for the structure of matter is needed	5.1
modelling the arrangement of particles in solids, liquids and gases	5.1, 5.2
using the particle model to explain observed phenomena linking the energy of particles to temperature changes	5.1, 5.3

Glossary terms

boiling
Brownian motion
chemical property
compress
concentration
condensation
contraction
density
deposition
diffusion
evaporation
expansion
freezing
gas
Kevlar
liquid
mass
matter
melting
melting point
particle model
physical property
pressure
radiation
solid
state
sublimation
vibrate
volume

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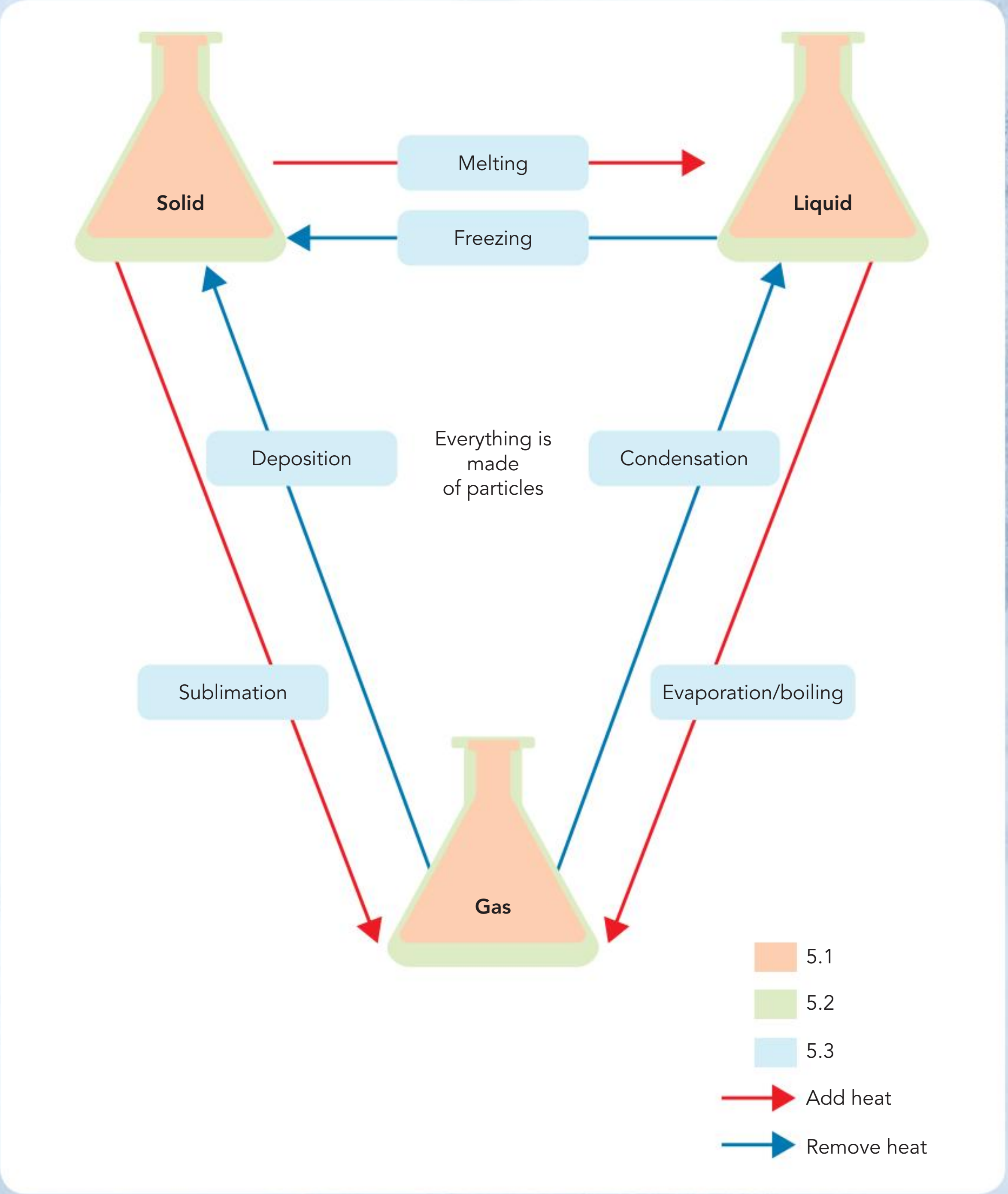
Concept map



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5.1 Particle model and states of matter

What do cars, milk and oxygen have in common? They are all made up of matter! **Matter** is essentially anything that takes up space and has **mass** and **volume**. Mass is the amount of matter in a substance or object, and volume is the amount of space the substance or object takes up. There are three **states** of matter that are commonly found in our world: **solids**, **liquids** and **gases**. (See Did you know? 5.1 for details about another state of matter.) Look at the images in Figure 5.1, and identify the solids, liquids and gases. What do the solids all have in common? What do the liquids all have in common? What do the gases all have in common? What makes them different?

WORKSHEET

matter
anything that has mass and volume

mass
the amount of substance in an object that never changes, even in space

volume
the space an object occupies

state
one of the distinct forms matter can exist in

solid
a substance that has a fixed shape and constant volume

liquid
a substance that flows freely and takes the shape of its container but has constant volume

gas
a substance that expands freely to fill space

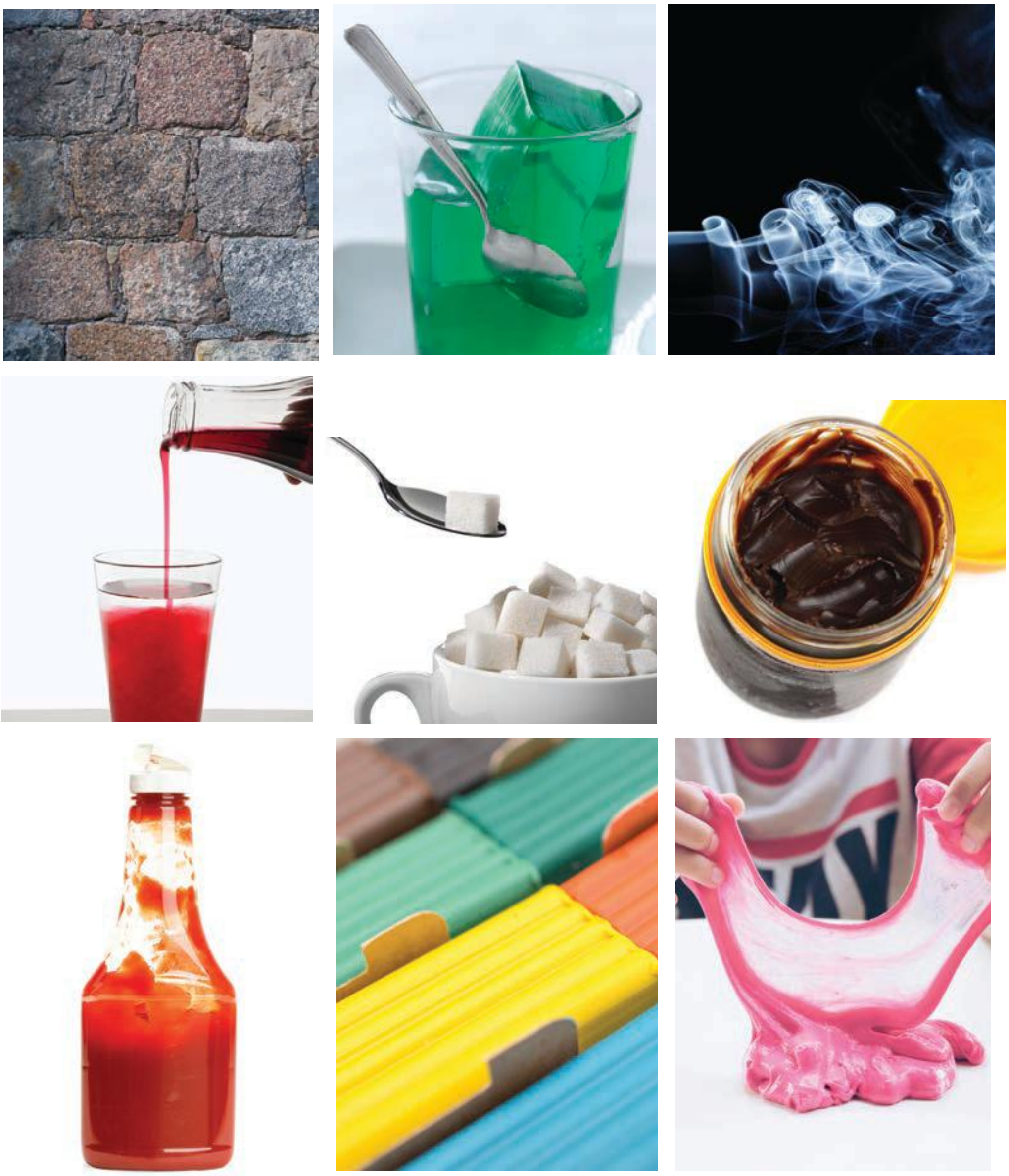

Figure 5.1 States of matter: solids, liquids and gases. What are the similarities and differences between the three states of matter illustrated above?

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Did you know? 5.1

Other states of matter

You have heard of solids, liquids and gases, but there is one other naturally occurring state of matter that is common in the universe: plasma! Plasmas are highly energised gases that are not common here on Earth, but stars, including the Sun, are covered in plasma. Plasma can be created by lightning strikes and is even used in plasma TVs in the form of ionised gas. There are actually other 'extreme' states of matter that can be created under experimental conditions and are very rare in the universe. Can you research what these are?

The particle model

The ancient Greeks wondered what would happen if you could keep dividing matter up into smaller and smaller pieces. Would you eventually come to a particle that you could not split? Although they had no way of observing them, they assumed that these particles existed and must explain some of the properties of matter. The **particle model** was born.

particle model
all matter is made of particles that behave differently depending on whether they are solid, liquid or gas

Brownian motion
the random movement of particles in fluids

Before you get into the nitty gritty, it is important to clarify what a model is. In science, models are used to represent different aspects of real-world objects (like models of trains and cars) and phenomena (like the Earth circling the Sun). Sometimes though, scientists make models to test out ideas, like making model bike helmets and seeing how well they prevent an uncooked egg from breaking when dropped. And other times, scientists use models to represent what they cannot see to try to explain how it might work. This is the case with the particle model.

Figure 5.2 Models: a model of the solar system from the 18th century and a modern model of the human body used in schools

So, to better understand what makes a solid a solid or a gas a gas, you will need to begin by looking at the particle model. This model suggests that all matter is made up of extremely small particles that are invisible to the naked eye. These particles are not only different sizes in different substances, but are also arranged differently in solids, liquids and gases. The closer the particles are to one another, the stronger the attraction between them. This helps us to understand why each state of matter has different properties.

According to the particle model, the particles that make up matter are always moving because of the energy they have; that is, the more energy they have, the faster they will move. Heat can also increase the energy of particles and therefore make them move faster. Particles will always have some energy and so will always move, even if it is just a little bit. In solids, the particles vibrate in fixed positions, but in liquids and gases, the way particles move is totally random, and in science, this is called **Brownian motion**.

Explore! 5.1

Brownian motion is named after the botanist Robert Brown, who first observed this in 1827. Do some research on the internet to answer the following questions.

1. Explain how Robert Brown first discovered that substances are made up of invisible particles.
2. Who also studied Brownian motion? What did they determine about this random movement of particles?

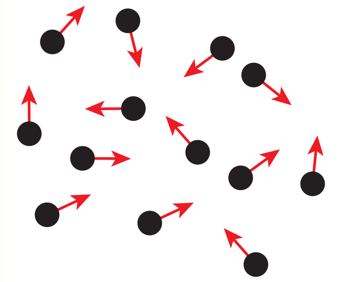

Figure 5.3 A representation of particles randomly moving

Quick check 5.1

1 Define 'matter'.
2 State the three common states of matter.
3 Summarise the key points of the particle model by completing the following sentences.
   a All matter is made up of ____________.
   b The particles are always ____________.
   c Particles move faster if the substance is ____________.

Try this 5.1

States of chocolate

Figure 5.4 One of the states of chocolate

Be careful

No chocolate is to be consumed in a laboratory classroom.

Aim

To demonstrate the three states of chocolate.

Materials

- chocolate buttons
- small beaker
- large beaker
- boiling water

Method

Heat the chocolate in a small beaker surrounded by boiling water in a large beaker.

Evaluation

1 After a few minutes, some of the chocolate will be partially melted. How many states of matter can you see?
2 What do you think is happening to the particles as they are heated up?

Solids

In a solid, the particles are packed tightly together. Due to their close proximity, the forces of attraction between particles is very strong. Because of this, the particles in solids cannot move freely; instead, they **vibrate** in their places.

vibrate periodic motion of particles

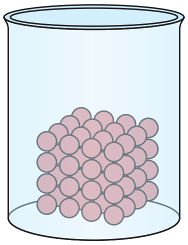

Figure 5.5 Diagram showing the arrangement of particles in a solid. Particles in a solid are very closely packed together and just vibrate in their places.

Liquids

In liquids, particles are held together by forces of attraction. As the particles are not as close together as in solids, these attractions are not as strong. This means that the particles do not vibrate in a fixed position but can move freely.

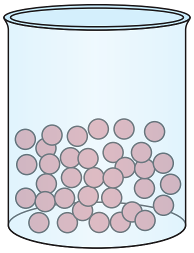

Figure 5.6 Diagram showing the arrangement of particles in a liquid. Particles in a liquid are packed closely together but can still move about and slide over one another. Gravity pulls the liquid into the shape of the container.

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Gases

The particles in a gas are in constant motion as they have much more energy than those in solids or liquids. The attraction between the particles in a gas is weak because the particles are so far apart, so the particles spread out to take up any space that is available. The movement of particles from an area of high **concentration** of particles to low concentration of particles is a process called **diffusion**.

concentration the number of particles present in a given volume

diffusion the movement of particles from an area of high concentration of particles to low concentration of particles

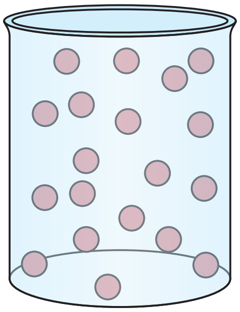

Figure 5.7 Diagram showing the arrangement of particles in a gas. Gas particles are always moving and spread out to fill any space they are in.

Try this 5.2

What state are you in?

Working with your classmates, role-play what a solid, liquid and gas look like. Make sure you can explain what the particles are doing in each state of matter.

Try this 5.3

Modelling the three states

Use polystyrene balls and pipe cleaners to make a model of each state of matter. Draw diagrams of what the three models look like.

Quick check 5.2

Copy and complete the following table.

State of matter	Describe and explain the strength of attraction between particles	Describe and explain the movement of particles	Diagram of particle arrangement
Solid			
Liquid			
Gas			

Practical skills 5.1: Self-design

Diffusion

Aim

Firstly, to investigate diffusion, the movement of liquid and gas particles as they spread out in another liquid or gas. Then, to design an investigation into how quickly particles can diffuse through water at different temperatures.

Be careful

Check to ensure that no one suffers from any respiratory issues before using the aerosol deodorant/perfume.

Materials

- aerosol deodorant/perfume
- food colouring
- eye dropper
- 4 × 250 mL beakers
- iced water, cold tap water and hot tap water
- thermometer
- stopwatch

continued...

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...continued

Method

1 Spray some aerosol deodorant/perfume in one corner of the room. Move to the opposite corner of the room and record the time it takes for the scent to reach you.
2 Put one drop of food colouring into a beaker of tap water. Observe how the colour spreads and record the time it takes for the colour to spread evenly in the water.
3 Design an experiment to determine if the diffusion of food colouring occurs faster in warm or cold water. In science experiments, every variable is kept the same except for the one being investigated. What are the dependent, independent and controlled variables in this experiment? Consider what you will need to record and how you can do it.
4 Write a hypothesis about what you think might happen.
5 After checking your design with your teacher, carry out your experiment and record your results.

Results

1 Draw a diagram showing how the deodorant/perfume particles moved through the air.
2 Draw a diagram showing how the food colouring particles moved through the water.
3 Draw up a table that summarises your results from your self-designed experiment.

Analysis

1 How do you think the particles of the food colouring were able to spread out through the water? Use the terms you have learned in class about the particle model and diffusion.
2 Explain why changing the temperature affected how fast diffusion occurred.
3 Many industries use diffusion to dispose of their waste products either as gases into the air or as liquids into rivers and the sea. Explain whether you think this is a suitable method in the long term.

Evaluation

Identify any sources of error and how you might prevent these from occurring again.

Conclusion

Draw a conclusion from this experiment on diffusion, supporting your statement with data.

Try this 5.4

Balloon pressure

Blow up a balloon slowly. You know the particles of air inside the balloon are gas particles, so they would move in all directions. They collide with one another and with the inside wall of the balloon. The collisions with the balloon wall exert an outward pressure on the wall. As more particles are added, the wall of the balloon will stretch until it cannot stretch anymore. What happens when you let go of the fully inflated balloon? Try to use the words 'gas particles' and **pressure** in your explanation.

Did you know? 5.2

Microwave ovens

Microwave ovens heat your food by using **radiation**. The radiation (in this case called microwaves) is absorbed by water particles in the food, which causes them to vibrate. This means they get hotter. The hotter the water particles, the hotter the particles in the food next to them, and it is this heat that cooks the food.

Figure 5.8 Microwave ovens work by causing the water particles in food to vibrate and heat up.

VIDEO
Animation of water particles in three states

pressure
the amount of force exerted on a given area

radiation
energy from heat or light that you cannot see, different from nuclear radiation

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Heating and cooling

The particle model suggests that if you heat up a substance, the particles will gain more energy and so they will begin to move more. As the particles start to move more, the distance between the particles increases and they begin to take up more space. Because the particles are further apart, the attraction between the particles decreases. This process of getting larger is called **expansion**. When heat is applied, gases can usually expand more than solids and liquids because the particles are not held together by strong attractive forces and so are free to spread out.

expansion the process of substances getting larger: the atoms of a substance move further apart as they heat up

So how does it work when a substance is cooled? The reverse of the process of expansion occurs: the substance cools down, the particles lose energy, they slow down, and the distance between the particles gets smaller. Because the particles are closer, they become more strongly attracted to one another, except in a gas, in which they are still relatively far apart. This process of getting smaller is called **contraction**.

contraction the process of substances getting smaller: the atoms of a substance move closer together as they cool

Try this 5.5

Are temperature and pressure related?
Take an empty plastic drink bottle, remove the lid, squeeze in the sides and put the lid back on. Now use some tongs to hold the bottle under the hot-water tap and then under the cold-water tap. Observe what happens to the dents you made in the bottle before starting. What is happening? Where is the pressure coming from? Can you explain what is happening in terms of the particle model?

Figure 5.9 In a hot air balloon, the heated air expands, becomes lighter than the air outside the balloon, so the balloon rises.

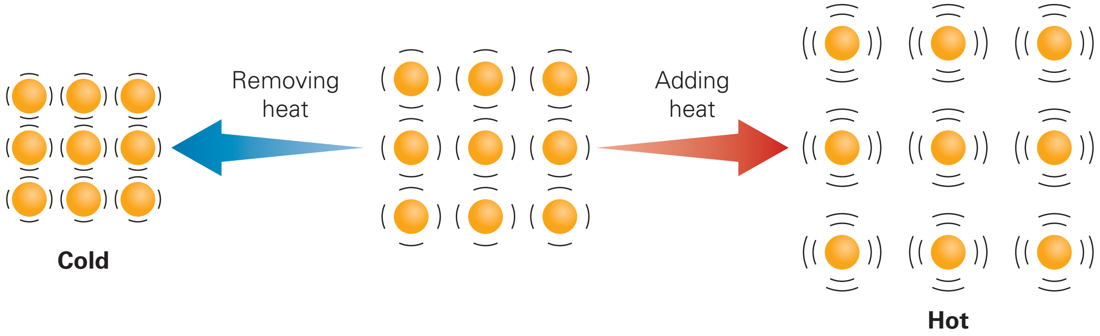

Figure 5.10 Diagram showing the changes experienced by particles with heating and cooling

Explore! 5.2

Building bridges
Architects must work with engineers when designing and constructing bridges and railway lines. They must allow for the expansion and contraction of the materials they use.

1 Explain what is done to allow for the expansion and contraction of bridges and railway lines.
2 Discuss why it is important for engineers to carefully select the materials they choose for building bridges and railway lines.

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Quick check 5.3

1 Compare the distance between particles in a gas, a liquid and a solid.
2 Use the particle model to explain what happens when a substance gains heat.
3 The particles of a substance in a sealed container are investigated at two different temperatures.
   - At temperature A, the particles are very close together but move about freely at moderate speed in the bottom of the container.
   - At temperature B, the particles are distant from one another and move about freely and very fast in all parts of the container.

   What is the state of the substance at temperature A and at temperature B?

Practical skills 5.2

Expansion and contraction

Aim

To observe and explain the expansion and contraction of solids and gases.

Figure 5.11 A ball and ring apparatus

Materials

- ball and ring apparatus
- tongs
- Bunsen burner
- bimetallic strip
- 2 metal bars of same size but different material
- wax candle
- stopwatch
- 1 balloon
- felt-tip pen
- ruler or tape measure
- coin
- bucket of ice water
- bucket of hot water

Method

1 Examine the ball and ring apparatus. Does the ball fit through the ring when it is cold? What do you predict will happen when you heat the ball? Heat the ball using the Bunsen burner and see if it still fits through the ring. What happens if you heat the ring and not the ball?
2 Look at the bimetallic strip – predict or hypothesise what will happen when you heat it. Now, heat the bimetallic strip. Describe and explain what happens.
3 Attach a coin to one end of the metal bar with the wax from a candle. Hold the metal bar using tongs and heat the other end of the metal bar with a blue Bunsen flame. Time how long it takes before the coin falls off.
4 Hypothesise what might happen if you used another metal bar of the same length and size but made of a different material. Test this hypothesis by repeating step **3** with the new metal bar.
5 Inflate a balloon. Draw two felt-tip pen lines exactly 10 cm apart on the balloon. Place the balloon in the bucket of ice water. What happens to the lines? Place the balloon in the bucket of warm water. What happens to the lines?

Results

Record all observations and descriptions from ***each*** step of the method.

Analysis

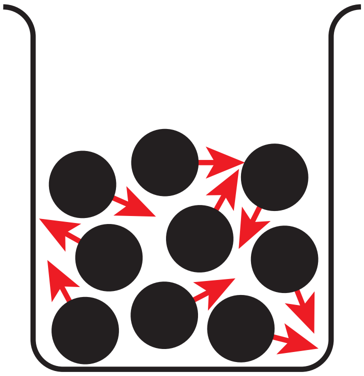
1 Write a sentence explaining your observations from ***each*** step of the method, referring to the particles, their energy, their movement, strength of their attraction etc.
2 Do you think a balloon can be used as a thermometer to measure temperature? Find out about how gas thermometers are made and used.

Section 5.1 questions

QUIZ

Retrieval

1 **Recall** the four key points of the particle model.
2 **Recall** the state where the particles are only able to vibrate in a fixed position.
3 **Identify** which state is shown in the diagram below.



4 **Name** the state that cannot flow from place to place.
5 **Name** the state where particles have the strongest forces of attraction between them.
6 **Define** the term 'diffusion'.
7 **Recall** the word that describes the change you expect to see when a metal is heated.
8 At room temperature, **recall** the state in which particles of a substance have the most energy. Provide evidence for your answer.

Comprehension

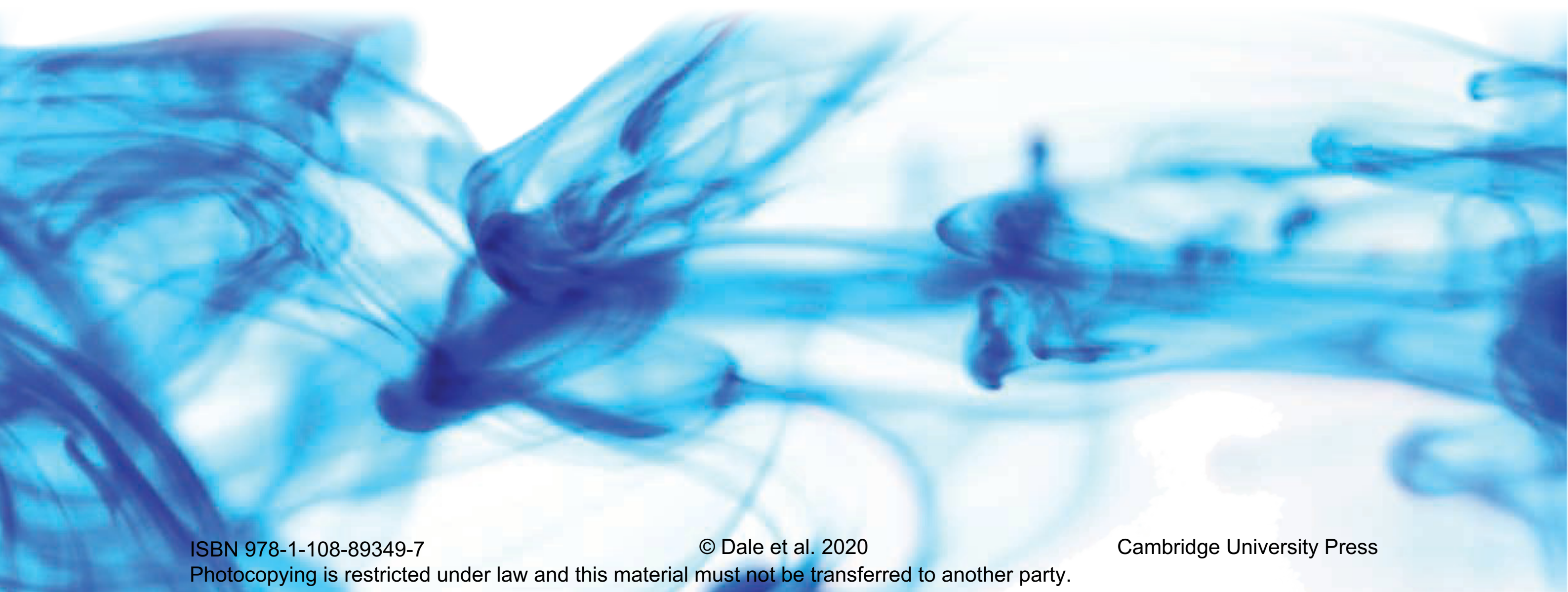
9 **Describe** what happens when you heat up particles.
10 Use the particle model to **explain** why food colouring and water mix together but food colouring and ice do not.

Analysis

11 Construct a table that distinguishes solids, liquids and gases. Include a diagram to model the different states. **Compare** the closeness of the particles and the speed at which they move, and list some examples for each.

Knowledge utilisation

12 **Discuss** how a mercury thermometer works.



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5.2 Properties of solids, liquids and gases

Scientists often refer to properties when they talk about the different states of matter, but what does that mean? The two types of properties scientists refer to are **physical properties** and **chemical properties**.

DOC WORKSHEET

physical property
the way a substance looks and acts; a characteristic of a substance that can be observed and/or measured without changing it chemically

chemical property
the behaviour of a substance when it reacts with another substance

density
how much matter (mass) is contained in a certain volume of a substance

	Property	
	Physical	Chemical
Definition	The way substances look and act. A characteristic of a substance that can be observed and/or measured without changing it chemically	The behaviour of a substance when it reacts with another substance
Examples	Colour, size solubility, melting point, hardness, boiling point, conductivity, shape and **density**	Burns or explodes in oxygen, rusts or corrodes, acidity, biodegradability
Picture		

Table 5.1 The two types of properties investigated when looking at matter

Science as a human endeavour 5.1

Superhydrophobic substances

Superhydrophobic substances have a remarkable ability to repel water. Developed by Australian researchers, they are useful for a number of purposes, such as coating fabrics or car windshields in order to improve driving visibility. They also have the potential to be used to waterproof mobile phones, prevent ice from forming on aircrafts and protect boat hulls from corroding. They are highly antimicrobial, so they could be heavily used in the protection of surgical instruments and medical equipment. Unfortunately, these coatings are very delicate and easily damaged by cleaning or any minor wear, leading to the loss of superhydrophobic properties. However, in 2020, scientists have developed a new armour-plated coating that can withstand wear and still repel water effectively.

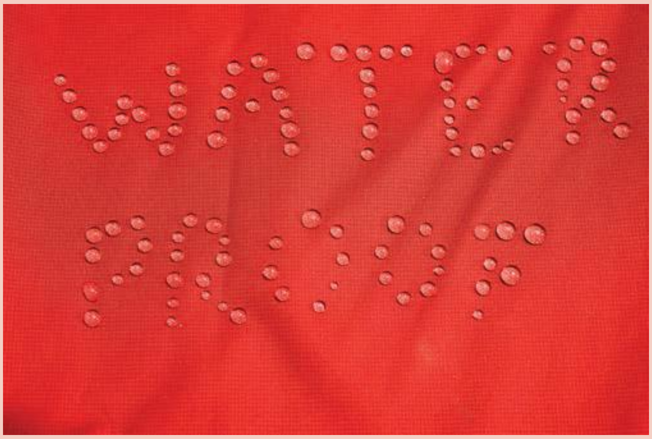

Figure 5.12 The properties of substances are used by scientists to design new materials with specific purposes.

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If you had a chance to explore the properties of solids, liquids and gases in the previous practical, you will have figured out a number of the key properties of solids, liquids and gases on your own! Let's just run through them and explain them using what you already know from covering the particle model.

Solids

Earlier in this chapter you learned that the particles in a solid are packed so tightly together and the forces of attraction between particles are so strong that the particles cannot move freely; they are fixed. This is why solids usually have a shape and volume that cannot be changed and why they are hard to break apart. This also explains why solids cannot easily be **compressed** (squashed) and cannot be poured.

compress
squeeze to make smaller

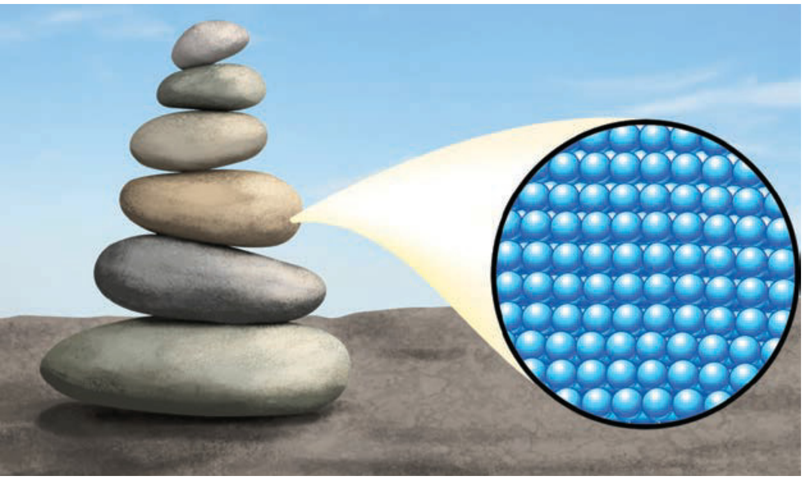

Figure 5.13 Consider these rocks and the arrangement of their particles shown in the diagram. Are their shapes fixed? Can they be compressed? Is their volume fixed? Can they flow?

Density

You may have noticed density was mentioned in Table 5.1. Density is an important physical property as it allows us to determine whether an object will float or sink. It describes how heavy or light something is for its size, but it is not the same as its weight or mass. For example, 1 kg of steel always weighs the same as 1 kg of feathers (they are both 1 kg), but the space they take up is very different. Density can therefore be defined as the measurement of how much matter (or mass) fits in a certain amount of space (or volume). So, the more dense an object is (like steel), the more mass there is in a particular volume. The relationship between density, mass and volume is written in this way:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

This is called a scientific equation.

Practical skills 5.3: Self-design

Calculating density

Aim

To design and conduct an investigation to measure the mass and volume of different objects. Then use this information to calculate the density of the objects and determine whether they would float or sink in water.

Materials

- ruler
- large measuring cylinder
- 8 small random objects

Method

When you design your experiment, consider the following questions.

- What measurements do you need to be able to work out the density of an object?
- How will you measure the mass of the random objects you have access to?
- How will you measure the volume of the random objects you have access to? What will you do with objects of regular and irregular shape?

continued...

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...continued

- How will you record your data? Perhaps a table would help.
- How will you calculate density?
- What is your prediction for the results? Which items do you expect will float and which will sink?

Before beginning, your teacher will show you how to determine volume using the water displacement method. You will then write up your intended method step by step, as though it was going to be published in a textbook. Then check with your teacher that you can begin your investigation.

Results

1 Record your prediction.
2 Write your method step-by-step.
3 Record your measurements in a table using the headers below:

Object	Mass (g)	Volume (cm³)	Float or sink?	Density (g/cm³)

4 Using the equation for density, calculate the density of the objects you had access to.

Analysis

1 The density of water is 1.00 g/mL. If an object has a density of less than 1.00 g/mL, it should float in water. If an object has a density of greater than 1.00 g/mL, then the object should sink when placed in water. Did your results show these statements to be true?
2 Were your predictions correct?

Evaluation

1 Identify the advantages and disadvantages of using the water displacement method for determining volume.
2 Would your results be different if you used a different liquid to water? Explain your reasoning.
3 Were there any steps of the practical that you would do differently if you were to repeat the task? How would you improve them next time?

Science as a human endeavour 5.2

Graphene

Graphene – a two-dimensional arrangement of the particle carbon – was discovered in 2004. It has the physical properties of being extremely strong and an excellent conductor of electricity. Since then, scientists found a way to turn this amazing material into three-dimensional structures. This may not seem very exciting, but these 3D structures are 10 times stronger than steel yet only 5% as dense! The breakthrough material can therefore help reduce the amount of steel used for infrastructure, but also excites scientists because of its applications in space programs.

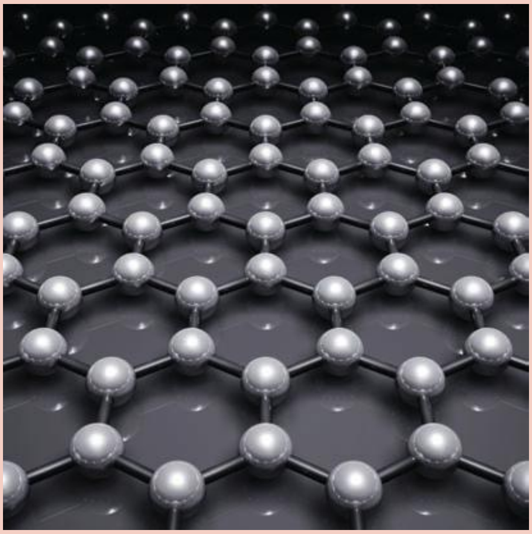

Figure 5.14 Model of the hexagonal lattice of a graphene layer

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Quick check 5.4

1. List some properties of a solid.
2. Copy and complete the table below by filling in the blank squares.

Properties of a solid according to particle model	Behaviour of a solid as a result of property
Packed tightly together	
	Hard to break apart
Particles in solids cannot move freely; they vibrate in one spot, which is called a fixed position.	

3. A substance like sand can be poured and does not have a fixed shape. Is it a solid? Explain.
4. a Explain the relationship between mass and density.
   b Explain the relationship between volume and density.

Did you know? 5.3

Artificial spider silk!

In 2017, researchers at the University of Cambridge designed an extremely stretchy, artificial spider silk that is tougher than DuPont™ **Kevlar**®. It is also environmentally sustainable as it is made from a material that is 98% water! This material offers the possibility of improving products such as bike helmets, parachutes, bulletproof jackets and aeroplane wings.

Kevlar fibres that have five times the strength of steel for the same weight and are used in a variety of clothing, accessories and equipment (Dupont™ Kevlar®)

Figure 5.15 The properties of substances are used by scientists to design new materials with specific purposes.

Liquids

Liquids are held together by the forces of attraction between particles, but these forces are not as strong as in solids. The particles of a liquid can move more freely and flow (be poured) and therefore take on the shape of the container they are in. Due to gravity, the shape the liquid takes on will always be at the bottom of the container into which it is placed. Although their shape can change, liquids have a fixed volume and mass. Like solids, they cannot be compressed into 'much' smaller spaces. The particles can actually be pushed a tiny bit closer together, but it takes a massive effort, and so we generally say that the particles in a liquid are so closely packed that they cannot be compressed.

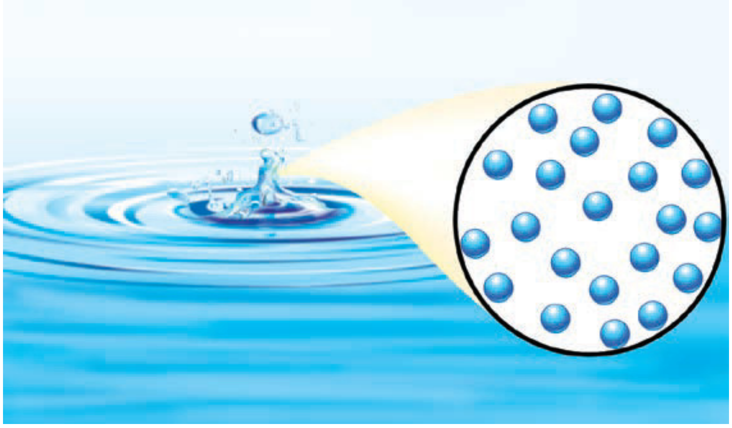

Figure 5.16 Consider the tap water and the arrangement of its particles shown in the diagram. Is its shape fixed? Can it be compressed? Is its volume fixed? Can it flow?

Remember, you learned about the idea of density being a physical property of solids earlier in this section. Density is also a physical property of liquids (and gases)! What is interesting to note, is that the density of a liquid is affected by temperature – the hotter a liquid is, the less dense it will be. Think about what you know about the particle model; how could you explain this?

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Try this 5.6

Does sugar-free help you float?

Put an unopened can of soft drink in a deep tub/jug of water. Does it float or sink?

Put an unopened can of the equivalent diet soft drink in a deep tub/jug of water. Does it float or sink? Try to explain your findings.

Try this 5.7

Make your own lava lamp!

Figure 5.17 A lava lamp demonstrates density, one of the physical properties of liquids.

Search the internet for instructions on how to make your own lava lamp at home. It is safe and easy to do. Begin by measuring the mass of a cup of oil and a cup of water (this is an equal volume). Which one is heavier? So, which one is more dense? How can you explain this using the particle model and your understanding of density? Think about how an effervescent tablet was used to power your lamp – what is used in real life? Explain how temperature affects the density of substances.

Gases

Scientists know the force of attraction between the particles in a gas is weak because the particles are far apart. This means that gases have no fixed shape or volume – they spread out to take up any space that is available. Keep in mind though, that if the container you put a gas in does not have a lid, the gas particles will bounce off the walls and spread out by diffusion. Due to the large spaces between gas particles, there is plenty of space for the particles of a gas to be squashed together or compressed.

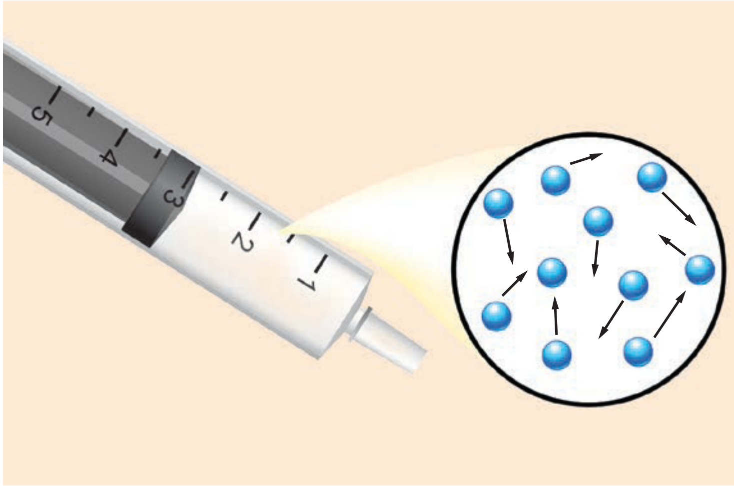

Figure 5.18 Consider the air in the first 3 cm of this syringe and the arrangement of the air particles shown in the diagram. Is its shape fixed? Can it be compressed? Is its volume fixed? Can it flow?

Explore! 5.3

Gases can be compressed because there is a lot of space between the particles. There are lots of different places where you can see the result of such compression; for example, oxygen tanks for diving, air freshener sprays, deodorants and fire extinguishers that are filled with carbon dioxide.

1. Why is carbon dioxide a good choice for extinguishing fires?
2. Use the particle model to explain why gases can be compressed.
3. Explain why carbon dioxide in a fire extinguisher is under a lot of pressure.

Figure 5.19 A common fire extinguisher you will find in the home and at school.

VIDEO
Why does an aerosol can get colder when sprayed?

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Quick check 5.5

1. Define the terms 'volume' and 'mass'.
2. Contrast the shape and volume of solids, liquids and gases.
3. Copy and complete the following table to describe the particle structure and properties of solids, liquids and gases.

State	Examples	Particle diagram	Properties
Solid			
Liquid			
Gas			

Try this 5.8

Making oobleck

Find a recipe on the internet for making oobleck (cornflour and water) and make some to play with. Ask yourself these questions.

- Can it be rolled into a ball? Can it be stretched? Does it flow and take the shape of its container? What happens when a ball of oobleck is dropped?
- What are the physical properties of oobleck?
- So, is it a solid or liquid?

Did you know? 5.4

Oobleck

Have you heard of Isaac Newton? He described how 'normal' liquids behave, and he observed that they have a constant resistance to flow (called viscosity). He said that the flow of liquids does not change unless you change the temperature or pressure. For example, it doesn't matter whether water is sitting in a cup or is being stirred in a beaker, the flow/or ease of stirring, doesn't change. Most liquids are therefore called Newtonian liquids or fluids because of his work. However, what about oobleck? What did you determine were its properties in the 'Try this' activity? Oobleck is a non-Newtonian fluid, as the flow of the liquid changes depending on the amount of stress you put onto it. You may have noticed, when you try to stir oobleck, its flow changes and it becomes thicker and difficult to stir. As you remove the force and stop stirring, it becomes like a liquid again. This is because of the way the particles move and lock together when a force is applied.

Figure 5.20 Oobleck is a non-Newtonian fluid.

Section 5.2 questions

QUIZ

Retrieval

1. **Recall** how a liquid behaves in a container and what happens if it is put in a different container.
2. **Recall** how a gas behaves in a container and what happens if it is put in a different container.
3. **Recall** how particles in a solid behave. Use these terms in your answer: fixed, vibrate, shape, compressed, attraction.

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Comprehension

4 **Summarise** the properties of a gas.

5 **Explain** why steam can be compressed but ice cannot.

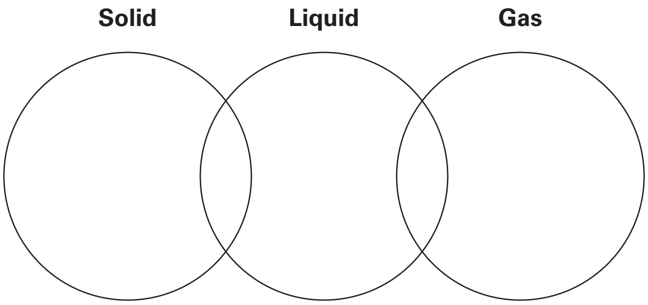
6 **Explain** two ways you could find out if a material is a solid.

7 The metal lid of a glass jar is stuck and cannot be undone. Kim runs the lid under hot water, and now the lid can be unscrewed. Using your understanding of the particle model and the properties of matter, **explain** why Kim used the hot tap.

Analysis

8 Copy the Venn diagram and **organise** the following statements into the correct place to describe solids, liquids and gases.

Strong attraction between particles that are not as close	Particles that are free to move, no strong attraction	Strong attraction between close particles
Easy to compress	Definite shape	Can be poured
Expand to fill a container	Particles in a fixed position	Difficult to compress
Fixed volume	Not a fixed shape	



9 A plastic toy unicorn floats in liquid X but sinks in liquid Y. **Infer** what this tells us about the densities of the unicorn, liquid X and liquid Y.

Knowledge utilisation

10 The table below lists the densities of several materials. **Deduce** which material will float in water. Explain your answer referring to the materials in the table as evidence.

Material	Density (g/mL)
Plastic	0.90
Water	1.00
Sulfur	2.07
Steel	7.80
Rubber	1.20

11 **Discuss** how and why the properties of a liquid are different from the properties of a gas.

12 Office chairs, like the one shown on the right, usually have a lever on the side for adjusting their height. The stand contains a cylinder and a piston that can move up and down inside it and consequently, the chairs often feel quite springy when you sit on them. **Decide** if the cylinder contains a solid, a liquid or a gas. Give reasons for your answer.

Figure 5.21 An office chair

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5.3 Changing states

DOC WORKSHEET

WIDGET
Metals and
melting points

Under the right conditions, all matter can change from one state to another; for example, from a solid to liquid, liquid to gas, or liquid to solid. This may occur because of a change in temperature or pressure, which may be naturally occurring or caused by humans.

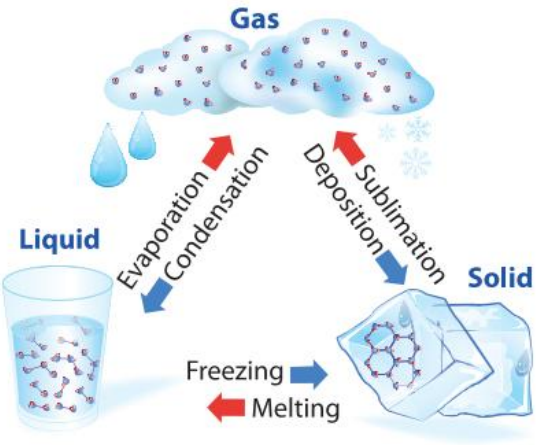

Figure 5.22 Changes in the state of water

Adding heat

You know that heating up a substance causes an increase in temperature, but did you know that if enough heat is added, the substance can actually change its state!

melting
when heat causes a solid to become a liquid

melting point
the temperature at which a specific solid melts

evaporation
when heat causes liquid to become gas

Melting: when heat causes a solid to become a liquid. Remember that heating a substance gives the particles of that substance more energy and this makes the particles move or vibrate faster. Well, if you add enough heat to the particles, the edge of the solid will eventually vibrate so much that the forces of attraction between the particles will be reduced slightly and some of them will break free. The temperature at which this occurs is called the melting point of the substance. Different substances respond to heat differently and therefore have different **melting points**. It is not surprising that when a substance changes from a solid to a liquid (by melting), its properties also change; however, the actual substance remains the same. For example, melting ice involves solid water forming a liquid form of water and the properties are very different (hardness, ability to be poured, shape), but they are both water.

Figure 5.23 Melting butter on a hot cob of corn involves a solid forming a liquid. The properties may change but it is still butter.

Evaporation (or vaporisation): where heat causes a liquid to become a gas. Adding heat, and therefore energy, to a liquid causes the particles of the liquid to move faster and spread out, and this increased distance decreases the attraction between particles. If there is enough heat added to the liquid, the particles at the liquid's surface can vibrate or move so fast they break away from the rest of the particles and form a gas. For example, at a natural hot spring, water changes state from liquid to vapour, and some of it changes back to liquid droplets

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forming clouds. Evaporation can, however, occur at a range of temperatures. Consider the clothes you hang on the line to dry. They will dry by the water evaporating from the surface of the clothes. Drying is faster when it is sunny and hot, but they still do dry on cooler cloudy days.

Boiling: the rapid vaporisation of a liquid which occurs when it is heated to a temperature called the boiling point.

When a substance reaches this temperature, it is very obvious that the substance is boiling. Vaporisation is starting to occur not just on the exposed surface but at various points throughout the liquid where bubbles of vapour form. You may have watched water boil at 100°C in a transparent kettle or saucepan. Bubbles containing water vapour begin to form low down in the water, which then expand, rise and break at the surface.

boiling
the rapid vaporisation of a liquid which occurs when it is heated to a temperature called the boiling point

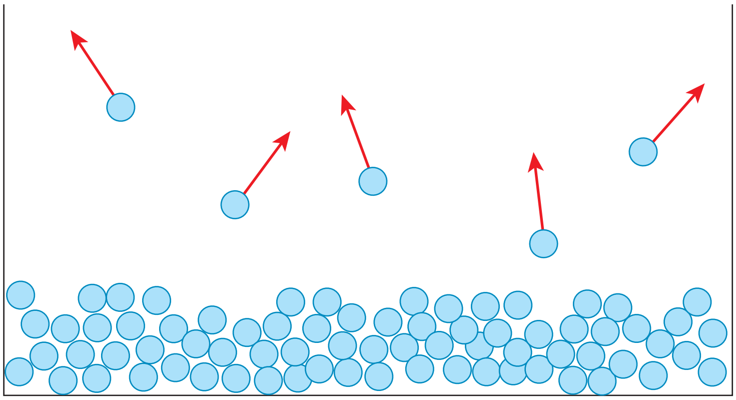

Figure 5.24 When heated, particles gain energy and spread out, allowing them to break free from the liquid and form a gas.

Figure 5.25 The bubbles in boiling in water form low down in the liquid, then expand and rise to the surface.

Explore! 5.4

As with melting points, different substances have different boiling points too.

1 Find out the melting and boiling points of some different substances.
2 Draw up a table to record the melting point and boiling point of each of the substances you investigated.

Did you know? 5.5

Melting and boiling points can change!

Melting and boiling points depend on how far above sea level you are. The higher up you are, the lower the melting and boiling points would be. Even in Toowoomba, which is only around 598 metres above sea level, the boiling point of water is around 98°C. Can you think of why this is the case?

Sublimation: where heat causes a solid to become a gas. Most substances go through the process of melting and evaporating when heated; however, there are a few rare substances that skip the liquid state at room temperature. Dry ice (solid carbon dioxide) is an example you may be familiar with.

sublimation
where heat causes a solid to become a gas, without passing through the liquid state

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Removing heat

You know that cooling a substance causes a decrease in temperature, and like heating a substance, if enough heat is lost, the substance can change its state.

freezing
where heat is lost and a liquid becomes a solid

Freezing (or solidification): where heat is lost causing a liquid to become a solid. The process of freezing is the reverse of melting. As liquid cools, the particles lose energy and move or vibrate slower. If you remove enough energy, the particles will end up just vibrating in a fixed position, and due to their closeness, the particles will form stronger attractions with their neighbours than before, and a solid is formed. The point at which this occurs is called the freezing point. Different substances have different freezing points. For example, the freezing (and melting) point of water is 0°C, while the freezing (and melting) point of oxygen is −218.8°C.

Figure 5.26 Snowflakes form when the liquid water turns into the solid ice.

Try this 5.9

Freezing water

Fill an empty plastic bottle with water (not quite to the top) and mark the water level with a waterproof marker. **Do not** use a glass bottle. Carefully place the open water bottle in the freezer and leave it to stand overnight. The next day have a look. Did the shape of the container change? Why? What might have happened if the container had been made of a hard material such as glass or stone? Explain what happened using the particle model and your knowledge of changes in state.

Did you know? 5.6

Ice is strange!

Solids usually take up a smaller volume than liquids because the particles are held closer together. However, ice is a very strange solid that actually takes up a bigger volume (and is therefore less dense) than liquid water! That is why icebergs float on the sea, rather than sink to the bottom. A bottle of water put into the freezer will puff out and sometimes break because the frozen ice takes up more space than the water. It has to do with the position of the water particles when they freeze versus when a liquid.

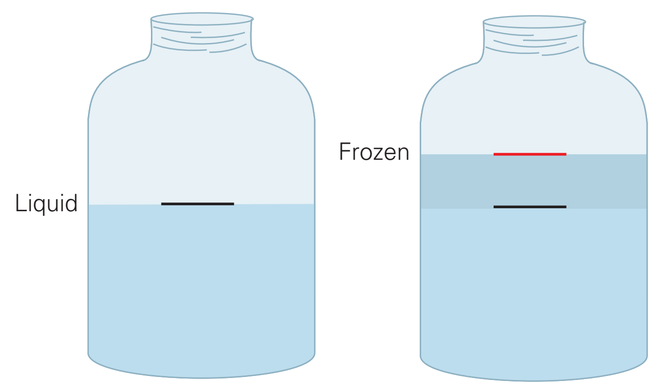

Figure 5.27 If you completed the 'Try this' Freezing water activity, you would have seen that water at a certain level (left image), stored in the freezer, increases its volume (right image). Weird!

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Condensation: where heat is lost causing a gas to become a liquid. As a gas cools, the particles of gas lose energy and slow down. When they have slowed down enough, the particles become close enough together that they begin to attract one another, and consequently form a liquid. An example you may see every day is when the steam from your shower condenses on the mirror of your bathroom as the water vapour (gas) hits the cool mirror and forms a liquid.

Deposition (also known as reverse sublimation or desublimation): where a reduction in heat causes a gas to become a solid, without passing through the liquid state. Like sublimation, deposition is rare. However, it can be seen when, in sub-freezing air, water vapour changes directly to ice without first becoming a liquid.

Figure 5.28 Condensation forms on a window overnight as the air cools.

condensation where heat is lost causing a gas to become a liquid

deposition where a reduction in heat causes a gas to become a solid, without passing through the liquid state

Try this 5.10

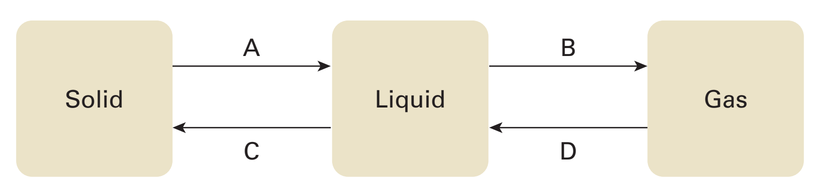
Changing state

Working with your classmates, role-play what heating a solid (a change in state between a solid and a liquid, liquid and a gas) would look like. Make sure you can explain what the particles are doing. What would occur if you were to enact what happens when a gas cools down?

Quick check 5.6

1 In your own words, define the processes of: melting, evaporation, boiling, sublimation, freezing, condensation and deposition. Add these terms to your glossary.

2 Solids, liquids and gases can change their state. In the diagram below, each arrow represents a change in state. Answer the questions below.



  a Which letter represents melting?
  b What is the name of the process represented by the letter B?
  c What happens to the particles in a solid when it becomes a liquid?
  d What is the name of the process represented by the letter C?

3 Use the particle theory to explain these questions.

  a What happens when you increase the temperature of a cube of frozen juice?
  b What happens when you increase the temperature of liquid water?

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Investigation 5.1

Heating and cooling curves

Aim

To investigate and construct the heating and cooling curves for stearic acid.

Be careful

Take care when using the Bunsen burner, heatproof mat, tripod and glass thermometer. Be aware of the boiling water.

Planning

1 Complete some research and write a rationale about kinetic theory, energy and changes of state.
2 Write a risk assessment for this investigation.

Materials

- boiling tube
- 250 mL beaker
- Bunsen burner
- stearic acid (octadecanoic acid): There should be enough to fill approximately a quarter of a boiling tube. Solidified stearic acid can be stored in the boiling tubes and reused again.
- tripod
- gauze mat
- heatproof mat
- thermometer/temperature probe
- retort stand and clamp
- stopwatch
- matches
- safety glasses

Method

1 Wearing your safety glasses, set up the equipment as shown in Figure 5.29.
2 Fill the beaker with 150 mL of water.
3 Heat the beaker on a tripod and gauze until the water just starts to boil. Maintain this at a gentle boil, pulling the Bunsen burner aside if it becomes too vigorous.
4 Record the temperature of the stearic acid every 30 seconds until it reaches 70°C. Make a note on your results table when the stearic acid starts to melt.
5 Carefully remove the boiling tube from the beaker using the clamp and record the temperature of the stearic acid every 30 seconds as it starts to cool.
6 Continue until it reaches 30°C. Make a note on your results table when the stearic acid starts to solidify.

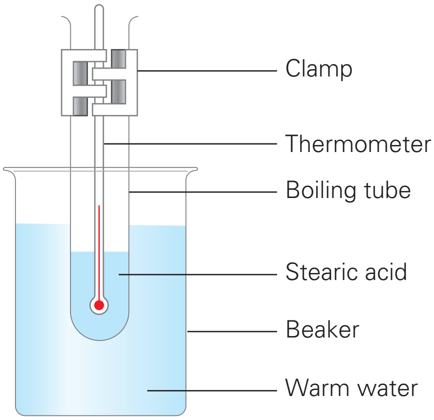

Figure 5.29 The equipment set-up you will need

Results

Draw suitable results tables for this investigation.

Draw a line graph to show how the temperature of the stearic acid changed over the total time you took measurements. You should plot both sets of results on the one graph. Use a blue pencil to plot your cooling data and a red pencil to plot your heating data.

Analysis

1 Analyse your graph to deduce the freezing point of stearic acid.
2 Compare this temperature with the melting point temperature indicated on the graph.
3 Explain what is happening to the particles in the solid stearic acid as they are melting.
4 Explain why parts of the graph are horizontal lines. Think about what is happening. Shouldn't the temperature be increasing if the Bunsen burner is still on? Where is the energy going?

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…continued

Evaluation

Limitations

1 Identify any potential sources of error in this experiment.

Improvements

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

Conclusion

Draw a conclusion from this investigation regarding kinetic theory and energy. Justify your answer with data.

Science as a human endeavour 5.3

Is hot water different from cold water?

You have just been investigating the three states of water – solid ice, liquid water and water vapour (gas). However, our understanding of the states of water is changing! In April 2016, an international team of scientists revealed that they had found signs that liquid water might actually come in two different states. The researchers were surprised to find a number of physical properties of water change their behaviour between 50°C and 60°C. This could have a massive impact on our understanding of biology and environmental science.

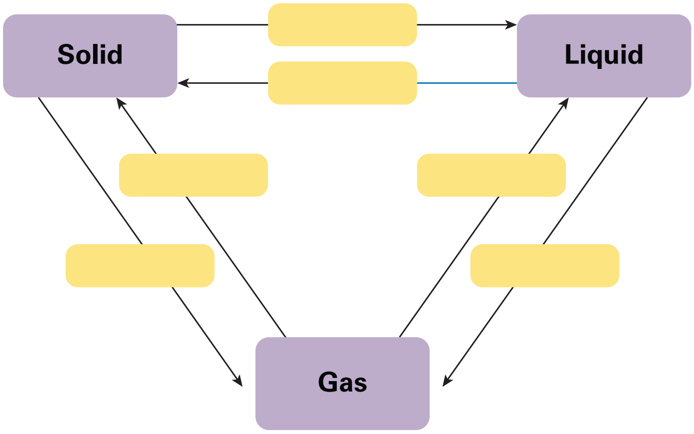
Section 5.3 questions

QUIZ

Retrieval

1 **Recall** what happens to the closeness and energy of particles when you heat up something. What about cooling something instead?

2 Copy this diagram into your notebook and **recall** the name of the process in each yellow box (for example, melting, evaporation). Then colour over the arrows with blue or red pen/pencil to indicate whether you add heat (red) or take it away (blue) to achieve that change of state.



3 For each of the following processes, **state** whether energy is added or taken away.

- a sublimation
- b evaporation
- c freezing
- d condensation
- e deposition
- f melting

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Comprehension

4 **Describe** the processes of a) ice melting and b) water boiling, using the following terms:

boil	boiling point	decrease
evaporate	gas	heat
increase	liquid	melt
melting point	particle	solid
space	speed	temperature

Analysis

5 Answer the following questions using the information in the diagram below.

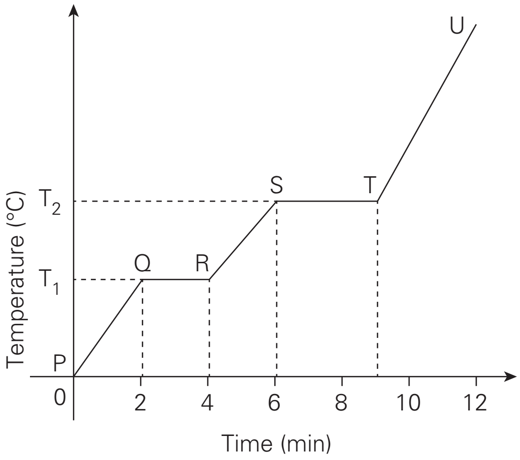

Figure 5.30 Heating curve of a substance that exists as a solid at time 0 minutes

a **Identify** what process is happening between 2 and 4 minutes.
b **Identify** the state of matter that is present at U.
c **Identify** the temperature of the boiling point.
d **Identify** the time period when the substance is all in liquid form.

6 Use the information in the table below to answer the following questions.

Substance	Melting/freezing point (°C)	Boiling point (°C)
Water	0	100
Aluminium	660	2467
Iron	961	2212
Alcohol	–130	78
Helium	–272	–268

a **Identify** the substance that has the highest melting point.
b **Identify** the substance that has the lowest melting point.
c **Sequence** the substances from lowest boiling point to highest boiling point.
d **Identify** one substance that is a gas at 20°C.
e **Identify** one substance that is a liquid at 20°C.
f **Identify** one substance that is a solid at 20°C.

Knowledge utilisation

7 In cold countries, rock faces can sometimes have pockets of water trapped inside cracks after it rains. **Decide** what might happen if the trapped water freezes when the temperature drops.

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Chapter review

Chapter checklist

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

1	**I can recall the particle model.** e.g. Define Brownian motion.	
2	**I can describe the three states of matter.** e.g. Describe the arrangement and motion of particles in solids, liquids and gases.	
3	**I can describe the properties of different solids, liquids and gases.** e.g. Distinguish between physical and chemical properties.	
4	**I can describe how matter can change state.** e.g. Construct a diagram that links the following terms together: melting, condensation, boiling, freezing, deposition, evaporation and sublimation.	

Review questions

SCORCHER

Retrieval

1 **Identify** the correct words or terms to answer the questions or fill in the blanks below.
  - a Something you can do if you want a metal to contract.
  - b Hot air ____________ because it expands and gets less dense.
  - c This metal is a liquid at normal temperatures and, because of the way it contracts and expands, can be used to measure temperature.
  - d A word that means the same as evaporation.
  - e The process of turning a solid into a liquid by heating it.
  - f When the water vapour in the air cools down overnight, it will often ____________ and form dew.
  - g Hot air balloons rise because the ____________ of its air increases.

2 **Recall** the correct properties of solids, liquids and gases to complete the following table.

	Solids	Liquids	Gases
Shape			
Volume			
Density			
Ability to flow			
Ability to be compressed			
Closeness of particles			

3 **Recall** the two measurements that you need to make to calculate the density of an object.

4 Read each statement and **state** if it is true or false, then rewrite any false statements as true ones.
  - a Oobleck behaves only like a solid.
  - b Oxygen can be compressed.
  - c A wooden toy has a fixed shape.

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- **d** Water will always boil at 100°C.
- **e** Melting points are different depending on the substance.
- **f** Steam changes back to a liquid at the boiling point.
- **g** Liquid particles have the highest speed of movement.
- **h** The particles in water are closer than in steam.
- **i** Solids and liquids have a fixed mass, while gases do not.

5 **Select** the property (A–D) that matches with the correct behaviour of the particles (1–4).

Property
A Take the shape of the container
B Are very difficult to be compressed
C Cannot be poured
D Can spread out in all directions

Behaviour of particles
1 Because their particles are very close already
2 Because their particles are not held together at all
3 Because their particles are free to move
4 Because their particles are not free to move

6 The particles of a substance are moving very fast with a lot of space between the particles. **Recall** the substance it is likely to be.

Comprehension

7 **Explain** why a solid is very difficult to compress when force is applied.

8 Temperature determines the state of a substance. **Explain** why.

9 **Describe** the likely outcome of heat being absorbed by particles.

10 Use your knowledge of the particle model to **explain** what happens in the following situations.

- **a** Decrease the temperature of steam (gas)
- **b** Decrease the temperature of liquid water

11 **Explain** the gas pressure in a full balloon in terms of the particle theory.

12 Imagine a single grain of sand. It is hard and has a definite shape. If you scoop up a handful of dry sand, you can pour it out of your hand, which sounds like the behaviour of a liquid, not a solid. It is very difficult to build a sand castle with dry sand. However, if you wet the sand, you can shape it into a sand castle.

Figure 5.31 Sand seems to have different properties when it is wet and when it is dry.

- **a** **Explain** why you might classify sand as a solid.
- **b** **Explain** why you might also classify sand as a liquid.

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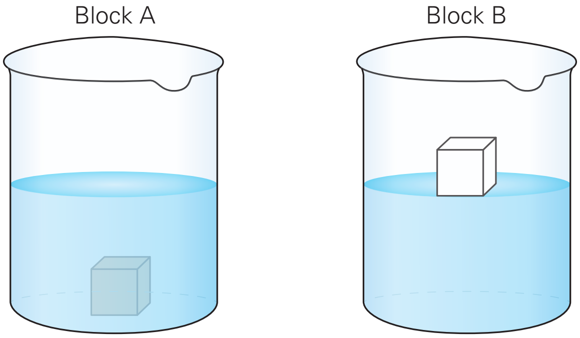
13 You get a can of creamy soda out of the fridge and leave it on the bench while you run to get a glass from the cupboard. When you return to your can, it has beads of water on the outside. **Explain** where the water came from and what change of state occurred.

14 Block A and block B are made of different materials. Each block is in a beaker with baby oil, as shown below.



- a **Explain** why block A sinks and block B floats The density of baby oil is 0.82 g/mL.
- b **Decide** if you would expect the same or different results if you warm up the baby oil in the beaker containing block B.

15 **Describe** how one gas diffuses through another.

16 The diagram below shows the process of diffusion occurring; that is, the movement of gases or liquids spreading out in another gas or liquid.

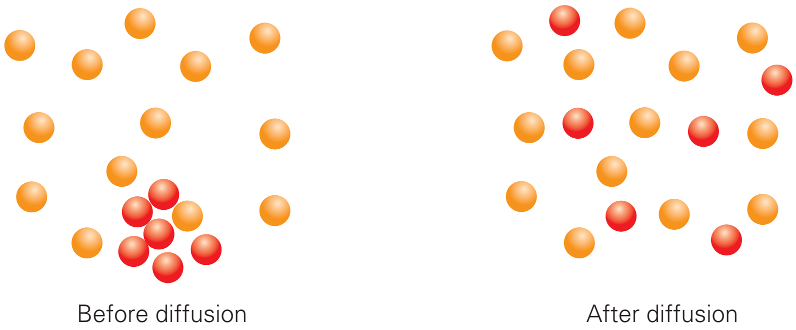


Figure 5.32 The process of diffusion illustrated as particle diagrams. The particles are constantly moving and over time, will spread out.

- a **Explain** what is happening to the red particles as they diffuse through the orange particles.
- b Factors like heat can affect how fast diffusion occurs. Would the red particles diffuse faster or slower in warm water? **Explain**, making mention of the particle model.
- c The state of the substances diffusing can also affect how fast diffusion occurs. **Decide** which one you think would diffuse faster – particles of perfume in the air or ink in water, giving reasons for your answer.
- d An effervescent tablet put into water bubbles away until it is gone and is an example of diffusion. **Decide** if this is an example of a solid moving through a liquid, liquid moving through a liquid or a gas moving through a liquid, giving reasons for your answer.

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Analysis

17 **Classify** the following diagrams as a solid, liquid or gas. What it is about substance **B** that enabled you to identify it?

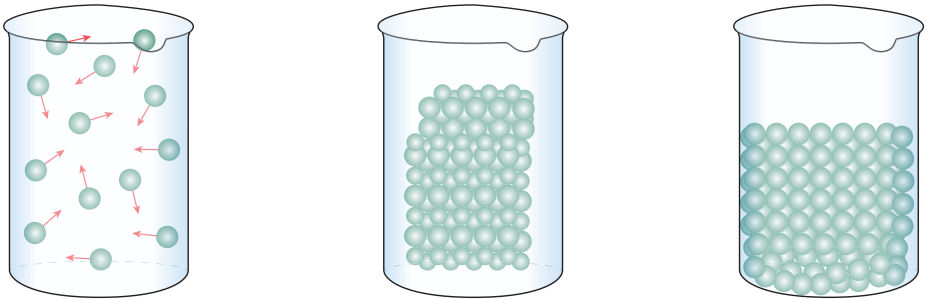

Figure 5.33 Substance A, substance B and substance C (left to right)

Knowledge utilisation

18 The particle theory of matter states that there are attractive forces and spaces between particles. **Decide** if you would expect the forces of attraction to be greater or lesser for particles that are further apart from one another.

19 Burning a fuel produces a lot of heat and the particles formed are usually in the gaseous state. **Discuss** why when solid or liquid fuels burn, the product is usually a gas.

20 When you are walking home from school, have a look at the concrete footpath. You may notice that it is not one long path but rather a series of large sections all in a row. **Propose** why you think concrete paths are constructed this way.

21 Dry ice is used in filmmaking to make creepy horror scenes. **Determine** how dry ice is useful in this case.

Figure 5.34 Horror movies often utilise the properties of dry ice.

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Data questions

Water exists naturally on Earth in three states: solid (ice), liquid (water) and gas (water vapour). Figure 5.35 shows the point at which water changes between these states at different temperatures and pressures.

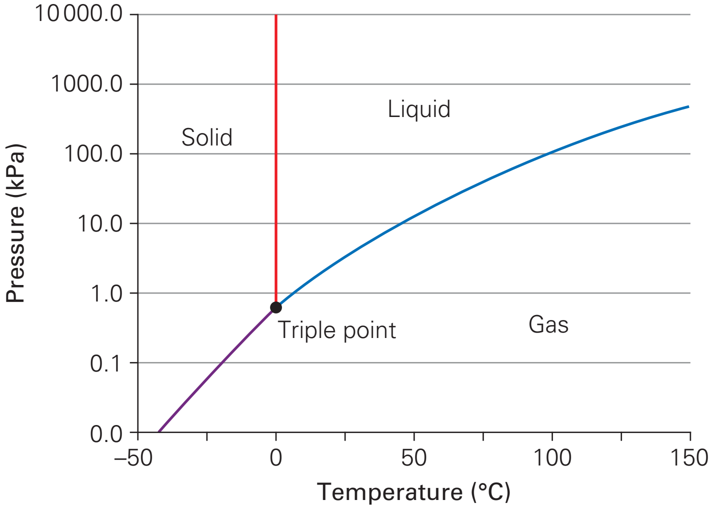


Figure 5.35 State changes of water at different temperatures and pressures. The purple line illustrates sublimation, the red line melting and the blue line the evaporation.

Apply

1 **Identify** the state of water at 50 °C and 100 kPa.

2 **Identify** the temperature of freezing at 1000 kPa.

Analyse

3 **Contrast** the boiling point of liquid water at 10 kPa pressure and 100 kPa pressure.

Interpret

4 **Infer** what is meant by the 'triple point'.

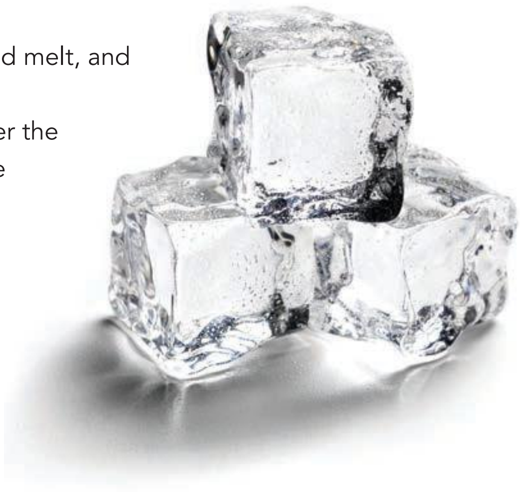
5 Given that atmospheric pressure (the pressure at sea level) is approximately 101 kPa, **explain** why we tend to encounter water in its liquid state in our daily lives (puddles, rain, rivers, lakes, coming out of taps, etc.).

6 **Predict** at what temperature liquid water will freeze at 20 000 kPa pressure.

7 **Justify** that, at atmospheric pressure (101 kPa), snow should melt, and not sublime.

8 Starting at atmospheric pressure (101 kPa), **deduce** whether the pressure needs to be increased or decreased at 0 °C for ice to sublime.

9 **Deduce** whether it is possible for water to exist as a liquid above 100 °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. Biomedical engineers act to combine engineering principles and problem-solving strategies to medicine for healthcare purposes. In this case, a biomedical engineer would study the strength and durability of our 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.

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. You will 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 based on 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.

Figure 5.36 Components of an artificial lower leg

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Suggested materials

- ruler or tape measure
- scissors
- prosthetic structural materials from home, e.g. cardboard tubes, sponges, pants, shoes, rope
- roll of duct tape

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 (socket that connects the prosthesis)		
Useability (how easy it is to use)		

Figure 5.37 An artificial limb restores functionality and independence.

Design

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, Minuses and Interesting observations, and evaluate your constructed lower leg prosthesis prototype. Make sure you reflect on the strength, durability, usability, and comfort of the prototype.

Positives	Minuses	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 6
Particles

Chapter introduction

This chapter goes beyond the idea of there being many small particles in matter and further into the exciting world of chemistry. You will look at atoms, elements, compounds and mixtures, the arrangement of the particles in these substances and compare their characteristics. You will also learn about their symbols and how to write chemical formulas. It's like learning a brand new language!

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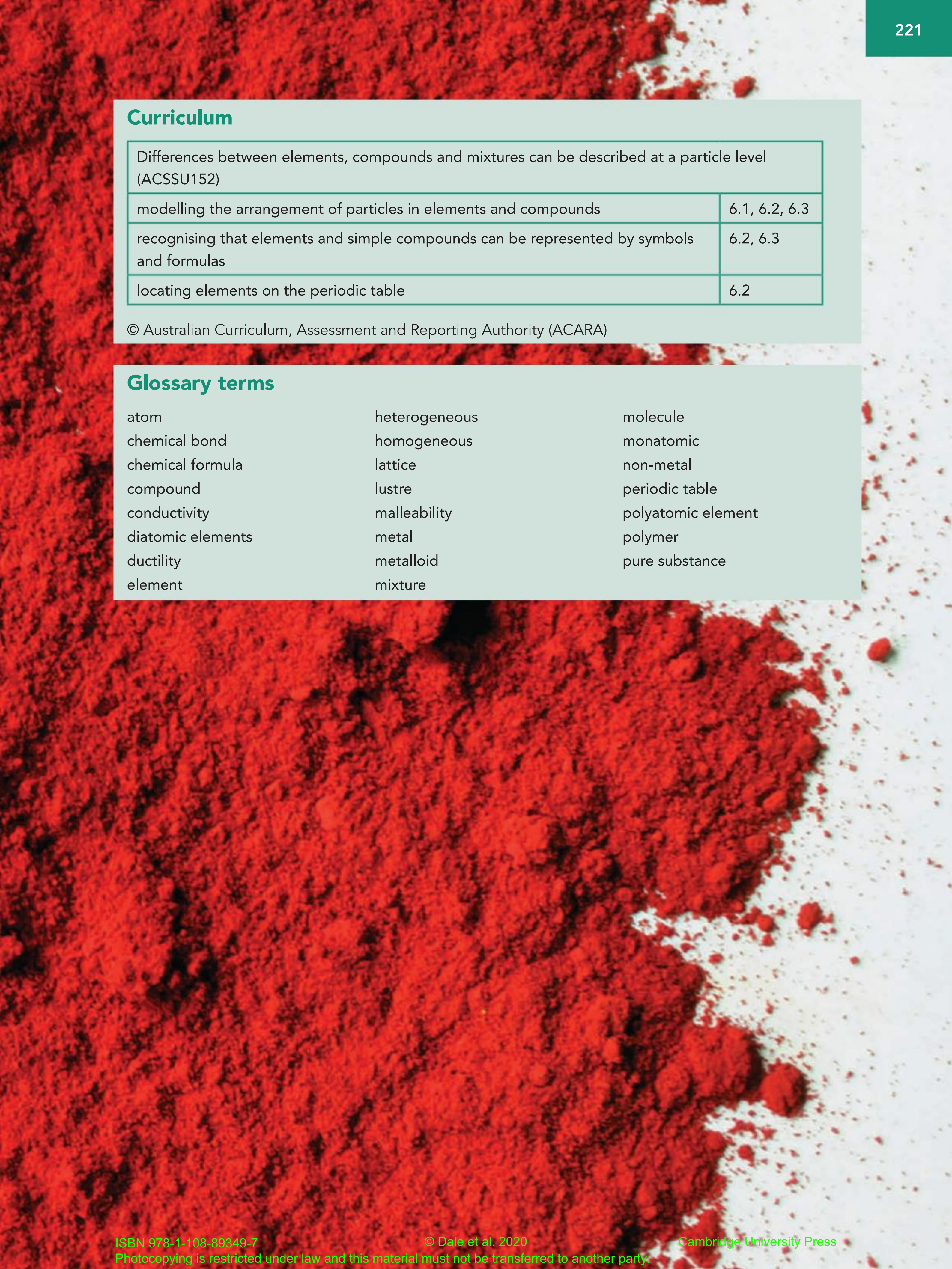

Curriculum

Differences between elements, compounds and mixtures can be described at a particle level (ACSSU152)	
modelling the arrangement of particles in elements and compounds	6.1, 6.2, 6.3
recognising that elements and simple compounds can be represented by symbols and formulas	6.2, 6.3
locating elements on the periodic table	6.2

Glossary terms

atom
chemical bond
chemical formula
compound
conductivity
diatomic elements
ductility
element
heterogeneous
homogeneous
lattice
lustre
malleability
metal
metalloid
mixture
molecule
monatomic
non-metal
periodic table
polyatomic element
polymer
pure substance

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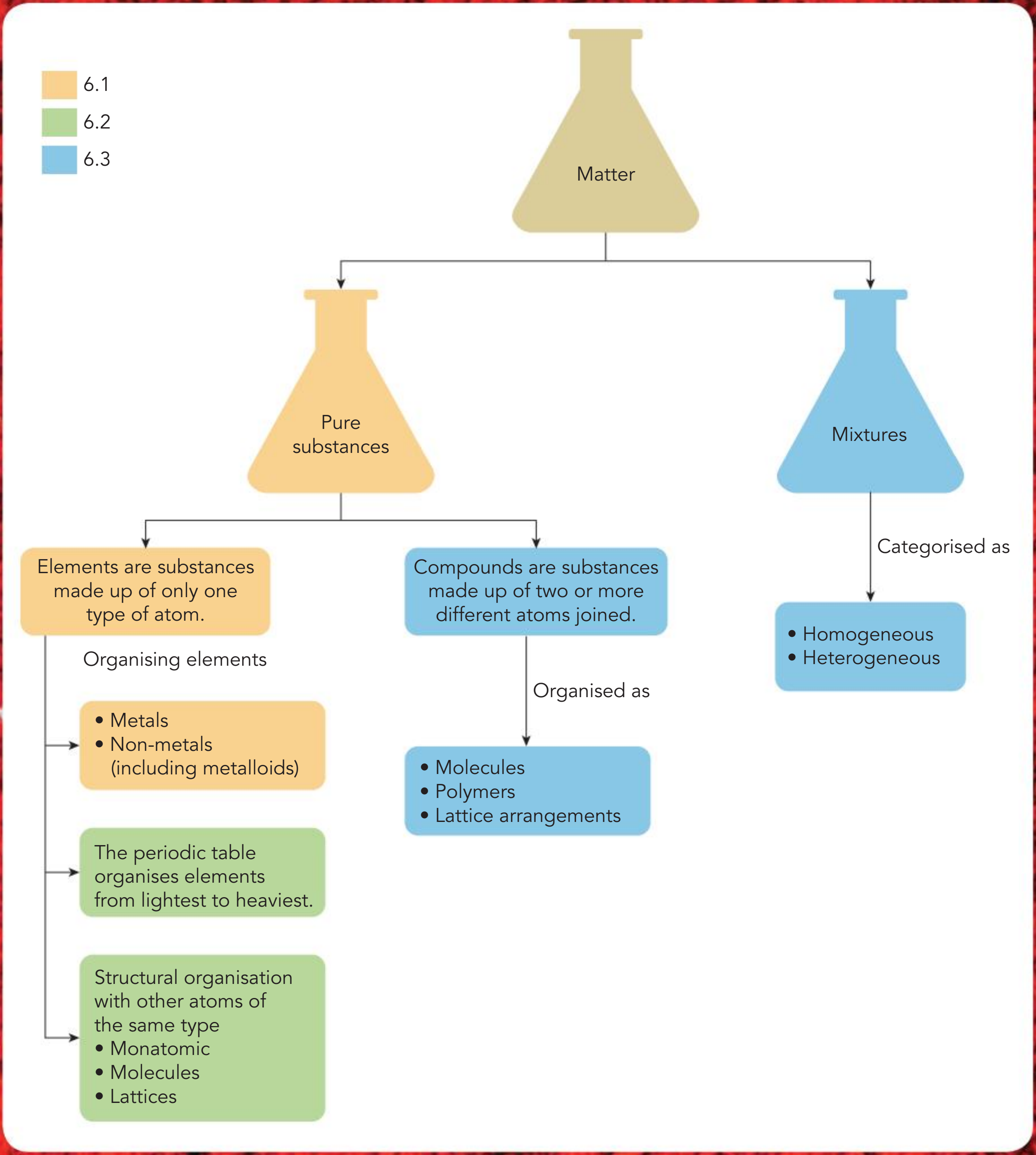
Concept map



Elements are substances made up of only one type of atom.

Compounds are substances made up of two or more different atoms joined.

The periodic table organises elements from lightest to heaviest.

Structural organisation with other atoms of the same type

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6.1 Atoms and elements

In the last chapter you learned about the particle theory of matter, and the relationship between solids, liquids and gases. Scientists refer to some of these tiny particles using the scientific term '**atom**'. This word comes from an ancient Greek word that means 'indivisible'. As you go through secondary school, you will learn more about atoms, but we are going to keep it simple for now. If you want to imagine how small atoms are, there are about 10 000 000 000 000 000 atoms in the dot at the bottom of this exclamation mark!

Try this 6.1

Cut a strip of paper 28 cm x 1 cm. Now cut it in half, and you will have two 14 cm lengths of paper. This is cut 1. 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 1 cut, 3 cuts, 5 cuts. How do you think you could keep cutting the paper smaller and smaller? Imagine this: it takes 31 cuts to get a piece of paper the size of an atom!

Pure substances and mixtures

In Chemistry, substances are often classified into pure substances or mixtures. You investigated this idea in Year 7, but now let's take it further.

A **pure substance** is made up of only one type of atom or the same groups of atoms. Atoms don't usually exist on their own – often there are two or more atoms joined together. 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).

WORKSHEET

In this chapter you will learn about two types of pure substances: elements and compounds.

An **element** is a substance made up of only one type of atom. These can be single atoms or atoms that are bonded together, but they are all the same type of atom. For example, gold is an element and is made up of many single gold atoms joined by metallic bonds. A combination of atoms are held together by strong covalent bonds is called a **molecule**. Atoms of the element hydrogen like to bind together to form molecules, each with two hydrogen atoms joined by covalent bonds.

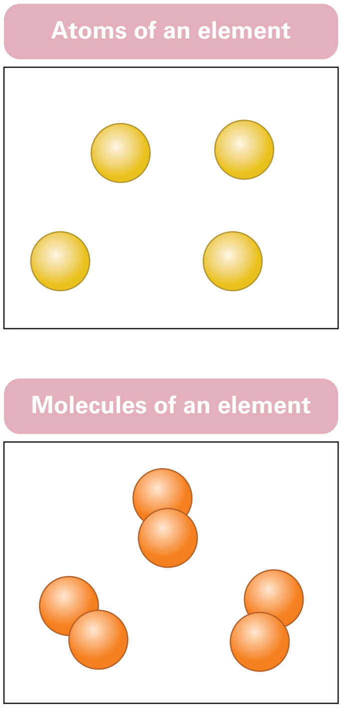
atom
the smallest possible piece of any substance; it makes up all matter

pure substance
a pure substance is made up of either the one type of atom or the same groups of atoms (molecules or compounds)

chemical bond
strong force of attraction that joins atoms together

element
substance made up of only one type of atom

molecule
two or more atoms joined together by strong covalent bonds


Atoms of an element

Molecules of an element

Figure 6.1 In an element, all the atoms are the same.

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compound
substance made up of two or more different types of atoms

mixture
a substance made up of two or more different pure substances (compounds or elements) that are not bonded together

A **compound** is a substance made up of two or more different types of atoms bonded together. For example, water is a covalent molecular compound, as it is made up of two hydrogen atoms bonded to one oxygen atom, joined by strong covalent bonds.

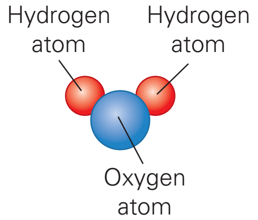

Figure 6.2 A water molecule is a compound, because it has two different types of atoms: one oxygen atom bound together with two hydrogen atoms. Water is also a pure substance, as it is made up of only one type of molecule, the one shown here.

A **mixture** is a substance that is made up of two or more different pure substances (compounds or elements) that are not bonded together. For example, air is a mixture of several different elements and compounds.

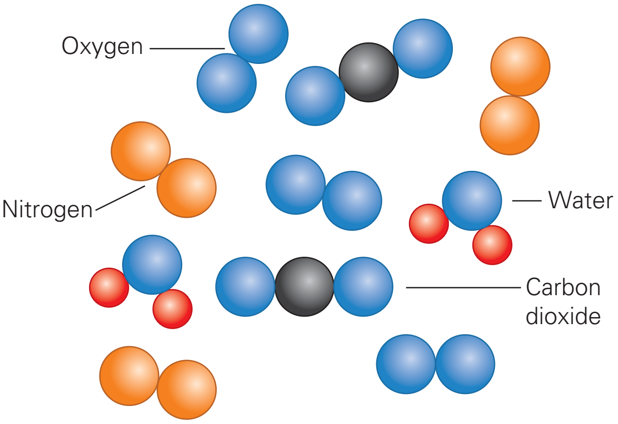

Figure 6.3 Air is a mixture of nitrogen, oxygen, argon, carbon dioxide, water vapour and very small amounts of other gases.

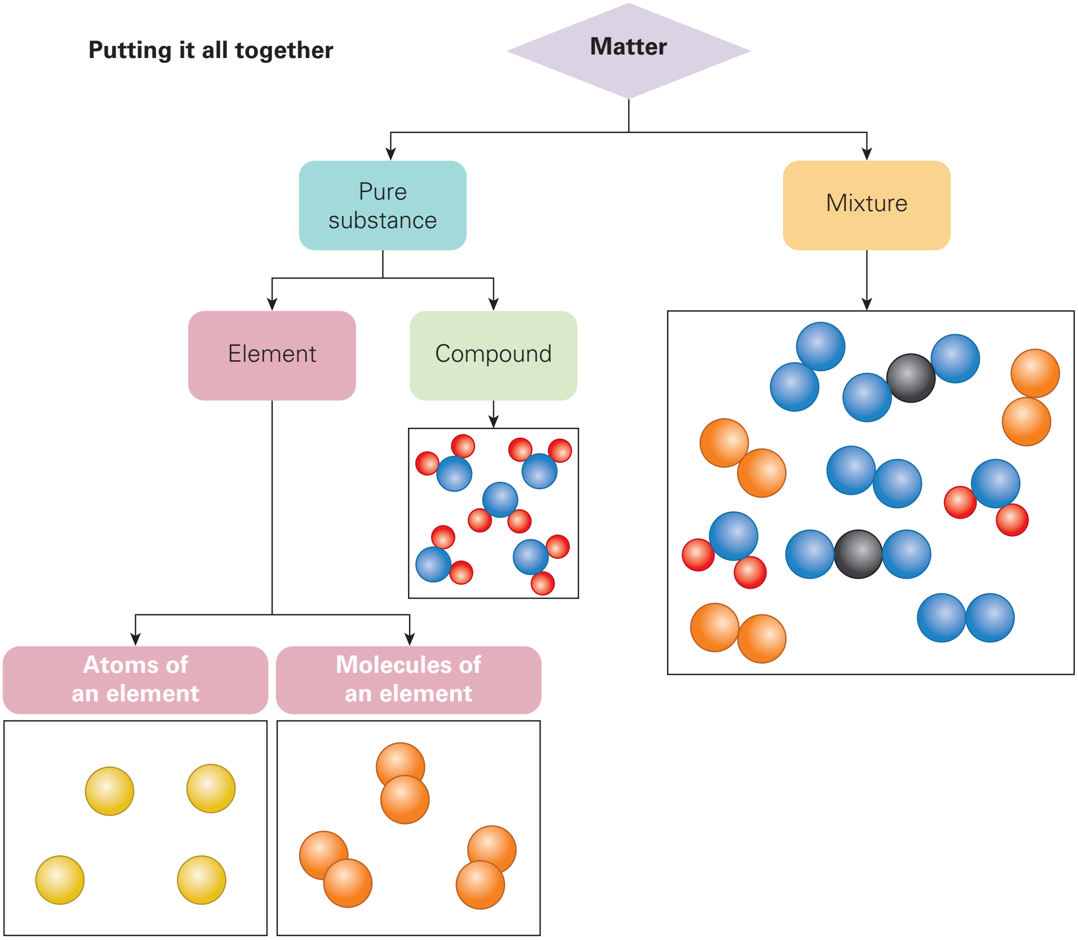

Figure 6.4 Putting it all together: matter is made up of pure substances (elements and compounds) and mixtures.

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Try this 6.2

Use Lego® or Molymod® kits to model different elements, compounds and mixtures.

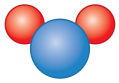
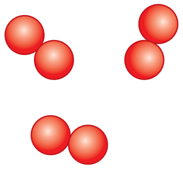
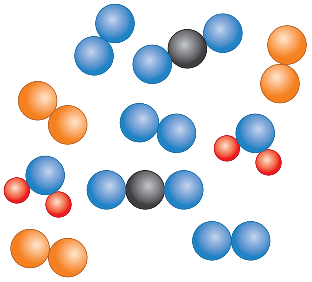
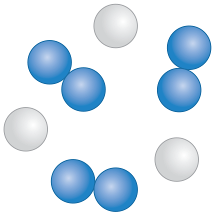
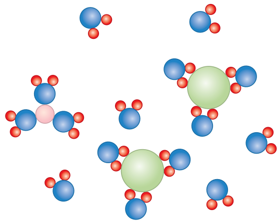
For a challenge, take it a step further: model pure elements, pure compounds, a mixture of elements, a mixture of compounds, and a mixture of elements and compounds.

Quick check 6.1

1 Rewrite the following terms matched with their correct definitions.

Molecule	The smallest piece of substance you can have; it makes up all matter
Compound	Substance made up of only one type of atom
Chemical bond	Substance made from two or more different types of atoms
Element	Two or more atoms (same or different) joined together by covalent bonds
Atom	Strong force of attraction that holds atoms together

2 Rewrite the following table, matching 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** 
Mixture of compounds	Salt and water	**D** 
Mixture of elements and compounds	Air	**E** 

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Did you know? 6.1

Scanning tunnelling microscopes

You cannot see an atom with a light microscope, which is the type of microscope you may have at school. In 1981, a type of microscope called a scanning tunnelling microscope (STM) was developed that allowed scientists to finally see atoms. Since then, the technology has improved further, and in 2018, the world record for the highest resolution microscope was achieved by researchers at Cornell University, USA. Their transmission electron microscope (TEM) measures down to an impressively small one billionth of a metre.

Figure 6.5 Transmission electron microscopic (TEM) image of coronavirus OC43, a member of the same family of viruses that causes SARS-CoV-2 (the novel coronavirus that causes coronavirus disease 2019, or COVID-19).

Figure 6.6 This scanning transmission electron microscope in the USA is able to see single atoms.

VIDEO
How does a scanning tunnelling microscope work?

Elements

You have learned 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 make up everything we know of. But what makes the elements differ from each other? They are made of different types of atoms.

The first elements to be identified were the metals gold, tin, copper and iron, and this happened thousands of years ago. Since then, more and more elements have been discovered in the Earth's rocks, soil, air and water. Can you find out how many elements have been found in nature? Scientists have also made synthetic elements, but these artificial elements are highly radioactive and, because they are so heavy, most of them break down almost as soon as they are created.

Science as a human endeavour 6.1

In 2016, scientists announced that four new elements had earned a permanent place in the periodic table: elements 113, 115, 117 and 118. They are called nihonium (Nh), moscovium (Mc), tennessine (Ts), and oganesson (Og). The search is now on to synthesise elements 119 and 120, but this is harder than it sounds! A potential recipe for element 119 would be to take a tiny mass of berkelium, a rare radioactive metal, and then blast the berkelium with a beam of titanium ions for about a year. It could take 10 quintillion (10^{18}) titanium ions hitting the berkelium and a lot of luck to potentially make an atom of element 119, and even then, it would only exist for a fraction of a second.

Figure 6.7 These rods are made of steel, a metallic compound made up of iron and carbon. Steel is ductile – it can be made into long thin rods and wires.

Grouping elements

Metals and non-metals

As in other areas of science, in chemistry we like to classify things into groups: pure substances/mixtures, solids/liquids/gases and so on. 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 general properties that the elements have in common (see Table 6.1).

metal
a substance that is shiny, can conduct electricity, can be bent, is usually silver/grey and is ductile

non-metal
a substance that is dull, cannot usually conduct electricity, is brittle and is not ductile

metalloid
a substance that has some of the properties of both metals and non-metals

Metalloids

Some of the elements in the non-metal group look like metals. One example is silicon (see Figure 6.8). Silicon can conduct heat and electricity a little, but it cannot be bent or made into wire. It is 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**. There are eight metalloids: antimony, arsenic, astatine, boron, germanium, polonium, silicon and tellurium.

Property	Metals	Non-metals
State at room temperature	Solid (exception is mercury)	Solid, gas or liquid
Colour	Silver/grey	A range of colours, including 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 is mercury)	Usually low temperature

Table 6.1 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

Figure 6.8 Three examples of metalloids. Left: Silicon is shiny and brittle, and can conduct electricity but not as well as a metal. Middle: Antimony is shiny like a metal, but brittle like a non-metal. Right: Boron conducts electricity but is brittle.

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Did you know? 6.2

Conductors and semiconductors

Some non-metals are good conductors. Carbon 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!

Metalloids have a heat conductivity between 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 the 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.

You may have heard of Silicon Valley in California and may think it's because of a number of technology company headquarters being located there. However, originally it was named after the silica sand found in the area.

Practical skills 6.1: Teacher demonstration or student practical

Metals vs non-metals

Aim

To investigate the properties of metals and non-metals

Be careful

Electrical shocks may occur.

Elements may become hot. Ensure the voltage output is not exceeded.

Turn the power supply off when changing the circuit.

Materials

- light bulb (LEDs can also be used)
- connecting wires and alligator clips
- battery or power pack
- fine sandpaper
- samples of six metals and non-metals – for example, sulfur, magnesium, silicon, copper, iron/steel, tin, zinc, aluminium, carbon

Method

1. Draw up a table like the one in the Results section. Include the six metals and non-metals you are investigating. Also select a property you would like to investigate as well as those already listed.
2. Use the fine sandpaper to rub each substance and determine its lustre – is it shiny or dull? Record your observations in your table.
3. Try to bend each of the substances – is it malleable or not? Record your observations in your table.
4. Make a prediction about the electrical conductivity of each of the substances.
5. Connect each substance as shown in Figure 6.9 – does it allow electricity to pass through, making the globe glow? Record your observations in your table.
6. Investigate your choice of property.

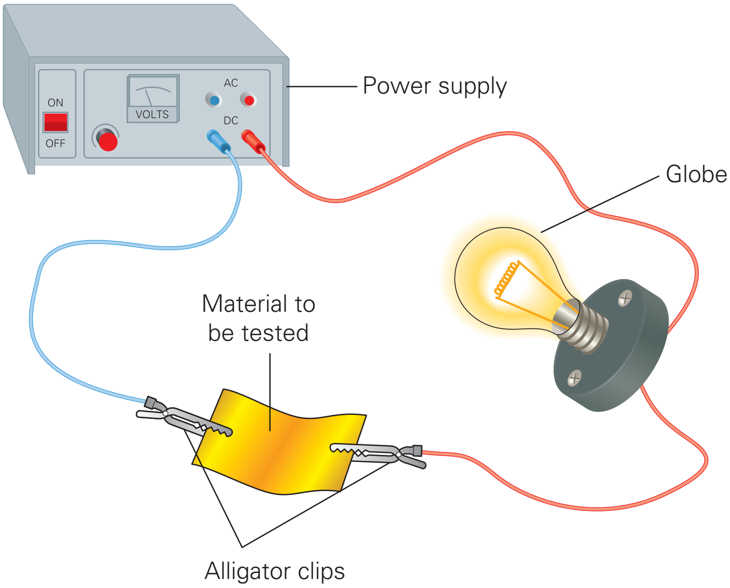

Figure 6.9 Experimental set-up for testing the electrical conductivity of different substances

continued…

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...continued

Results

Element	Lustre	Malleability	Electrical conductivity	Your choice of property
			Prediction:	
			Observation:	
			Prediction:	
			Observation:	
			Prediction:	
			Observation:	
			Prediction:	
			Observation:	
			Prediction:	
			Observation:	
			Prediction:	
			Observation:	

Analysis

1 Which of the substances you tested were metals and which were non-metals? Were there any exceptions? List them and name the group that these exceptions belong to.
2 Explain how you tested for your choice of property.
3 Recall the difference between a physical property and a chemical property. Then, summarise the physical properties that metals have in common and the physical properties that non-metals have in common. Name some exceptions and state how they are different.
4 Are the substances you tested elements, compounds or mixtures? Explain your answer by including definitions of these terms.
5 Imagine you have discovered a new element. What tests would you carry out in order to determine whether the substance was a metal or a non-metal?

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Quick check 6.2

1 Define the following key terms: element, metals, non-metals, metalloids, 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
Solid	Shiny 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 be bent

Explore! 6.1

Uses of the elements

There are many different elements, each with their own properties. Some are rare, and some are common. Some have more uses when they are combined with other elements than they do when they are on their own. Some have several different forms.

1 Investigate and report on three uses of carbon. Keep in mind that carbon has different forms.

2 Investigate and report on the medical uses of iodine.

3 Investigate and report on the uses of hydrogen in the chemical industry.

Section 6.1 questions

QUIZ

Retrieval

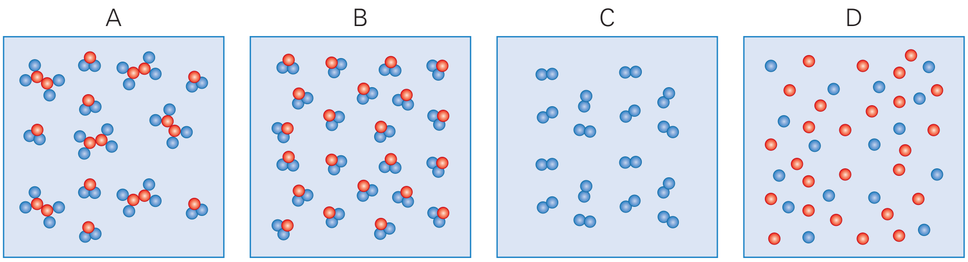
1 **Define** the terms ‘pure substance’ and ‘mixture’, providing examples of each.

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 ________ covalently bonded together.

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.

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Comprehension

6 **Describe** how Lego® blocks could be used to illustrate the difference between elements and compounds.

7 **Summarise** three of the tests you can do to find out whether a substance is a metal or a non-metal.

Analysis

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.

Knowledge utilisation

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.

11 Here are the answers to some questions. For each answer, **determine** three options for a potential question.
   - a properties
   - b atom
   - c conducts electricity
   - d compound

6.2 Organising elements

Symbols for elements

Chemistry has its own language, with all the elements represented by symbols. It is a shorthand way of writing the name of the element so that every scientist in every country can understand it.

In Table 6.2 on the following page, notice that sometimes an element's symbol comprises of the first and second letters of the English name. For example, the symbol for Hydrogen is H, and the symbol for Helium is He. This is because if Helium were to also have the symbol H, it would be confused with Hydrogen. Note that the first letter of the symbol is always capitalised and the second letter is never capitalised. But what about chlorine? You would think that chlorine would have the symbol Ch, but it is actually Cl. In this case it is distinguished by its third letter.

Sometimes the letters from the element's Latin or Greek name are used. For example, the symbol for copper is Cu. The Latin word for copper is *cuprium* and this is where its symbol comes from. 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.

DOC WORKSHEET

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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
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 6.2 Twenty elements, their symbols and some of their properties

Quick check 6.3

1 Explain why not all the elements are named after the first letter of their name.

2 Recall the reason for using symbols instead of the elements' full names.

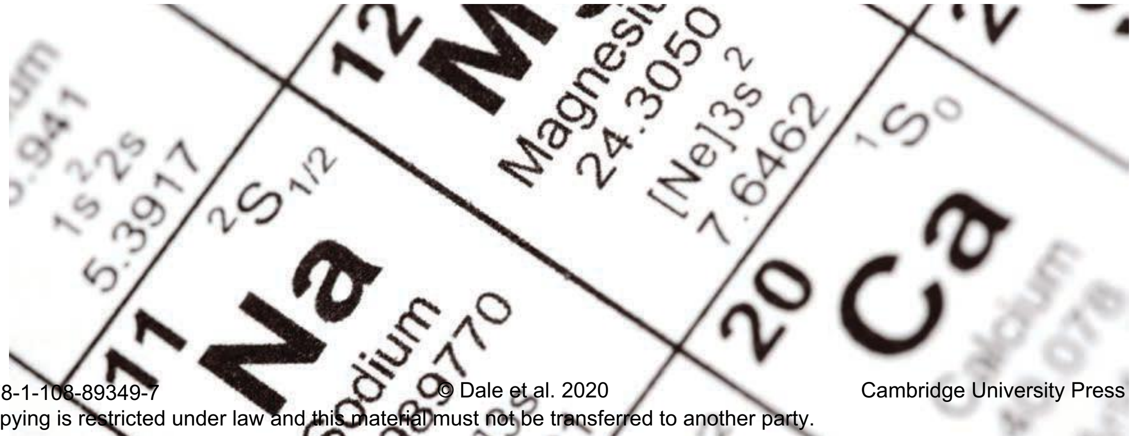
3 Refer to Table 6.2 with the 20 elements listed.

  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 Demonstrate your understanding of the periodic table by writing each element name followed by its correct symbol.
Names: hydrogen, carbon, oxygen, nitrogen, helium, sulfur, magnesium, aluminium
Symbols: Mg, O, Al, S, N, H, C, He



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Did you know? 6.3

The fabulous four!

The ancient Greeks believed that there were four elements that everything in the world was made up of: earth, water, air and fire. These elements are referred to as the classical elements. This theory was first suggested around 450 BC and was the cornerstone of philosophy, science and medicine for around two thousand years. At one stage, the four elements were even used to describe the four temperaments a person could have! Even though we no longer categorise things like this, in a way, the four elements do align with the four states of matter that modern science has agreed on: solid (earth), liquid (water), gas (air) and plasma (fire).

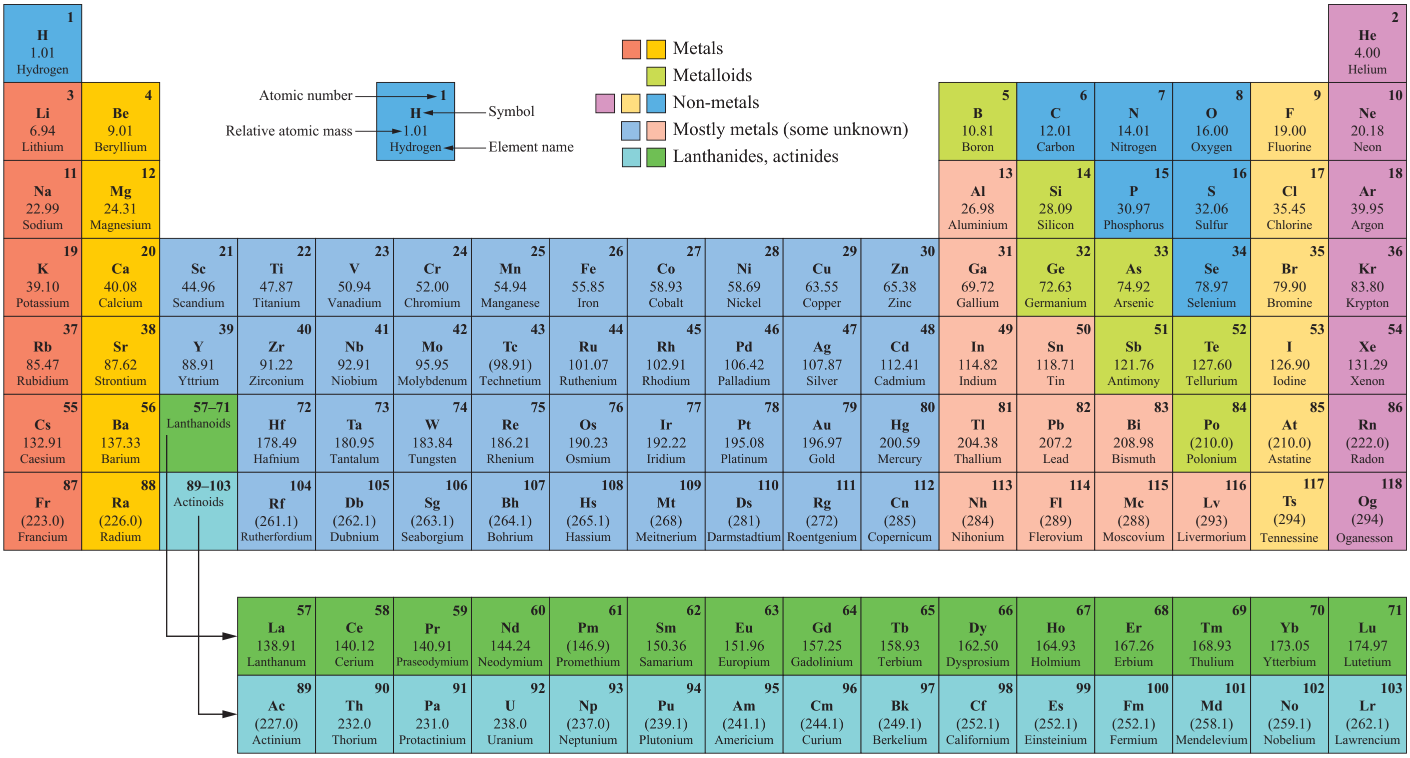
Figure 6.10 Earth, water, air and fire

Periodic table

A list of all the known elements and their symbols is called the **periodic table** (see Figure 6.11). It shows the elements in order from lightest to heaviest, and even clearly shows which elements are metals, which are non-metals and which are metalloids.

We know scientists like grouping similar things together, but imagine the challenge it would have been to organise 118 elements according to size and properties! Some elements are naturally occurring, and others have been created by humans. Some elements are radioactive.

periodic table
a list of all the known elements and their symbols



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** (226.0) Radium	89–103 Actinoids	104 **Rf** (261.1) Rutherfordium	105 **Db** (262.1) Dubnium	106 **Sg** (263.1) Seaborgium	107 **Bh** (264.1) Bohrium	108 **Hs** (265.1) Hassium	109 **Mt** (268) Meitnerium	110 **Ds** (281) Darmstadtium	111 **Rg** (272) Roentgenium	112 **Cn** (285) Copernicum	113 **Nh** (284) Nihonium	114 **Fl** (289) Flerovium	115 **Mc** (288) Moscovium	116 **Lv** (293) Livermorium	117 **Ts** (294) Tennessine	118 **Og** (294) Oganesson
			57 **La** 138.91 Lanthanum	58 **Ce** 140.12 Cerium	59 **Pr** 140.91 Praseodymium	60 **Nd** 144.24 Neodymium	61 **Pm** (146.9) Promethium	62 **Sm** 150.36 Samarium	63 **Eu** 151.96 Europium	64 **Gd** 157.25 Gadolinium	65 **Tb** 158.93 Terbium	66 **Dy** 162.50 Dysprosium	67 **Ho** 164.93 Holmium	68 **Er** 167.26 Erbium	69 **Tm** 168.93 Thulium	70 **Yb** 173.05 Ytterbium	71 **Lu** 174.97 Lutetium
			89 **Ac** (227.0) Actinium	90 **Th** 232.0 Thorium	91 **Pa** 231.0 Protactinium	92 **U** 238.0 Uranium	93 **Np** (237.0) Neptunium	94 **Pu** (239.1) Plutonium	95 **Am** (241.1) Americium	96 **Cm** (244.1) Curium	97 **Bk** (249.1) Berkelium	98 **Cf** (252.1) Californium	99 **Es** (252.1) Einsteinium	100 **Fm** (252.1) Fermium	101 **Md** (258.1) Mendelevium	102 **No** (259.1) Nobelium	103 **Lr** (262.1) Lawrencium

Figure 6.11 This periodic table includes all 118 known elements as of the year 2020.

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Try this 6.3

Look at the periodic table in Figure 6.11. Begin by finding some of the metalloids you know of, like boron (B), silicon (Si) and germanium (Ge). What colour are they in the periodic table? All the metalloids are the same colour. What are the symbols for the other metalloids?

Next, identify some of the metals you know of. Where are they in relation to the metalloids? What about the non-metals – where are they positioned in the table?

Quick check 6.4

1 Recall the purpose of the periodic table.

2 Here are some of the symbols in the periodic table that start with C or S. State the full element name for each symbol.

C	Si
Cl	S
Ca	Sc
Cr	Se
Co	Sr
Cu	Sn
Cd	Sb
Cs	Sm
Ce	
Cm	
Cf	

Practical skills 6.2

Flame tests

Be careful

Ensure appropriate personal protective equipment is worn.

Aim

To investigate the colour that a flame will go when an element is heated, and use this information to determine the metal element in four unknown samples

Materials

- heatproof mat
- Bunsen burner
- 10 flame test wires
- 5 M hydrochloric acid in labelled test tubes
- known test solutions in a test tube rack:
  - barium (barium chloride)
  - calcium (calcium chloride)
  - copper (copper(II) chloride)
  - strontium (strontium chloride)
  - sodium (sodium chloride)
  - four unknown samples

Method

1 Clean your flame wires 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.

Figure 6.12 A substance burning in the flame of a Bunsen burner, producing an orange flame

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...continued

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 in your table.

Results

	Barium	Calcium	Copper	Strontium	Sodium
Flame colour					

Flame colours of known substances

	Sample 1	Sample 2	Sample 3	Sample 4
Flame colour				
Metal				

Flame colour of each unknown substance, and the metal indicated by the colour

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.

Evaluation

Describe some sources of faults for this experiment and the improvements you would make if you were to repeat this task.

A closer look at the organisation of elements

In Section 6.1, you learned that elements are substances made up of only one type of atom. These can be single atoms or molecules, but all are the same type of atom. Let's now look at the different ways that elements can be organised: as single atoms (**monatomic**), as molecules and as **lattices**.

Monatomic

Monatomic literally means 'single atom'. A monatomic element is made up of single atoms. There aren't many of these elements in the periodic table, and all of them are non-metallic gases. You are probably most familiar with neon, as neon signs are everywhere! But perhaps you are not as familiar with the monatomic elements helium (He), 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 6.11.)

monatomic
made up of 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 all directions

diatomic element
a molecule consisting of two atoms of the same type

Molecules

Most non-metal elements have atoms organised as molecules. We are discussing elemental molecules, and so the atoms in these molecules are all the same type. Some gases, such as hydrogen and oxygen, form **diatomic elements**. These molecules have two atoms of the same type bonded together.

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polyatomic element a molecule containing more than two atoms of the same type

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 6.13. It is important, as you look at the diagram, 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.

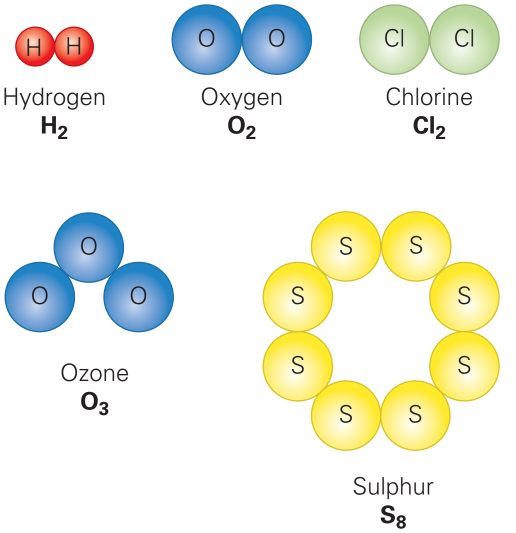

Figure 6.13 Some elemental molecules: hydrogen, oxygen, chlorine, ozone and sulphur

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 the strongest bonds. The bonds are extremely strong because the atoms bond to each other in all directions, and so it is hard to separate them completely. With metals, it is easier to make them slide past each other, provided they stay in contact with each other. What properties of metals does this behaviour remind you of?

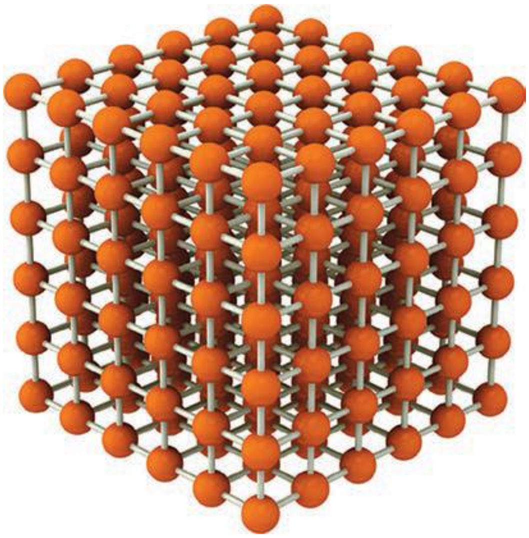

Figure 6.14 A lattice structure: every atom is attached tightly to other atoms in all directions

Try this 6.4

To imagine how metal atoms pack together and form a lattice, imagine marbles that need to be packed in a box. The marbles would be placed on the bottom of the box in neat, orderly rows and then a second layer of marbles would move into the spaces between marbles in the first layer. Give this a try, and you will model the lattice formed by metal atoms.

Figure 6.15 Stacking glass marbles of the same size in a box can be used to model how metal atoms pack together and form a lattice.

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Quick check 6.5

1. Describe the three ways in which elements can be organised.
2. Draw a simple diagram to show the arrangement of atoms in a monatomic element, a molecule of an element and a lattice of an element.

Explore! 6.2

Carbon is an element that occurs in many different forms. They all consist 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 including a picture.

Science as a human endeavour 6.2

Carbyne

Carbon comes not just as diamond and graphite, and not just as buckyballs and nanotubes, but also carbyne! In 2013, Mingjie Liu and her team in the USA calculated the properties of this superstar material and discovered that it would have more strength than any known material. In 2016, scientists in Austria were able to make carbyne. It is difficult to build, as it is a long, one-dimensional chain of carbon atoms that are linked to each other, and it is unstable – as quickly as it is made, it is destroyed. The Austrian scientists got around this by building the carbyne inside a tube made of graphene (another form of carbon).

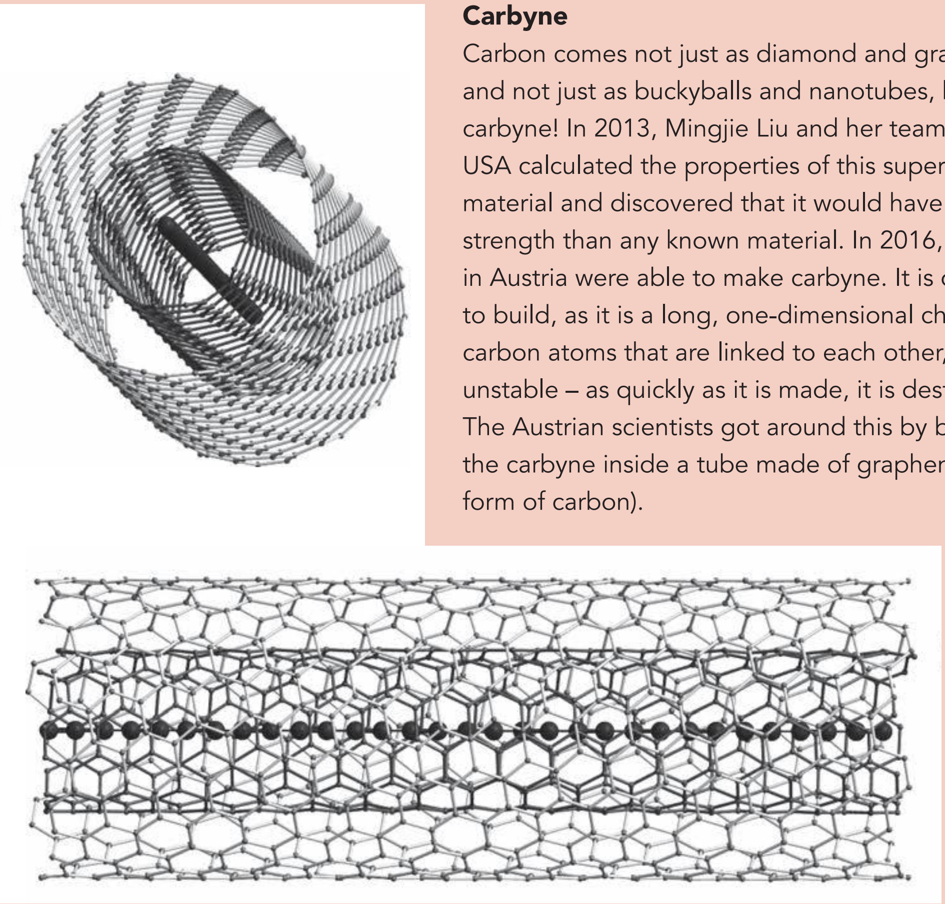

Figure 6.16 Scientists have made carbyne, a very strong material that lasts for a very long time.

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Section 6.2 questions

QUIZ

Retrieval

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 Na
  - g Zn
  - h Pb

3 **Name** all the elements in the periodic table that have symbols beginning with A.

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 **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)

Comprehension

6 **Describe** a monatomic element and an elemental molecule.

Analysis

7 **Classify** the following elements as monatomic, molecular or lattice:
helium, diamond, hydrogen, aluminium, oxygen, argon, chlorine, copper, neon.

8 **Distinguish** between an elemental molecule and a lattice. Include examples in your answer.

Knowledge utilisation

9 We use symbols to describe elements. **Propose** the reasons why we do this.

6.3 Compounds and mixtures

WORKSHEET

Compounds

At the start of this chapter, it was mentioned that in chemistry, substances are grouped into either pure substances or mixtures. Elements and compounds are both examples of pure substances. In Section 6.2, you learned about elements. Now you will look at compounds. To recap: a compound is a substance made up of two or more different types of atoms. For example, water is a compound. It is made up of two hydrogen atoms 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.

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 can be 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 Section 6.2 (in the Explore! box): graphite, diamond and buckyballs. Hydrogen has the following properties: it is colourless, odourless, tasteless, non-toxic, non-metallic and highly combustible. However, the properties of the compounds formed from carbon and hydrogen are very different from the two elements on their own. Figure 6.18 shows examples of the uses and properties of compounds made of only carbon and hydrogen.

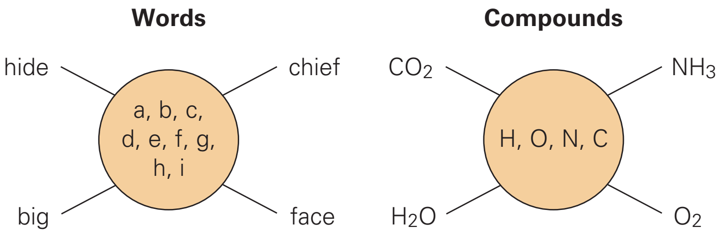

Figure 6.17 Elements are like the letters of the alphabet – letters can form thousands of words, and elements can form millions of compounds.

Figure 6.18 Substances that contain only carbon and hydrogen. From top to bottom: methane (natural gas); hexane (solvent in glue for shoes); octane (a component of automobile fuel)

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Organisation of compounds

polymer
a long molecule made of a chain of atoms in a pattern that repeats

A molecular compound is always the same size and shape, and it always has the same elements and number of atoms. It can be relatively small – a few atoms joined together – or it can be huge, like plastics that are made up of thousands of atoms and stretch for metres. The atoms in compounds can be arranged in three different ways: as a molecule, a **polymer** or a lattice. These are summarised in Table 6.3.

Arrangement	Description	Examples
Molecule	Groups of different atoms held together by covalent bonds. A particular compound always has the same elements in the same ratio.	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 3D 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 6.3 The atoms in a compound can be arranged into a molecule, a polymer or a lattice.

Science as a human endeavour 6.3

Bioplastics

More plastic has been produced in the past 10 years than in the previous 100 years! Because of plastic pollution, in the past decade companies have been developing bioplastics. Bioplastics differ from conventional plastics in that they can be:

- biodegradable – tiny micro-organisms that are in the environment convert these materials into natural substances, such as water, carbon dioxide and biomass
- biobased – the material is derived from biomass (plants) to some degree; for example, some bioplastics are made from corn
- both biodegradable and biobased.

Figure 6.19 There are companies around the world making plastic bags from biodegradable materials such as starch. Some companies are even developing plastic that can dissolve in water and claim that the water is still drinkable!

The term 'bioplastic' refers not just to biodegradable plastics, but also to petroleum-based plastics that are degradable, plant-based plastics that are not biodegradable, and plastics that contain both petroleum-based and plant-based materials that may or may not be biodegradable. Given that many retailers now do not provide single-use plastic bags, scientists and engineers are hopeful that the way we use plastic polymer products will change.

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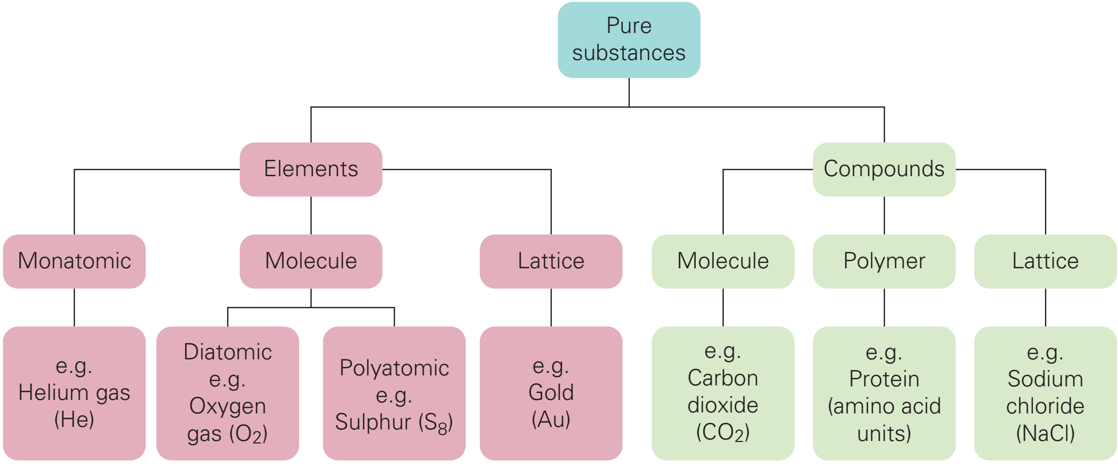

Figure 6.20 Summing up: the organisation of atoms in elements and in compounds

Did you know? 6.4

Polymer bank notes

In 1988, Australian scientists at the CSIRO developed the polymer bank note – the first in the world. Now polymer bank notes are also used in thirty other countries. Australian bank notes 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 film.

Figure 6.21 Australian polymer bank notes

Quick check 6.6

1 Define 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.

Symbols for compounds

A **chemical formula** is a shorthand way of describing 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

Let's go through some examples.

- Carbon dioxide in the air has the chemical formula CO_2. This means that one 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.
- Sodium sulphate, 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), sulphur (S) and oxygen (O). Each basic unit of sodium sulphate contains two atoms of sodium, one atom of sulphur and four atoms of oxygen.

Figure 6.22 Sodium sulphate is a compound used in common household detergents.

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What if the formula has a bracket 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 molecule 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.

Try this 6.5

Consider the compound sodium bicarbonate, more commonly known as baking powder, $NaHCO_3$. 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 rules to follow depending on whether the compound contains a metal and a non-metal, or only non-metals.

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*.

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 and non-metal compounds

4 When you are working with 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 a prefix di- and 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 6.4 summarises the prefixes used, depending on how many atoms of the second element there are in the compound.

5 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!

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 6.4 Prefix used at the start of the second element when naming compounds containing only non-metals

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Practical skills 6.3

Making a compound

Be careful

Do not look directly at the reaction. The reaction is very bright and can damage your eyes.

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
- wooden tongs
- Bunsen burner and matches
- heatproof mat

Method

1. Examine the piece 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 6.23.

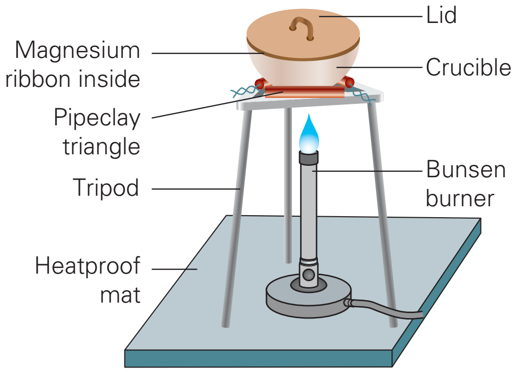

Figure 6.23 Experimental set-up

3. Put on your safety glasses. Heat the crucible with a blue flame, and every so often, monitor the reaction by using the tongs to carefully lift the edge of the crucible lid.
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.

Results

Record your observations.

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.

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Quick check 6.7

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	$CaCO_3$		

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, twelve 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 and one oxygen atom.

Practical skills 6.4

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
- limewater
- straw
- three test tubes
- Bunsen burner
- matches
- heatproof mat
- wooden tongs
- paper towel
- retort stand and clamp
- delivery tube and stopper
- spatula

continued…

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...continued

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 6.24 as a guide to the steps that follow.

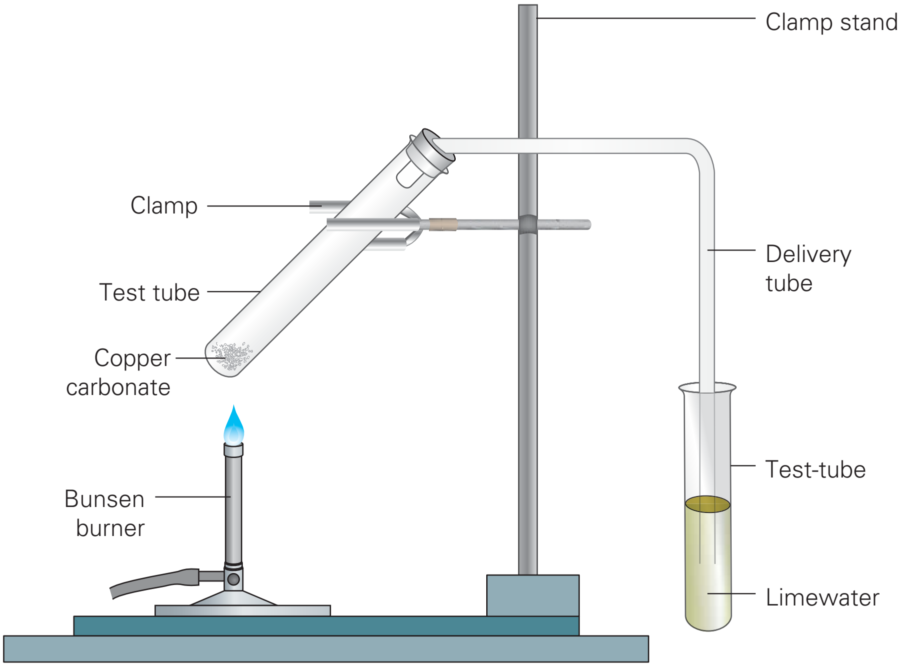

Figure 6.24 Experimental set-up

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.

Analysis

1 What caused the change in the limewater when you blew into it?

2 Describe the copper carbonate before and after heating. Mention the changes you observed in the limewater.

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?

Evaluation

Identify any faults in the method for this experiment and how the experiment could be improved if it were to be carried out again.

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Mixtures

Mixtures are not pure substances like elements and compounds. You may remember from Year 7 that a mixture is a substance made from two or more different pure substances that have been mixed together and can be physically separated. The components of a mixture can be separated, as they are not combined in a chemical way. Some examples of mixtures that you may be familiar with are soft drinks (a mixture of sugar, water, carbon dioxide and colouring), a cup of tea (a mixture of tea leaves and water), tap water (a mixture of water, fluoride and chlorine) and spaghetti bolognaise (a mixture of tomatoes, beef, garlic, chillies and thyme).

Mixtures have different properties from those of compounds, as there is no chemical bond between the parts of a mixture.

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

Figure 6.25 This caesar salad is an example of a mixture – the components are not chemically combined, and so they can be separated.

Table 6.5 summarises the differences between compounds and mixtures.

Mixtures can be broadly classified into two categories: **homogeneous mixtures** and **heterogeneous mixtures**.

	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 is easily 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

Table 6.5 The differences between a compound and a mixture

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Homogeneous mixture
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. Examples: air, water, chocolate pudding, soft drink.

Figure 6.26 Soft drink is an example of a homogeneous mixture.

Heterogeneous mixture
Can easily be separated into its parts, and those parts retain their original properties. The mixture is not blended together evenly and is 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. Examples: trail mix, choc chip cookies, pizza topping.

Figure 6.27 Pizza is an example of a heterogeneous mixture.

Symbols for mixtures

You know about writing symbols for the different elements and how to write the symbols for compounds, but what about mixtures? Because mixtures are substances made from two or more different pure substances mixed together that can be physically separated and are not combined in a chemical way, you will never have to write a chemical formula for mixtures. The elements and compounds that make up the mixture retain their own symbols/formulas.

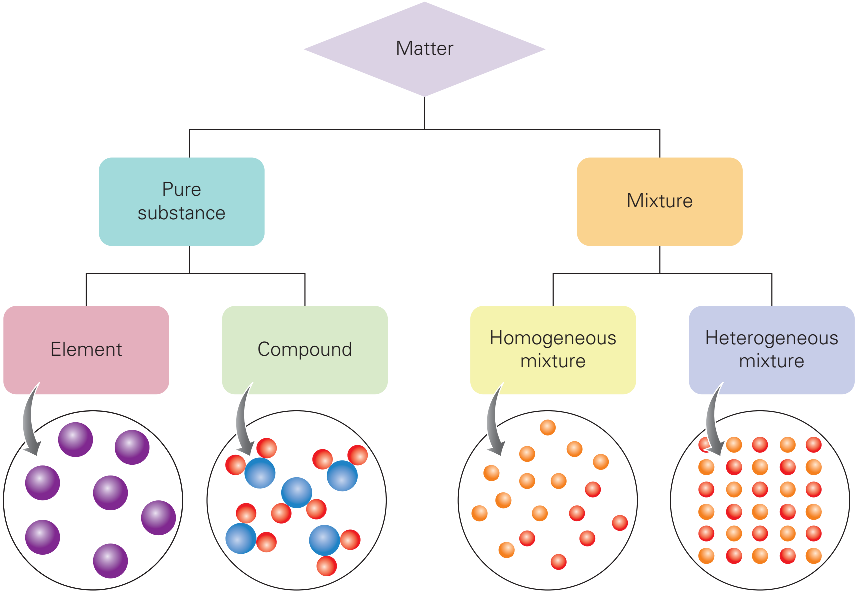

Figure 6.28 Matter consists of pure substances and mixtures. In this chapter, you have learned about both these groups.

WIDGET
Elements, compounds and mixtures

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Try this 6.6

Make a revision flip book

Using three pieces of white A4 paper, in portrait orientation, cut from the middle of the top to the middle of the bottom of the paper, so you end up with six long, thin rectangles. Stack the rectangles on top of each other, turn the rectangles to landscape orientation, and place three staples, equally distant, across one long edge. Using your scissors, and Figure 6.29 as a reference, cut the rectangle into thirds.

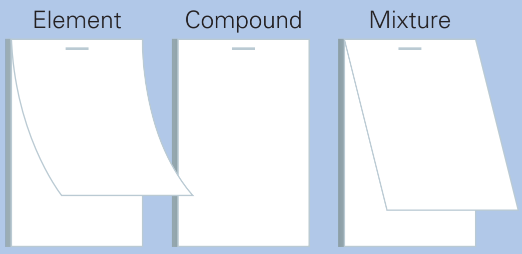

Figure 6.29 Your revision flip book

First, label the three top panels with the words 'element', 'compound' and 'mixture'. Next, decide what key concepts you have learned in this chapter, to add to your flip book. Consider examples, definitions, symbols/formulas, diagrams, organisation and so on. Then hop to it!

Investigation 6.1

Investigating heat energy from alcohols

Be careful

To be conducted in a fume hood or well ventilated area.

Aim

To compare the heat energy produced by burning alcohols that have different numbers of carbon atoms.

Planning

1. Write a rationale about carbon-based fuels, the number of carbon atoms in them and how they release energy.
2. Write a specific and relevant research question for your investigation.
3. Identify the independent, dependent and controlled variables.
4. Write a risk assessment for this investigation.

Materials

- stand and clamp
- 150 mL conical flask
- 100 mL measuring cylinder
- thermometer
- spirit burners containing:
  - methanol
  - ethanol
  - propanol
  - butanol
- stopwatch
- matches
- eye protection

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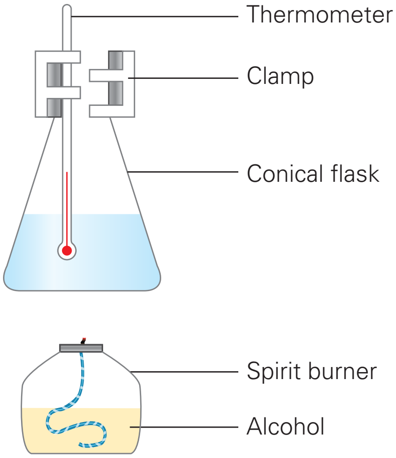
Method



1. Add 100 mL of water to a conical flask and clamp it at a height where a spirit burner can be placed below.
2. Record the initial temperature of the water in your results table.
3. Light the wick of the spirit burner and let it burn for one minute.
4. Replace the spirit burner cap to extinguish the flame.
5. Record the final temperature of the water in your results table.
6. Repeat stages **1–5** with the three other alcohols.

Results

Name of alcohol	Formula	Number of carbons in the chemical compound	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)
Methanol	CH_3OH	1			
Ethanol	C_2H_5OH				
Propanol	C_3H_7OH				
Butanol	C_4H_9OH				

Draw a graph that shows the relationship between the number of carbons in an alcohol and the change in temperature.

Analysis

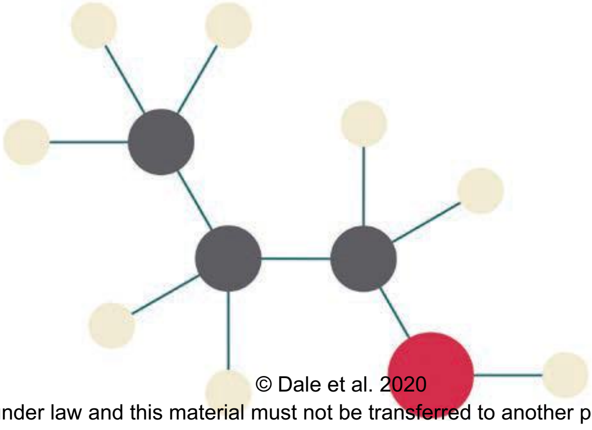
1. Describe any patterns, trends or relationships in your results.
2. Explain any trends you have identified.

Evaluation

1. Identify any limitations in your investigation.
2. Suggest some improvements for this experiment.

Conclusion

Draw a conclusion from this experiment regarding the effect of the number of carbons in the alcoholic compound on the energy released in burning the alcohol. Use data to support your statement.



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Section 6.3 questions

QUIZ

Retrieval

1 Read each of the following statements and **state** 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 **Name** the 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.

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.

Comprehension

4 **Describe** the following key terms, related to the organisation of compounds: molecule, polymer, lattice.

Analysis

5 Draw a Venn diagram and label one circle 'compounds' and the other 'mixtures'. Write statements in each circle to **distinguish** between the two, and in the middle to identify what they have in common.

6 **Compare** a heterogeneous mixture with a homogeneous mixture.

Knowledge utilisation

7 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.

8 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.

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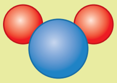
9 **Determine** the correct answers to complete the following table.

Name	Diagram	Formula	Number of different elements in the compound	Number of atoms in each molecule
Water		H_2O	2	3
Carbon monoxide		CO		
Sulfuric acid		H_2SO_4		
Nitrogen monoxide		NO		
Dinitrogen monoxide				
Methanol		CH_3OH		

10 Use the information you provided in your answer to the previous question to answer the following questions.

- a **Describe** the difference between nitrogen monoxide and dinitrogen monoxide.
- b **Deduce** which is bigger: a molecule of sulfuric acid or a molecule of carbon monoxide. Explain.
- c **State** the ways dinitrogen monoxide and water are similar.

Chapter review

Chapter checklist

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

1	**I can define the following key terms: atom, molecule, element, pure substance, compound, mixture.** e.g. Construct a diagram that shows how the following terms are connected to each other: atom, molecule, element, pure substance, compound, mixture.	
2	**I can distinguish between metals, non-metals and metalloids.** e.g. Recall some properties of metals.	
3	**I can describe monatomic, diatomic, molecular and lattice structures.** e.g. Describe the structure of a lattice.	
4	**I can recall some rules that are required when naming compounds.** e.g. Determine the name of a compound that has one carbon atom and four chlorine atoms.	
5	**I can distinguish between homogenous and heterogenous mixtures.** e.g. State an example of a homogenous mixture.	

Review questions

SCORCHER

Retrieval

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

3 Baking soda is a common substance in pantries. Its formula is $NaHCO_3$. **Recall** what the 3 means.

4 **Identify** the correct word to complete the blanks in the following sentences.
- a Elements are pure substances containing only one kind of ________________.
- b All existing 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.

Comprehension

5 **Explain** how the properties of an element relate to its use. Include examples.

6 **Explain** why carbon dioxide does not appear in the periodic table.

7 **Summarise** the arrangement of atoms in an element, a compound and a mixture.

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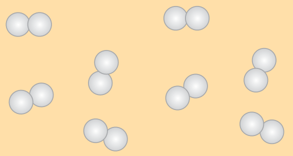
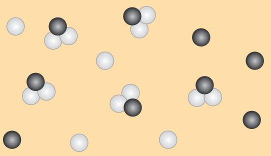
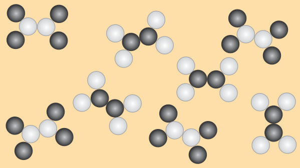
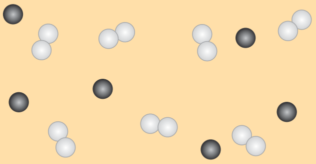
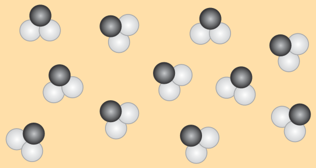
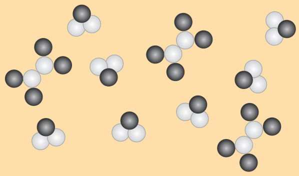
Analysis

8 **Distinguish** between mixtures and compounds.

9 **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	

10 **Compare** the properties of metals and non-metals.

Knowledge utilisation

11 Marie heated an unknown powder with the Bunsen burner, and some gases were released (nitrogen dioxide and oxygen).

- a **Deduce** if the original unknown substance was an element or a compound.
- b **Identify** the elements that you can confirm were in the original substance.
- c Marie then continued to heat the substance and more oxygen gas was released. There was also a silvery residue in the test tube (the element mercury). **Determine** what other element/s you can now confirm were in the original substance.

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, **justify** what would best represent compounds, mixtures and elements – letters, words or paragraphs?

15 **Propose** why elements and compounds can be represented by chemical formulas, but mixtures cannot.

Data questions

Refer to the melting points and boiling points for various elements shown in Table 6.6 and Figure 6.30.

Classification	Element	Melting point (°C)	Boiling point (°C)
Non-metals	Carbon	3550	4827
Non-metals	Nitrogen	−210	−196
Non-metals	Oxygen	−219	−183
Noble Gases	Helium	−272	−269
Noble Gases	Neon	−249	−246
Halogen	Fluorine	−220	−188
Halogen	Chlorine	−102	−34
Halogen	Bromine	−7	59
Halogen	Iodine	114	184
Metal	Magnesium	650	1091
Metal	Iron	1538	2861
Metal	Nickel	1455	2913
Metal	Copper	1085	2560
Metal	Silver	962	2162
Metal	Platinum	1768	3825
Metal	Gold	1064	2836
Metal	Mercury	−39	357

Table 6.6 Classification, melting and boiling point of various elements

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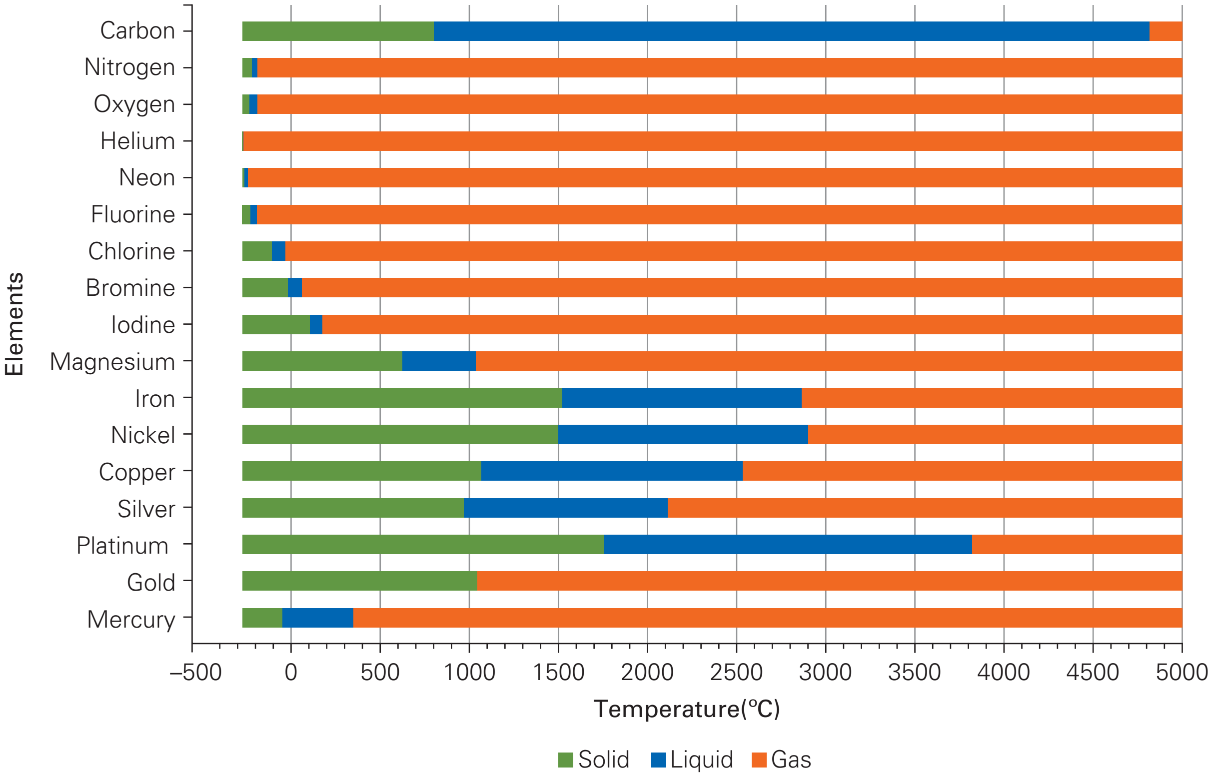

Figure 6.30 States of various elements at different temperatures.

Apply

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 **Identify** which elements in Table 6.6 are classified as halogens.

Analyse

4 **Contrast** the general melting point of the noble gases and the metals in Table 6.6.

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'.

Interpret

7 **Compare** the temperature range for which each metal is present in the liquid state.

8 Given the data in Table 6.6, **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: Reduce, re-use, repurpose, recycle

Background information

Waste is a huge issue for the whole world. Queensland has banned retailers supplying plastic bags, and now has a container refund scheme to raise awareness and decrease waste, with the hope that Queensland will become a zero-waste society.

Being a zero-waste society involves rethinking how we use our resources to eliminate all waste products. Queensland councils in a meeting of the Local Government Association of Queensland voted to have zero waste to landfill by 2028. With this huge goal, society needs to be educated about having a zero waste philosophy.

Design brief: Design an educational poster for the Queensland Government to distribute through schools about zero waste and the science behind making a zero waste society.

Activity instructions

Your group has been employed by the Queensland Government to produce an educational poster about zero waste for primary school children. It should include the science behind how different waste products are made, and how different items can be re-used, repurposed and recycled, as well as include the reasons behind why certain products must be avoided.

Figure 6.31 The zero waste personal hygiene items shown have minimal plastic elements.

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Suggested materials

- pens/pencils
- butchers paper
- PowerPoint/poster making software
- computers

Research and feasibility

1 Research, discuss in your group and list different types of waste produced by society.

2 Discuss in your group which types of waste you think should be the focus of your poster and research how they are made, used and then re-used/repurposed/recycled.

3 Create a table like the one shown below, to help determine which types of waste are easiest or most difficult to become zero waste.

Waste	**Household/society quantity**	**Can this product be made zero waste?**	**How? Level of difficulty**
E.g. Cling wrap	Varies depending on household	Yes	It can be recycled, but it is more difficult, and should be avoided as a product.

Design and sustainability

4 Decide, as a group, five key ideas you want to have on your poster, and discuss if you have enough important research to help convince students of their importance.

5 Sketch, as a group, different poster designs and annotate the locations of the most important information. Discuss as a group if the poster is effective visually.

Create

6 Use butchers paper or a computer to create your information poster. Remember this is a poster designed for primary school children.

Evaluate and modify

7 Present your poster to your class as a group, and encourage questions and feedback from your class.

8 Evaluate the effectiveness in transforming the message of zero waste to your class.

9 Discuss modifications you would make to your poster based on feedback from the class.

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Chapter 7
Chemical change

Chapter introduction

This chapter introduces you to the physical and chemical changes that occur in our world. You will also learn about how substances react to form new substances, and the evidence that a reaction has occurred. You will look at how glow sticks work, how marshmallows go gooey and delicious over a fire, how fruit ripens, and how fireflies glow in the night.

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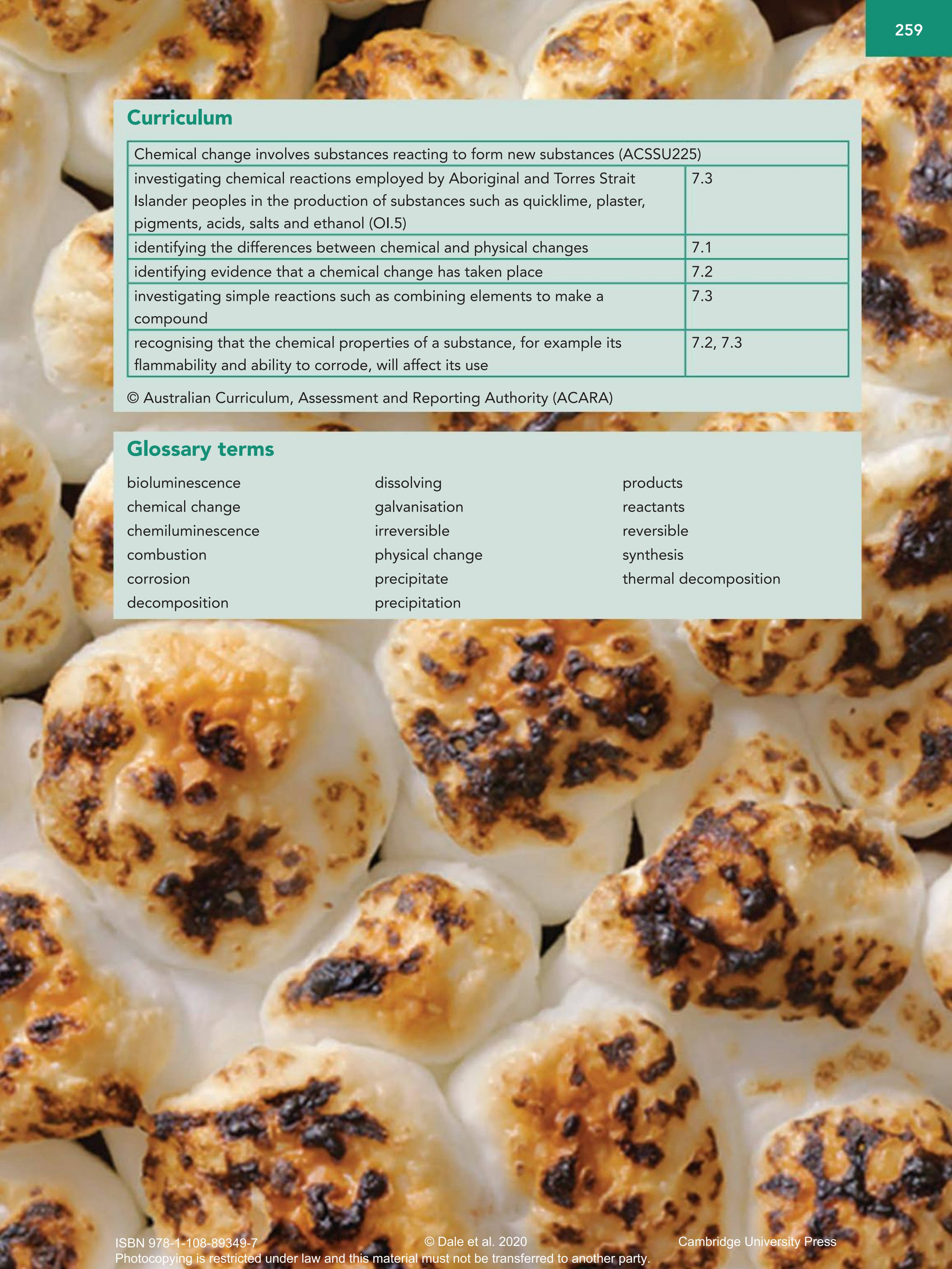

Curriculum

Chemical change involves substances reacting to form new substances (ACSSU225)	
investigating chemical reactions employed by Aboriginal and Torres Strait Islander peoples in the production of substances such as quicklime, plaster, pigments, acids, salts and ethanol (OI.5)	7.3
identifying the differences between chemical and physical changes	7.1
identifying evidence that a chemical change has taken place	7.2
investigating simple reactions such as combining elements to make a compound	7.3
recognising that the chemical properties of a substance, for example its flammability and ability to corrode, will affect its use	7.2, 7.3

Glossary terms

bioluminescence
chemical change
chemiluminescence
combustion
corrosion
decomposition
dissolving
galvanisation
irreversible
physical change
precipitate
precipitation
products
reactants
reversible
synthesis
thermal decomposition

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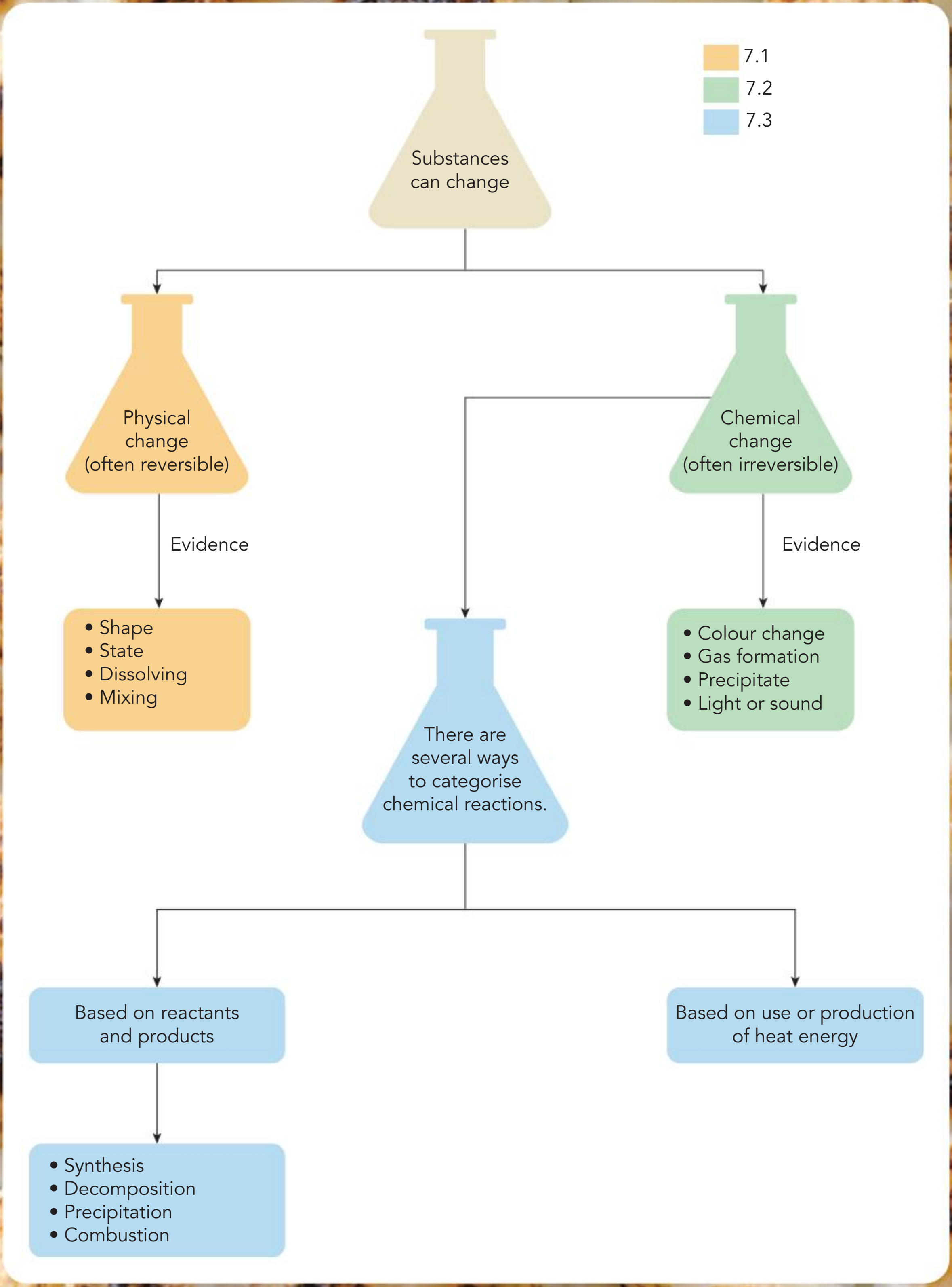
Concept map



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7.1 Evidence of physical change

Physical change

During a **physical change**, the characteristics of a substance, or its physical properties, change in some way, but nothing new is formed. Examples of physical properties are texture, shape, size, colour, odour, volume, mass, and density. As the chemical nature of the substance is not altered, physical changes are usually considered to be **reversible**.

When trying to determine whether a physical change has occurred, there are several pieces of evidence to look for, such as:

- a change in shape
- expansion or contraction
- a change in state
- mixing or dissolving occurring
- a non-permanent colour change.

Evidence of physical change

Changing shape

When an object changes shape, we say it has undergone a physical change. For example, when an elastic band is stretched, the physical properties of the elastic band change but not its chemical structure, nothing new has formed and it is reversible. Think about a soft drink can being crushed. Have its physical properties changed? Has its chemical structure changed? Has anything new been made? Is it reversible? So is it a physical change?

WORKSHEET

physical change
when the physical properties of a substance change in some way, but no new substance is formed; it is reversible

reversible
capable of going in the opposite direction

Figure 7.1 Different types of evidence that a physical change has occurred: change in shape (top left), expansion or contraction (top right), change in state (bottom left) or mixing (bottom right)

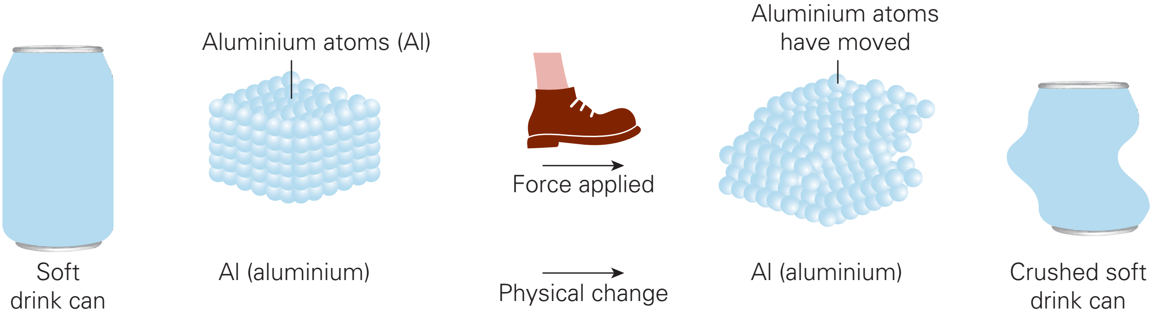

Figure 7.2 When an aluminium can is crushed, the characteristics of the can have changed, but nothing new is formed. Therefore it is a physical change.

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Figure 7.3 An example of a physical change is when glass breaks: its physical characteristics change, but it is still glass.

Breaking glass is another example of physical change. Can you explain why?

Quick check 7.1

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.

Expansion and contraction

In Section 5.1 you learned about the particle model and different states of matter. The particle model, which describes the behaviour of atoms in solids, liquids and gases, suggests that if you heat up a substance, the atoms in the substance will also gain energy, move faster, and expand if the container allows. This means the atoms will gain energy, move more and increase the distance between one another. This process of atoms moving away from one another is called expansion. Expansion is an example of physical change – the properties of the substance have changed (volume increases and density decreases), but no new substance has formed, and it is reversible. Hot air balloons and thermometers are two examples of where we can see evidence of a physical change occurring in this way.

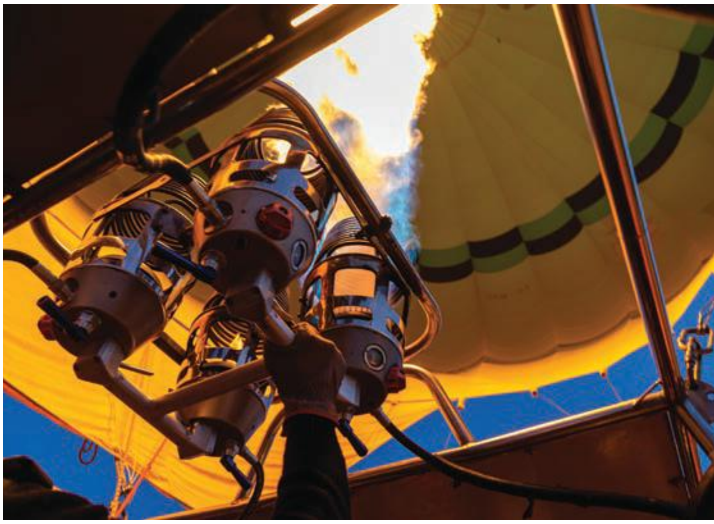

Figure 7.4 When the air inside a hot air balloon is heated, the atoms in the heated air gain energy, move faster, moving away from each one another and therefore taking up more space. This is an example of a physical change occurring and it results in the air being less dense on the inside of the balloon, so the balloon rises.

The reverse of expansion is contraction, and this is also evidence of a physical change occurring. The substance cools down, the atoms lose energy, they slow down, and the distance between the atoms gets smaller (volume decreases and density increases).

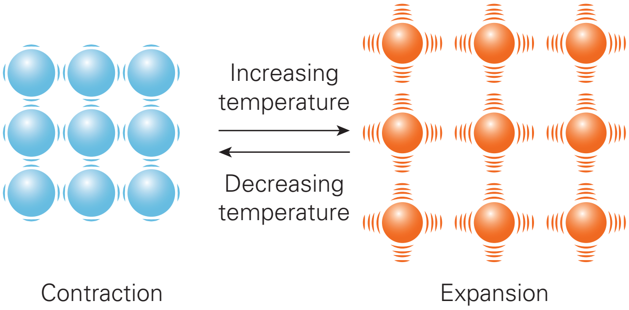

Figure 7.5 The physical changes experienced by atoms during expansion and contraction

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Practical skills 7.1

Making a model thermometer

Aim

To demonstrate expansion and contraction by making a model thermometer

Materials

- 250 mL conical flask
- glass thermometer
- clear narrow plastic straw
- ice-cream container
- red food colouring
- kettle or hotplate
- 250 mL beaker
- permanent marker
- modelling clay (or Blu Tack)
- water
- ice

Method

1. Half fill the conical flask with water.
2. Add a drop or two of food colouring.
3. Place the straw in the flask, but do not let it touch the bottom. Use the clay to seal the edges of the flask's top with the straw in the middle. The clay will hold the straw 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 straw (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 ice and allow 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.
6. Now heat up some water on the hotplate and add to the ice-cream container. Let the flask sit there for several minutes. Record the new temperature using the glass thermometer and mark the side of the flask to document where the liquid level is.
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 by changing 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 straw.

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 straw? Use your knowledge of the particle theory to aid in your explanation.
3. Imagine you repeated your experiment but with a narrower straw. How would you expect the measurements to be different for a narrower straw? Explain whether this new thermometer would be likely to be more or less accurate than your first thermometer.

Evaluation

1. Outline possible faults 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.

Changing state

In Chapter 5.3, you learned that solids, liquids and gases can change their state. You know that heating up a substance causes an increase in temperature. If enough heat is added, the substance can change its state. When a substance changes state, it is a physical change – it can be reversed, and the actual substance is still chemically the same, it is just its physical properties that have altered. The different changes of state are summarised in Figure 7.6 below.

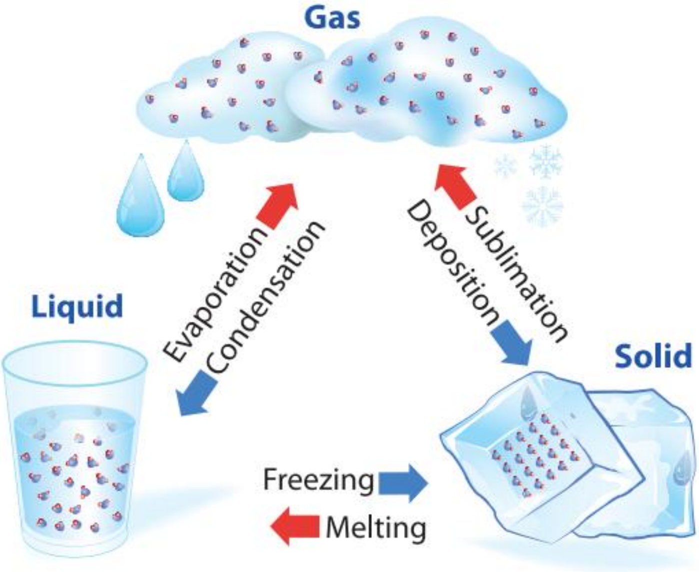

Figure 7.6 When some substances gain or lose heat, they undergo a physical change: no new substance is produced and the substance changes its physical properties but is still the same substance.

Figure 7.7 A snowman melting is an example of physical change. Can you explain why?

Figure 7.8 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.

Science as a human endeavour 7.1

Physical changes have happened on Mars too!

Mars has a number of surface features such as dried-out river valleys and gigantic outflow channels that could have been caused by glaciers. Scientists believe that in the distant past, Mars featured a thick atmosphere and lots of surface water, including a huge ocean that may have covered 40% of its northern hemisphere.

As you know, a change of state is an example of physical change, so physical changes have happened on Mars too. Four billion years ago, the atmosphere of Mars started to thin, causing any liquid on the surface to quickly freeze and evaporate.

However, data collected by the European Space Agency's Mars Express spacecraft suggests that there is a pool of liquid water buried under layers of ice and dust in the south of Mars. A 2020 study predicted that very salty water (which doesn't freeze as easily) could be found on the surface, and this is only possible for very short periods of time each year, but the water would be a very chilly −48°C!

Figure 7.9 The surface of Mars is thought to have been shaped by physical changes.

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Quick check 7.2

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

When you mix substances or dissolve one substance in another, a physical change occurs. Think about **dissolving** sugar (solute) in water (solvent) to form a solution. The way the molecules of sugar spread out within the water is called diffusion. In Chapter 5, you learned that diffusion is the movement of particles from an area of high concentration to low concentration. When the sugar is all spread out in the water, you still have sugar, but the molecules have been separated and surrounded by water molecules. The characteristics of the sugar have changed from a crystalline, solid structure to one where all the sugar particles can move around freely in the water. No new substance has been formed, and the process is reversible if you evaporate the water. It is for this reason that mixing and dissolving are considered evidence of physical change.

dissolving
the process where individual particles of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

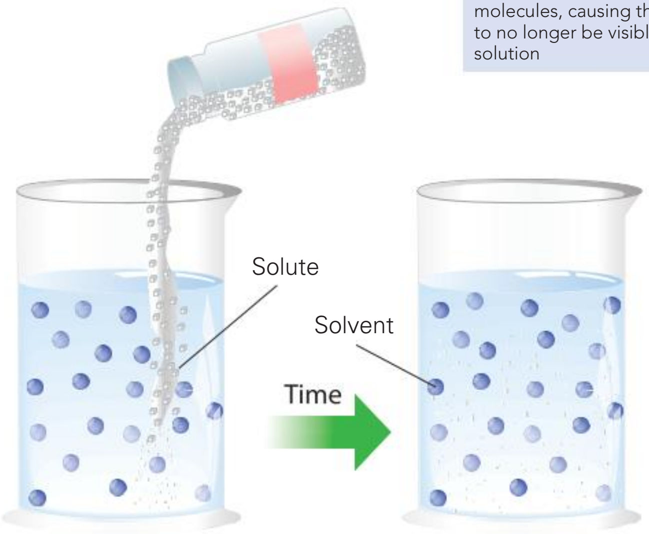

Figure 7.10 Molecules of water (blue) move randomly in a glass. Add sugar (white) and the new, dissolved molecules will eventually become distributed uniformly throughout the water. This is diffusion.

Try this 7.1

Skittles and diffusion

Note: This activity uses lollies containing food colouring, which may present a risk if students have food allergies. No food items are to be consumed.

Collect the following materials: Petri dish, stopwatch, filter paper or white paper, five skittles of different colours, and a beaker of water.

Now place the Petri dish on the filter or white paper and place the five skittles equally spaced in the Petri dish. Slowly pour water into the Petri dish to fill it up, and start timing. Record your observations. Explain your observations using the term ‘diffusion’.

Repeat, but this time use warm water. Explain the differences you observe.

Figure 7.11 Skittles can help demonstrate diffusion.

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Quick check 7.3

1 Explain how mixing and dissolving are examples of physical change.
2 Identify which of the following are physical changes.
  a slicing bread
  b turning on a light
  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 ‘off’
  o popping popcorn
  p squeezing an orange

Explore! 7.1

More physical changes?

Are there other examples of physical change that you have not investigated, or have you covered them all? Your job is to find out what you can about the following three situations, and provide evidence why each is or is not an example of physical change:

1 the heating of an iron bar until it turns red
2 the magnetising of a piece of iron
3 the glowing filament of a light globe.

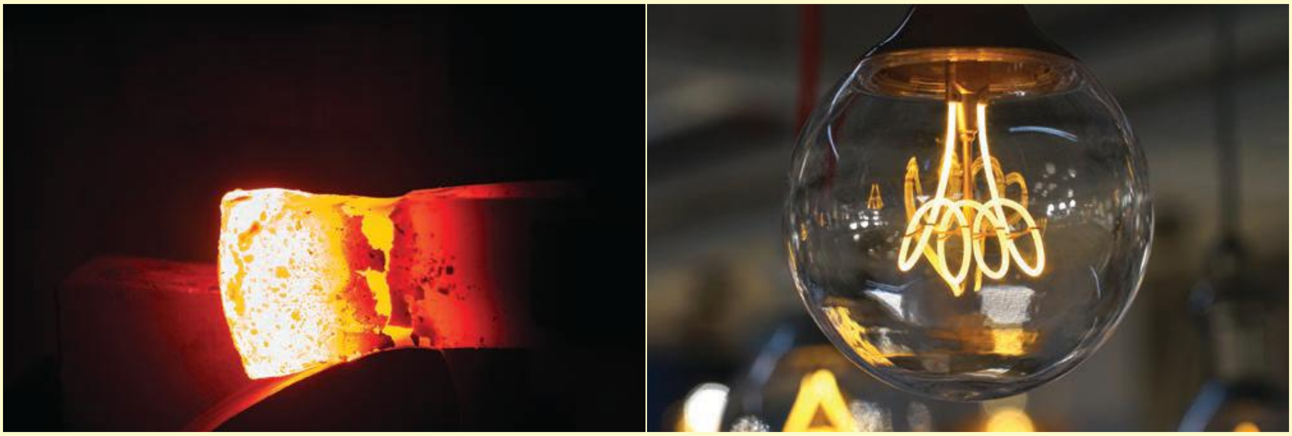

Figure 7.12 An iron bar glows red when heated, and a filament glows in a light globe. Are these examples of physical change?

Explore! 7.2

Recycling

Recycling of waste makes use of the unique physical properties of a range of waste materials to separate components, including cardboard, glass, aluminium cans and magnetic metals. Investigate the design of a recycling plant for the separation of components of waste based on their physical properties.

1 How are paper and cardboard separated from larger plastic bottles using a screening machine?
2 How are magnetic metals separated from non-magnetic components of a mixture?

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Section 7.1 questions

QUIZ

Retrieval

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

2 **Identify** which of the following are physical changes.
  - a cutting an apple
  - b milk going 'off'
  - 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.

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; 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 – this is a physical change.
  - g Burning wood in a fire forms charcoal and ash – 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.

Comprehension

6 **Summarise** the following physical changes, using your knowledge of the particle theory.
  - a why the tyres on your family car seem more deflated on a cold day
  - b how a liquid in a glass thermometer works
  - c why on extremely hot days there are concerns about train tracks not working well

7 **Summarise** the process whereby a strong-smelling deodorant is sprayed in one corner of the room but eventually everyone in the room can smell it.

Analysis

8 **Consider** how you could you reverse the following physical changes.
  - a salt dissolving in water
  - b inflating a balloon
  - c ice melting
  - d glass breaking

Knowledge utilisation

9 **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

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7.2 Evidence of chemical change

Chemical change

WORKSHEET

chemical change
where one or more substances undergo a chemical reaction and a new substance, or substances is formed; mostly irreversible

precipitate
the solid that forms when two clear solutions are mixed and undergo a chemical change

irreversible
incapable of going in the opposite direction

During a **chemical change**, a new substance is formed. This new substance could be a solid, a liquid or a gas. To help determine whether a new substance has been formed, and therefore a chemical change has occurred, there is evidence you can watch for. Occasionally you will get exceptions to this list, but most of the time, one or more of the following would be observed:

- a permanent colour change
- a gas being given off (as an odour, or smoke 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)

Consider the fireworks that light up the night sky each year on New Year's Eve. The bright explosions of colour that we see are actually metals, like magnesium and copper. They change chemically as they burn, producing fantastic colours. What signs are there that a chemical change has occurred? Referring to the previous list, we see colour, light and smoke, we hear cracking and fizzing, and we know the fireworks are dangerous to get close to, because of the heat they produce.

Chemical changes are also considered to mostly be **irreversible**. 'Irreversible' means that the products cannot easily (if ever) be converted back to the substances that formed them. Reversing a chemical change often requires a chemical reaction to take place, or the input of energy.

Figure 7.13 These fireworks on the Story Bridge, Brisbane, are an example of chemical change

Quick check 7.4

1 What is the key piece of evidence that a chemical change has occurred?
2 List the five pieces of evidence to look for, to determine whether a chemical change has occurred.
3 What is the evidence that a chemical change has occurred in each of these situations?
  a Leaves turning red in the autumn.
  b Sherbet fizzes in your mouth.
  c Bread is baking in the oven.

Science as a human endeavour 7.2

Chemical reactions caught on film

Scientists are now able to 'film' inter-molecular chemical reactions. They are able to do this using the electron beam from a transmission electron microscope (TEM), like stop-motion or stop-frame filming. This technique can show chemical reactions as they are happening and, among other challenging questions, can help us understand how molecules interact or react with one another at the atomic level. We may also be able to find out why one product, rather than another, forms.

Evidence of chemical change

It is finally the school holidays and your family is going camping. One cool evening you are all relaxing around the campfire to keep warm. The adults are cooking sausages on the grill over the flames and damper in the coals beneath. You toast marshmallows using sticks held over the edge of the fire, letting them get all brown, gooey and delicious. On this lovely evening, chemical changes are happening all around you!

Figure 7.14 Damper bread that has been cooked in the coals of a fire shows evidence of a chemical change occurring.

Colour change

VIDEO Evidence of chemical reactions

Remember: a chemical change is any change that causes a new substance to be formed. For example, when your campfire has burned completely out, ashes are left behind – these are a new substance formed by the burning of wood. This is a chemical change. But what about permanent colour change? This is another indicator that a chemical change has occurred.

Your marshmallows, sausages and damper are all browning on the outside from being exposed to the heat of the campfire flames. This is due to a reaction between amino acids and sugar. This is a permanent colour change, indicating that a chemical change has occurred, although there may also be a new substance (charcoal) forming on the outside if your food is burning! Generally speaking, the changes caused by cooking food are all chemical changes.

The ripening of fruit and vegetables is another example of a colour change indicating that a chemical change has occurred. For example, when a tomato reaches the green stage of its development, it starts to produce ethylene gas.

The ethylene then interacts with the tomato fruit to start the ripening process, which involves chemical reactions, and so it is evidence of chemical change.

Figure 7.15 Tomatoes ripening and changing colour are evidence that a chemical change has occurred.

corrosion
the gradual and natural process of metals breaking down; an example is rusting

galvanisation
the process of coating iron or steel in zinc to prevent 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 things like buildings, bridges and train tracks, which are made of iron and steel. Rusting occurs when iron reacts with water and with the oxygen in the air to form iron oxide (rust). This is a new substance forming and so, clearly, rusting is a process producing a chemical change.

Given the widespread use of iron and steel, we need ways to prevent rusting. The word equation for the process of rusting is:

$$\text{iron} + \text{water} + \text{oxygen} \rightarrow \text{iron oxide}$$

This equation means that all three substances on the left of the arrow are required to produce the substance on the right of the arrow. If iron and steel are not exposed to water and/or oxygen, then iron oxide cannot be made and rusting is halted. You may have noticed that, in hardware stores, there are two options for stopping water and oxygen coming into contact with the iron and steel:

- 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 to the elements
- **galvanisation**, 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 7.16 Screws exposed to water and oxygen will start to corrode or rust, providing evidence of chemical change.

Figure 7.17 A galvanised corrugated iron roof: the zinc coating will corrode before the iron underneath, preventing rusting of the iron.

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Try this 7.2

Steganography

Steganography is the practice of sending hidden messages. For this activity you will need some lemon juice in a small container, white paper, a plastic tray, some cotton buds and access to an iron or a hairdryer. Begin by placing a piece of white paper on your tray. Dip a cotton bud into the lemon juice and write a message on the paper. When your message is dry, your teacher will reveal your message using a heat source (iron or hairdryer). Explain why this is an example of a chemical change.

Investigation 7.1

To rust or not to rust

Aim

To determine the conditions required for the chemical change of rusting

Planning

1. Write a rationale about rusting and the factors that affect it.
2. Consider what you learned earlier in the chapter and in your rationale about the conditions that are required for the chemical change of rusting.
3. Design an experiment that will demonstrate that the conditions you believe to be required for rusting are indeed 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.
4. Write a specific and relevant research question for your investigation.
5. Identify the independent, dependent and controlled variables.
6. Write a hypothesis for your investigation.
7. Write a risk assessment for your investigation.
8. Draw a diagram of your method, showing what will be added to each test tube.
9. Check your design with your teacher before starting your experiment.

Materials

- iron nails
- sandpaper
- large glass test tubes with stoppers
- vegetable oil
- water

Results

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

Analysis

1. Describe any patterns, trends or relationships in your results.
2. Define the terms ‘chemical change’ and ‘rusting’. List any chemical changes you see in this experiment.
3. Write a word equation for the reaction that occurs when rust is produced.

Evaluation

1. Identify any limitations in your investigation.

continued…

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…continued

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

Draw a conclusion from this experiment regarding the conditions required for rusting, using data to support your statement.

Gas is formed

To produce a soft, fluffy loaf of bread or a delicious piece of cake, you need a chemical change to occur. One of the key indicators in this case is a gas being produced. This gas could be in the form of an odour, bubbles or even smoke.

Bread can be made using a substance known as bicarb soda (or sodium bicarbonate), which is added to the main ingredients – flour, salt, oil and water. The ingredients are mixed into a dough before baking. When heated, the bicarb soda breaks down and produces carbon dioxide gas. As the carbon dioxide is released into the dough, it expands with the heat (note that this is a physical change). Large bubbles of gas form in the dough, and this is what gives the bread its spongy texture.

decomposition
a reaction in which one substance breaks up into smaller ones

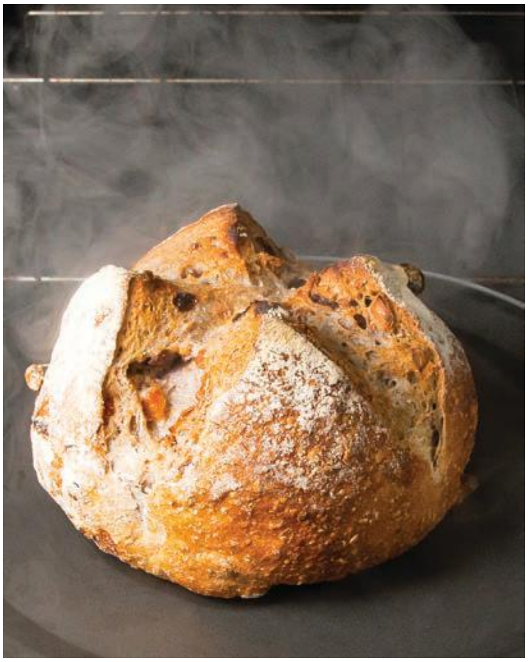

Figure 7.18 Hot bread is a delicious consequence of chemical change

Bread can also be made using micro-organisms called yeast. The yeast uses the starch and sugars in the flour to produce alcohol and carbon dioxide. The alcohol escapes during cooking, but the carbon dioxide expands inside the dough, creating bubbles of gas and making the bread rise.

Rotting things often produce gas, and again, this is a sign that a chemical change is occurring. For example, vegetable scraps in the compost bin are broken down by micro-organisms in a process called **decomposition**, and this produces carbon dioxide gas.

Try this 7.3

Ready, set, bake!

Jump online and find a simple bread recipe. Give it a go at home. Write a word equation for the reaction – that is, write the ingredients that go into the bread, and then an arrow to represent the change, and then write the substances that are formed, to the right of the arrow. What evidence is there that a chemical change has occurred? Also list any physical changes you notice.

Precipitate is formed

Another indicator that a chemical change has occurred is the formation of a precipitate. A precipitate is the name given to a solid that forms when two clear solutions are mixed. 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. You will learn more about chemical reactions that produce a precipitate in the next section.

Quick check 7.5

1. Name three examples where a colour change indicates that a chemical change has occurred.
2. Recall the process of rusting as a word equation.
3. List two examples where a gas being formed provides evidence of chemical change. In each case, explain the chemical reaction.
4. Define the term 'precipitate'.

Change in temperature

You already know that during a chemical change, new products are formed. But did you know that heat energy may be given off or absorbed during a chemical change? This is another sign that a chemical change has occurred. For example, the burning of natural gas in the kitchen when you are cooking is a chemical change that gives off a great deal of heat. Heat is used in cooking to speed up the many chemical changes that result in a delicious meal. Remember how all matter consists of atoms joined together to form different substances? Heat can help atoms break free of one another and form different substances. For example, when you cook an egg, the heat makes the atoms in the egg white recombine in a different way, and this appears to us as cooked egg!

Essentially, any time you burn something, heat energy is produced, and the increase in temperature indicates that a chemical change has occurred. But the opposite can also happen: heat energy can be absorbed, and the temperature decreases. Chemical ice packs are probably the most 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 absorb heat from the surrounding environment, making the pack feel cold. You will investigate chemical processes that produce heat energy and absorb heat energy, in the next section.

Light or sound produced

Another piece of evidence that a chemical change has occurred is light or sound. Remember the fireworks discussed earlier? During that chemical change, both sound and light are produced. Can you think of other examples where light or sound (or both) are evidence that a chemical change has occurred? The information on the next page may help you.

WIDGET
Physical vs chemical change

Figure 7.19 When natural gas burns, a lot of heat energy is released, and we use this heat to cook our food.

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Did you know? 7.1

Fireflies glow because of chemical reactions!

bioluminescence a chemical reaction that produces light in living things

chemiluminescence a chemical reaction that produces light

A chemical reaction occurs in fireflies' abdomens, 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**.)

Figure 7.20 The tail of a firefly produces light through a chemical reaction known as bioluminescence.

When oxygen combines with calcium, adenosine triphosphate (ATP) and the chemical luciferin, and a bioluminescent enzyme is also present, light is produced. When oxygen is available, the firefly's light organ glows, and when it is not available, the light goes out. The firefly is able to control the beginning and end of the chemical reaction, and thus start and stop the production of light. Unlike a light bulb, which gets hot when it produces light, a firefly's light is cold light, and so very little energy is lost as heat. This is very lucky for the firefly, because it would not survive getting as hot as a light bulb!

Fireflies light up for a number of reasons. The larvae produce short glows that act as a warning to predators that they taste bad. As adults, many fireflies have flash patterns unique to their species, and use them to discriminate between members of the opposite sex. In males, a higher rate and intensity of flashing has been shown to be most attractive to females in several firefly species.

Explore! 7.3

Glow sticks

Have you ever played minigolf in the dark with glow-in-the-dark balls? Have you ever celebrated New Year's Eve with glow sticks? It all comes down to chemical reactions.

1. Define the following key terms: fluorescence, chemiluminescence, bioluminescence.
2. Find out about the structure of glow sticks and explain what is involved in the chemical reaction that produces the light. Summarise your findings and include a picture/diagram.

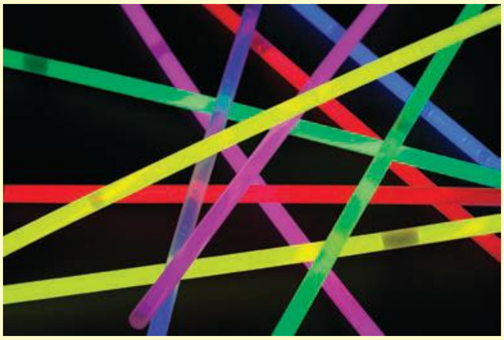

Figure 7.21 Glow sticks work because of chemiluminescence, a chemical reaction that produces light.

Quick check 7.6

1. List some examples of where a change in temperature provides evidence of chemical change.
2. List some examples of where light or sound being formed provides evidence of chemical change.

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Practical skills 7.2

Chemical change

Be careful

Personal protective equipment is to be worn. All waste is to be collected and disposed of appropriately.

Aim

To conduct a series of activities/experiments in order to explore chemical change and be able to identify the evidence of change

Materials

- Bunsen burner
- matches
- wooden skewer
- strontium chloride solution
- copper II sulfate solution
- ammonium hydroxide solution
- test tubes and test-tube rack
- 2 cm strip of magnesium ribbon
- 1 M hydrochloric acid
- thermometer
- 100 mL glass beaker
- lemon juice
- baking soda

Method

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 the above steps with the copper II sulfate solution.

Activity 2

1. Place three eye droppers full of ammonium hydroxide into a test tube in a rack.
2. Add the copper II sulfate solution, drop by drop, no more than 10 drops, into the ammonium hydroxide.
3. 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 a 2 cm strip of magnesium ribbon into a test tube in a rack.
2. Gently stand a thermometer in the same test tube.
3. Add approximately 2 cm of dilute hydrochloric acid 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. Put approximately 40 mL of lemon juice in a 100 mL glass beaker.
2. Gently stand a thermometer in the beaker.
3. Add 1 teaspoon of baking soda to the lemon juice.
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.

continued…

...continued

Results

Copy and complete the table to show the evidence that a chemical change has occurred.

Activity	Change in colour	Change in temperature (°C)	Gas produced	Light produced	Precipitate produced	Observations
1						
2						
3						
4						

Analysis

1 Define 'chemical change'.
2 Outline the different pieces of evidence that a chemical change has occurred, and provide an example from your activities.
3 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.

Try this 7.4

Physical and chemical changes are all around us. Figure 7.22 shows some photos from a family holiday. List the physical and chemical changes you can see in the photos. For every change you notice, state the evidence that a change has occurred or is occurring – for example, colour change, a gas being produced or a new product being formed.

Figure 7.22 Can you spot the physical and chemical changes in these photos from a family holiday?

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Did you know? 7.2

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 muscles contract 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 7.1 Some of the many physical and chemical changes that occur in the digestive system

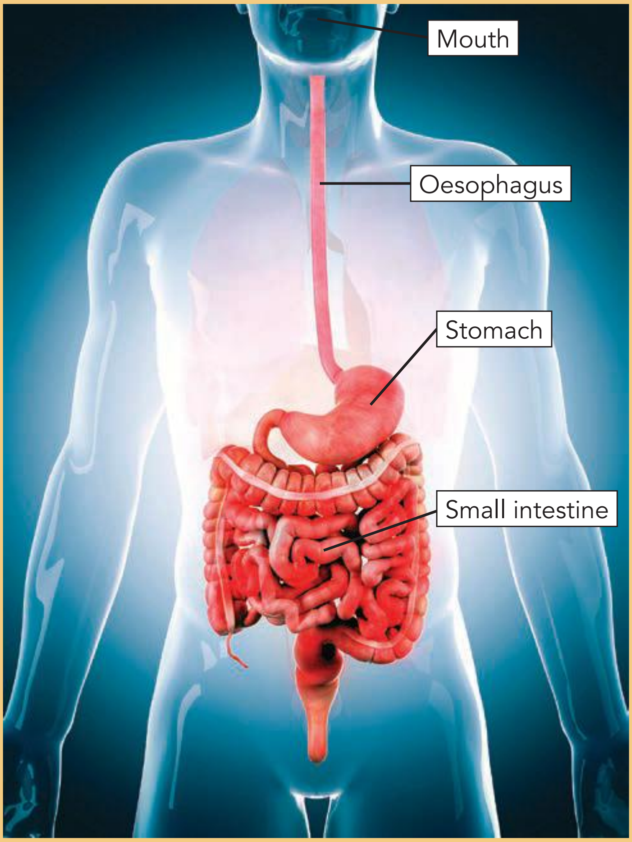

Figure 7.23 The digestive system uses physical changes and chemical changes to break down your food for absorption.

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Science as a human endeavour 7.3

Forensic detection of fingerprints

In 2015, an Australian scientist's home was broken into. This inspired him to develop a new technique for fingerprint detection at a crime scene. Fingerprints can be used as an identification tool for suspects as each pattern is unique to each individual. However, while some fingerprints such as those from a dirty hand may be visible, others are often invisible on surfaces.

Dr Kang Liang from the CSIRO found that by adding a drop of liquid containing crystals to surfaces, investigators using a UV light are able to see latent (invisible) fingerprints 'glow' in about 30 seconds. The benefits of the crystals are that they are cheap, react quickly and can emit a bright light. The chemical reaction doesn't create dust or fumes, reducing waste and the risk of inhaling dangerous gases.

Figure 7.24 Detecting latent (invisible) prints left at a crime scene is now easier, with new detection methods involving chemical reactions.

Section 7.2 questions

QUIZ

Retrieval

1 **Select** the correct definition for each term.

Term	Definition
Physical property	a new substance is formed and the process is irreversible
Physical change	a characteristic of a substance that can be observed/measured without changing it, e.g. colour, melting point, hardness, boiling point, density
Chemical property	nothing new has formed and the process is reversible
Chemical change	the behaviour of a substance when it reacts with another substance

2 **State** some examples of physical properties.

3 **State** some examples of chemical properties.

4 **Recall** the five common signs that a chemical change has occurred.

5 **Name** three examples of chemical change occurring in your home.

6 For each of the following situations, **summarise** the signs of chemical change you would observe.

- a Birthday candles are burning.
- b Glow sticks emit light when you break them.
- c Sandwiches go mouldy.
- d Baking soda and vinegar are mixed.

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Comprehension

7 **Explain** the process of rusting and why it is an example of chemical change.

8 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.

Analysis

9 **Distinguish** between bioluminescence and chemiluminescence.

10 **Classify** each of the following as 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

11 **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.

Knowledge utilisation

12 **Determine** the reasons why galvanised iron does not rust.

13 **Propose** why rusting occurs faster on door hinges of boat sheds compared to door hinges a kilometre inland from the beach.

14 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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7.3 Investigating reactions

DOC
WORKSHEET

You now know what evidence to look for when a physical change occurs, and when a chemical change occurs. And, you know the difference between physical and chemical change. In this section, you will investigate what happens when a chemical change occurs – that is, a chemical reaction.

Reactants and products

reactants
the substances that are present at the beginning of a chemical reaction

products
the substances that are present at the end of a chemical reaction

In a chemical reaction, the substances you start with are called **reactants**, and the substances you finish with are called **products**. A chemical reaction can be represented in different ways, such as a word equation or a chemical equation.

An example of a chemical reaction is when light hits photographic film coated with tiny crystals of the compound silver chloride.

Figure 7.25 Photographic film works because of chemical reactions.

When the film is exposed to light, a chemical reaction occurs, and this darkens the film to produce an image. This reaction can be represented by a word equation and by a chemical equation.

Word equation:
silver chloride → silver + chlorine

Chemical equation:
$2AgCl \rightarrow 2Ag + Cl_2$

The reactants or, in this case reactant, is on the left of the 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 arrow – silver and chlorine. Note that chlorine has the formula Cl_2 as it exists as a molecule, never as an atom on its own.

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. Why are these extra numbers in the equation when they are not part of the formula of the compound AgCl? This is 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 destroyed or made, they just move around during chemical reactions. So this means the number of silver atoms in the reactants must be the same as the number in the products, and the number of chlorine atoms in the reactants must be the same as in the products. The extra numbers you see in the equation are there to balance the numbers of atoms on each side of the equation.

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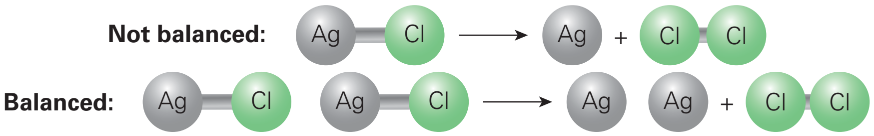

Figure 7.26 Keeping it simple: balancing equations is like working out whether you need one or two cups of flour to make bread. The top equation is not balanced, because the number of chlorine atoms is not the same on both sides of the reaction.

Quick check 7.7

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 we can represent chemical equations.

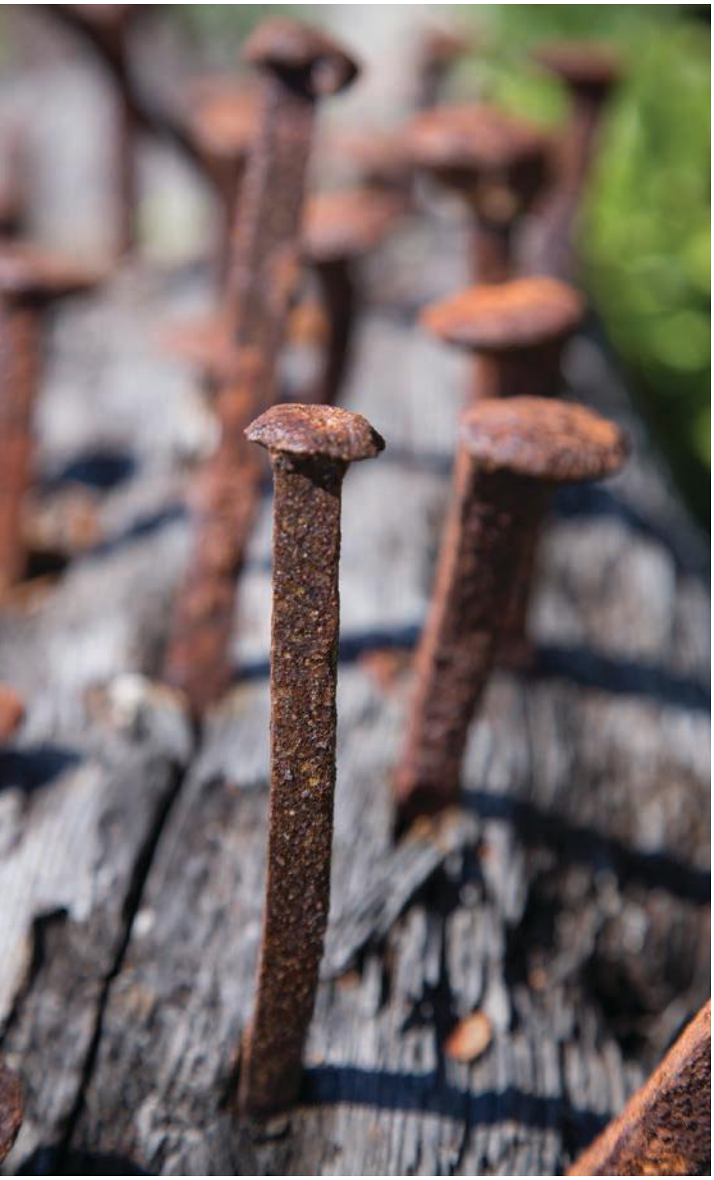

Figure 7.27 A nail rusting is an example of a synthesis chemical reaction.

Types of chemical reactions

We will focus on the four basic types of chemical reactions listed below:

- synthesis reactions (sometimes called combination)
- decomposition reactions (sometimes called breaking down)
- precipitation reactions
- combustion reactions.

Synthesis

The simplest type of **synthesis** reaction involves two or more elements or reactants combining to form one or more new substances or products. Synthesis reactions can be represented in this way:

synthesis
a reaction in which two (or more) elements or reactants combine to form new substances or products

$$A + B \rightarrow AB$$

where A and B are the reactants and AB is the product.

You have already read about many synthesis reactions in this chapter, such as the rusting of iron. Iron reacts with oxygen gas in the air, to form rust.

Word equation:
iron + oxygen → iron oxide

Chemical equation:
$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

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Try this 7.5

The Hulk's hand

You are probably familiar with the Hulk and know that he has large hands when he takes on his green form. You are going to make the Hulk's hand using a chemical reaction! Put on safety glasses and move over to the sink, as this can get messy. Take a disposable latex glove (preferably green) and, working with a partner, place 10 g of sodium bicarbonate into the thumb of the glove. Then pour 50 mL of vinegar into the three fingers of the glove furthest from the thumb. Carefully seal the wrist of the glove, ensuring the different fingers don't mix. When you are ready, shake the glove and watch what happens. Can you guess what is being synthesised in this chemical reaction? What are the signs that this is a chemical reaction and chemical changes are occurring?

Figure 7.28 You too can have a hand like the Hulk's.

Decomposition

thermal decomposition decomposition that occurs when a substance is heated

Reactions where one substance (reactant) breaks up into smaller ones (products) is called a decomposition reaction. Decomposition reactions are essentially the opposite of synthesis reactions and can be represented in this way:

$$AB \rightarrow A + B$$

where AB is the reactant and A and B are the products.

Figure 7.29 The foaming and spraying that occurs when you open a can of soft drink is an example of a decomposition chemical reaction.

For example, carbonic acid (H_2CO_3) is an ingredient in soft drinks. When you open a can of soft drink, the carbon dioxide that escapes is a result of a decomposition reaction that has occurred within the drink.

Word equation:
carbonic acid → water + carbon dioxide

Chemical equation:
$H_2CO_3 \rightarrow H_2O + CO_2$

Some compounds break down when heated – in this case, the reaction is called **thermal decomposition**.

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Try this 7.6

Thermal decomposition

Many metal carbonates can be involved in thermal decomposition reactions. For example, copper carbonate breaks down easily when it is heated:

Word equation: copper carbonate → copper oxide + carbon dioxide
Chemical equation: $CuCO_3 \rightarrow CuO + CO_2$

Your teacher may demonstrate this. Wearing safety glasses, add two spatulas of copper carbonate to a test tube. Then, using tongs, gently heat the base of the test tube. Make sure the mouth of the test tube is pointing towards a wall. You may like to hold a flame or a lit match over the mouth of the test tube. What do you observe? What evidence is there of a chemical change? What happened to the flame? What gas was produced?

Calcium carbonate ($CaCO_3$) behaves in the same way. Can you write both a word equation and a chemical equation for its thermal decomposition?

Did you know? 7.3

Airbags use a decomposition chemical reaction

Figure 7.30 Deflated airbags after an accident. Airbags inflate because of a decomposition chemical reaction.

We all know airbags are essential in cars for safety reasons, but how do they work? Airbags are not inflated from some gas source but rather from the products of a chemical decomposition reaction. The chemical responsible for the airbag reaction is called sodium azide, NaN_3. An electronic sensor in the car detects a sudden change of speed and/or direction of the car, and sends a signal to an ignitor, which provides heat. This causes the sodium azide to break down rapidly into sodium and nitrogen gas, and it is this gas that causes the airbags to inflate. Amazingly, a handful of sodium azide will produce 67 litres of nitrogen gas! What is even more amazing is that from the time the sensor detects the collision to the time the airbag is fully inflated is only 0.03 second!

It is important to know that the sodium produced from the decomposition is dangerous, and so manufacturers of airbags must add other chemicals into the mix so that the sodium quickly binds with something else to make it less dangerous.

Quick check 7.8

1 Name four different types of chemical reactions.
2 Explain how you would identify that a chemical reaction was a synthesis reaction.
3 Explain how you would identify that a chemical reaction was a decomposition reaction.

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Precipitation

precipitation
a reaction that involves the mixing of two clear solutions to produce a solid called a precipitate

Chemical reactions that involve the mixing of two clear solutions to produce a solid are called **precipitation** reactions. This is because the solid that is formed is a called a *precipitate*. These solids are insoluble, which means they are unable to dissolve in water. Precipitates are often very colourful and some are even used as pigments in paint.

For example, when colourless solutions of lead nitrate and potassium iodide are added together, a canary yellow precipitate forms (lead iodide).

Figure 7.31 When two clear solutions are mixed and a solid forms, this is a precipitation reaction.

Word equation:
lead nitrate + potassium iodide → lead iodide + potassium nitrate

Chemical equation:
$Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$

Practical skills 7.3: Teacher demonstration

Precipitation reactions

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To demonstrate and observe how to mix two clear solutions in order to produce an insoluble, and often coloured, solid called a precipitate, and to name the precipitates formed

Materials
- 0.1 M solutions of the following chemicals in dropper bottles: silver nitrate, lead nitrate, copper sulphate, potassium iodide, sodium carbonate, sodium hydroxide and potassium chromate
- micro test tubes
- micro test-tube rack
- safety glasses

Method
1. Place approximately 10 drops of silver nitrate in six micro test tubes standing in a rack.
2. Add 10 drops of lead nitrate to the first micro test tube containing silver nitrate.
3. Observe whether there is reaction and record your observations in the results table.
4. Repeat steps **2–3** with each of the other solutions in the top row of the results table.
5. Now test lead nitrate with each of the other solutions in the same way.

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…continued

6 Name the precipitates that were formed. To do this, take the first name of the first solution and add it to the last name of the second solution. For example,
Lead nitrate and potassium iodide react to form lead iodide (the product).
Follow this rule for the rest of the precipitates formed in this experiment.

Results

Draw up a table like the one shown here, to record the results of mixing two clear solutions to produce a precipitate.

Chemical	Silver nitrate	Lead nitrate	Copper sulphate	Potassium iodide	Sodium carbonate	Sodium hydroxide	Potassium chromate
Silver nitrate							
Lead nitrate				Yellow precipitate			
Copper sulfate							
Potassium iodide		Yellow precipitate					
Sodium carbonate							
Sodium hydroxide							
Potassium chromate							

Analysis

1 Define the terms 'chemical change' and 'precipitate'.
2 What observations did you make that suggest a chemical change has taken place?
3 Write word equations for each of the pairs of solutions that reacted to form a precipitate.
4 Challenge: Use formulas to write a chemical equation for each of the pairs of solutions that reacted to form a precipitate.

Evaluation

Suggest some possible faults in the experimental method used and how these would be resolved if the experiment were to be carried out again.

Combustion

combustion
a reaction that involves the burning or exploding of a substance in the presence of oxygen

Chemical reactions that involve the burning or exploding of something are called **combustion** reactions. In this case, there is a substance that reacts with oxygen, and heat and light are released along with the formation of the products.

For example, methane is the gas that comes out of your school Bunsen burner. It reacts with oxygen to produce carbon dioxide, water, light and heat.

Word equation:
methane + oxygen → carbon dioxide + water

Chemical equation:
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Another example is octane, the fuel used to power your family car. It reacts with oxygen to produce carbon dioxide, water, light and heat.

Word equation:
octane + oxygen → carbon dioxide + water

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

Figure 7.32 Octane is a component of gasoline (petrol).

Explore! 7.4

Fire and agriculture

Many plants in Australia can be cultivated or propagated by fire. Conduct research on yams and cycads to describe how Australia's Aboriginal and Torres Strait Islander peoples utilised fire to cultivate these crops.

Figure 7.33 Fire is used in the cultivation of yams (top) and cycads (bottom), which are sources of carbohydrates.

Did you know? 7.4

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 contact with oxygen in the air in a combustion reaction. 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 has allowed candles to be a perfect candidate for lighting purposes for thousands of years.

Figure 7.34 The wick provides a surface on which the wax can vaporise in a combustion reaction.

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Practical skills 7.4: Teacher demonstration

Sugar snake

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 4 teaspoons of powdered sugar with 1 teaspoon of baking soda.
2. 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.

Results

Take photos of each stage of the method and record the chemical reaction using a phone or video camera.

Analysis

1. Define the terms ‘chemical change’ and ‘combustion’. What evidence do you see that a chemical change has occurred?
2. What ingredient do you think is undergoing combustion? What gas is being made?
3. Can you explain why the snake goes black? Why does it keep growing?
4. Explain the purpose of the sand.
5. Why is it recommended that this experiment is done wearing safety glasses, in a well-ventilated area or fume hood?

Quick check 7.9

1. Explain how you would identify that a chemical reaction was a precipitation reaction.
2. Explain how you would identify that a chemical reaction was a combustion reaction.

Science as a human endeavour 7.4

Synthesis of pharmaceuticals

In this chapter, you have explored four basic types of reactions. However, scientists employ a wide range of other chemical reactions to create new complex molecules. An example of this is the development of pharmaceuticals to specifically target certain diseases.

Scientists are always working to create new vaccines, antiviral and antibiotic agents for a range of new and old diseases. The synthesis of such molecules may require more than 10 or 20 steps of chemical reactions to achieve the complex pharmaceutical.

In early 2020, scientists around the world were hastily using chemical reactions to attempt to create a molecule that would act as an antiviral agent to the COVID-19.

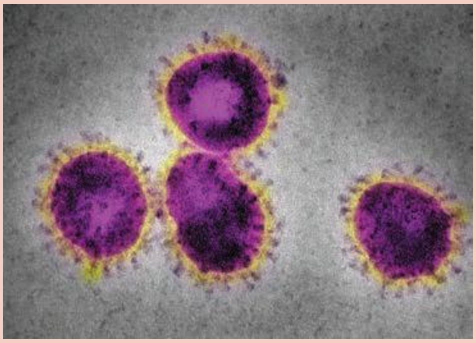

Figure 7.35 The coronaviruses are a family of viruses that includes SARS (shown in the image), MERS and more recently, COVID-19.

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Practical skills 7.5: Teacher demonstration

Elephant's toothpaste

Aim

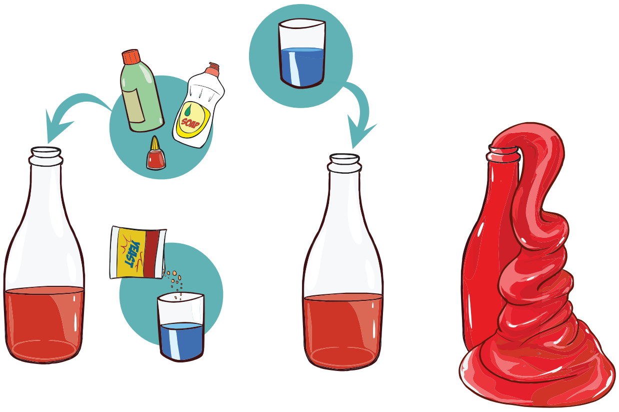
To observe the evidence that shows the decomposition of hydrogen peroxide is a chemical reaction

Materials

- empty 500 mL plastic soft drink bottle
- ½ cup hydrogen peroxide (6% for a big reaction or 3% for a smaller reaction)
- 1 packet of dried yeast
- warm water
- dishwashing detergent
- dishwashing gloves
- cup
- food colouring
- funnel
- large plastic tray

Method

1. Pour the peroxide into the bottle using a funnel.
2. Add a large squirt of detergent to the bottle and swirl to mix.
3. Add some food colouring.
4. In the cup, mix about 4 tablespoons of warm water and the dry yeast, and stir to combine.
5. Pour the yeast into the bottle with the peroxide, using a funnel. Quickly 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 and the edge of the bottle, and record your observations of the temperature.

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 (H_2O_2).
5. Write the chemical equation for the decomposition of hydrogen peroxide.
6. Investigate yeast and find out why it is included as an ingredient in this reaction.

Section 7.3 questions

QUIZ

Retrieval

1 **Recall** the characteristics of a precipitation reaction.
2 **Recall** the products of a typical combustion reaction of a hydrocarbon.
3 **Define** the term 'precipitate'.
4 **Demonstrate** how a reaction might fit into more than one category. Use an example.
5 **Summarise** the four types of reactions in a table like the one below.

Reaction type	Definition	Example

6 **Identify** the reactants and products in the following reactions.
  a $2Mg + O_2 \rightarrow 2MgO$
  b In fermentation, sugar decomposes to form ethanol + carbon dioxide + energy.
7 **State** the word equations for each of the following reactions.
  a Hydrogen gas and oxygen gas explode to form water.
  b When fruit ripens, fructose (a sugar) is formed from starch and water.
  c Solid iron is combined with sulfur and forms iron sulfide.
8 A chemical reaction occurs between two clear solutions, baking soda and calcium chloride. Calcium carbonate is the solid that forms, along with carbon dioxide gas, sodium chloride and water.

  Chemical equation: $2NaHCO_3 + CaCl_2 \rightarrow CaCO_3 + 2NaCl + CO_2 + H_2O$

  a **State** the word equation for this reaction.
  b **Identify** the reactants and the products in the reaction.
  c **Identify** the type of reaction.

Comprehension

9 **Explain** what gas is necessary for a combustion reaction.
10 **Explain:**
  a how a synthesis reaction is different to a decomposition reaction.
  b how you could tell whether a precipitation reaction is occurring.

Analysis

11 **Classify** each of the following reactions as synthesis, decomposition, precipitation or combustion.
  a $A + B \rightarrow C$
  b methane + oxygen → carbon dioxide and water
  c $Fe + S \rightarrow FeS$
  d $C_6H_{12}O_6 \rightarrow 6C + 6H_2O$
  e $2Mg + O_2 \rightarrow 2MgO$
  f carbon dioxide → carbon + oxygen
  g sodium chloride + silver nitrate → silver chloride$_{\text{(solid)}}$ + sodium nitrate

Knowledge utilisation

12 You are carrying out a chemical reaction in class and observe that condensation appears on the inside of the test tube. **Propose** if this is evidence of a physical change or a chemical change. Has heat energy been absorbed or released? Give reasons for each of your answers.

Chapter review

Chapter checklist

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

1	**I can describe ways to identify if a physical change has occurred.** e.g. Recall the evidence we can use to identify if a physical change has occurred.	
2	**I can describe ways to identify if a chemical change has occurred.** e.g. Recall the evidence we can use to identify if a chemical change has occurred.	
3	**I can identify the reactants and products in a reaction.** e.g. Define the terms 'reactants' and 'products'.	
4	**I can describe the four basic types of chemical reaction.** e.g. Describe a decomposition reaction.	

Review questions

SCORCHER

Retrieval

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 **Name** the products released when a hydrocarbon compound undergoes a combustion reaction.

4 **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

5 **State** if each of the following statements are true or false. Rewrite the false statements so they are true.
  - a Synthesis reactions are when two (or more) elements or reactants combine to form new substances or products.
  - b Precipitation reactions involve the creation of a colourful and soluble solid that can settle.
  - c Decomposition reactions are those in which several reactants break up into even smaller products.
  - d Combustion occurs whenever there is oxygen.

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6 **Recall** the only real proof that a chemical reaction has occurred.

7 When Tori reacts a lump of calcium carbonate with sulfuric acid, she sees 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.

8 **State** the following as word equations.

- a Dean mixed together eggs, flour and milk. He then heated the mixture and produced delicious pikelets!

Figure 7.36 Pikelets

- b Suzi dropped a chunk of magnesium into a test tube containing hydrochloric acid, and magnesium chloride was formed. She also noticed a gas forming and when she held a glowing splint nearby, it went *pop*, just like hydrogen gas does when it burns.

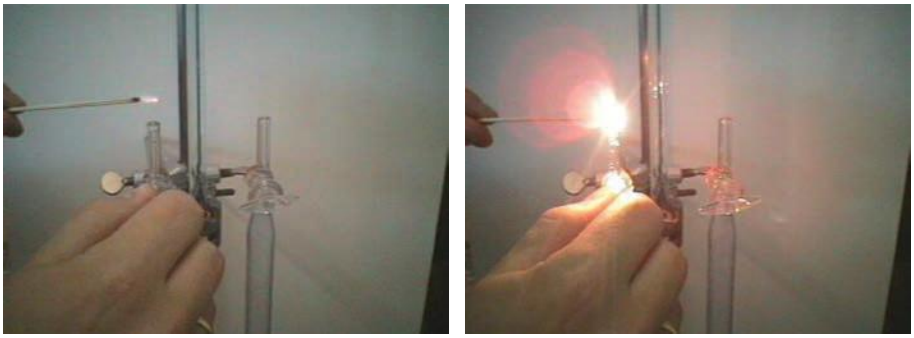
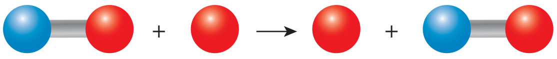


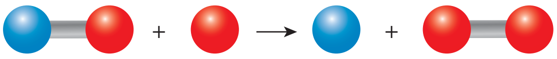
Figure 7.37 A splint is a long thin piece of wood used in labs. It is lit and then blown out. While still glowing, it can be introduced to a gas sample.

- c Maisie used some nitric acid from science class to mix with iron oxide and produce iron nitrate and some water.
- d Edward put some copper scraps with a little sulfur powder in a test tube and heated it over a Bunsen burner. At the end of the reaction, he observed a greenish colour on the copper – a sulfide.

9 **Identify** which of the following are examples of chemical reactions.

A 

B 

C 

10 When a substance burns, it reacts with a gas in the air and forms an oxide.
- a **Name** this gas.
- b **Identify** the type of chemical reaction.
- c **State** the word equations for the two examples shown below. You will need to refer to a periodic table to determine the names of the elements involved.
  - i $2Mg + O_2 \rightarrow 2MgO$
  - ii $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

11 Barium sulfate, $BaSO_4$, is used in medical imaging of the gastrointestinal tract, because it absorbs X-rays and can show up in an imaging scan. It is formed when the two clear solutions, barium chloride and sodium sulfate, react together. Sodium chloride is also formed.
- a **State** the reactants of this chemical reaction.
- b **List** the products of this reaction.
- c Barium sulfate is a solid produced during this chemical reaction. **Identify** the type of chemical reaction.
- d **Identify** the piece of evidence that you have that your answer to part **c** is correct.

Comprehension

12 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.

13 **Summarise** the observations you could make if a chemical change had occurred.

14 **Explain** why a colour change occurring is not always a sign that a chemical change has occurred.

Analysis

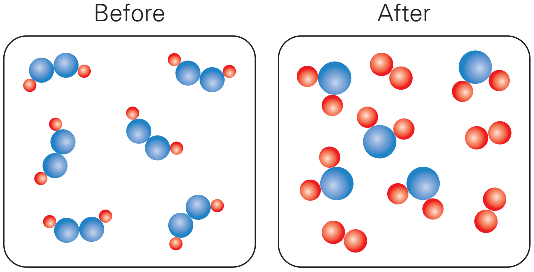
15 **Critique** the following statement: 'Atoms that are not in the reactants can end up in the products of a chemical reaction'.

Knowledge utilisation

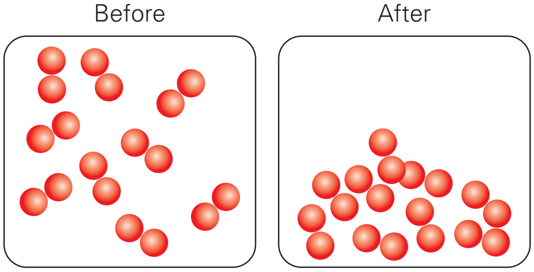
16 a When you combine bicarbonate soda and buttermilk, a gas is produced. **Propose** why the gas is considered evidence that a chemical reaction occurred.
- b **Propose** whether it is possible to continue adding more and more of one reactant and expect to get more and more product. Give reasons why or why not.

17 **Determine** whether each of the particle diagrams below indicates a chemical or physical change. Justify your answer.

a



b



Data questions

A theoretical chemical reaction occurs such that reactant A reacts to form an intermediate product B, which 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 species is plotted in Figure 7.38, with respect to time passed in the reaction.

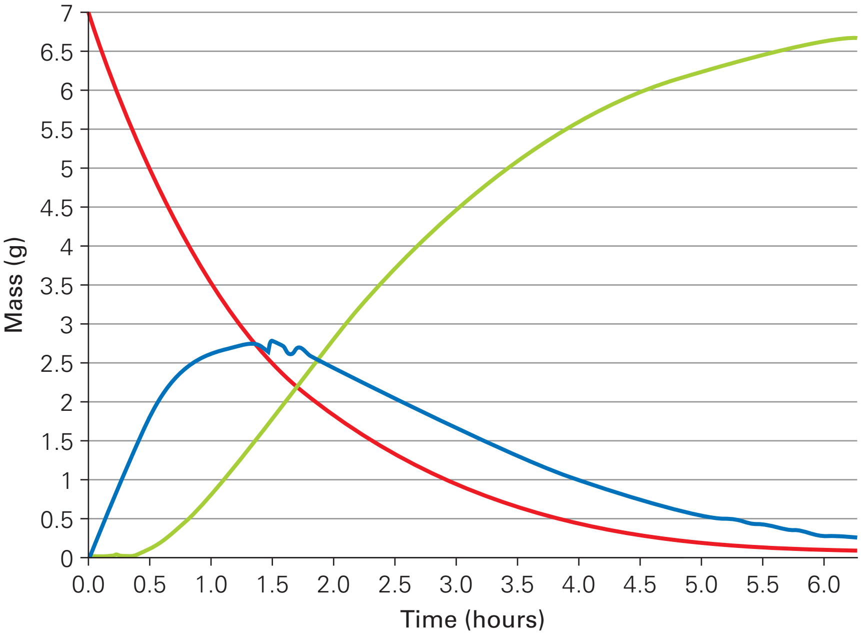


Figure 7.38 Change in mass of each reactant (in red), intermediate (in blue) and product (in green) of time in a chemical reaction.

Apply

1 **Identify** the colour of the line which represents the reactant A; the line with a mass greater than zero at the beginning of the reaction.

2 **Identify** which coloured line represents the intermediate; the species that is formed in a reaction of A, and then reacts to form C.

3 **Identify** the time at which the mass of intermediate B is greatest.

Analyse

4 **Identify** the relationship between the mass of reactant A and the mass of product C.

5 **Contrast** the curve for intermediate B and product C and account for the shape of the blue line.

Interpret

6 **Infer** why the green line does not increase steadily until after 0.5 h.

7 **Justify** what the total mass of all species will be at 3.0 h if the mass of reactant A was 7 g at time zero.

8 **Predict** whether the mass of product C will increase above 7 g.

9 The intermediate, B, has a blue colour when it is produced, and in this reaction this blue colour was only evident when B composed the most mass of all species. **Deduce** which time period after the start of the reaction would the reaction mixture have appeared blue.

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STEM activity: Building a rocket

Background information

Rockets are exciting machines that are designed by engineers and used to explore space. It is amazing to think that someone has worked out how to get these heavy vehicles into space! Rockets depend on a combustion reaction to provide the thrust they need to overcome the force of gravity and shoot up into orbit. Combustion is a fast heat-producing (exothermic) reaction between a fuel and oxygen, in which the fuel is burnt. As you know, during a chemical reaction, new compounds are made – in this case, these compounds are the rocket's exhaust. The exhaust coming out from the bottom of the rocket produces a great thrust or force, and the reaction force to this pushes the rocket upward.

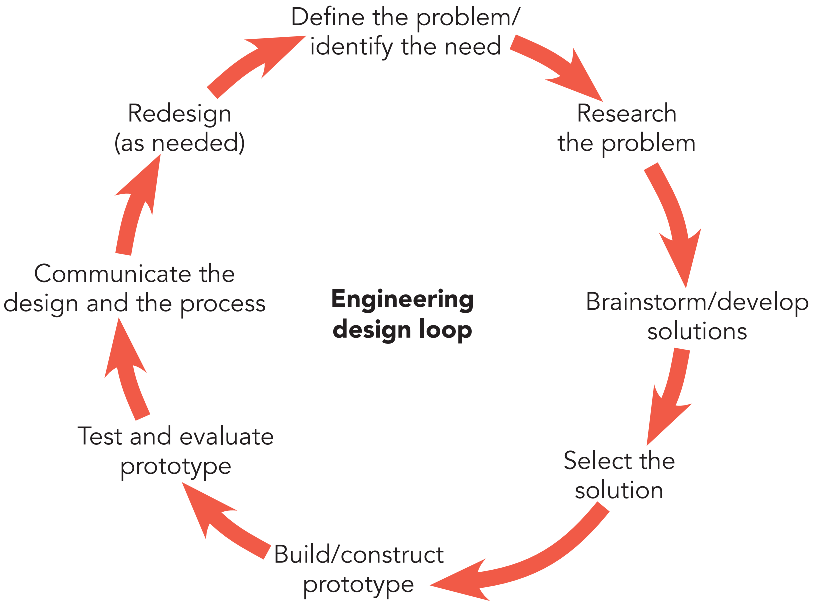

Figure 7.39 Designing and testing of a model comes before construction of the real thing.

Figure 7.40 Space launch

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 make sure 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 they can.

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.

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Suggested materials

- 35 mm film canister (or anything similar with an internal snapping lid)
- an antacid tablet, such as Alka-Seltzer®
- water
- scissors, sticky tape, textas, paper
- chopping board, mortar and pestle, knife, spoon
- safety glasses

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 film canister and lid as a reaction vessel: good engineers use existing technology and work on improvements, and also completely reinvent the concept sometimes.

3 Research rocket design and the size ratios of the dimensions of the rocket.

Design and sustainability

3 Discuss in your group how to make the rocket reaction vessel re-usable to reduce waste, and think of methods to limit excess production of carbon dioxide.

4 Sketch multiple possibilities of the rocket design and how the rocket would obtain lift from the reaction vessel, making sure that your rocket is not 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 need to work on discovering the correct amount of antacid and water in the film canister to obtain a time to launch of 10 seconds. The build team needs to ensure the rocket can launch safely, and sustainably.

Evaluate and modify

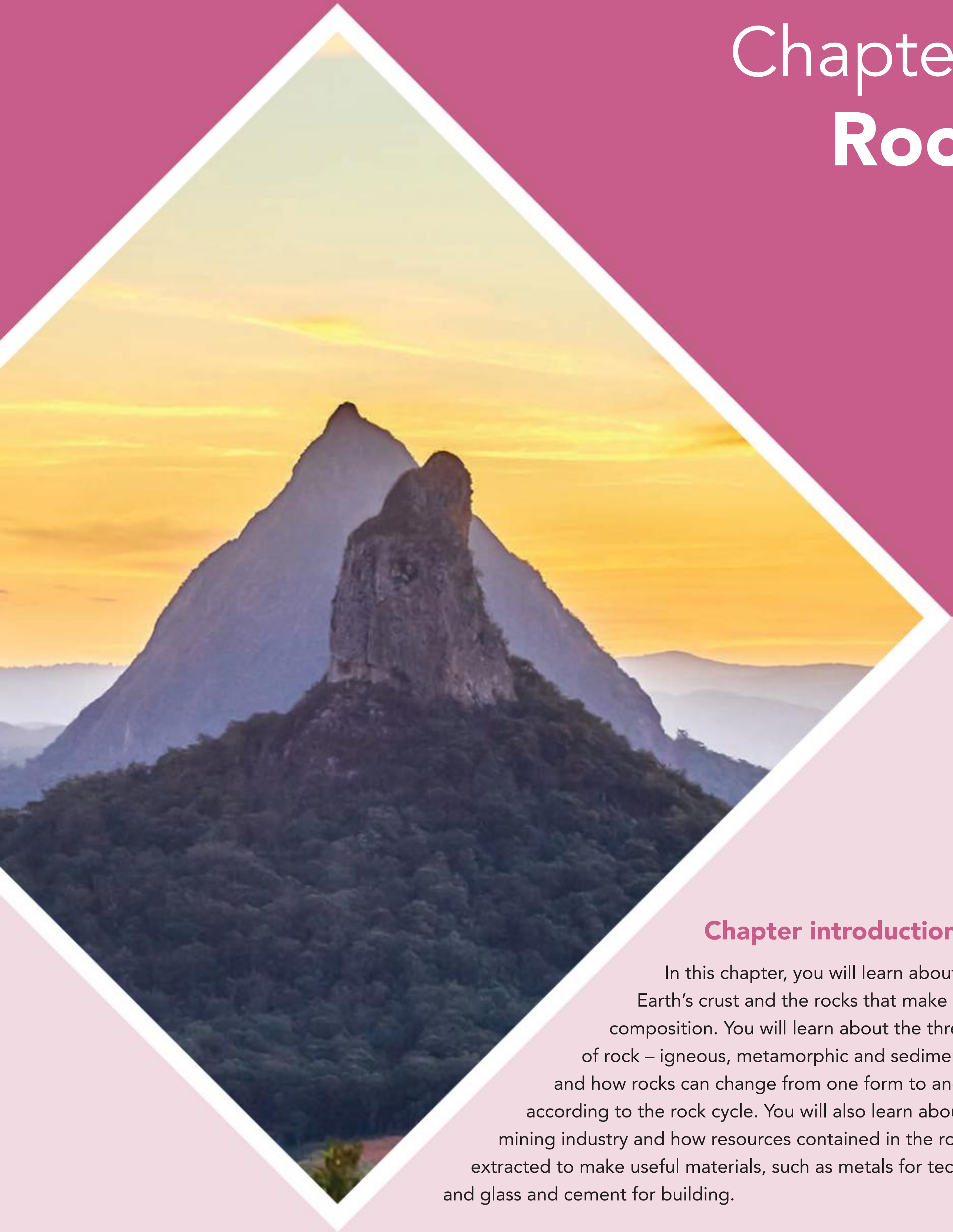
8 Discuss the different conditions you investigated and what you found out about the effect of temperature, surface area and mass of the antacid tablets on the rocket launch times.

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 change/ improvement 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.

Chapter 8
Rocks



Chapter introduction

In this chapter, you will learn about the Earth's crust and the rocks that make up its composition. You will learn about the three types of rock – igneous, metamorphic and sedimentary – and how rocks can change from one form to another, according to 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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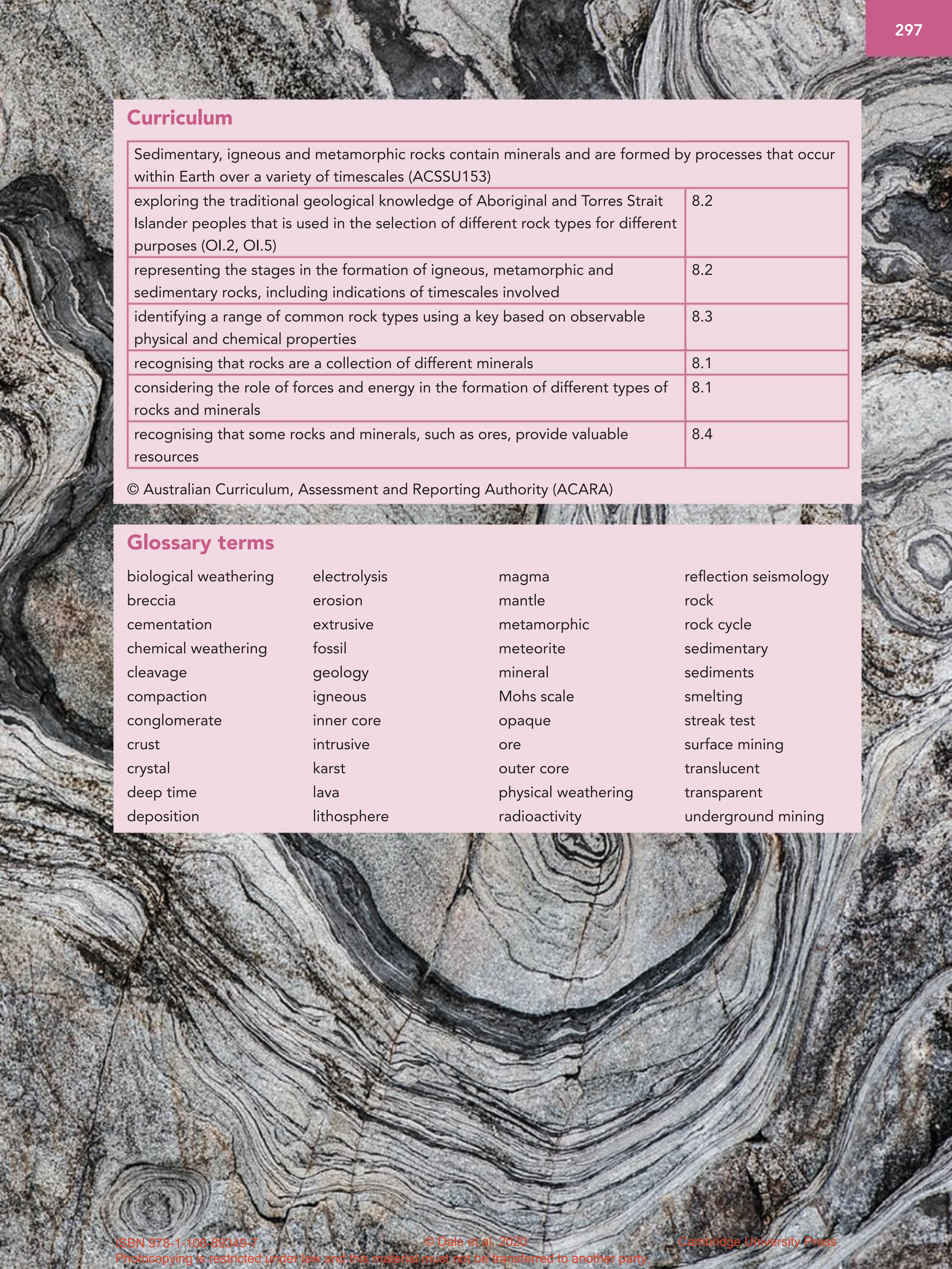

Curriculum

Sedimentary, igneous and metamorphic rocks contain minerals and are formed by processes that occur within Earth over a variety of timescales (ACSSU153)	
exploring the traditional geological knowledge of Aboriginal and Torres Strait Islander peoples that is used in the selection of different rock types for different purposes (OI.2, OI.5)	8.2
representing the stages in the formation of igneous, metamorphic and sedimentary rocks, including indications of timescales involved	8.2
identifying a range of common rock types using a key based on observable physical and chemical properties	8.3
recognising that rocks are a collection of different minerals	8.1
considering the role of forces and energy in the formation of different types of rocks and minerals	8.1
recognising that some rocks and minerals, such as ores, provide valuable resources	8.4

Glossary terms

biological weathering
breccia
cementation
chemical weathering
cleavage
compaction
conglomerate
crust
crystal
deep time
deposition
electrolysis
erosion
extrusive
fossil
geology
igneous
inner core
intrusive
karst
lava
lithosphere
magma
mantle
metamorphic
meteorite
mineral
Mohs scale
opaque
ore
outer core
physical weathering
radioactivity
reflection seismology
rock
rock cycle
sedimentary
sediments
smelting
streak test
surface mining
translucent
transparent
underground mining

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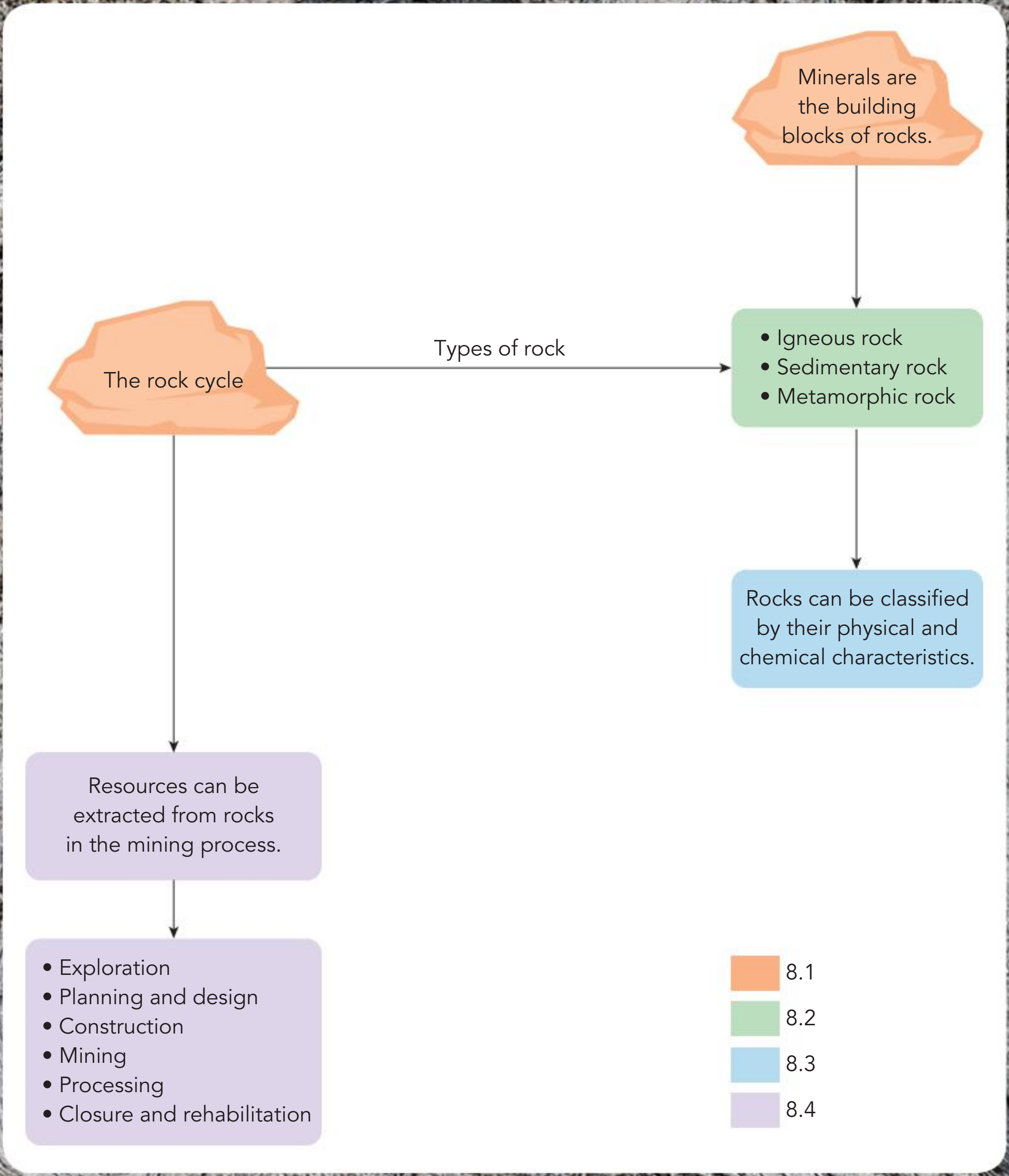
Concept map


Minerals are the building blocks of rocks.
Types of rock
The rock cycle
• Igneous rock
• Sedimentary rock
• Metamorphic rock
Rocks can be classified by their physical and chemical characteristics.
Resources can be extracted from rocks in the mining process.
• Exploration
• Planning and design
• Construction
• Mining
• Processing
• Closure and rehabilitation
🟧 8.1
🟩 8.2
🟦 8.3
🟪 8.4

8.1 Rock formation

WORKSHEET

Rocks and minerals

Rocks are a naturally occurring substance made up of one or more **minerals**. Minerals are considered to be the building blocks of rocks, and each mineral has a specific chemical structure. Rocks can be:

- **igneous** – formed from molten rock
- **sedimentary** – formed from the products of erosion
- **metamorphic** – altered by heat and pressure.

A mineralogist is a person who studies minerals. It can be an interesting job, because there are over 5000 minerals to study. Some minerals are found in the form of **crystals** and this can be an easy way to identify them.

Figure 8.2 Granite is an igneous rock. It is usually made up of four minerals. The large crystal size in the rock indicates that the rock cooled slowly, probably underground.

rock
solid material forming the Earth's crust; rocks are formed as part of the rock cycle

mineral
a chemical substance that is formed naturally in the ground

igneous
describes rocks made from lava on the surface or magma below the 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

crystal
a mineral in which the atoms are arranged in an ordered way to form a geometric shape

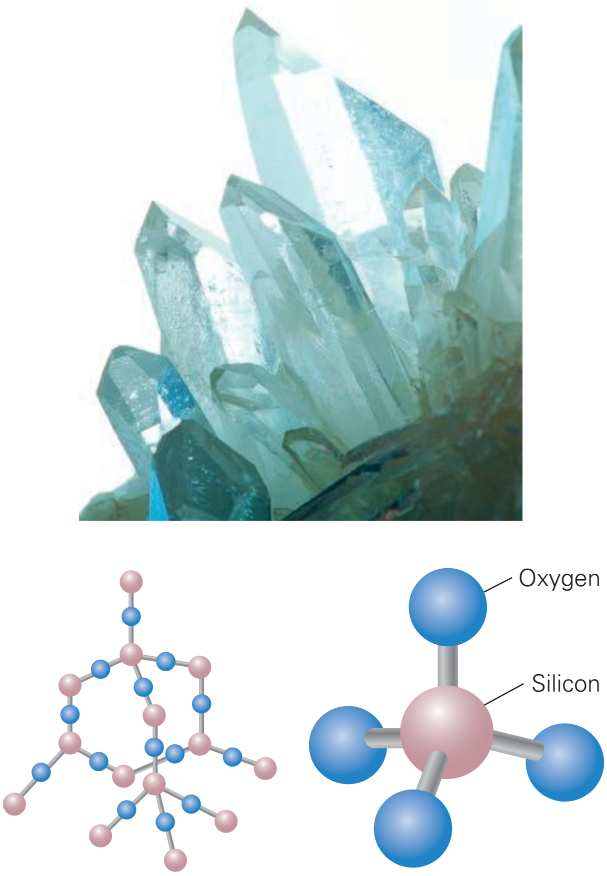


Figure 8.1 Quartz (shown at top) is a mineral made of silicon and oxygen atoms arranged in a continuous framework.

Did you know? 8.1

Minerals include gemstones that are used in jewellery. Most gemstones are brightly coloured or transparent crystals. Diamond, for example, is a crystal made from carbon. Carbon is the same chemical element that is in graphite, which is used to make pencil leads.

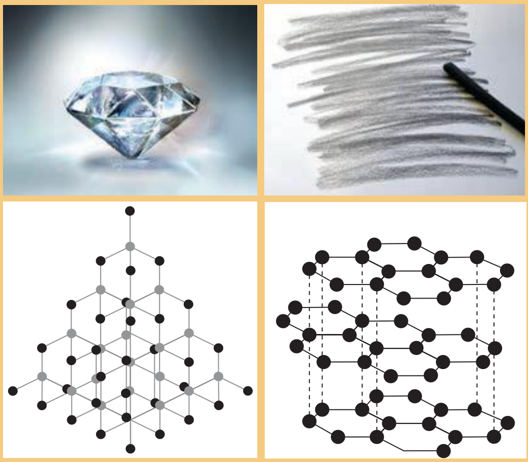


Figure 8.3 Diamond (shown at left) and graphite (shown at right) are both made of carbon atoms. However, the arrangement of the atoms makes a big difference to their properties.

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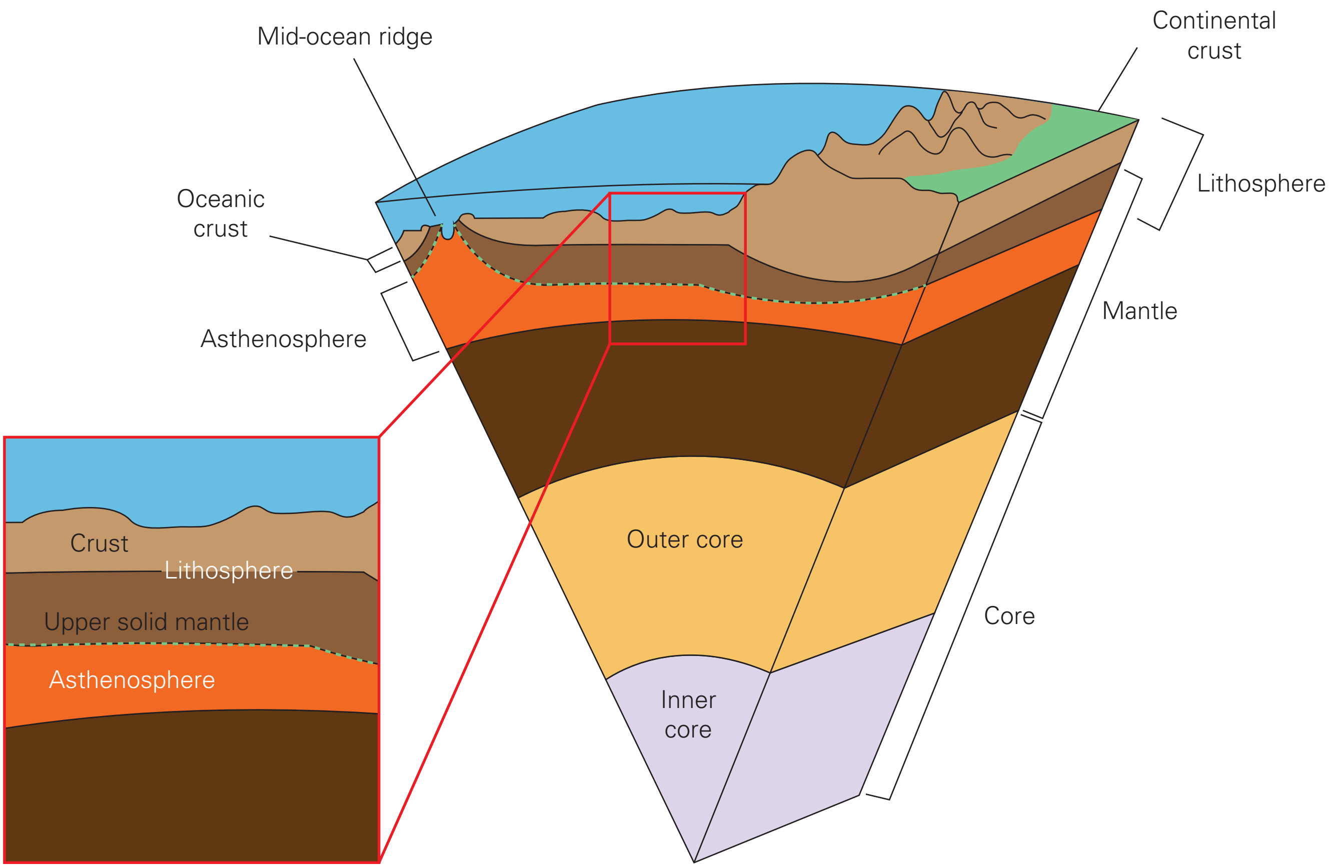

Figure 8.4 The Earth is composed of several layers.

Rocks and the Earth

The **inner core** of the Earth is currently thought to be mostly solid iron, while the **outer core** is made of liquid iron and nickel. Surrounding the outer core is the **mantle**, comprising mostly solid and semi-molten rock. Earth's outer layer is the solid **crust**. Rocks are formed and reformed in the **lithosphere**, which includes the crust and the uppermost mantle.

The Earth's mass is predominantly made up of iron, then oxygen, silicon and magnesium. Small amounts of all the other elements can also be found. This is what makes geology (the study of the rocks and similar substances that make up the Earth's surface) fascinating, as each type of rock contains different components and has different properties.

inner core
the solid centre of the Earth; probably made of iron

outer core
the liquid layer surrounding the inner core; probably made of liquid iron

mantle
the layer of solid and semi-molten rock that surrounds the outer core and extends up to the Earth's crust

crust
the solid outer layer of the Earth; continental crust is on average 35 km thick and the average thickness of oceanic crust is 10 km

lithosphere
the solid outer layer of the Earth; includes the crust and uppermost mantle

Element	% of Earth's mass
Iron	35
Oxygen	30
Silicon	15
Magnesium	13

Table 8.1 These four elements make up most of the Earth's mass.

Quick check 8.1

1. Define and distinguish between rocks and minerals.
2. Where are rocks formed in the Earth?
3. What elements make up most of the Earth's mass?

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The rock cycle

The Moon has stayed unchanged for millions of years, but the **geology** of the Earth is very different. James Hutton, the father of modern geology, tried to explain why the surface of the Earth is so complex. He came up with two conclusions.

- The Earth is very old – Hutton called this **deep time**.
- The Earth's surface has been constantly changing throughout its history. The rock component changes constantly due to some key processes, which together are called the **rock cycle**.

Melting and cooling

As you can see in Figure 8.5, 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 the 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 the 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 the Earth's surface, magma takes a long time to cool, and the crystals formed in it are large. Magma that reaches the Earth's surface is called **lava**. Because lava cools more quickly, the crystals formed are small and may even be microscopic. You will learn more about igneous rocks in the next section of this chapter.

geology
the study of the rocks and similar substances that make up the Earth and other planetary objects

deep time
the idea first suggested by James Hutton that the Earth is very old

rock cycle
the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

magma
molten rock under the Earth's surface

lava
molten rock from inside the Earth (called magma) that has reached the surface

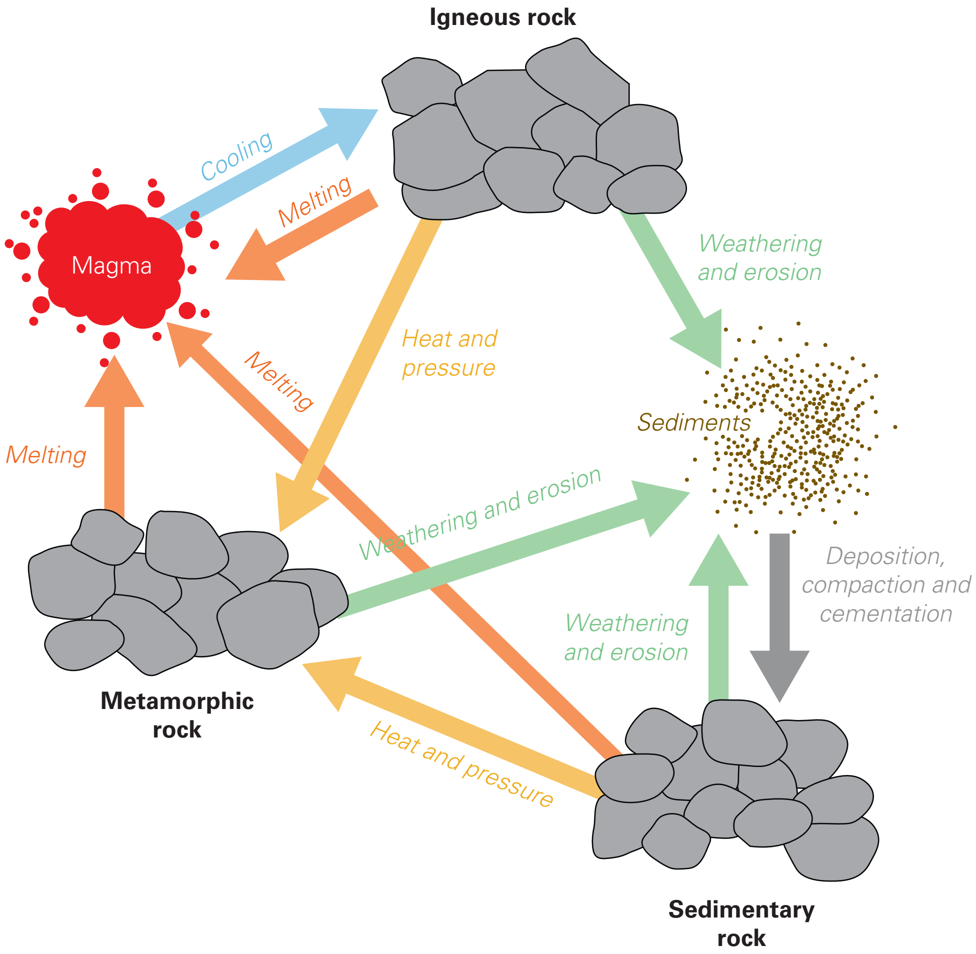

Figure 8.5 In the rock cycle, the three types of rock can change, through the action of weathering and erosion, deposition, compaction and cementation, melting and cooling, and heat and pressure.

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Did you know? 8.2

'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 hot magma.

Figure 8.6 'Igneous' comes from a Latin word meaning 'fire'.

Explore! 8.1

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 your preferred search engine to answer the following questions.

meteorite
a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground

Figure 8.7 An iron meteorite that landed on Earth from space

1. What is the composition of meteorites?
2. How does a meteorite end up on Earth?
3. Propose whether or not meteorites pose a threat to life on Earth. Justify your argument using examples of meteorites that have landed on Earth, and their impact.

Try this 8.1

Making crystals

You will need the following materials:

- soluble crystals such as copper sulphate, sugar or salt
- beaker
- warm water
- two Petri dishes.

Figure 8.8 Copper sulphate crystals

Stir the crystals in the water until they dissolve. Keep adding crystals until no more can be dissolved – this will give you a concentrated solution. Filter the solution to remove any solids. Put the resulting liquid into two Petri dishes and place one in a hot sunny place and the other in a dark cupboard at room temperature. Leave for a few days. The water will evaporate and you should see crystals form. The liquid placed in direct sunlight will evaporate quickly, leading to small crystals being formed. The liquid placed in the cupboard will evaporate more slowly and the crystals should be larger. This same process takes place if a liquid solidifies to form crystals – the slower the rate at which it cools, the larger the crystals formed.

Use your observations to explain how the process of melting and cooling forms rocks. Draw on the similarities between this activity and the process of igneous rock formation.

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Quick check 8.2

1. What are the three types of rocks formed in the rock cycle?
2. What roles do melting and cooling play in the rock cycle?

Weathering

Weathering occurs when exposed rocks are broken down – for example, by ocean waves hitting a cliff face. Weathering breaks up large rocks into small particles called **sediments**. It includes physical weathering, chemical weathering and biological weathering.

Physical weathering is the breaking down of rocks into smaller particles by temperature, pressure or weather – for example, by extreme temperatures, high wind, snow, hail, rain and flooding. Ice is a very powerful agent in the weathering process, because of a process known as 'freeze–thaw action'. In this process, water enters a crack in a rock and freezes. As it freezes, it expands with great force and widens the crack. This can happen many times, widening the crack slowly until eventually the rock breaks apart.

Figure 8.9 A rock split in two by freeze–thaw action

Chemical weathering occurs when rocks are slowly dissolved by substances in rainwater that make it slightly acidic. It is more effective on limestone and silicon compounds, as these will react with the acid in the water. Rainwater that seeps underground in a limestone area can slowly create vast underground caves over millions of years, as well as long underground rivers. Limestone caves often contain stalactites hanging from the roof and stalagmites on the ground; when these meet, they form columns. Limestone caves such as the Jenolan Caves (see Figure 8.10) are often developed as tourist attractions because of the beautiful limestone features they contain.

When limestone contains underground rivers, it can give a very characteristic landform called a **karst** landscape (see Figure 8.11 on the following page), which has caves, sinkholes, 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.

sediments
sand, stones, etc. that slowly form a layer of rock

physical weathering
the breaking down of rocks into smaller particles by contact with other rocks, wind, water or ice

chemical weathering
the disintegration of rocks caused by acidic rainwater

karst
an area of land formed of rock such as limestone that is worn away by water to make caves and other formations

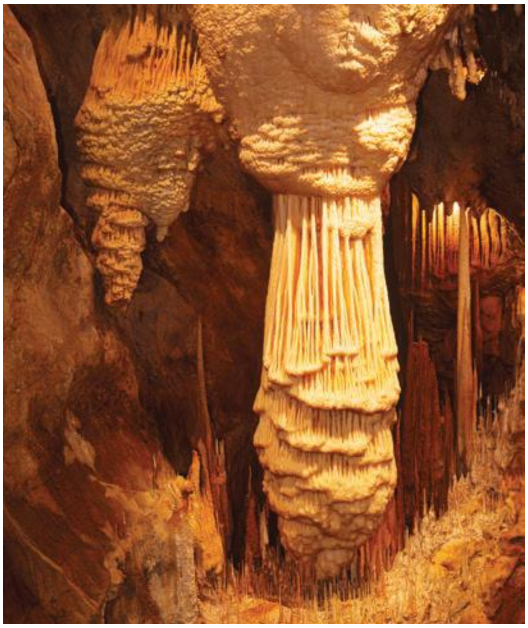


Figure 8.10 A pillar in the Jenolan Caves in New South Wales

Figure 8.11 The entrance to a cave in a typical karst landscape. Rainwater enters the cave and can travel underground for many kilometres.

Did you know? 8.3

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 8.12 Cavers explore underground cave systems, looking for amazing rock formations like this.

Science as a human endeavour 8.1

Early Ipswich limestone quarries

Ipswich was originally known as The Limestone Hills or The Limestone Station, before it was shortened to Limestone in 1842. Limestone was mined in the area and then sent to Brisbane in small boats to be used for building. The Old Hummock Limestone Residue recognises that limestone was quarried in the area.

Figure 8.13 The Old Hummock Limestone Residue

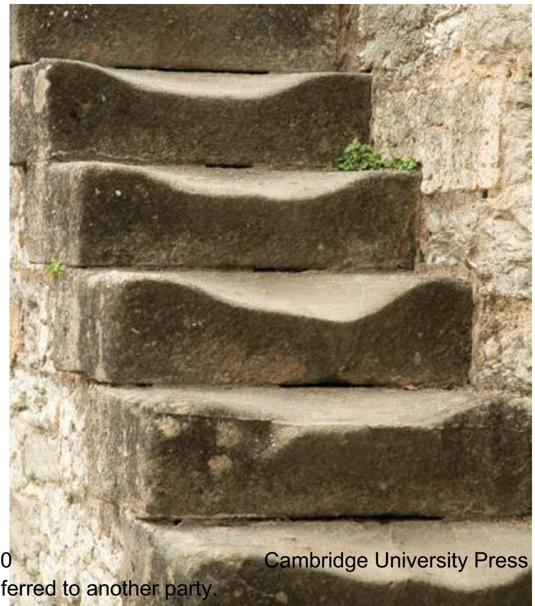
Biological weathering occurs when rock is broken down into smaller particles by living things. For example, human feet can wear dips into the tops of stone steps (see Figure 8.14), plant roots grow into small cracks in rocks and make the cracks bigger, and people who do not stay on pathways in national parks damage the vegetation, which can eventually lead to erosion.

biological weathering the disintegration of rocks that is caused by living things

Quick check 8.3

Distinguish between the three types of weathering: physical, chemical and biological.

Figure 8.14 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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Erosion

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.

The size of particle that can be carried is highly dependent on the way it is transported. Only small particles, such as sand, can be blown by the wind, but pebbles and even boulders can be transported in rivers and oceans. The size of particle that can be moved depends on the speed of the wind or water – for example, mud can be carried by slow-moving rivers, sand requires faster water, and stones and boulders can only be transported by a river in flood. Glaciers can carry giant boulders trapped in the ice, for many kilometres. They are also powerful weathering agents, because the ice leaves a smooth surface as it passes over the bedrock.

During the 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 Australia 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.

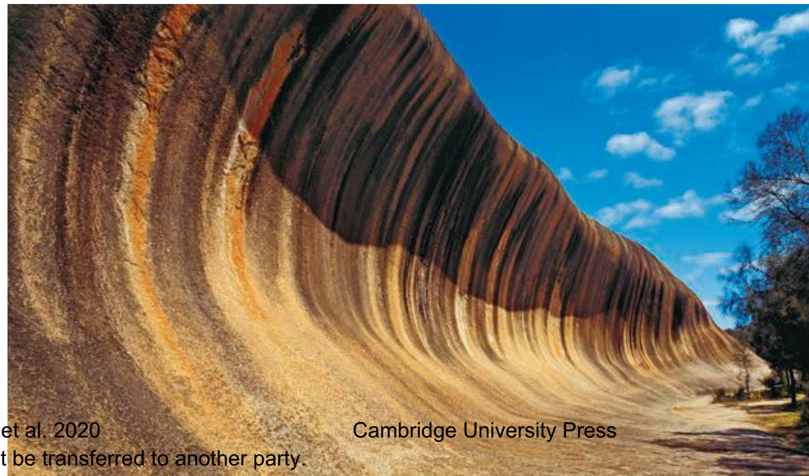
Figure 8.15 The Twelve Apostles, off the shore of the Port Campbell National Park. These limestone stacks were formed on the seabed. Today the seabed has been raised and the limestone is being weathered and eroded by the ocean waves.

Figure 8.16 Dove Lake on Cradle Mountain in Tasmania. The smooth appearance of the rocks is due to the action of glaciers twenty thousand years ago.

erosion
the transport of rocks from one place to another as a result of weathering

The profile of Wave Rock in Western Australia (see Figure 8.17) 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 8.17 Wave Rock in Western Australia is made of granite that is over two billion years old.



Try this 8.2

Erosion by wind

You will need the following materials:

- Petri dish
- water
- dry sand
- pebbles of various sizes
- 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? Does the sand blow away more from under the pebbles or around the pebbles?

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
process that occurs when eroded particles stop moving and build up to form sedimentary rocks

compaction
the process of parts 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 8.18 Sedimentary rocks are very common, covering over 70% of the Earth's surface. Some contain fossils that are billions of years old. Note the different layers of sediment, all cemented together.

Quick check 8.4

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 and can create layers of sediment many metres high.

Try this 8.3

Deposits on a riverbed

Aim

To model and observe how sediments are deposited on a riverbed

Materials

- soil
- sand
- gravel
- water
- jar with lid

Method

1 Add soil, sand and gravel to a jar, and mix them. Fill the jar to halfway.
2 Add water. Fill the jar ¾ 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.

Results

Draw a diagram representing the different layers, and label them.

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?

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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 8.19 Slate is a metamorphic rock formed when mudstone is subjected to high pressure and temperature.

Figure 8.20 Pieces of schist, formed when slate is subjected to high temperature and pressure.

Try this 8.4

Metamorphic pasta

You will need the following materials:

- 2 textbooks
- 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 8.21. 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?

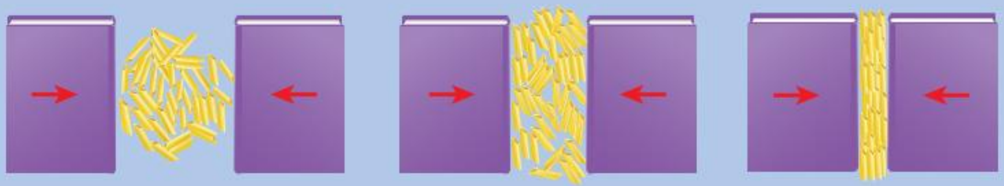

Figure 8.21 As you compress the pasta, the pieces align.

Quick check 8.5

1 List the three different types of rock.
2 Distinguish between the three kinds of rock in terms of how they are formed.

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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.

radioactivity energy released from the nucleus of an atom when the atom decays; the age of rocks can be determined by measuring their radioactivity

Type of rock	Source of energy	Details
Igneous Metamorphic	Earth's formation and elements that are **radioactive**	When the 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 the Earth at a high temperature.
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 8.2 The energy required for the formation of the different rock types comes from different sources.

Did you know? 8.4

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 rock to be discovered on Earth is a piece of 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 the Earth itself.

Figure 8.22 This piece of rock is a sample of Acasta Gneiss, the oldest body of rock yet discovered on Earth.

Try this 8.5

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.

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Section 8.1 questions

QUIZ

Retrieval

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 on the Earth's surface.

Comprehension

4 Copy this image of the rock cycle in Figure 8.23 and label the missing processes. Then **explain** each of the processes.

5 **Summarise** how the different types of rock from the previous question are formed.

Analysis

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 the Earth's core suddenly lost its thermal energy. **Identify** which type(s) of rock formation would be affected and why?

Knowledge utilisation

9 Examine Figure 8.24 and **decide** whether it is a mineral or a rock. Justify your answer.

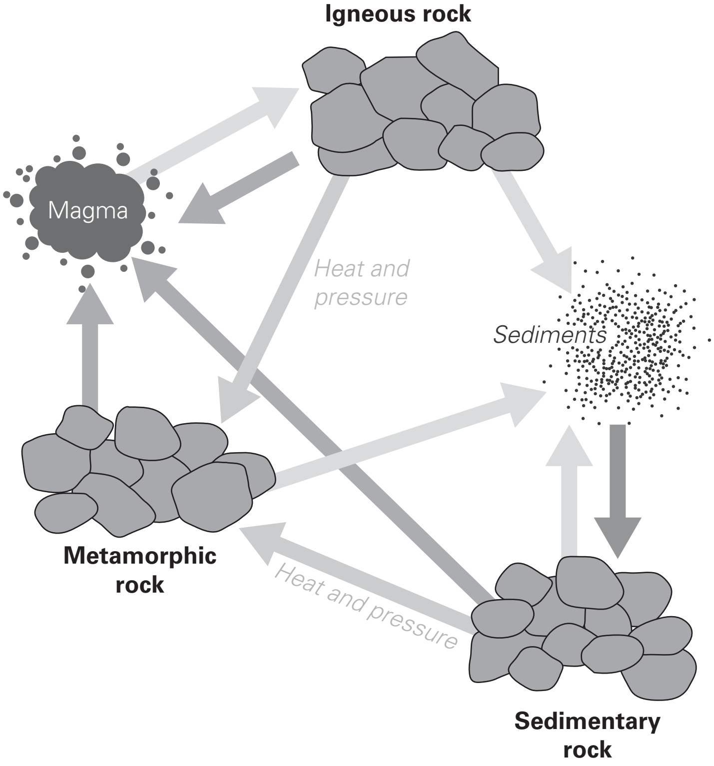

Figure 8.23 The rock cycle

Figure 8.24

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.

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8.2 Types of rocks

WORKSHEET

Igneous rocks

Beneath the 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, or when magma cools and solidifies slowly underground in a magma chamber after it has been pushed close to the surface.

extrusive describes igneous rocks formed on the Earth's surface; also called volcanic rocks

Figure 8.25 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. When magma breaks through the crust and flows on the surface, it is called lava. The lava solidifies to form **extrusive** igneous rocks. Basalt, an igneous rock, has the interesting property of forming large hexagonal structures as it cools. Pumice, also an extrusive igneous rock, floats on water!

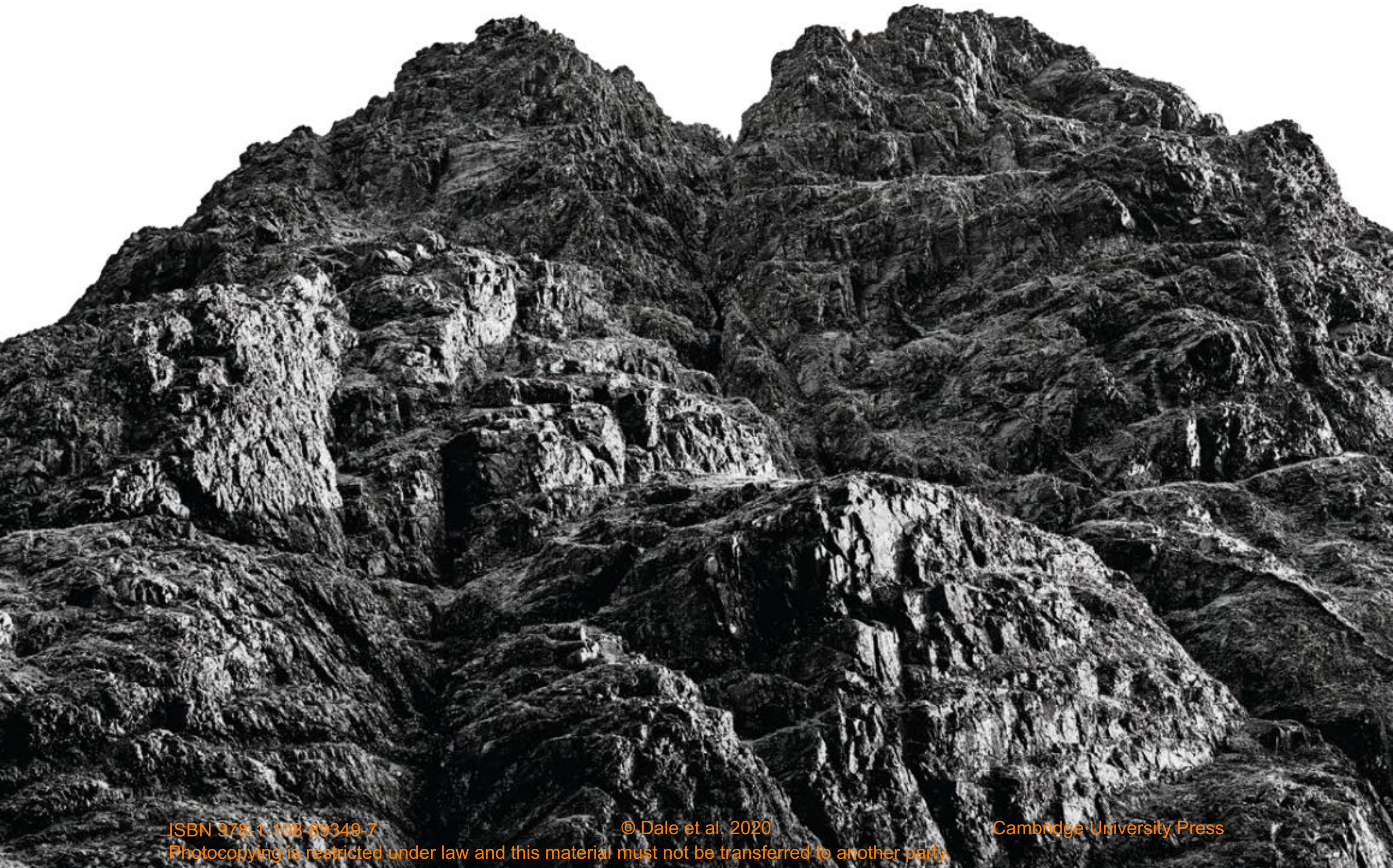

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Figure 8.26 The hexagonal pillars of basalt found at the Giant's Causeway in Ireland are an example of magma flowing onto the surface, solidifying and forming igneous rock.

Figure 8.27 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.

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 igneous rock formed beneath the surface of a volcano. This stone is often used to make kitchen benchtops.

intrusive
describes igneous rocks formed underground; also called plutonic rocks

Figure 8.28 Granite has a distinctive mosaic of crystals of different colours.

Did you know? 8.5

Magnetic Island's granite

Magnetic Island is an island off the coast of Townsville, Queensland, and is home to large boulders and deposits of the plutonic igneous rock, granite. After years of erosion of the overlying rocks, the granite is now exposed on parts of the island. While the granite might not be the reason for James Cook's naming of 'Magnetic Island', it is certainly a distinct component of the landscape of the island!

Figure 8.29 The Aboriginal peoples of Magnetic Island are the Wulgurukaba people; they call the island 'Yunbenun'.

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Quick check 8.6

1 List some examples of igneous rocks.
2 Describe in your own words how intrusive and extrusive igneous rocks are formed.
3 Describe the relationship between crystal size and the time the crystal takes to form.

Investigation 8.1

Crystals and cooling rate

Aim

To determine the effect that cooling rate has on crystal size formation

Planning

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 Identify the independent, dependent and controlled variables.
4 Write a hypothesis for your investigation.
5 Write a risk assessment for your investigation.

Materials

- saturated potassium nitrate or magnesium sulfate
- 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 of 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.

Analysis

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

Evaluation

1 Identify any limitations in your investigation.
2 Suggest some improvements for this experiment.

Conclusion

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

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Sedimentary rocks

The Earth's surface is covered partly by water and partly by land. As you saw in the previous section, weathering from waves, flowing water, wind, frost, rain, ice, chemicals and even living organisms, can break down the surface of exposed rocks. The particles of weathered rock are eroded: carried away by water, gravity, wind or ice. Eventually the particles can no longer be carried, and sedimentary rocks are formed when these particles or sediments are deposited, compacted and cemented together. Sedimentary rocks take thousands to millions of years to form.

Uluru is an example of sedimentary rock that you are probably very familiar with. Uluru is made of sandstone, but the sedimentary layers are almost vertical. This is evidence that the Earth is very old indeed. The rock that forms Uluru would originally have been horizontal, but over time the movement of the Earth's crust tilted it. The top of the rock has been weathered and eroded, until today just the end is showing.

Figure 8.30 Uluru is an ancient sedimentary rock tilted by nearly 90° by the movement of the Earth's crust.

The type of sedimentary rock formed depends on the particles that are deposited. Chalk is a common sedimentary rock and is formed from the remains of sea creatures whose bodies fell to the ocean floor. Chalk is made of calcium carbonate and can be identified by a simple test: when acid is placed on the surface, bubbles form. Chalk often contains fossils, and the age of the chalk can be determined from the fossils it contains.

Sea creatures that had tiny skeletons made of carbonates formed beds of chalk. Often gaps in the chalk filled with dissolved silica (also from sea creatures) and formed flint nodules. Flint is a type of chert and was one of the first substances used to make tools.

Figure 8.31 A chert nodule, found in chalk. Chert is also a sedimentary rock.

Sand made of quartz is another familiar material that forms sedimentary rocks. Sand is commonly found all over the world on beaches, and at the bottom of rivers, lakes and the sea. The sedimentary rock formed from sand is called sandstone. It is a common building material because it is relatively easy to cut and is strong.

Mud sediment forms mudstone and shale. It is not used extensively for building because it breaks easily. However, mudstone turns into

Figure 8.32 Jimbour is a homestead on one of the earliest stations established on the Darling Downs. Its buildings are made of sandstone.

Figure 8.33 Fossilised leaves in mudstone

slate at high temperature and pressure, and slate is used as a roofing material in some parts of the world. Half of the sedimentary rocks on Earth are made of mudstone or similar.

conglomerate sedimentary rock composed of rounded rock fragments larger than 2 millimetres

breccia sedimentary rock composed of angular broken pieces of rock larger than 2 millimetres

Sedimentary rock formed from small stones is called either **conglomerate** or **breccia**. Conglomerate is formed from rounded stones, whereas breccia consists of angular stones.

Figure 8.34 Sedimentary rock made from rounded pebbles is called conglomerate.

Explore! 8.2

How coal is made

Organic material from living creatures can also form sedimentary layers. Layers of plant material form coal, while oil was formed mostly from plankton. Although oil is a liquid, it is still sedimentary.

Use your preferred browser to 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?

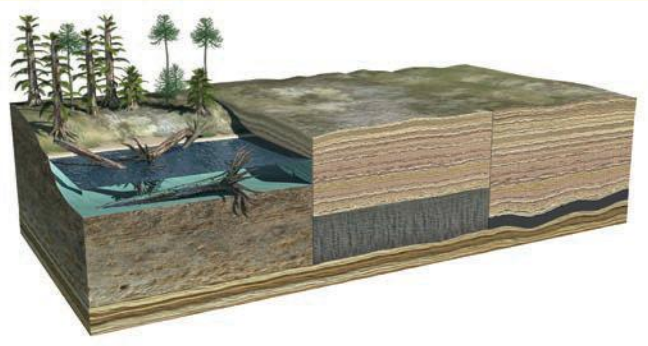

Figure 8.35 How coal is formed. Left: In the Carboniferous Period, trees died and formed a layer of wood. Middle: The wood was compressed by the layers of sediment above. Right: The compressed wood was transformed by heat and pressure into coal.

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Did you know? 8.6

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.

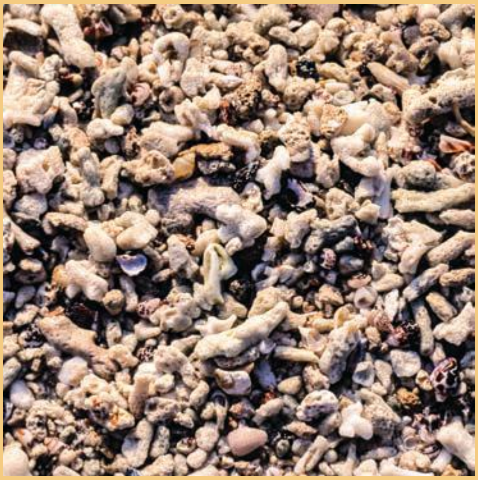

Figure 8.36 Fragments of coral found on a coral beach

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). Generally, fossils are only formed in rocks that start as sedimentary rocks. But rocks are always changing, and if the rock is later subjected to intense temperature or pressure, it may become metamorphic without the fossil being destroyed.

Fossils can be used to trace the history of life on Earth. Because sedimentary rocks form slowly, the passage of time is traced in their layers, with the oldest rocks at the bottom. Fossils found in the same layer must have lived at the same time in the same location, and so were part of the same ecosystem.

Fossils found in different layers must have lived at different times, with newer fossils being found above older fossils. Evidence of extinction events can be seen when a certain type of fossil suddenly disappears. For example, by studying sedimentary rocks, it is known that all the dinosaurs became extinct at the same time, about 60 million years ago.

Explore! 8.3

Fossil formation

Use your preferred search engine to find out about the process of fossilisation.

1. Not all living things become fossils. Describe the conditions necessary for fossils to form.
2. Evaluate some things that scientists have learned 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 8.3.

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Fossil type	Details	Image
Mould	When a plant or animal decays in sediment, it may leave a hollow impression of itself.	 **Figure 8.37** 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 8.38** A fossilised trilobite, extinct creatures that once dominated life on Earth
Imprint	These fossils leave behind a two-dimensional (flat) print.	 **Figure 8.39** Leaves are pressed flat by the pressure in the sedimentary layers and all that is left is a dark area, like a shadow.
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 8.40** Whole body 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 8.41** 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 8.3 Five common types of fossils

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Quick check 8.7

1 Recall how sedimentary rocks are formed.
2 List some examples of sedimentary rocks.
3 Distinguish between the five types of fossils discussed in this section.

Science as a human endeavour 8.2

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! 8.3*, 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 paleontologists (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 the 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.

Paleontologists Steven Holland and Mark Patzkowsky designed computer models to aid the study of mass extinction, and are using the models to more accurately decipher the fossil record. Their work is still in progress; however, it provides an initial guideline for analysis and assessment of extinction events.

Figure 8.42 Computer models can aid research in various fields, including the study of fossils.

Metamorphic rocks

The third type of rock in the rock cycle is metamorphic rock. Recall that metamorphic rocks are either igneous or sedimentary rocks that have been irreversibly changed by being subjected to high temperature or pressure. The Earth's crust is very thin in proportion to its size, and rocks that lie beneath the surface can be subject to high pressure and temperature. The crystals inside these rocks may become deformed and the chemical nature of the rock may change. Rocks that have been changed into metamorphic rock tend to be denser and harder than before. Layers may become twisted when rocks are metamorphosed.

Figure 8.43 Folded layers are a feature of metamorphic rock.

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VIDEO
Describe the three rock types

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 the Earth's surface. Because of their toughness, they are often used for building materials. For example, if limestone (sedimentary) is subjected to high pressure and temperature, it turns into marble (metamorphic). Marble is slightly denser and harder than limestone. Can you think of what marble is used for? Other common metamorphic rocks are slate, which is metamorphosed shale (sedimentary), and quartzite, which is metamorphosed sandstone (sedimentary).

Figure 8.44 Limestone (left) is a sedimentary rock. Marble (right) is a metamorphic form of limestone.

Explore! 8.4

Stone tools

Aboriginal and Torres Strait Islander peoples have developed techniques of crafting stone tools for various purposes. Stone tools are used in day-to-day life for activities such as hunting, harvesting and preparing. 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 a knowledge of the geological, biological, chemical and physical sciences helps to create stone tools that are fit for the intended purpose.
2. Determine the rock type for the following rock uses in Aboriginal and Torres Strait Islander culture:
   a. The use of basalt as a stone tool.
   b. The use of slate as a food grinding tool.
3. Examples of techniques and methods are knapping, lithic reduction, percussion flaking, pressure flaking, grinding. Describe what each of these processes involve and how they help create stone tools from the raw material.

Figure 8.45 A young girl from Bow River grinds stone to a powder that will be used for art works.

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Try this 8.6

Heat, changes and pizza

The same level of heat affects different foods to various extents. For example, in the pizza shown below, the base mostly appears the same before and after heating. The meat is caramelised. The grated cheese has undergone major physical and chemical change, as it has melted and joined. What does this tell you about the effects of heat on different materials? How can this apply to rock formation?

Figure 8.46 The same level of heat affects different substances differently.

Quick check 8.8

1 Describe how metamorphic rock is formed.
2 Recall some examples of a metamorphic rock and what components make up each one.

Try this 8.7

Summing up

Using the poster you began in Section 8.1, annotate it with information about the three different rock types you have learned about, and their characteristics and examples.

Explore! 8.5

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 historically used by Aboriginal and Torres Strait Islander peoples.

Figure 8.47 Stencil art paintings on sandstone walls at Carnarvon Gorge, Queensland, contain paintings from thousands of years ago.

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Section 8.2 questions

QUIZ

Retrieval

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.

Comprehension

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 the Earth is old.

7 Figure 8.48 shows the Organ Pipes rock formation at the Organ Pipes National Park in Victoria. Use what you have learned about igneous rocks to **explain** how this formation came to be.

Figure 8.48 A set of basalt columns at Organ Pipes National Park in Victoria

8 Look at the following igneous rocks. Identify which one is intrusive and which is extrusive. **Explain** your reasoning by first recalling the difference between intrusive and extrusive.

Figure 8.49 Which one is intrusive and which is extrusive?

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Analysis

9 **Classify** the types of fossils shown in Figure 8.50.

Figure 8.50 Types of fossils

Knowledge utilisation

10 **Discuss** why the water in the Brisbane River is brown (see Figure 8.51). Use the following terms in your explanation: particles, sediment, weathering, erosion, deposit, rock.

Figure 8.51 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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8.3 Classifying rocks

DOC WORKSHEET

Classifying rocks is a skilled job, but it can be simplified by knowing some of the key characteristics of the different rock types, as well as the tests that can be done on rocks, and by using a dichotomous key.

Figure 8.52 Painite, the world's rarest gem

Are all rocks harmless?

Most 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 and should be avoided.

ore
a rock that can be mined and smelted to produce a metal

Figure 8.53 Asbestos is a dangerous mineral and should not be handled.

Characteristics of the different rock types

Recall that rocks are made of one or more minerals and can be classified into three groups according to how they have been formed.

1 Igneous rocks – formed from cooling magma, either intrusive or extrusive. They can differ in colour and texture. Some have holes because of gas that is trapped as the lava cools. Some are characterised by visible crystals.

Figure 8.54 Examples of igneous rock are pumice (left) and diorite (right).

2 Sedimentary rocks – 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 8.55 Examples of sedimentary rock are rock salt (left) and limestone (right).

3 Metamorphic rocks – igneous or sedimentary rocks that have been subjected to high pressure and/or temperature. They often appear layered, and may have crystals arranged in bands.

Figure 8.56 Examples of metamorphic rock are gneiss (left) and granulite (right).

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Explore! 8.6

Classifying rocks

You now know that rocks are made of minerals, there are three groups of rocks, and that rocks come in various shapes, sizes, colours and other characteristics. Conduct some research and find out how a rock's characteristics can be used to determine whether the rock is igneous, sedimentary or metamorphic.

1 What are the characteristics of igneous rock?
2 What are the characteristics of sedimentary rock?
3 What are the characteristics of metamorphic rock?

Try this 8.8

Describing rocks

In groups of three or four, take a careful look at the rocks your teacher has supplied, and try to separate the rocks into groups. Some characteristics by which you may want to classify your rocks are size, colour, hardness, crystal size and shape.

What tests can help us classify rocks?

Some common types of rocks are easy to identify, but others can be challenging. There are many different tests geologists use to help classify a rock. Each test allows you to identify the presence or absence of a chemical or the physical property of the rock, and this then allows you to classify the rock and name it.

Crystal size and shape

Does the rock contain crystals? Crystals are a feature of rocks, especially igneous rocks. Some rocks, such as quartz or diamond, are one giant crystal. These are known as crystalline rocks. Other rocks are made of tiny crystals or have crystals that can only be seen with a microscope. The shape and size of the crystals can help in identifying the rock. Earlier you learned that fast-cooling magma can produce small crystals in extrusive igneous rock, while slow-cooling magma can produce larger crystals in intrusive igneous rock.

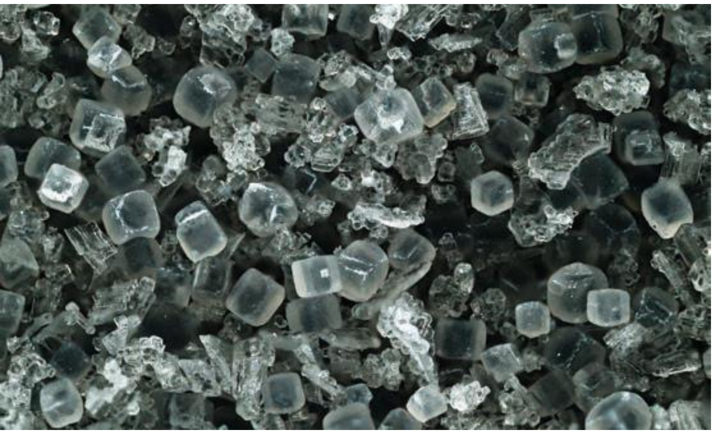

Figure 8.57 Table salt contains tiny crystals that are cubic in shape.

Hardness

How hard is the rock? A useful method to help identify rocks is to determine how hard the rock surface is. In 1812, Friedrich Mohs classified all minerals according to their ability to scratch each other, on a scale from 1 to 10.

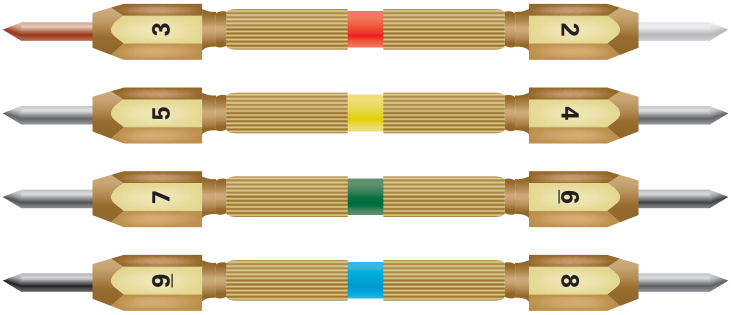

Figure 8.58 A set of Mohs hardness picks, which can be used to help identify a rock by its hardness

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Mohs scale	a scale from 1 to 10 that indicates the hardness of a rock
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
cleavage	the tendency of a mineral or a rock to break in a particular way because of its structure

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 6 and not by pick number 7, then it has a hardness of 6.

Behaviour in light

Most rocks are **opaque**, which means no light can pass through them. Some are **translucent**, which means light can pass through the rock but no clear image is visible through it. **Transparent** rock, such as diamond (metamorphic) and quartz (igneous), allow light to pass through and images are visible through them.

Figure 8.59 Amethyst (mineral) is a translucent crystal and can be found inside all three types of rocks, igneous, metamorphic and, less commonly, sedimentary.

Behaviour in acid

Weak hydrochloric acid can be used to test for carbonates. Bubbles form on the surface of marble (metamorphic), limestone (sedimentary) and chalk (sedimentary) when acid is dropped onto their surface. Rocks that do not contain carbonates will not fizz or bubble in acid.

Behaviour when struck

Some rocks break more easily in some directions than others. This feature is called **cleavage** and can help identify rock (such as slate, which is a metamorphic rock containing mica).

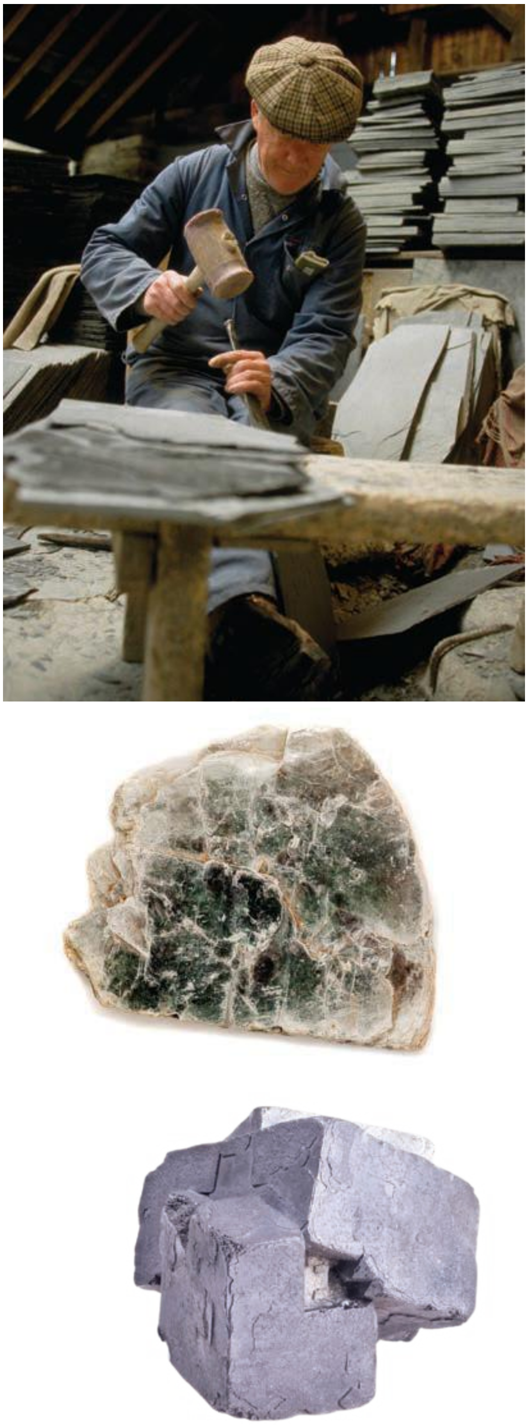

Figure 8.60 Slate (top) can be split into thin sheets for building. Slate is composed mostly of quartz and mica (middle). Galena (bottom) is another mineral which, like mica, has an identifiable cleavage plane.

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Behaviour with magnets

Some iron-bearing rocks are attracted to a magnet, and others are naturally occurring magnets themselves. One of the most common magnetic minerals found in rocks is magnetite, named for its magnetic properties.

Figure 8.61 Magnetite is a mineral found in igneous, metamorphic and sedimentary rocks. It is also found in meteorites.

The streak test

When a rock 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 chalcopyrite have a similar surface colour, so a **streak test** is useful to distinguish between them.

Figure 8.62 Examples of a streak test

Figure 8.63 The streak test for gold (left) shows up as gold, while the streak test for chalcopyrite (right) – also known as 'fool's gold' – shows up as dark green-grey.

Quick check 8.9

1 Describe ores and why some of them are harmful.
2 Explain the seven characteristics that can be used to help classify rocks.
3 Identify which of the characteristics from the previous question involves a chemical property.

Classifying and identifying rocks

WIDGET
A key to identify rocks

In order to classify and identify types of sedimentary, igneous and metamorphic rocks, you need to use a magnifying glass and work your way through the different tests. A dichotomous key, like the ones you used in Year 7, will also help.

streak test
a test used to help identify a mineral by scratching a rock on a hard ceramic tile

Table 8.4 gives the general characteristics of the three different rock types.

Igneous rock	Sedimentary rock	Metamorphic rock
• May contain holes • Crystals can be small or large • Usually hard	• Grains are cemented together • Can be soft	• Sometimes has a layered look • Can often be cleaved to a straight plane • Ranges from soft to hard

Table 8.4 Some characteristics of rocks

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Practical skills 8.1

Identifying 12 common rocks

Aim

To practise identifying and finding patterns, by classifying 12 of the most common rocks found in the Earth's crust

Materials

- hydrochloric acid 0.1 M
- dropper
- beaker of water
- hand lens
- disposable gloves
- 12 Petri dishes for the hydrochloric acid test
- two of each of the following rocks: basalt, chalk, gneiss, granite, limestone, mica, pumice, quartz, quartzite, sandstone, schist, slate

Figure 8.64 Twelve common rocks found on the Earth's crust, in random order

continued…

…continued

Method

1 Use this dichotomous chart to identify the rock and the rock type. You can work in 12 groups, each group being responsible for one rock (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 crystals 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 finger nail?	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 break to form layers with a flat surface?	Yes	Slate (metamorphic)
		No	Basalt (igneous)

Figure 8.65 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. Copy and complete the results table.

continued…

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…continued

Results

Copy and complete this table to identify 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				

Analysis

1. Recall what the hydrochloric acid test reveals about the rock material.
2. Discuss why you think pumice floats in 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.

Science as a human endeavour 8.3

It used to be hotter

Studying the first billion years of the 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 8.66 Komatiite

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Section 8.3 questions

QUIZ

Retrieval

1 **Name** seven characteristics that can be used to help classify rocks.

Comprehension

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.

Analysis

5 **Identify** the following rocks, using the dichotomous key in *Practical skills 8.1*.

a The rock in Figure 8.67 does not bubble when acid is placed on it.

Figure 8.67

b The rock in Figure 8.68 does not bubble when acid is placed on it.

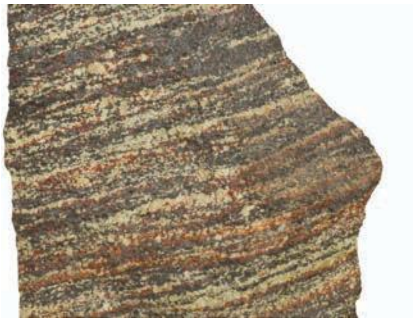

Figure 8.68

c The rock in Figure 8.69 bubbles when acid is placed on it. It cannot be scratched easily with a fingernail.

Figure 8.69

d The rock in Figure 8.70 does not bubble when acid is placed on it. The crystals are not easily removed.

Figure 8.70

Knowledge utilisation

6 Using the rocks in Question **5** and the dichotomous key in *Practical 8.1*, **determine** the rock type of each example, and explain how the appearance of each rock links to the rock type.

7 'All types of rock can be classified according to their physical characteristics only'. **Discuss** whether or not you agree with this statement.

8.4 The mining process

DOC
WORKSHEET

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 the 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 such as cement.

The mining process has several stages: exploration, planning and design, construction, mining, processing and closure.

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 any important cultural sites are protected. In 2020, Rio Tinto blasted a 46 000-year-old Aboriginal sacred site 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 heritage sites at risk of demolition.

Figure 8.71 Geologists sampling rocks during iron ore exploration in the outback (Pilbara, Australia)

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Science as a human endeavour 8.4

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 material 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

Figure 8.72 Miners can use a PMI gun to determine the composition of a rock.

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 8.73 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, finance consultants and other experts to design safe, sound, economically viable and socially responsible plans.

Figure 8.74 Social responsibility in planning includes considering how a new mine will affect society and the natural environment.

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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 8.75 Constructing a mining site involves many people, such as construction workers, builders, landscape architects and engineers.

4 Mining

Mining is the process by which the 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 deeper depths then surface mining.

underground mining traditional method of mining by digging tunnels underground to extract ore

surface mining method of mining that extracts a mineral from the surface, such as by digging an open pit

Figure 8.76 An underground coal mine

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.

There has been interest in mining deep sea deposits such as manganese–cobalt nodules in Pacific Ocean; however, there are strong environmental concerns associated with deep sea mining and to date, it is too difficult and expensive.

Figure 8.77 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.

Explore! 8.7

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 are most environmentally friendly? Justify your answer.
4. Describe some of the ethical issues that need to be considered with regards to mining.

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Explore! 8.8

World's first fully automated mine

Use your preferred web browser to search for 'Syama automated mine'. Do some research with regards 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?

Quick check 8.10

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 these stages.

Mining process	Details	Examples of people involved
1 Exploration		
2 Planning and designing		
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

The process of extracting the metal from its ore is called **smelting**. Basically, the metal ore consists of the metal combined with oxygen in the rock. The ore is heated in the presence of carbon (charcoal) and a chemical reaction takes place.

$$\text{metal oxide} + \text{carbon} \xrightarrow{\textit{yields}} \text{metal} + \text{carbon dioxide}$$

The extraction of metals, ores and other materials from the 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.

smelting
the process of getting a metal from rock by heating it to a very high temperature

electrolysis
a method of extracting a metal from its ore or purifying it using electricity

Purifying

Electricity can be used to purify an impure sample of metal, in a process called **electrolysis**.

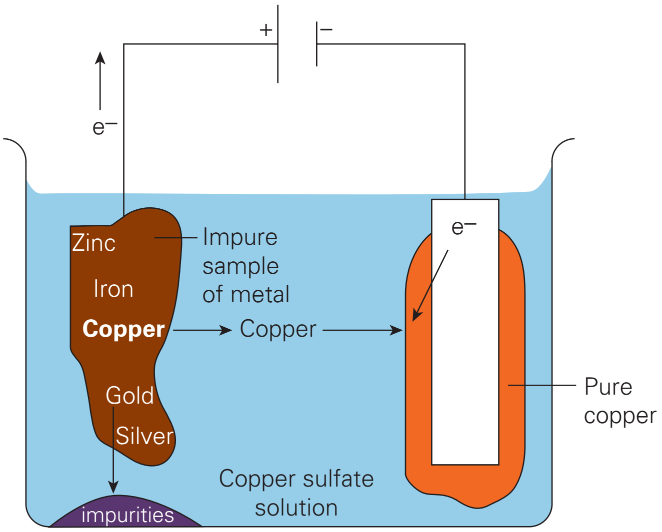

Figure 8.78 Use of electrolysis in purifying copper

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.

Practical skills 8.2

Electrolysis of copper

Be careful

Ensure personal protective equipment is worn. All materials and solutions are to be collected. Electrical shocks may occur. Ensure the voltage output is not exceeded. Turn off the power supply when changing the circuit.

Aim

To see how metals can be purified using electricity, and to demonstrate electroplating

Materials

- 2 copper plates to act as electrodes
- 2 alligator leads
- an old metal fork or spoon
- copper sulfate solution, 0.5 M
- beaker
- 3 V DC power supply

Method

Part 1

1 Place two copper electrodes in a beaker containing a solution of copper sulphate.
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.

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.

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Did you know? 8.7

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. An example of mining rehabilitation is the Woodcutters lead–zinc mine in the Northern Territory, which was closed in 1999. In 2002 it was acquired by Newmont, a mining corporation, which has rehabilitated and monitored the site as part of its commitment to sustainable business, in partnership with the Kungarakan and Warai people, who are the traditional owners of the land. The rehabilitation process has several stages, and the latest stage started in 2018, with the planting of wetland vegetation. The final goal is to hand back the land to the traditional owners.

Figure 8.79 Another example of rehabilitation is the Westside Mine, a coal mine near Lake Macquarie in New South Wales The rehabilitation was completed in 2012, two months after operations stopped.

The mining industry in Australia

The mining industry is one of the most important industries in Australia. Table 8.5 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.

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 8.5 Some important metals mined in Australia

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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.

Figure 8.80 An Australian opal. Australia produces around 95% of the world's opals.

Explore! 8.9

Coal mining in Queensland

Coal mining makes up a significant portion of Queensland's mining industry, but coal mine sites often face community concerns over the environmental impact of mining and burning coal. Conduct some research and answer the following questions.

1 Name the type of rock that coal is sourced from in Queensland.
2 Describe the cost and energy advantages of coal.
3 Describe the environmental impacts of mining and burning coal.

Quick check 8.11

1 Add the last two mining processes to your table from *Quick check 8.10*.

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.

Section 8.4 questions

QUIZ

Retrieval

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.
4 **State** an example of technological progress in the mining industry and explain how it helps the mining process.

Comprehension

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.

Analysis

7 **Compare** surface mining with underground mining, giving at least two advantages and disadvantages of each.

Knowledge utilisation

8 **Propose** why electroplating with silver or gold is a very popular technique in jewellery making.

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Chapter review

Chapter checklist

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

1	**I can recall the names of the three types of rock.** e.g. State the three types of rock found on Earth.	
2	**I can name the different layers of the Earth.** e.g. Illustrate a diagram that shows the different layers of the Earth.	
3	**I can describe the rock cycle.** e.g. Illustrate a diagram that shows the main processes of the rock cycle.	
4	**I can distinguish between physical, biological and chemical weathering.** e.g. Distinguish between the three types of weathering: physical, chemical and biological.	
5	**I can describe the following processes: weathering, erosion, deposition, cementation and compaction.** e.g. Define deposition.	
6	**I can discuss the formation of sedimentary, igneous and metamorphic rocks.** e.g. Discuss how metamorphic rocks are formed.	
7	**I can classify rocks by their different features.** e.g. Recall some of the characteristics of sedimentary rocks.	
8	**I can discuss the process of mining.** e.g. Summarise the following stages of mining: exploration, planning and design, construction, mining, processing and closure.	

Review questions

SCORCHER

Retrieval

1 **Name** the two types of igneous rock.

2 **Name** the process of extracting metals from their ores.

3 **Recall** the stages in the formation of sedimentary rock.

4 **Name** the two conditions that are required for metamorphic rocks to form.

5 Figure 8.81 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.

Comprehension

6 **Describe** how you can physically distinguish between a rock and a mineral.

Figure 8.81 Naracoorte Caves, South Australia

Analysis

7 a **Infer** the geological process that occurred to produce the formation shown in Figure 8.82.

Figure 8.82

b One feature of metamorphic rock is that it can appear layered. The rock shown in Figure 8.83 is layered. However, it is sedimentary rock. **Evaluate** why this might be the case.

Figure 8.83

Knowledge utilisation

8 Examine the image in Figure 8.84 and **determine** whether it is a rock or a mineral.

9 A rock is made of a single crystal. **Deduce** whether or not this rock is a mineral, and explain your reasoning.

Figure 8.84

10 a The sedimentary rocks in Figure 8.85 are lying at an angle. **Determine** the geological event that might have caused this to happen.

Figure 8.85

b Figure 8.86 shows a fossil lying on a beach. **Deduce** where the sedimentary rock would have come from.

Figure 8.86

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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 8.6, and an example of the percentage of mineral components at different depths of an iron ore deposit drill sample is shown in Figure 8.87.

Mineral	Formula	Iron content	Colour
Hematite	Fe_2O_3	70%	red
Magnetite	Fe_3O_4	72%	black
Pyrite	FeS_2	47%	yellow

Table 8.6 Examples of minerals found in Australian iron ores.

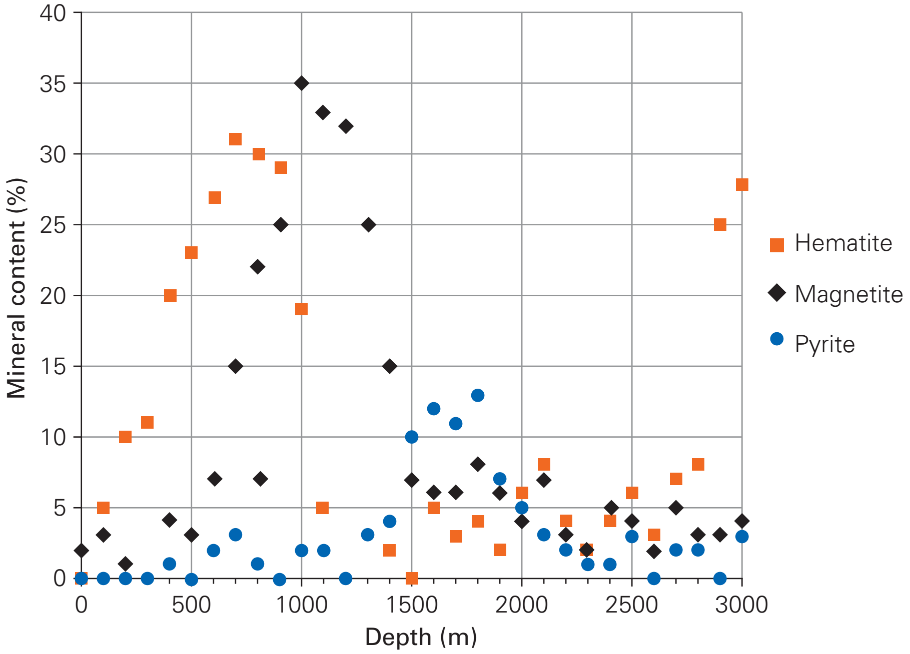

Figure 8.87 Mineral content of an iron ore exploration extract, depending on the depth of drilling.

Apply

1 **Identify** which mineral described in Table 8.6 presents the highest iron content.

2 **Identify** the mineral with the highest content in the ore at 400, 1100 and 1800 m.

Analyse

3 **Classify** the minerals hematite, magnetite and pyrite as 'oxides' or 'sulfides'.

4 **Contrast** the iron content in hematite, magnetite and pyrite and suggest which of these minerals is the least sought after.

Interpret

5 **Deduce** which mineral has the lowest overall content in the ore at depths from 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. **Justify** their observation with respect to the colours of iron containing minerals.

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 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 the Earth. For example, many homes in parts of the world that are prone to tornados have a bunker to protect the home owners. During the Second World War, 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 8.88 A bunker provides protection from dangers above.

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.

Figure 8.89 Only 20 days to find cover!

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Suggested materials/presentation formats

- 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 hardness scale for the rock type. 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 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 modification

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 about quality of life for the people living in your bunker, to save space? Explain how you came to your decisions.

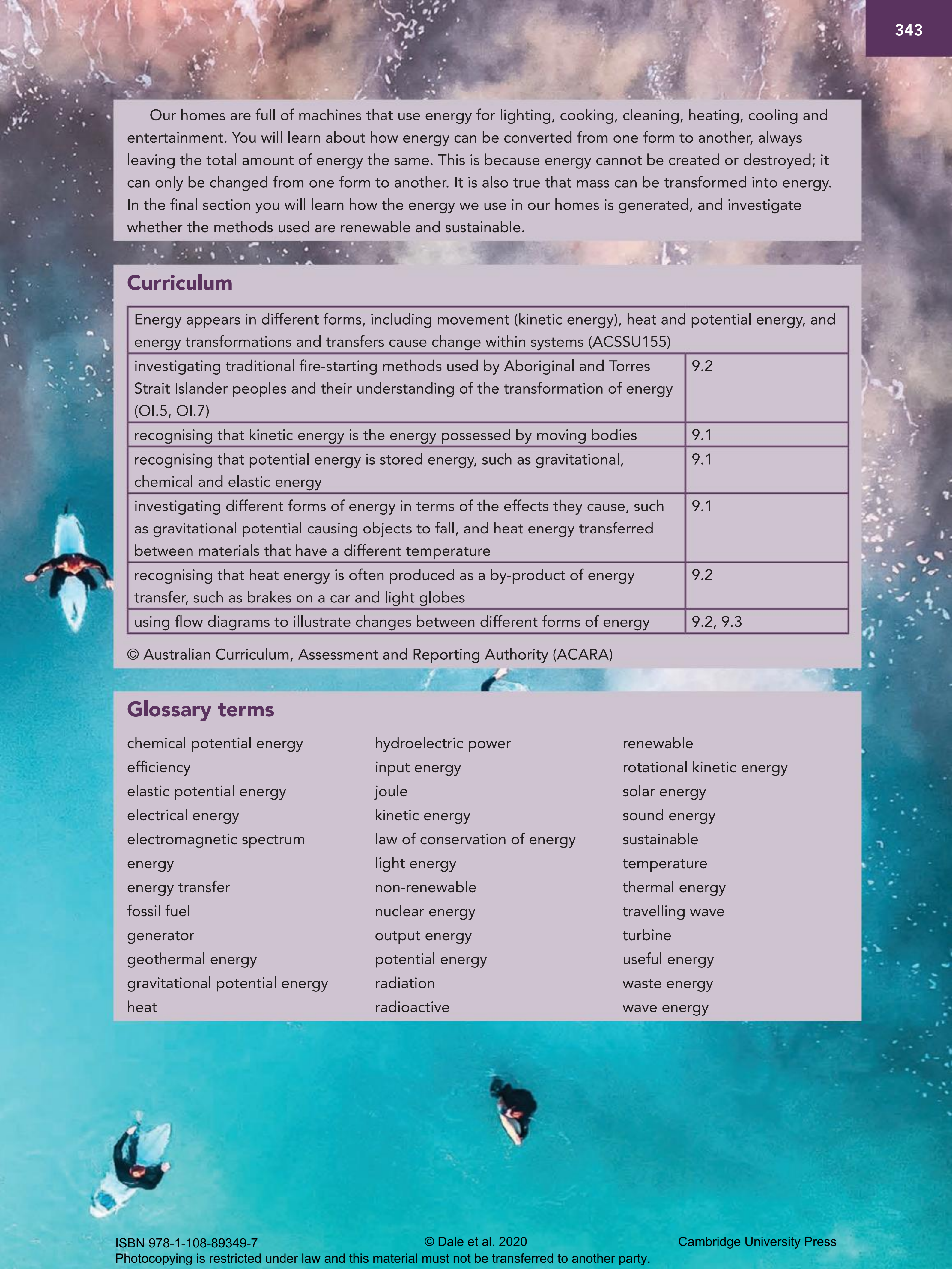
8 Describe some modifications you could make to your bunker to withstand more force.

9 Evaluate the feasibility of constructing a bunker located within the rock type you have chosen.

Chapter 9
Energy

Chapter introduction

This chapter provides an introduction to the different forms of energy that we encounter in our everyday lives. The idea of energy is already familiar to you. Your senses can detect several types of energy – your eyes detect light, your ears detect sound, and your skin can feel hot and cold. You use your muscles to move, gaining kinetic energy, or to lift things, giving them gravitational potential energy. The food you eat contains chemical energy, which allows you to move and keep warm. 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.



Our homes are full of machines that use energy for lighting, cooking, cleaning, heating, cooling and entertainment. You will learn about how energy can be converted from one form to another, always leaving the total amount of energy the same. This is because energy cannot be created or destroyed; it can only be changed from one form to another. It is also true that mass can be transformed into energy. In the final section you will learn how the energy we use in our homes is generated, and investigate whether the methods used are renewable and sustainable.

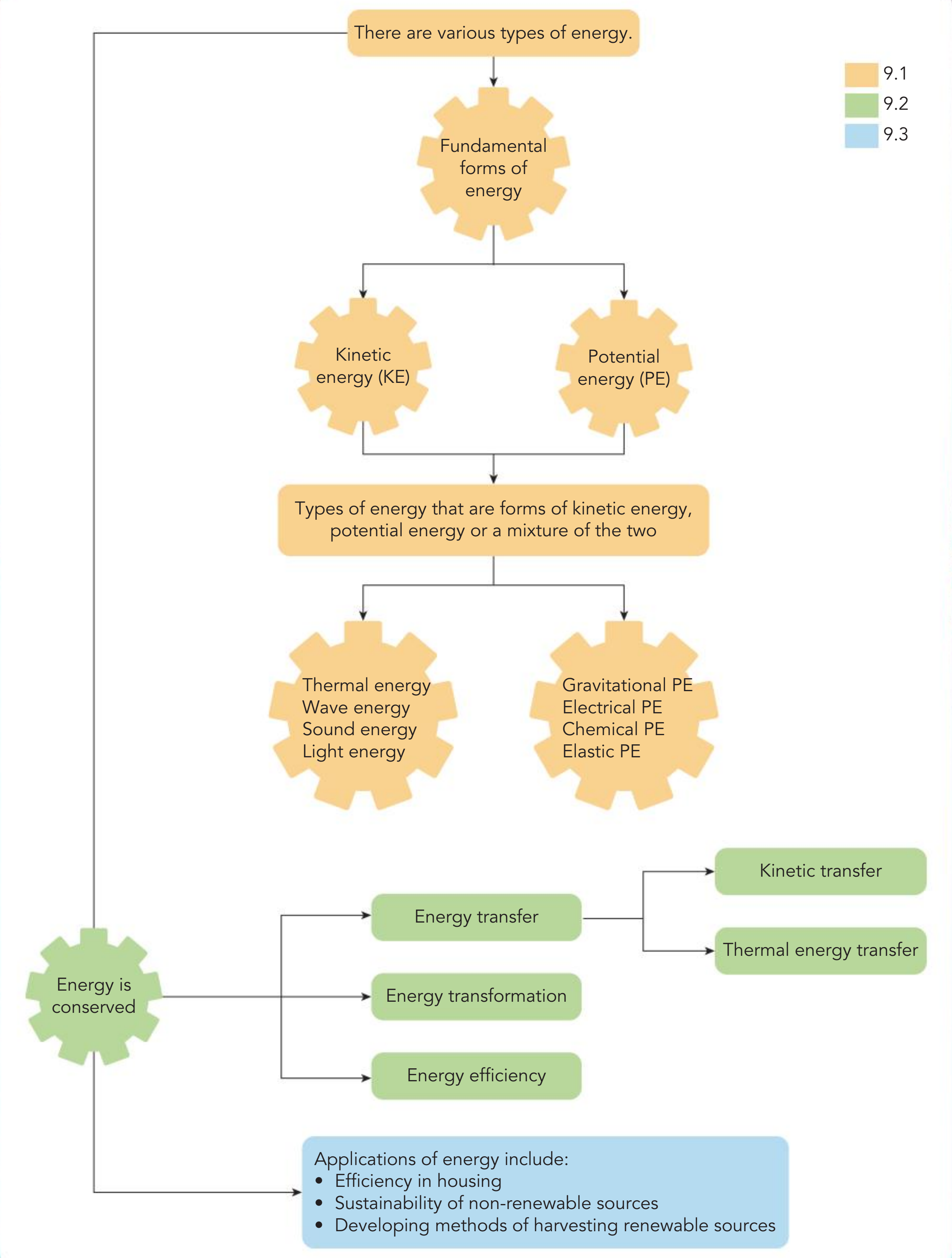
Curriculum

Energy appears in different forms, including movement (kinetic energy), heat and potential energy, and energy transformations and transfers cause change within systems (ACSSU155)	
investigating traditional fire-starting methods used by Aboriginal and Torres Strait Islander peoples and their understanding of the transformation of energy (OI.5, OI.7)	9.2
recognising that kinetic energy is the energy possessed by moving bodies	9.1
recognising that potential energy is stored energy, such as gravitational, chemical and elastic energy	9.1
investigating different forms of energy in terms of the effects they cause, such as gravitational potential causing objects to fall, and heat energy transferred between materials that have a different temperature	9.1
recognising that heat energy is often produced as a by-product of energy transfer, such as brakes on a car and light globes	9.2
using flow diagrams to illustrate changes between different forms of energy	9.2, 9.3

Glossary terms

chemical potential energy
efficiency
elastic potential energy
electrical energy
electromagnetic spectrum
energy
energy transfer
fossil fuel
generator
geothermal energy
gravitational potential energy
heat
hydroelectric power
input energy
joule
kinetic energy
law of conservation of energy
light energy
non-renewable
nuclear energy
output energy
potential energy
radiation
radioactive
renewable
rotational kinetic energy
solar energy
sound energy
sustainable
temperature
thermal energy
travelling wave
turbine
useful energy
waste energy
wave energy

Concept map



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9.1 What is energy?

WORKSHEET

Energy is the ability to do work or make things happen. It can't be created or destroyed; that is, the amount of energy in our universe is always the same. However, energy can change form, 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).

Our senses enable us to experience energy in different ways such as heat, light and movement. There are several different ways to classify these different types, but actually there are just two fundamental forms of energy: kinetic energy and potential energy. All the other forms are one or other of these, or a mixture of the two.

Kinetic energy

The energy an object has when it is moving is called **kinetic energy** (KE). The amount of energy depends on the mass of the object and its speed.

Figure 9.1 Fast-moving cars have a lot of kinetic energy.

Objects that are spinning 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 or make things happen. 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 9.1.

energy
the capacity to do work; the total amount of energy is conserved in any process

joule
the unit of energy or work done

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 height above the ground, or because it is stretched or compressed, or in chemical form

VIDEO
Types of stored energy

Form of potential energy	Description
Gravitational potential energy (GPE)	Energy stored when an object is lifted off the ground; 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 fuel and in batteries (when connected to an electric circuit, 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 original size and shape
Nuclear energy	Energy stored in unstable (radioactive) atoms; energy released when atoms decay or undergo fission or fusion in unstable (radioactive) atoms

Table 9.1 Potential energy is a form of energy that can be stored.

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Forms of energy we can detect with our senses

We can detect kinetic energy with our senses, and other types we can sense are listed in Table 9.2.

Form of energy	Description
Thermal energy	The energy in an object due to the random motion of its particles
Wave energy	The energy carried by a wave
Sound energy	The energy carried by a sound wave
Light energy	The energy carried by light waves (electromagnetic energy)

Table 9.2 Types of energy, other than kinetic energy, that we can sense

Forms of energy

Thermal energy

heat
thermal energy that is in transit due to differences in temperature

thermal energy
the energy contained within a material that is responsible for its temperature

temperature
a measure of the average random kinetic energy of the particles in a substance

In Chapter 5 you learned in particle theory that **heat** is related to the vibration and movement of the particles of matter. So heat is related to the kinetic energy of particles of matter. 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 amount of thermal energy in an object depends on three things:

- 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.

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.

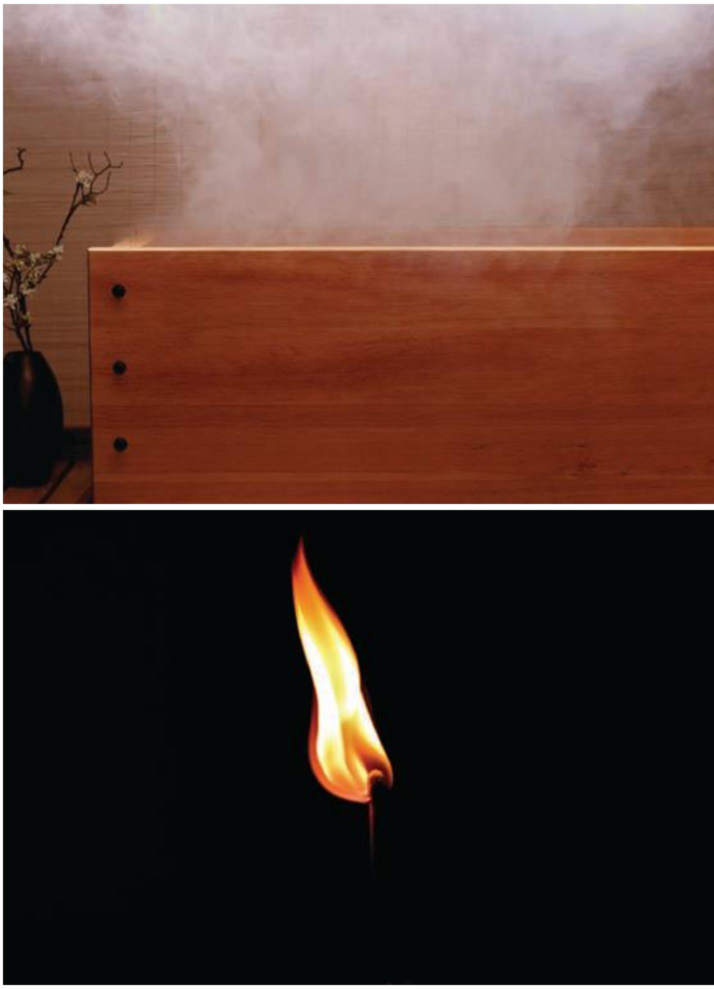

Figure 9.2 A warm bath contains more thermal energy than a burning match.

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Investigation 9.1

Investigating thermal energy

Be careful

Ensure safety equipment is worn at all times. Do not stand over beaker once it has been heated.

Aim

To investigate the thermal energy of different volumes of water

Planning

1 Write a rationale about thermal energy.
2 Write a specific and relevant research question for your investigation.
3 Identify the independent, dependent and controlled variables.
4 Write a hypothesis for your investigation.
5 Write a risk assessment for your investigation.

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 using a Bunsen burner for one minute.
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.

Results

Complete the following table with your results.

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

Data processing

1 Calculate the thermal energy in each volume of water by using the equation:
Mass in kg × specific heat capacity × change in temperature
The specific heat capacity of water is 4200 J/kg/°C

Analysis

1 Describe any patterns, trends or relationships in your results.
2 Explain any trends you have identified.
3 How did the change in temperature differ between volumes of water?
4 Complete some research regarding specific heat capacity. What do you think would happen if a different liquid was used? Explain the reasoning behind your prediction.

Evaluation

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

Conclusion

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

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Quick check 9.1

1 Recall the unit for energy.
2 Look at Figure 9.3 and identify some of the different forms of energy you can see.

Figure 9.3 Birthday parties always involve energy!

3 Define the term 'thermal energy' of an object.
4 Recall three factors that the total thermal energy of any object depends on.
5 Explain why a warm bath contains more thermal energy than a burning match.

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

sound energy
a form of travelling wave; sound consists of vibrations in the air

Wave energy

Water waves carry **wave energy** as the waves move on the surface of the water. 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. Because waves in water are generally able to move from place to place, they are called **travelling waves**.

Figure 9.4 Water waves can have a lot of energy.

Water waves are not the only type of waves that can carry energy. Waves can travel through the 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 9.5 Major earthquakes can cause severe damage to infrastructure, like this road in New Zealand.

Sound energy

Sound energy is a form of wave energy; it consists of vibrations in the air. You will learn more about sound in the next section.

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Science as a human endeavour 9.1

Printing using sound

Researchers at Harvard University have developed a method of printing using sound waves. The researchers used sound to control the size of the droplet being ejected from the printer nozzle, regardless of the viscosity (thickness) of the liquid. A higher amplitude of sound wave makes a smaller droplet. A wide range of liquids can be used, which means this technology has applications in many different industries, from pharmaceuticals to food.

Figure 9.6 Using sound waves in printing.

Light energy

Light energy is a kind of wave that is the visible part of the **electromagnetic spectrum**. Light can travel through air or through a vacuum (such as space).

Did you know? 9.1

Light waves

A light wave is made up of energy in the form of magnetic and electric fields. These fields vibrate at right angles to the wave's direction of movement and at right angles to each other.

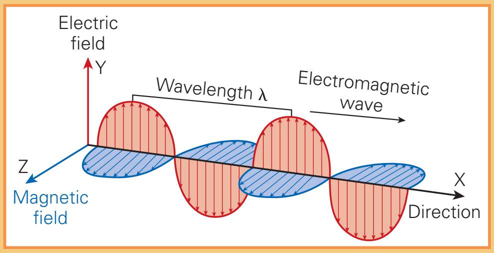

Figure 9.7 A light wave has an electric field and a magnetic field.

Quick check 9.2

1 Provide five examples of objects that could have kinetic energy.
2 Give two types of wave energy.

Gravitational potential energy

When an object is lifted, it gains **gravitational potential energy**. 'Gravitational' means related to the pull of the Earth, and 'potential' means the energy is stored for later. Gravitational potential energy (GPE) depends on three things: the strength of gravity, the mass of the object, and the height the object is lifted.

Figure 9.8 Rock climbers gain gravitational potential energy as they climb.

light energy
a form of energy that we can see with our eyes; also called visible light; a part of the electromagnetic spectrum

electromagnetic spectrum
a way of organising electromagnetic waves according to their frequency

gravitational potential energy
a type of potential/stored 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 m and g is acceleration due to Earth's gravity

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Try this 9.1

Investigating energy with a bouncy ball

Take a bouncy ball and hold it higher than your head. Allow the ball to fall onto the floor and continue bouncing until it comes to rest.

Describe the transformations involved as GPE changes to KE until the ball stops. Explain where elastic potential energy fits in.

Did you know? 9.2

Tiny charges

An electron is so small that the unit we use for charge represents 6.24 million million million electrons.

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

Electrical energy is carried by tiny, negatively charged particles, called *electrons*, that can move from one atom in a wire to the next, carrying energy as they do. Voltage (V) is related to the amount of electrical energy each electron 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; cell phones operate at 5 volts; car batteries are 12 volts; in Australia, electricity in the home is 230 volts.

Did you know? 9.3

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 thunder storms: what other forms of energy are released when lightning strikes?

Figure 9.9 Lake Maracaibo in Venezuela holds the Guinness World Record for the highest concentration of lightning strikes. The phenomenon is called 'Catatumbo lightning', named after the river which empties into the lake.

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Quick check 9.3

1 State some types of energy that can be stored.

2 Look at the following image of a playground. Explain where you would stand to have the greatest gravitational potential energy.

Figure 9.10 Where is GPE greatest?

3 Figure 9.11 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).

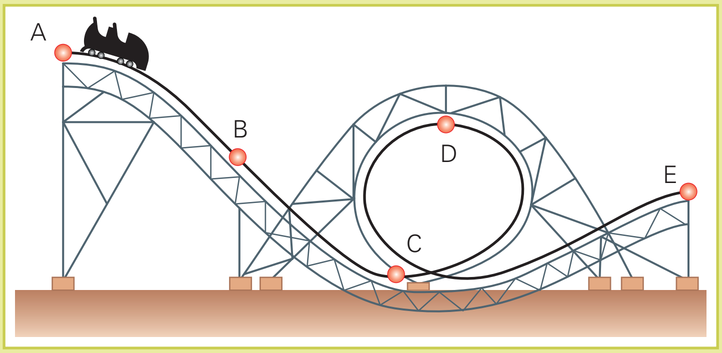

Figure 9.11 Roller coaster

 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:

- When fireworks are lit, chemical potential energy is released as heat, sound and light.
- 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.

chemical potential energy the energy stored in the bonds between atoms

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Explore! 9.1

Car evolution

The car has come a long way since the invention of the first true automobile in 1886 by Austrian, Karl Benz. Starting off then as a three-wheeled vehicle with a simple internal combustion engine, modern cars have evolved all the way to self-driving models powered by the Sun.

Figure 9.12 Karl Benz's Model 3 patent motor car

1. Research the development of the car and identify key models throughout its more than 100 year history.
2. Describe the technological or scientific discoveries that were required for the development of each of the key models identified in Question **1**.
3. How is car manufacturing important to the economies of countries in the Asia-Pacific region?

Figure 9.13 Fireworks in Brisbane. Fireworks contain chemical potential energy, which is released when the fireworks are lit.

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Elastic potential energy

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 9.14 A giant rubber band stores energy when it is stretched.

Figure 9.15 A bungee cord stores elastic potential energy when it is stretched.

Try this 9.2

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.

Nuclear energy

The *nucleus* (plural *nuclei*) of an atom contains **nuclear energy**, a form of potential energy. Most nuclei are stable and don't release energy, but the **radioactive** nuclei of some elements break down, emitting electromagnetic wave energy and/or particles with kinetic energy. The energy released shows up as a change in temperature when absorbed by the surrounding material. One kind of radioactivity is called fission ('splitting'). Nuclear power stations use *fission* reactions in 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. Great care has to be taken to prevent people being exposed to it in nuclear power stations.

elastic potential energy
the energy stored when an elastic material is compressed or stretched

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 atoms

radiation
the emission of energy from unstable nuclei

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Did you know? 9.4

Nuclear energy and the Sun

Energy can also be released when two smaller atoms join to make a bigger atom, in a process called *fusion*. The Sun generates all its energy from this process. In fact, it is not just the Sun – the whole universe is full of stars that are fusing hydrogen into helium, releasing light and thermal energy as they do so. Two atoms of hydrogen are fused to make one atom of helium, and a small amount of mass is turned into a large amount of thermal energy.

In its core, the Sun fuses 5 billion kilograms of hydrogen to produce 5 billion kilograms of helium each second.

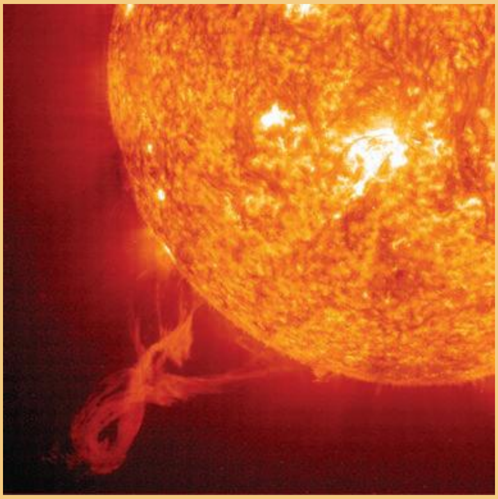

Figure 9.16 Nuclear energy has allowed the Sun to keep shining for at least 4 billion years. and it will take about 5 billion more years before it runs out of hydrogen.

For years, researchers have been trying to replicate this process on Earth with a plan to take a type of hydrogen gas, heat it to more than 100 million degrees until it forms a plasma. They then want to fuse the atoms using powerful magnets. If researchers are successful in this plan, it would solve every energy problem on the planet.

An international collaboration of 35 countries called the Iter Project is constructing a huge test reactor in France and they hope to have the first plasma by 2025.

Quick check 9.4

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 9.3

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.

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Section 9.1 questions

QUIZ

Retrieval

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 could flow from an object.
3 **State** the form of energy contained in a piece of wood.
4 **State** the form of energy a piece of wood gives out when it burns (Figure 9.17).
5 **Identify** the form of energy other than thermal gained when a person climbs stairs (Figure 9.18).
6 **Identify** the forms of energy emitted by lightning (Figure 9.19).
7 **Identify** a form of energy that is *not* a form of wave energy.
8 **Identify** the forms of energy possessed by a hot air balloon when it is up in the air (Figure 9.20).

Figure 9.17 Wood stores energy that can be released in a form of useful energy when burnt.

Figure 9.18 Man climbing stairs

Figure 9.19 Lightning

Figure 9.20 Hot air balloon

9 **Identify** the main form of energy that peanuts contain.
10 Look at the diagram in Figure 9.21 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 there be an overall gain or loss of GPE.

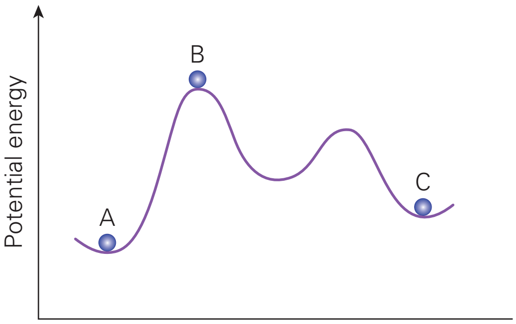

Figure 9.21 Gravitational potential energy.

Comprehension

11 **Describe** a situation that involves elastic potential energy.
12 **Describe** how sound energy travels.
13 **Explain** what is meant by the term ‘potential energy’.

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14 **Explain** which balloon in Figure 9.22 has the most elastic potential energy.

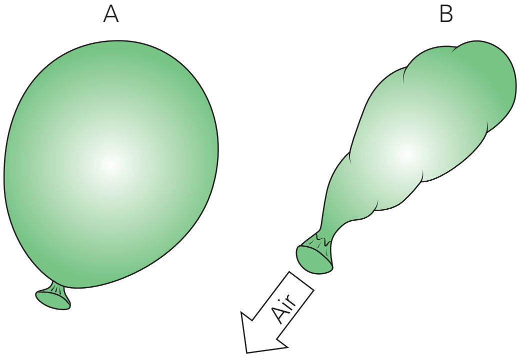

Figure 9.22 Elastic potential energy of balloons.

Analysis

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 9.23 and **identify** all the different forms of energy that you can see evidence of.

Figure 9.23 A kitchen contains many different forms of energy.

Knowledge utilisation

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 them) and the forms of energy that they output (include the 'useful' output as well as the outputs that represent wasted energy).

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9.2 Energy is conserved

WORKSHEET

Objects possess energy, and energy can be changed from one form to another. When energy changes from one form to another, it 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. In everyday life this law always holds. However, early in the last century, Einstein made a significant discovery: mass and energy are equivalent and can be converted into one another!

law of conservation of energy
the law that states that energy cannot be created or destroyed

Figure 9.24 City lights in Brisbane. 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? 9.5

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.

This explains where the Sun has been getting its energy from, to shine so bright for so long. Deep inside the Sun, nuclear reactions are converting 5 billion kilograms of matter into energy every second. This energy is emitted at the Sun's surface as light.

Figure 9.25 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 than in a billion years, a 10% brighter Sun would have rendered Earth inhospitable to life. It will take a few more billions of years before running out of fuel.

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Quick check 9.5

1. State the law of conservation of energy.
2. Explain the meaning of the law of conservation of energy.

Energy transfer

energy transfer	the movement of energy from one place or object to another
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, for example a windmill

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, this kinetic energy is transferred to the ball, making it move.

Figure 9.26 When a golfer hits a golf ball, they transfer kinetic energy from the golf club to the ball.

Heat transfer

Thermal energy is another type of energy that can be transferred. If an object of high temperature is placed next to an object of lower temperature, thermal energy will flow from the object of higher to that of lower temperature. This will continue until the objects are the same temperature. This flow of energy is always from high to low temperature, never the other way around.

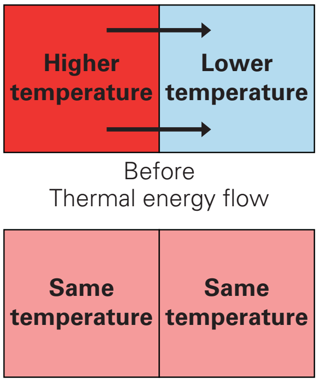

Figure 9.27 Heat (thermal energy in transit) flows from an object of higher temperature to one of lower temperature, until the objects are at the same temperature.

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 energy and light. 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 is often produced as a by-product of energy transfers.

Energy transformations can be represented in a flow diagram (see Figure 9.28). On the left-hand side of the flow diagram are the energy inputs. On the right-hand side are the energy outputs. Waste energy may be included as an energy output, but is sometimes omitted. A brief description of how the machine works may be placed between them, and arrows can be added to show the flow of energy.

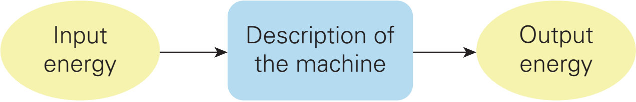

Figure 9.28 A simple energy flow diagram

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For example, Figure 9.29 shows the energy flow diagram for a candle that has been lit.

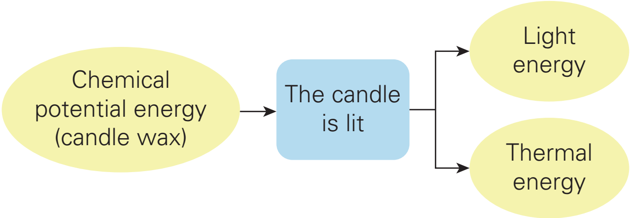

Figure 9.29 Energy flow diagram for a burning candle

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 9.30).

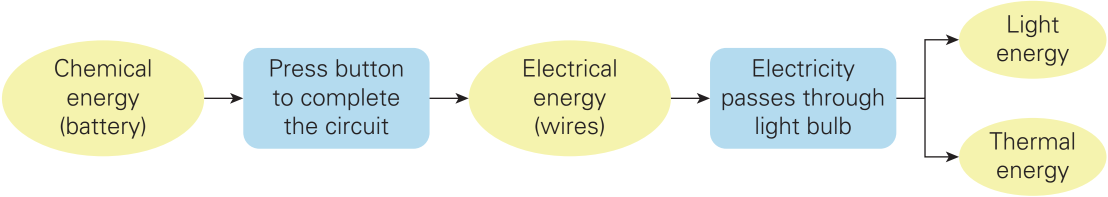

Figure 9.30 Energy flow diagram for a battery-powered torch

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 9.31 An electric kettle converts electrical energy into thermal energy.

Figure 9.32 shows a flow diagram representing the changes in energy in the example of the kettle.

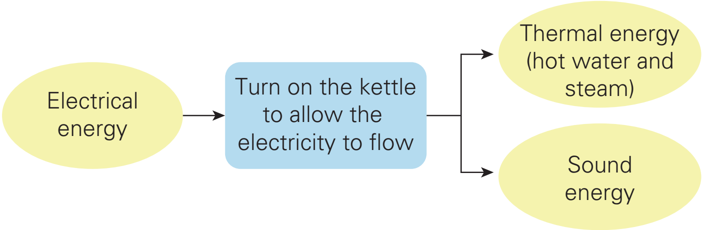

Figure 9.32 Energy flow diagram for an electric kettle

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Quick check 9.6

1 Explain what occurs during an energy transformation.
2 Provide two examples of an appliance that transforms energy.

Explore! 9.2

Fire starting

Aboriginal and Torres Strait Islander peoples used several different methods to light fires. 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 thin, long 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 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 sharp edge (for example, a boomerang). The hardwood saws the notched piece until embers form, which ignite flammable material placed beneath it.

Figure 9.33 Can you identify the drill method and the saw method in this illustration?

Two other methods used less commonly were the *fire plough* and *percussion* methods. The first method was mainly used by people in the northwest 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 were used by groups in south-central Australia, which involved striking stones together to create sparks that would 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 stick 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 9.34 An accelerating car is gaining kinetic energy.

Figure 9.35 shows a flow diagram for a petrol-driven car accelerating from rest.

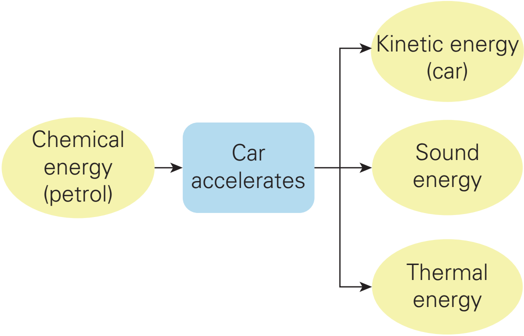

Figure 9.35 Energy flow diagram for a petrol-driven car accelerating from rest

If the car was powered by an electric battery, then the energy flow diagram would be slightly different (Figure 9.36).

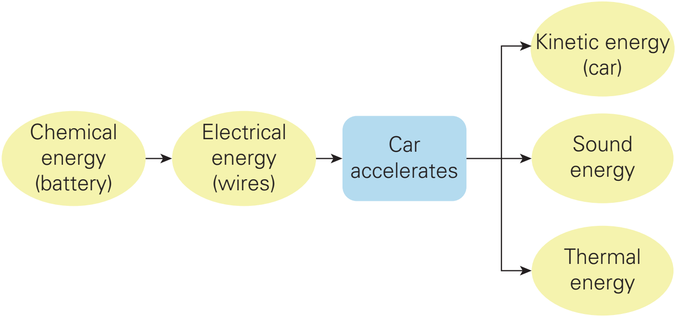

Figure 9.36 Flow diagram for a battery-powered car accelerating from rest.

Try this 9.4

Transforming potential energy into kinetic energy

Stand with your legs far apart and your arms above your head, in a star-jump position. Discuss what type of energy you are storing as you hold this position. As you complete a star-jump, think about what type of energy your stored energy is being transformed into. With your classmates, discuss which parts of your star-jump contain stored energy and which parts use kinetic energy.

Investigating a bow and arrow

When a bow is stretched to shoot an arrow, the wood bends with an elastic force, and this stores energy. The further the bow 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.

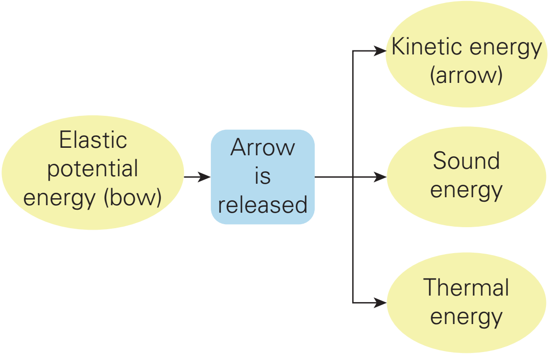

Figure 9.37 Energy flow diagram for an arrow being shot from a bow

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VIDEO
Energy transformations in a hot air balloon

Investigating a hot air balloon

The operation of a hot air balloon involves two 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. 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

Sometimes a machine can convert a source of energy into two forms at the same time. 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.

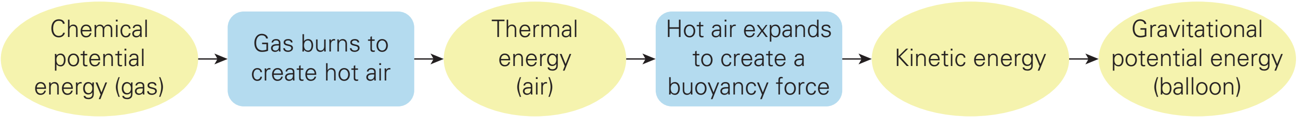

Figure 9.38 Energy flow diagram for a hot air balloon

Figure 9.39 A hot air balloon converts chemical energy to thermal energy, then kinetic energy as it moves, then gravitational potential energy as it gets higher.

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Figure 9.40 An aircraft converts chemical potential energy to kinetic energy and gravitational potential energy.

Look closely at the picture of the aircraft taking off, and you can see that the air behind the aircraft's engines is blurred. This is because it is at a high temperature, heated by the energy produced by the aircraft's engines, and that energy should be added to the energy flow diagram. Aircraft are also very noisy when taking off, so sound energy is also produced.

In Figure 9.41, 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

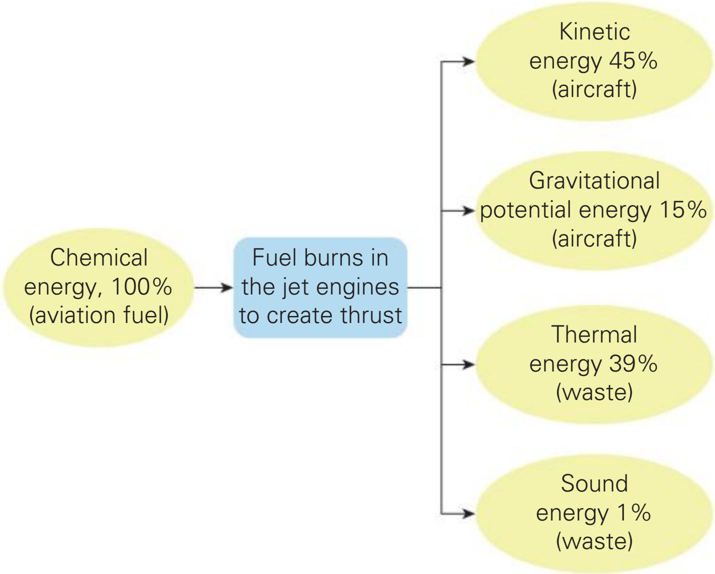

Figure 9.41 Energy flow diagram for a jet aircraft taking off.

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

Quick check 9.7

1 Draw flow diagrams for the following energy transformations.
  - a A television converting electrical energy to sound, thermal and light energy
  - b A light bulb converting electrical energy to light and thermal energy
  - c A human converting chemical potential energy from food into kinetic energy when moving

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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

efficiency
the percentage of input energy that is converted to useful energy by a machine

useful energy
the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it creates

Waste energy

An electric light 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.

Figure 9.42 The chemical energy in petrol is converted into kinetic energy to move the lawnmower.

When a candle burns, chemical potential energy is converted by combustion into light, with thermal energy released as waste energy. A television converts electrical energy to light and sound, which are useful, and thermal energy, which is waste.

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 bulb, 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.

Useful energy is the output energy the process is designed to produce. Waste energy is any other form of energy, usually thermal energy or sound, that is not wanted.

Figure 9.43 A battery radio converts chemical energy in the batteries into sound energy.

Energy efficiency

The **efficiency** of a machine is a measure of how good the machine is at converting the input energy to **useful energy**. The percentage of input energy that is converted to useful energy is used to give the machine an efficiency rating.

The formula used to calculate the efficiency rating of a machine is:

$$\text{Efficiency (\%)} = \frac{\text{useful output energy}}{\text{input energy}} \times 100$$

Figure 9.44 Running upstairs converts chemical energy into KE. Once the women reach the top of the stairs, energy has been converted to GPE.

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Examples of efficiency calculations

Example 1

A kettle uses 261 500 J of electrical energy to heat 500 mL of water. If the thermal energy of the water is 209 200 J, calculate the efficiency of the kettle.

$$\begin{aligned}\text{Efficiency (\%)} &= \frac{\text{useful output energy}}{\text{input energy}} \times 100\\ &= \frac{209\,200}{261\,500} \times 100\\ &= 80\%\end{aligned}$$

Example 2

A girl runs upstairs and uses up 4000 J of energy from food she has eaten. If she gains 1000 J of gravitational potential energy, calculate the efficiency of her muscles.

$$\begin{aligned}\text{Efficiency (\%)} &= \frac{\text{useful output energy}}{\text{input energy}} \times 100\\ &= \frac{1000}{4000} \times 100\\ &= 25\%\end{aligned}$$

The other 75% would be waste energy, lost mainly as thermal energy as she climbs.

Try this 9.5

Calculating energy efficiency

Calculate the energy efficiency of each of the globes shown below. State which globe is no longer recommended for household use, and justify your choice.

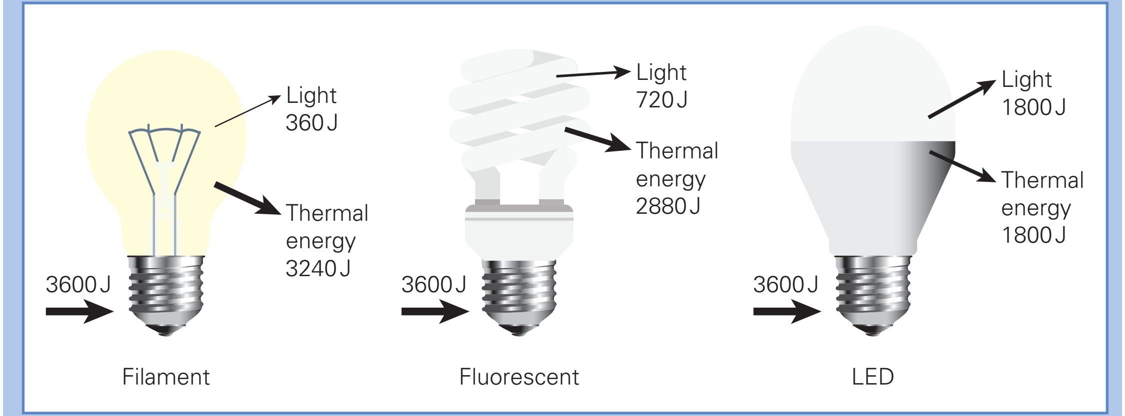

Figure 9.45 How efficient is each type of globe?

Did you know? 9.6

Efficient light globes

Old-fashioned incandescent light bulbs work by passing electricity through a thin metal filament, which glows white hot. However, about 90% of that electrical energy is transformed into thermal energy. These days, compact fluorescent lights (CFLs) and light-emitting diodes (LEDs) are more efficient. About 50% of the electrical energy is wasted as thermal energy.

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Quick check 9.8

1 Define 'energy efficiency'.

2 State an example of the useful and waste energy produced by each of the following devices.

Device	Useful energy output	Waste energy output
Light bulb		
Car		
Lawnmower		

3 A light bulb uses 3000 J of electrical energy. Of this, 600 J is transformed into light energy and 2400 J is transformed into thermal energy. Calculate the energy efficiency of this globe.

Try this 9.6

Energy efficiency of bouncy balls

Aim

To investigate which type of bouncy ball is most energy efficient

Materials

- a range of bouncy balls
- metre rulers

Method

Design an experiment that will test the rebound height of a range of bouncy balls. In a group, discuss how you will carry out this experiment, and write out a step-by-step method.

Results

Draw a results table for your experiment.

Produce a suitable graph for your experiment.

Analysis

By using the energy efficiency equation, calculate the efficiency of each type of ball. Use the drop height and the rebound height in your calculations.

Evaluation

1 Identify sources of uncertainty in your experiment.

2 Suggest how your experiment may be improved.

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Section 9.2 questions

QUIZ

Retrieval

1 Look closely at Figure 9.46.

Figure 9.46 Playground.

- 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.

Comprehension

2 **Describe** the difference between an energy transfer and an energy transformation.

3 **Describe** the energy transformation that occurs in the Sun.

4 **Describe** four situations that involve potential energy.

5 **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 tram starts from rest and builds up to full speed.
- f A person rides on an escalator from the bottom to the top.
- g A sheepdog runs up a hill.

Figure 9.47 Cooking food on a BBQ.

Figure 9.48 An electric tram.

Figure 9.49 People riding escalators.

Figure 9.50 A dog in action.

Analysis

6 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.

Knowledge utilisation

7 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.

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9.3 Applications of energy

DOC

WORKSHEET

Energy in housing

solar energy
a renewable source of energy that converts sunlight directly into electrical or thermal energy

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 and **solar energy** are also widely used. Items that use little energy, such as radios and torches, can use batteries as the source of energy.

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 (once you have paid for the solar panels and their installation). Electricity can be generated on the roofs of houses using solar panels. Energy from the Sun can also be used to heat water directly using solar water heaters.

Figure 9.51 This house has solar panels on the roof to generate electricity. It also has two panels (at the top right-hand side of the picture) for generating hot water.

Energy ratings

Most appliances have an energy rating label. This is to help people make an informed decision about an appliance they are thinking of buying, by giving them information about its energy efficiency.

The star rating of an appliance allows you to compare the energy efficiency of similar models. The more stars an appliance has, the more energy efficient it is. The label also informs you of the energy consumption of the appliance. The lower this number, the less it will cost to run the machine.

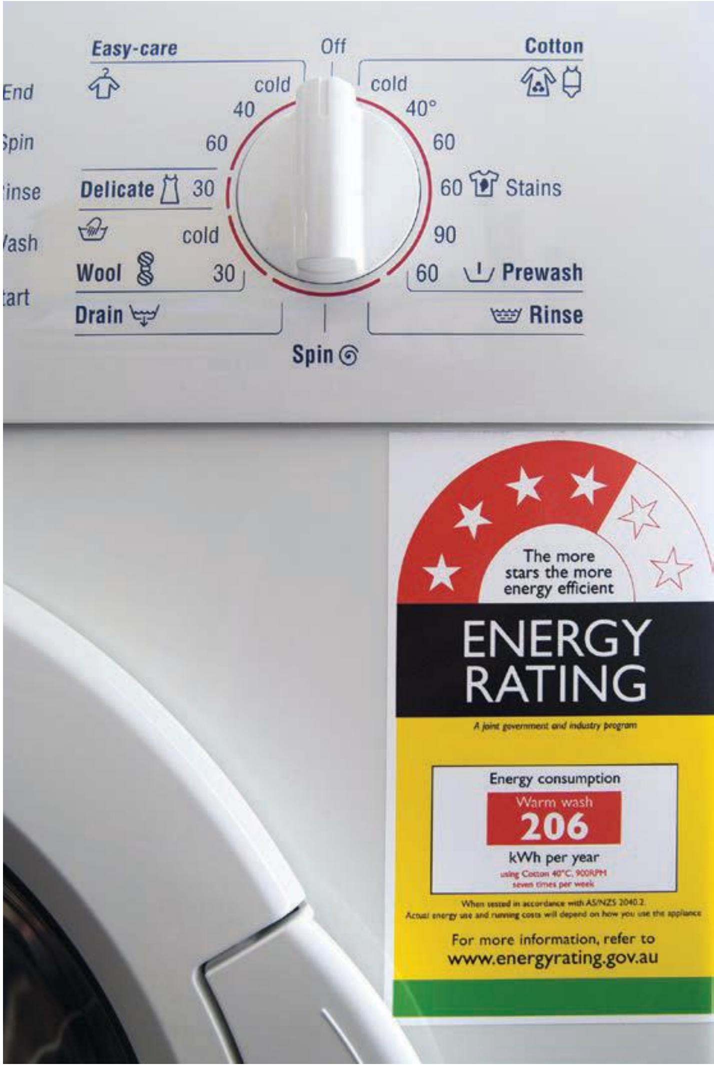

Figure 9.52 The energy rating labels on washing machines help consumers compare the energy efficiency of different models.

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Try this 9.7

Home electricity audit

Use the Australian Government's 'Energy rating calculator' website to audit the energy efficiency of appliances around your house. You may choose to investigate your TV, washing machine, dishwasher or fridge. Compare how much it costs to run each appliance for a year.

Which appliance costs the most to use? Choose one appliance and compare its yearly running costs with a classmate. Who has the more cost-saving model?

Explore! 9.3

Homes of the future

Imagine it is the year 2100. The way homes are designed and constructed has changed as we have been tackling energy efficiency problems. Passive housing has become commonplace. Passive housing means designing houses so they are as efficient as they can be without having to rely on technology such as heaters and air conditioners. Go online to research the following questions.

1. What is passive housing?
2. What are the benefits of passive housing?
3. Which parts of a house lose and gain the most thermal energy?
4. Explain the five design principles of passive housing.

Science as a human endeavour 9.2

Net zero home

Leading climate scientist Mark Z. Jacobson is helping the world transition to renewable energy sources. To show us how it can be done, he has built a 'net zero' home, which uses only renewable energy sources.

The house features a thermal shell, which acts as an insulating layer and reduces heating requirements, and is equipped with solar panels. Battery packs store any extra energy generated by the solar panels. This alone is enough to not only meet the energy needs of the home, but to put power back into the grid.

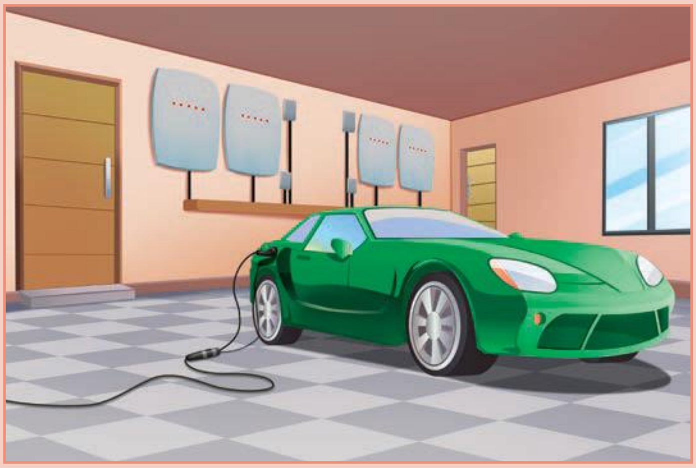

Figure 9.53 The house has battery packs to store solar energy.

Quick check 9.9

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.

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renewable	can be produced as quickly as it is used
sustainable	causing little or no damage to the environment and therefore able to continue for a long time
fossil fuel	a non-renewable energy source such as oil, coal or natural gas
non-renewable	existing in limited quantities that cannot be replaced after they have all been used

Energy problems

Some energy sources, such as wind and solar, will never run out. Methods of energy production that do not use up natural resources are called **renewable**. Other energy sources, such as coal, oil and gas, are not renewable. Once these sources run out, they are gone forever.

Another major consideration in choosing an energy source is the effect it has on the environment. Some methods of energy production, such as burning coal, create pollution that damages the environment. In addition, when wood, oil, gas or coal is burned, greenhouse gases, which have the potential to cause climate change, are created. Methods of energy production that are non-polluting or have a small effect on the environment are called **sustainable**.

The demand for energy has increased steadily since the Industrial Revolution 300 years ago, and it is still increasing today as more countries become industrialised. Scientists are constantly looking for ways to make the production of energy more efficient and to reduce its effect on the environment. Some of the main methods of generating energy are summarised below.

Figure 9.55 A wind-energy turbine (foreground) provides renewable energy, while a coal-fired power station (background) is an example of a non-renewable energy source.

Non-renewable sources of energy

Coal

Fossil fuels are a **non-renewable** source of energy. Most deposits of coal formed 300 million years ago during the Carboniferous Period. This was 100 million

Figure 9.54 The production of greenhouse gas from burning fossil fuels is leading to habitat loss for many animals, including polar bears in the Arctic.

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Figure 9.56 Open-cut coal mines show how coal is formed in layers.

Figure 9.57 The Loy Yang power station converts the chemical potential energy in coal into electrical energy.

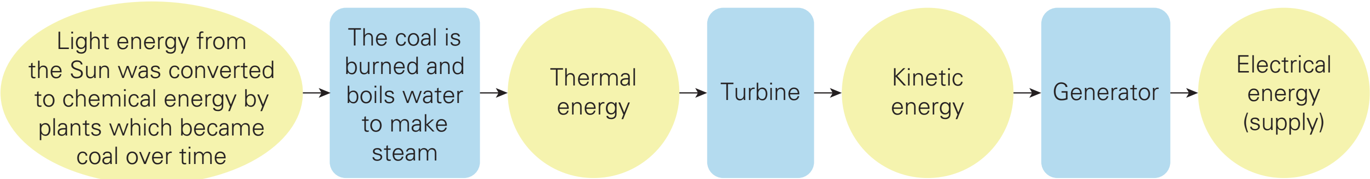

Figure 9.58 Energy flow diagram for a coal-fired power station

years before the dinosaurs, when the Earth was warm, wet and covered with giant forests. Eventually the forests died and layers of sand, which later turned into rock, covered the dead trees. Deep underground and under high temperature and pressure, the remains of the forest trees changed into coal.

Coal is mined and then transported to a power station where it is used to generate electricity. When all the coal has been used up, there will be no more left. That is why coal is considered non-renewable.

The energy flow diagram for a coal-fired power station is shown in Figure 9.58.

Nuclear energy

Nuclear energy is an option for countries that have the technology to build nuclear power stations. Unlike all other forms of energy production, nuclear energy does not rely ultimately on the Sun. Instead, the fuel comes from radioactive materials, mainly uranium, found within the Earth's crust. These materials were inside the Earth when it formed, around 4.5 billion years ago. The mass of fuel required is a tiny fraction of that required to run a coal-burning power station. Although the materials used in nuclear power generation are not renewable, it is unlikely that the world will ever run out of nuclear fuel. Nuclear power stations do not release greenhouse gases.

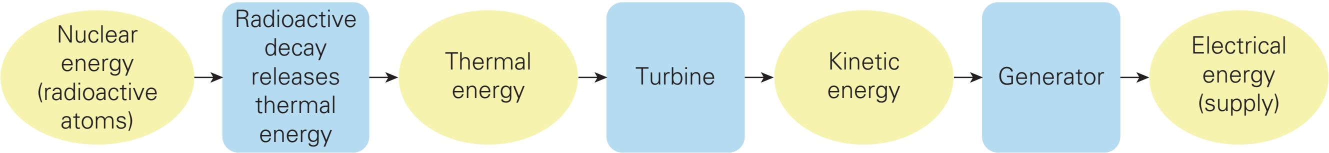

Figure 9.59 Energy flow diagram for a nuclear power station.

Although nuclear energy has the potential to supply the world's energy needs when fossil fuels start to run out, there are some problems with nuclear energy that need to be taken into account. Can you remember the problems associated with nuclear energy from your investigations in Year 7?

Did you know? 9.7

Australian uranium

Australia is the world's third-largest uranium producer, after Kazakhstan and Canada. All the uranium mined in Australia is exported, because there is no nuclear power plant here to use it. However, there is a nuclear reactor at Lucas Heights on the outskirts of Sydney, operated by the Australian Nuclear Science and Technology Organisation. It is used for research and nuclear medicine purposes. It generates 20 megawatts. One megawatt of capacity will produce electricity that is approximately the same amount of electricity consumed by 400 to 600 homes in a year.

Quick check 9.10

1. Define the term 'non-renewable'.
2. Recall the types of non-renewable energy sources used in Australia.
3. State where non-renewable energy sources in Australia can be found.
4. State how and why the demand for energy has changed over the years.

Renewable energy sources

Most people recognise that our current use of fossil fuels cannot be sustained indefinitely, because eventually these fuels will run out. This has led to a great deal of research into finding and implementing renewable energy sources.

Figure 9.60 Wind turbines are a striking sight in the countryside.

Wind energy

Wind energy is a renewable energy source in which electrical energy is generated using large wind turbines, usually built in groups called wind farms. The advantage of wind energy is that, once the wind turbine has been built, wind energy is free, non-polluting and available at night. The main disadvantage is that it depends on the availability of the wind. For this reason, the energy that wind turbines produce is intermittent and must be combined with a storage capability, such as a battery, to provide a continuous energy supply.

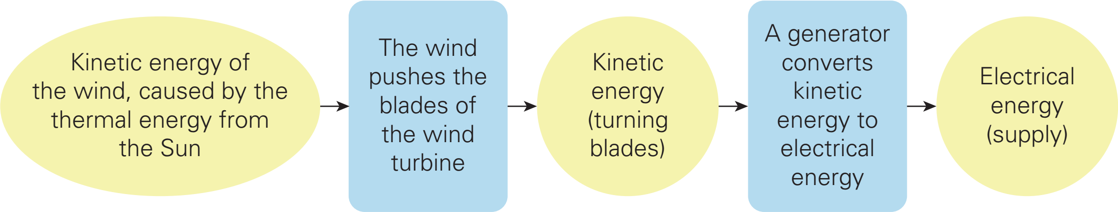

Figure 9.61 Energy flow diagram for a wind turbine

Solar energy

Solar energy is a renewable energy source. Solar panels are used to convert the energy in sunlight directly into electrical energy and can also supply energy to provide hot water. The advantages of solar panels are that the energy they produce is free once the initial cost is met, and they are non-polluting to use. When solar panels are combined with storage batteries, they can provide a constant supply of energy, as the batteries store energy during the day and release it at night.

Figure 9.62 Solar panels convert sunlight into electricity.

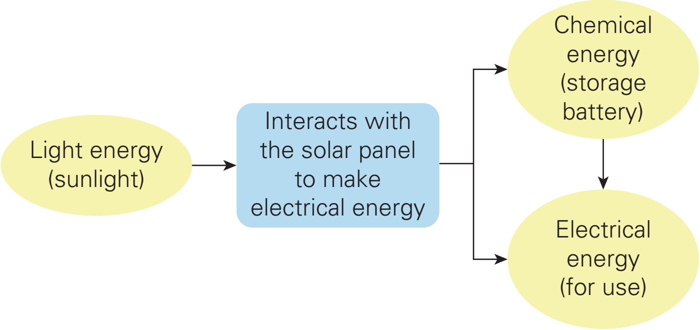

Figure 9.63 Energy flow diagram for a photovoltaic solar panel with a storage battery

Hydroelectric power

Hydroelectric power is generated by using the gravitational potential energy of water held in dams to drive turbines that generate electricity. The dams are designed so that the water surface is as high above the turbines and generators as possible. The water's gravitational potential energy is converted to kinetic energy by turbines at the base of the dam or as far below it as possible. These turbines turn generators that convert this kinetic energy into electrical energy.

hydroelectric power
a renewable source of energy harnessing the gravitational potential energy of water to generate electrical energy

Some countries are mountainous and are well suited to hydroelectric energy generation. Norway, for example, generates around 95% of its energy in this way. In Australia, hydroelectric energy accounts for around 6% of total energy production. The biggest single producer of hydroelectric power in Australia is the Snowy Mountains Scheme.

Figure 9.64 In this hydroelectric power station in the Snowy Mountains, water is carried by gravity through the pipes shown, from a dam located near the top of the mountain down to turbines and generators in the power station, converting gravitational potential energy into electrical energy.

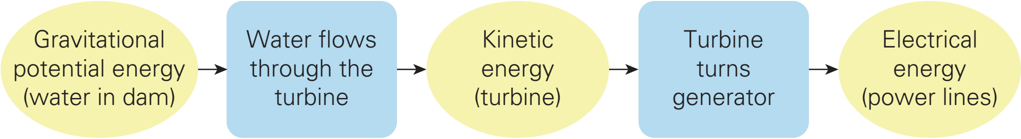

Figure 9.65 Energy flow diagram for hydroelectricity generation

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Geothermal energy

Geothermal energy is both sustainable and renewable. It is thermal energy left over from the Earth's formation, as well as radioactive decay. Where the Earth's crust may be fractured or thin, it is possible to drill down to find rocks hot enough to boil water. Cold water is pumped down to this hot rock. The water boils, producing steam, which is brought to the surface and used to generate electrical energy.

geothermal energy thermal energy that originates from inside the Earth

Figure 9.66 The Wairakei Power Station in New Zealand uses geothermal energy to produce electricity.

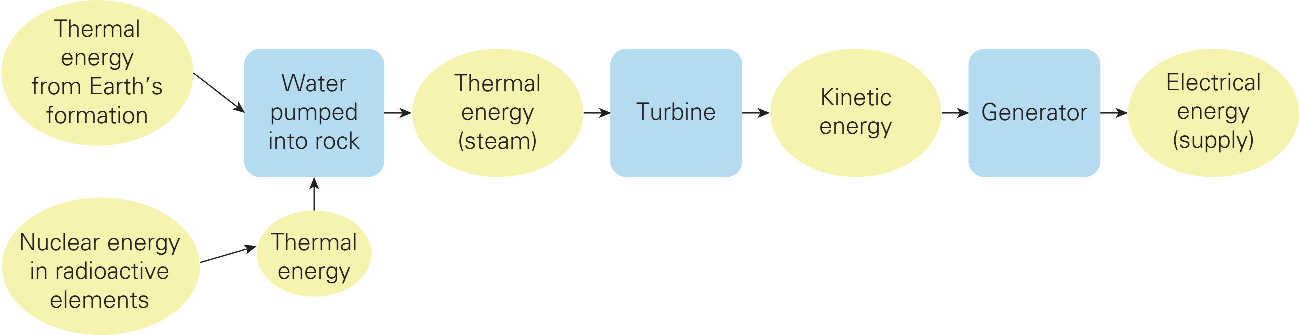

Figure 9.67 Energy flow diagram for geothermal energy.

Quick check 9.11

1. Define the term 'renewable energy source'.
2. Recall some different types of renewable energy.
3. Draw a flow diagram to show the energy transformations that occur while producing electricity from wind turbines.

Explore! 9.4

Providing technology to remote communities

Approximately one in five Aboriginal and Torres Strait Islander peoples are located in remote and isolated parts of Australia. Providing access to basic services such as electricity and clean water in these areas is very difficult, let alone modern technology such as mobile phone and internet coverage. Despite these difficulties, individuals remain in these areas as they have a connection to the land.

1. Research what is being done to provide basic modern services to remote communities, including any new technology such as solar thermal collectors and battery banks.
2. What are the economic and ethical implications of providing these services to small groups of people at such remote locations?

Figure 9.68 Around 10% of Alice Spring's energy is generated from renewables. The challenge is serving communities that are as far as 130 km from the town.

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Explore! 9.5

Turning waste into energy

A lot of energy in modern life goes unused in the form of food scraps and animal wastes. A UK-based company is trying to change that by harnessing the power of detritus (waste material). Use the website of SEaB Energy (a UK company that converts organic waste into energy) to answer the following questions.

1 Why is food and animal waste such an issue for the world and the environment?
2 Explain how SEaB Energy's two main products, the Muckbuster® and the Flexibuster®, work.
3 Draw a flow diagram showing the energy transformations that would occur in harnessing energy from food and animal waste.

Section 9.3 questions

QUIZ

Retrieval

1 **State** the fossil fuels used to provide energy in Australia.
2 **Recall** approximately how many years ago coal deposits were formed.
3 **State** some sources of energy that harness water.
4 A cyclist used 1000 kJ of energy riding to work. Of this, 250 kJ was transformed into kinetic energy to move his muscles. The other 750 kJ was transformed into thermal energy. **Calculate** the energy efficiency of the cyclist.

Comprehension

5 **Describe** the main reason behind switching to renewable energy sources.
6 **Explain** how energy is produced using thermal energy from the Earth.
7 **Draw** an energy flow diagram for a hydroelectric power station.
8 **Explain** the difference between the terms 'renewable' and 'sustainable'.
9 **Explain** why nuclear energy is not considered renewable.
10 **Explain** how non-renewable energy sources are causing global warming.
11 **Explain** why each of the renewable sources of energy is considered 'renewable'.
12 **Draw** an energy flow diagram for a petrol engine car travelling at a constant speed on a flat road.
13 **Summarise** ways in which you can make your house more energy efficient. For each suggestion, explain how it works.

Analysis

14 The following information applies to two different models of fridge. Note that the cost of electricity in Queensland is about $0.24 per kilowatt hour (kWh).

	Model 1	Model 2
Energy star rating	4	3
Energy consumption per year (kWh)	185	240
Price ($)	550	499

Compare the fridges and decide which one you would buy. Give reasons for your choice.

15 **Consider** what the man is doing in Figure 9.69. Explain why the homeowners have hired him to do this job.

Figure 9.69 What is this man doing?

Knowledge utilisation

16 **Propose** one drawback of using solar energy as an energy source.

17 **Propose** two reasons why coal may not be suitable as a long-term energy source.

18 **Discuss** why inner city trains and trams are powered by electrical energy.

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Chapter review

Chapter checklist

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

1	**I can define energy.** e.g. Define energy.	
2	**I can describe the different types of energy.** e.g. Define potential energy.	
3	**I can distinguish between temperature, thermal energy and heat.** e.g. Contrast the following terms: temperature, thermal energy and heat.	
4	**I can recall the law of conservation of energy.** e.g. Recall the law of conservation of energy.	
5	**I can describe how energy is transferred and transformed.** e.g. Explain what occurs during an energy transformation.	
6	**I can calculate the efficiency of different machines.** e.g. A toaster uses 131 500 J of electrical energy: 80 650 J is used to produce heat to toast bread. Calculate the efficiency of the toaster.	
7	**I can describe the energy transformations that occur when producing electricity in different ways.** e.g. Draw a flow diagram to show the energy transformations that occur while producing electricity in nuclear power stations.	

Review questions

Retrieval

SCORCHER

1 **Recall** the name of the energy associated with moving.

2 **State** the kind of energy you increase if you climb a mountain.

3 **Recall** the term for energy that is stored when a spring is compressed.

4 **Select** the correct description for each term.

Term	Description
Sound energy	Moving objects have this sort of energy
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

5 **Recall** what is meant by the term 'energy efficiency'.

6 **State** the energy transformations that occur when someone climbs a set of stairs.

7 **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.

8 **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.

9 **Recall** as many sources of light energy as you can think of.

10 Look around your environment and **identify** as many examples of energy as you can see.

11 As you go about your day, **identify** all the different types of energy transformations that occur.

Comprehension

12 **Draw** a flow diagram showing the energy transformation that occurs in a gas stove.

13 **Explain** why a light globe with an input energy of 1200 J cannot produce 1500 J of light energy.

14 **Explain** the difference between an energy-efficient light globe and a less efficient light globe.

15 Use the diagram of a waterwheel in Figure 9.70 to **draw** an energy flow diagram for this process.

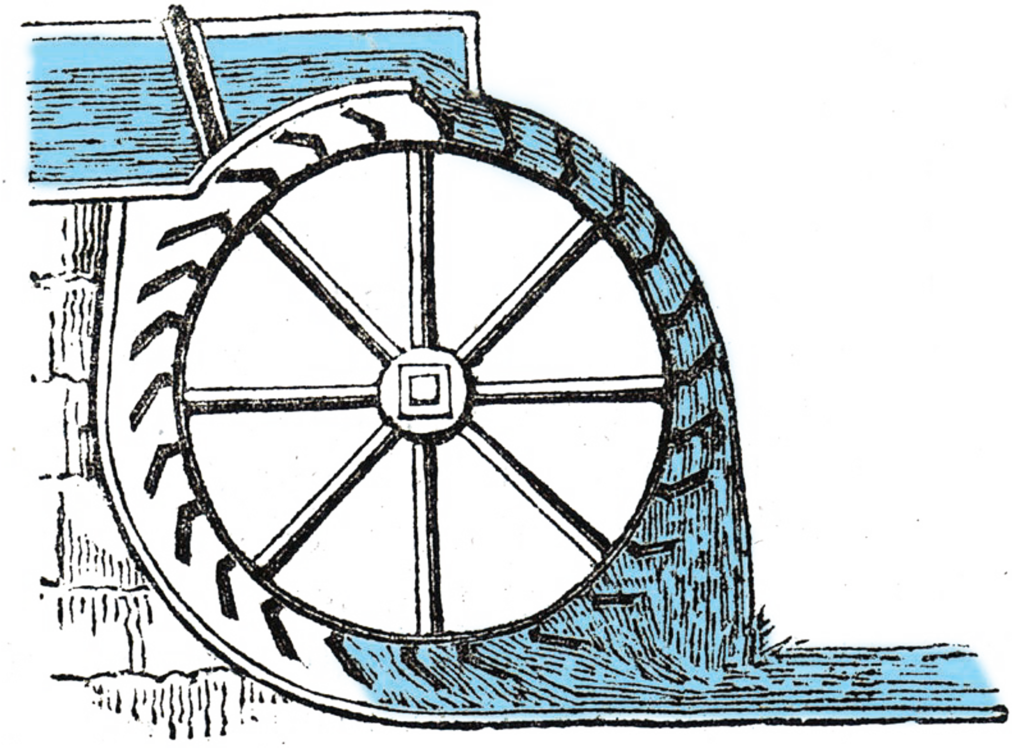

Figure 9.70 An overshot waterwheel.

Analysis

16 Some people use wood-burning stoves to heat their homes. **Consider** whether or not this source of energy is renewable and/or sustainable. Explain your answer.

17 **Consider** the Sun's role in life on Earth. Explain why there would be no life on Earth without the Sun.

Knowledge utilisation

18 Heavy items of freight are often sent by cargo ships. These boats are powered by diesel, which has replaced coal during the past 100 years.

Evaluate the alternative modern sources of energy and determine whether you think diesel is likely to be replaced soon. Possible alternatives to consider are: wind turbines, solar panels, nuclear power.

19 **Discuss** the pros and cons of using nuclear energy.

Data questions

Solar panels are used across Australia to convert the energy provided by sunlight into electricity. The electricity produced by a typical commercial solar panel in Queensland throughout a sunny day is shown in Figure 9.71. The efficiency and price of six different solar panel models is also shown in Table 9.3.

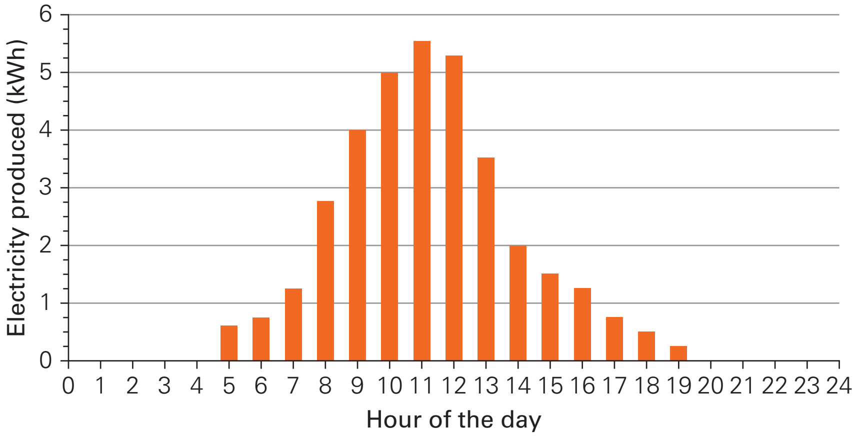

Figure 9.71 Electricity produced, in kilowatt hours, by a typical commercial solar panel throughout a sunny day

Solar panel model	Efficiency (%)	Estimated price ($ / m²)
A	46	> 2 000 000
B	44	> 1 000 000
C	37	> 100 000
D	22	120
E	17	80
F	15	70

Table 9.3 Efficiency and cost of different solar panel models

Apply

1 **Identify** the time of the day the solar panel presented in Figure 9.71 produces the most electricity.

2 **Calculate** how many hours per day the solar panel can produce electricity.

Analyse

3 **Identify** the pattern of electricity production throughout a sunny day.

4 Refer to Table 9.3 and **identify** the trend between the efficiency of a solar panel and the price per square metre.

Interpret

5 **Infer** whether the cost of a solar panel is directly proportional to the efficiency.

6 **Deduce** why electricity is not produced between midnight and 4 am and again between 8 pm and midnight.

7 **Predict** the effect on the data in Figure 9.71 if the weather was an overcast and rainy day.

8 A domestic household owner in Queensland would like to install solar panels on the roof of their home. The owner would like a solar panel with an efficiency above 20% to cover 3 m². **Deduce** the type of solar panel and the lowest price that the homeowner could pay for these requirements.

9 Based on the general shape of the data presented in Figure 9.71, **justify** why the angle at which the solar panel is oriented on a roof is important for a higher electricity production.

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STEM activity: Wind power

Background information

Wind power has been used for generations as a method of generating usable energy. Wind turns the turbine and generates mechanical energy, which has been used for many things over the years. From providing energy to pump water from a reservoir to electricity generation, wind power has many uses, and a major benefit is its ability to be generated in remote areas.

Figure 9.72 Different types of wind turbines

Design brief: Design a wind turbine capable of lifting an object.

Activity instructions

In groups you will design and construct a simple wind turbine capable of lifting weights from the floor up to bench height. Your turbine must be efficient in its energy conversion and sustainable in its design.

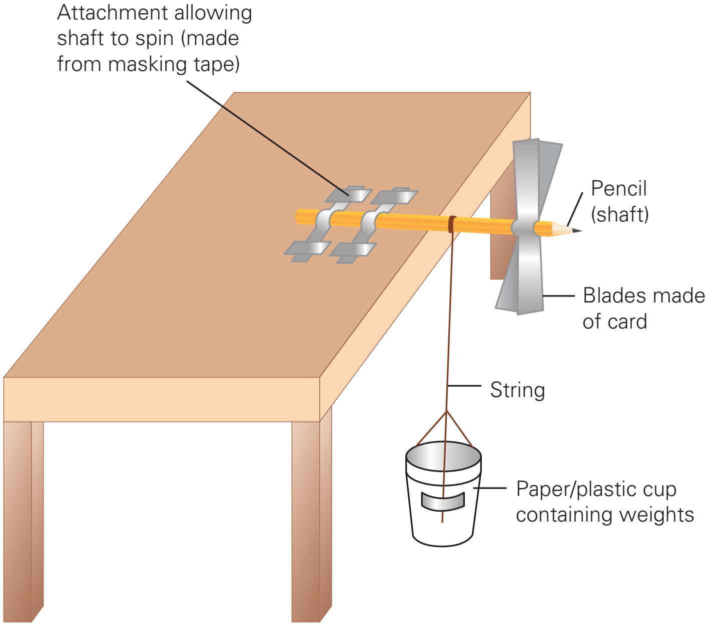

Figure 9.73 You can build ideas around this basic design.

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Suggested materials

- a medium-sized fan (to simulate a constant flow of wind)
- cardboard (different thicknesses if possible)
- masking tape (optional)
- string
- pencils
- scissors
- paper or plastic cup for carrying the load
- weights (you can use Lego® characters as well)
- electronic scale (optional)

Research and feasibility

1 Research and discuss in your group how wind turbine blades are shaped to capture the maximum amount of wind. Consider the materials used in construction, different shaped turbines, and their use in high/low wind areas.

2 Discuss in your group the constraints of your building materials and testing area.

Design and sustainability

3 Sketch and label multiple turbine designs within your group and discuss the effectiveness of the design features based on research.

4 Propose a measure of design efficiency. Think about how you can quantitatively measure how effective one design/prototype is compared with another. This may include measures for sturdiness, speed of lift, and maximum capacity. Discuss in your group the relationship between blade shape and blade spin for your design.

5 Design a table you can use to test different designs and to find the optimal shape for the wind conditions you are testing for. Trial different fan speeds to see their effect.

6 Discuss how sustainable your design is, and its effect on the environment. Does blade design affect this?

Create

7 Build your design and test using the weights.

Blade length	Blade width	Blade thickness	Blade angle	Fan speed	Weight being lifted	Time to lift weight

Evaluate and modify

8 Discuss and suggest three possible solutions to the problems you encounter.

9 Predict what would happen to the cup if you turn the fan (wind) off when the cup is halfway between the floor and the tabletop. Now test this scenario and write down your observations. Does it match your prediction?

10 Evaluate and present the most effective design to the class, and discuss why you believed this to be the most effective wind turbine design in this situation.

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Glossary

Cognitive verbs

analyse examine something in order to find meaning or a relationship

apply use knowledge to answer a given situation

calculate find a numerical answer by using mathematical processing

categorise place something in a particular group

classify place something in a group based on shared characteristics

compare give an account of the similarities and differences between two or more items

comprehend understand the meaning of something

connect bring two or more ideas together

consider (In analysis) think carefully about something

construct create something by arranging ideas

contrast give an account of the differences between two or more items

create produce something from a set of thoughts or ideas

critique review something in a critical way

decide make a decision from a range of alternatives

deduce reach a conclusion based on the information given

define provide the meaning of a word

demonstrate prove or make something clear

describe give a detailed account of something

determine establish after research or investigation

develop add detail or elaborate on something

differentiate identify differences between two or more things

discuss write about a topic in detail

distinguish recognise something as different

draw conclusions make a judgment based on evidence

elaborate add detail to expand upon an idea

evaluate appraise something by assessing strengths and limitations

explain make an idea clear by describing it in more detail

explore look at information in detail

extrapolate estimate an unknown value by extending known information

identify establish what something is

illustrate display information in a diagrammatic or pictorial form

infer conclude something from evidence and reasoning

investigate (In knowledge utilisation) carry out a comprehensive examination or review of something to discover new information and develop conclusions

justify give reasons to support an answer or prove a statement is correct

name indicate what something is

organise arrange in an ordered way

predict say what will happen based on available information

propose put forward an idea or suggestion

recall remember a fact

reflect on (in analysis) think about something carefully

select choose the most appropriate answer

sequence arrange in a particular order

state express something clearly

summarise produce a short statement that conveys information about a larger piece of information

Chapter 1

accuracy how well a measuring instrument determines the variable it is measuring. It refers to how close a measurement is to the true value. You can increase the accuracy by choosing more appropriate equipment, or by ensuring it is properly calibrated.

bar graph a type of graph used to display the frequency of a qualitative variable (category)

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

continuous data quantitative (numerical) data points that have a value within a range; this type of data is usually measured

controlled variable a variable in an experiment that must be kept constant, so it does not affect the dependent variable

dependent variable the variable in an experiment that you measure

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

exponential a population that grows at a rate proportional to its size

extrapolation using existing data (such as a line of best fit) outside the original data set to make a prediction

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hypothesis a prediction, or educated guess, about the effect that the independent variable will have on the dependent variable; a prediction of the outcome of an experiment

independent variable the variable in an experiment that you manipulate, change or test

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

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

nominal data qualitative (categorical) data where the categories have no order, e.g. male, female

ordinal data qualitative (categorical) data where the categories have an order, e.g. small, medium, large

origin the point (0, 0) where the x-axis and y-axis intercept

outlier an extreme data value that is very different from the other data and could be the result of faulty procedure

precision how close repeated measurements are to each other

primary source a source of information that comes from your own findings or experiments

qualitative data data values that are worded/descriptive/categorical in nature

quantitative data data values that are numerical in nature

relevant connected to the topic being investigated

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.

secondary source a source of information that comes from someone else's research or findings

specific clearly defined or identified

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

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

Chapter 2

antibiotic a medicine or chemical that can destroy harmful bacteria in the body or limit their growth

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

binary fission a mode of asexual reproduction by bacteria, where genetic information is copied and the cell splits in half

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

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

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

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

differentiation the process by which stem cells become more specialised

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

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

endoplasmic reticulum a network of tubes within a cell that are involved in protein and lipid synthesis

eukaryote any cell or organism that possesses membrane-bound organelles and a nucleus

genetic material the material containing the code that allows the cell to produce copies of itself and to regulate the functions within the cell

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

macroscopic visible to the naked eye

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

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

mitosis the type of cell division in which one cell divides into two cells that are exactly the same

multicellular made of many cells

nucleus part of a cell that contains the genetic material

organelle a specialised structure in a cell, which has a specific function or job

pathogen an organism that causes disease

prokaryote unicellular organisms that lack membrane-bound organelles and a nucleus

protist a eukaryotic organism that is part of the kingdom Protista

ribosome a structure in a cell that reads genetic information to produce protein from amino acids

stem cell a cell that is able to develop into many different types of cell

steroids compounds made by cells that are used in cell membrane stability and for cell signalling

unicellular made of just one cell

vacuole a structure in a cell that stores water and nutrients

zygote a fertilised egg cell

Chapter 3

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

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

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

biconcave concave on both sides

bile a substance produced in the liver and stored in the gall bladder, which helps emulsify fats

bolus a lump of partially digested food

bronchi 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

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

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

chemical digestion a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

chyme a partially digested mass of food after it leaves the stomach

diaphragm a dome-shaped muscle that separates the chest and abdominal cavities; it contracts to cause us to inhale

differentiation the process by which stem cells become specialised

duodenum the first section of the small intestine

enzyme a protein that can help speed up chemical reactions

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

filaments red, fleshy part of the gills with thousands of fine branches that take oxygen from water into the blood

function the job that an object does

gall bladder a small gland near the liver that stores bile and secretes it into the duodenum

guard cells cells on either side of a plant stoma that control gas exchange by opening and closing the stoma

haemoglobin the red pigment in blood that binds to oxygen, allowing red blood cells to carry oxygen

herbivore a consumer (heterotroph) that feeds on plant matter

heterotroph any organism that obtains its nutrients by consuming other organisms

ileum the third section of the small intestine, where further food breakdown and nutrient absorption occur

intolerance an inability to eat a food without undergoing adverse effects

jejunum the second section of the small intestine, where food breakdown and nutrient absorption occur

large intestine the organ that is connected to the small intestine at one end and the anus at the other

lenticels small slits on trunks or branches of trees that allow gas exchange

liver a large organ that has many metabolic and secretory functions, including the production of bile

mechanical digestion a series of mechanical processes that breaks food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

neuron a nerve cell

omnivore an organism that eats a variety of plant and animal matter

organ a group of tissues working together to perform a function

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

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

pancreas an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

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

plasma the yellow liquid component that makes up 55% of the blood; carries water, dissolved gases and hormones

platelets tiny cells that assist with blood clotting

rectum the second-last section of the large intestine; stores faeces

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saliva liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

sinoatrial node a natural pacemaker that controls the heartbeat and is located in the wall of the right atrium

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

stomata tiny pores (holes) in leaves that allow entry/exit of gases such as oxygen and carbon dioxide

structure a physical part of an object

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

vein a thin-walled vessel with valves that carries blood back to the heart

vena cava the large vessel that returns deoxygenated blood to the heart, emptying into the right atrium

ventricle one of the lower two 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

xenotransplantation transplanting organs from one species into another

Chapter 4

asexual reproduction a method of reproduction in which there is one parent organism and all offspring are genetically identical

binary fission a mode of asexual reproduction by bacteria, where genetic information is copied and the cell splits in half

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

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

cross-pollination pollination that occurs by pollen from another flower or plant

differentiation the process by which stem cells become specialised

embryo a fertilised egg cell in the early stages of growth and differentiation; in humans, this would be from between two and eight weeks after fertilisation

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

fragmentation a mode of asexual reproduction where organisms can be cut in half and regrow into two genetically identical organisms

gametes the sex cells (eggs and sperm), each of which contains half the genetic material required to make an organism

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

gonads the reproductive organs, where gametes are produced; testes for males and ovaries for females

hormone a chemical produced by cells that controls and regulates different processes in the body

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

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

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

nectar a sweet liquid produced by flowers to attract pollinators

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

ovule a structure in a flowering plant where the female gamete is produced and where seeds develop; also used to mean the female gamete

ovum egg, or female gamete

parthenogenesis a mode of asexual reproduction where females give birth to unfertilised eggs that hatch to produce offspring that are genetically identical to the mother

pollen the male gamete in flowering plants

pollination the process by which pollen sticks to the female structures of a plant and fertilises the ovule

puberty the time of transition from juvenile form to adult form

scrotum a sac that encloses the testes

seed a plant embryo enclosed in a protective coating

seed dispersal the spread of seeds away from the parent plant

self-pollination pollination that occurs by pollen from the same flower or from another flower on the same plant

sexual reproduction a method of reproduction in which there are two parent organisms and genetic variation in the offspring

sperm the male reproductive cell, or gamete

spore an asexual reproductive cell produced by organisms such as fungi and ferns

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testes the male reproductive gland that produces sperm

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

zygote a fertilised egg cell

Chapter 5

boiling the rapid vaporisation of a liquid which occurs when it is heated to a temperature called the boiling point

Brownian motion the random movement of particles in fluids

chemical property the behaviour of a substance when it reacts with another substance

compress squeeze to make smaller

concentration the number of particles present in a given volume

condensation where heat is lost causing a gas to become a liquid

contraction the process of substances getting smaller: the atoms of a substance move closer together as they cool

density how much matter (mass) is contained in a certain volume of a substance

deposition where a reduction in heat causes a gas to become a solid, without passing through the liquid state

diffusion the movement of particles from an area of high concentration of particles to low concentration of particles

evaporation when heat causes liquid to become gas

expansion the process of substances getting larger: the atoms of a substance move further apart as they heat up

freezing where heat is lost and a liquid becomes a solid

gas a substance that expands freely to fill space

Kevlar fibres that have five times the strength of steel for the same weight and are used in a variety of clothing, accessories and equipment (Dupont™ Kevlar®)

liquid a substance that flows freely and takes the shape of its container but has constant volume

mass the amount of substance in an object that never changes, even in space

matter anything that has mass and volume

melting when heat causes a solid to become a liquid

melting point the temperature at which a specific solid melts

particle model all matter is made of particles that behave differently depending on whether they are solid, liquid or gas

physical property the way a substance looks and acts: a characteristic of a substance that can be observed and/or measured without changing it chemically

pressure the amount of force exerted on a given area

radiation energy from heat or light that you cannot see, different from nuclear radiation

solid a substance that has a fixed shape and constant volume

state one of the distinct forms matter can exist in

sublimation where heat causes a solid to become a gas, without passing through the liquid state

vibrate periodic motion of particles

volume the space an object occupies

Chapter 6

atom the smallest possible piece of any substance; it makes up all matter

chemical bond strong force of attraction that joins atoms together

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

compound substance made up of two or more different types of atoms

conductivity the ability of a substance to conduct or carry electricity or heat

diatomic element a molecule consisting of two atoms of the same type

ductility the ability of a substance to be drawn into a wire

element substance made up of only one type of atom

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

homogeneous mixture describes a mixture of two or more substances that are evenly distributed and do not separate out easily

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 all directions

lustre the ability of a substance to become shiny when polished

malleability the ability of a substance to be bent or flattened into a range of shapes

metal a substance that is shiny, can conduct electricity, can be bent, is usually silver/grey and is ductile

metalloid a substance that has some of the properties of both metals and non-metals

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mixture a substance made up of two or more different pure substances (compounds or elements) that are not bonded together

molecule two or more atoms joined together by strong covalent bonds

monatomic made up of single atoms, all of one type

non-metal a substance that is dull, cannot usually conduct electricity, is brittle and is not ductile

periodic table a list of all the known elements and their symbols

polyatomic element 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

pure substance a pure substance is made up of either the one type of atom or the same groups of atoms (molecules or compounds)

Chapter 7

bioluminescence a chemical reaction that produces light in living things

chemical change where one or more substances undergo a chemical reaction and a new substance, or substances, is formed; mostly irreversible

chemiluminescence a chemical reaction that produces light

combustion a reaction that involves the burning or exploding of a substance in the presence of oxygen

corrosion the gradual and natural process of metals breaking down; an example is rusting

decomposition a reaction in which one substance breaks up into smaller ones

dissolving the process where individual particles of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be seen in a solution

galvanisation the process of coating iron or steel in zinc to prevent corrosion

irreversible incapable of going in the opposite direction

physical change when the physical properties of a substance change in some way, but no new substance is formed; it is reversible

precipitate the solid that forms when two clear solutions are mixed together and undergo a chemical change

precipitation a reaction that involves the mixing of two clear solutions to produce a solid called a precipitate

products the substances that are present at the end of a chemical reaction

reactants the substances that are present at the beginning of a chemical reaction

reversible capable of going in the opposite direction

synthesis a reaction in which two (or more) elements or reactants combine to form new substances or products

thermal decomposition decomposition that occurs when a substance is heated

Chapter 8

biological weathering the disintegration of rocks that is caused by living things

breccia sedimentary rock composed of angular broken pieces of rock larger than 2 millimetres

cementation the sticking together of sediment

chemical weathering the disintegration of rocks caused by acidic rainwater

cleavage the tendency of a mineral or rock to break in a particular way because of its structure

compaction the process of parts becoming closely positioned together, using very little space

conglomerate sedimentary rock composed of rounded rock fragments larger than 2 millimetres

crust the solid outer layer of the Earth; continental crust is on average 35 km thick and the average thickness of oceanic crust is 10 km

crystal a mineral in which the atoms are arranged in an ordered way to form a geometric shape

deep time the idea first suggested by James Hutton that the Earth is very old

deposition process that occurs when eroded particles stop moving and build up to form sedimentary rocks

electrolysis a method of extracting a metal from its ore or purifying it using electricity

erosion the transport of rocks from one place to another as a result of weathering

extrusive describes igneous rocks formed on the Earth's surface; also called volcanic rocks

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

geology the study of the rocks and similar substances that make up the Earth and other planetary objects

igneous describes rocks made from lava on the surface or magma below the surface

inner core the solid centre of the Earth; probably made of iron

intrusive describes igneous rocks formed underground; also called plutonic rocks

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karst an area of land formed of rock such as limestone that is worn away by water to make caves and other formations

lava molten rock from inside the Earth (called magma) that has reached the surface

lithospere the solid outer layer of the Earth; includes the crust and uppermost mantle

magma molten rock under the Earth's surface

mantle the layer of solid and semi-molten rock that surrounds the outer core and extends up to the Earth's crust

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

mineral a chemical substance that is formed naturally in the ground

Mohs scale a scale from 1 to 10 that indicates the hardness of a rock

opaque blocking light completely

ore a rock that can be mined and smelted to produce a metal

outer core the liquid layer surrounding the inner core; probably made of liquid iron

physical weathering the breaking down of rocks into smaller particles by contract with other rocks, wind, water or ice

radioactivity energy released from the nucleus of an atom when the atom decays; the age of rocks can be determined by measuring their radioactivity

reflection seismology the use of shockwaves to investigate the structure of rocks underground

rock solid material forming the Earth's crust; rocks are formed as part of the rock cycle

rock cycle the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

sedimentary describes rocks made from deposited materials that are the products of weathering and erosion

sediments sand, stones, etc. that slowly form a layer of rock

smelting the process of getting a metal from rock by heating it to a very high temperature

streak test a test used to help identify a mineral by scratching a rock on a hard ceramic tile

surface mining method of mining that extracts a mineral from the surface, such as by digging an open pit

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

underground mining traditional method of mining by digging tunnels underground to extract ore

Chapter 9

chemical potential energy the energy stored in the bonds between atoms

efficiency the percentage of input energy that is converted to useful energy by a machine

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

electromagnetic spectrum a way of organising electromagnetic waves according to their frequency

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

fossil fuel a non-renewable energy source such as oil, coal or natural gas

generator a device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

geothermal energy thermal energy that originates from inside the Earth

gravitational potential energy a type of potential/stored 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 m and g is Earth's gravity

heat thermal energy that is in transit due to differences in temperature

hydroelectric power a renewable source of energy harnessing the gravitational potential energy of water to generate electrical energy

input energy the energy that a machine or device uses as its source of energy

joule the unit of energy or work done

kinetic energy the energy of moving matter

law of conservation of energy the law that states that energy cannot be created or destroyed

light energy a form of energy that we can see with our eyes; also called visible light; a part of the electromagnetic spectrum

non-renewable existing in limited quantities that cannot be replaced after they have all been used

nuclear energy a non-renewable source of energy that uses the energy released by the nucleus of radioactive atoms

output energy the energy that a machine or device provides or wastes

potential energy the energy stored in something because of its height above the ground, or because it is stretched or compressed, or in chemical form

radiation the emission of energy from unstable nuclei

radioactive having or producing the energy that comes from the breaking up of atoms

renewable can be produced as quickly as it is used

rotational kinetic energy the energy an object has because it is rotating

solar energy a renewable source of energy that converts sunlight directly into electrical or thermal energy

sound energy a form of travelling wave; sound consists of vibrations in the air

sustainable causing little or no damage to the environment and therefore able to continue for a long time

temperature a measure of the average random kinetic energy of the particles in a substance

thermal energy the energy contained within a material that is responsible for its temperature

travelling wave a wave that can carry energy from one place to another

turbine a device that converts the kinetic energy of a fluid into useful work, for example a windmill

useful energy the output energy that a machine is designed to produce; an efficient machine will maximise the useful energy it creates

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)

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