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

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Lead author

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Dr Brodie Reid

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

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About the cover

Homoranthus montanus is a rare shrub found only in a small area of southern Queensland. It is listed as critically endangered under Queensland's *Nature Conservation Act 1992*. The shrub grows to just over a metre tall and flowers mostly from October to November. Its small, tubular flowers, featured on the cover of this publication, turn from cream to red as they age.

Homoranthus montanus

Contents

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

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How to use this resource

Elements in the print book

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

Explore!

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

Quick check

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

Learning goals

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

Did you know?

These are short facts that contain interesting information.

Science as a human endeavour

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

Section questions

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

Hands-on activities

Try this

Classroom activities help explore concepts that are currently being covered.

Making thinking visible

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

Practical skills

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

Investigation

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

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End-of-chapter features

Chapter review

Chapter checklist

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

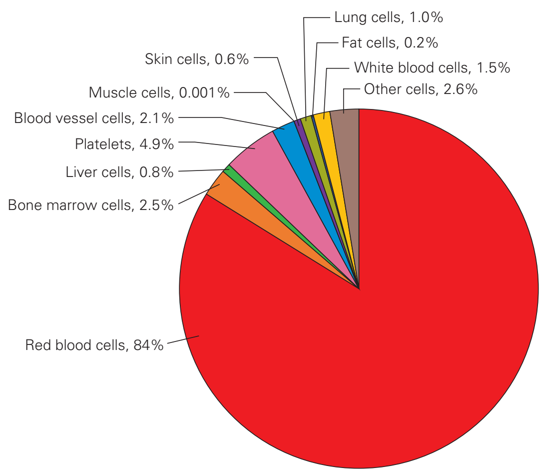
Success criteria		Linked questions	Check
2.1	I can describe how the invention of the microscope has contributed to understanding of cell structure.	8, 9	
2.1	I can label the parts of a microscope.	4	
2.2	I can distinguish between prokaryotic and eukaryotic cells.	15	
2.2	I can identify the structure and function of organelles in cells.	5, 6, 11	
2.3	I can compare the similarities and differences of plant, animal, protist and fungi cells.	1, 12, 5c	
2.3	I can design a physical or digital model of a cell and explain how the representation models the cell.	10, 16	

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

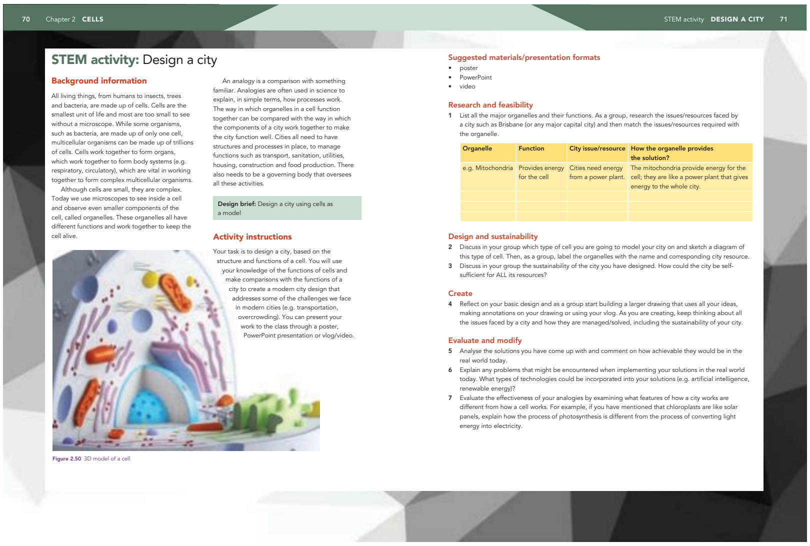
Chapter review question sets are categorised under four headings: Retrieval, Comprehension, Analysis and Knowledge utilisation. Cognitive verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

Data questions

The human body is composed of trillions of cells that work together to carry out various functions necessary for life. Estimating the total number of cells in an adult human body is a challenging task, but researchers have made significant progress in recent years. By studying individual organs and tissues and using various methods, such as microscopy, scientists have developed estimates for the number of cells in the human body, divided by cell type. These are shown in Figure 2.48.



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



70 Chapter 2 CELLS

STEM activity: Design a city

Background information

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

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

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

Design brief: Design a city using cells as a model

Activity instructions

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

Figure 2.50 3D model of a cell

STEM activity DESIGN A CITY 71

Suggested materials/presentation formats

- poster
- PowerPoint
- video

Research and feasibility

1 List all the major organelles and their functions. As a group, research the issues/resources faced by a city such as 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.

STEM activities encourage students to collaboratively come up with designs 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.

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

Practical skills 2.1

Using a microscope

Aim
To become proficient in using a microscope

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

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

Method
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. 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.

continued…

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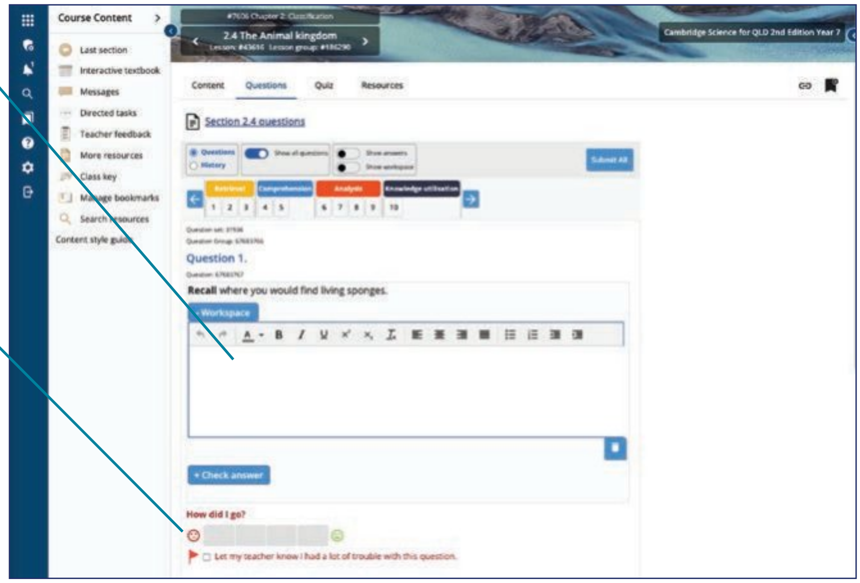
Workspaces enable students to enter working and answers online and to save them. Input is by typing, handwriting and drawing, or by uploading images of writing or drawing.

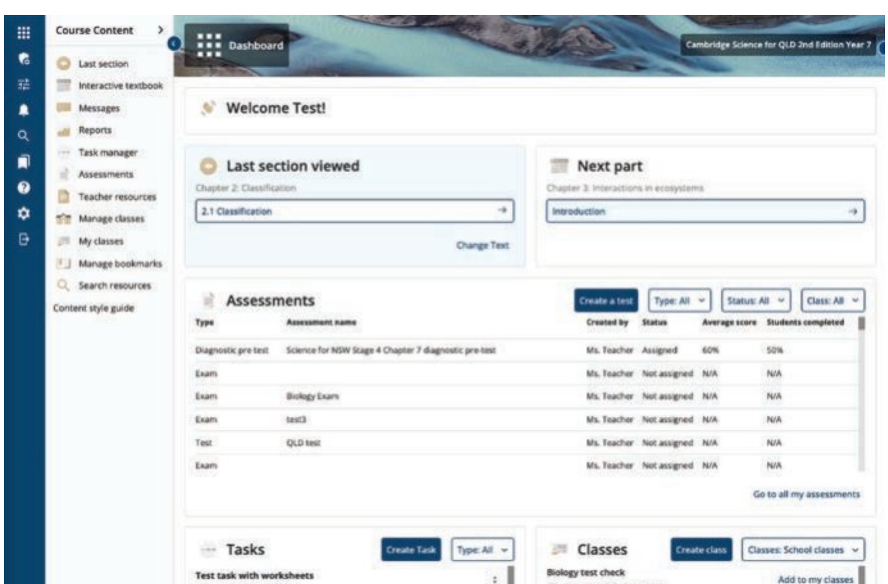
Self-assessment tools enable students to check answers, mark their own work, and rate their confidence level in their work. Student accounts can be linked to the learning management system used by the teacher in the Online Teaching Suite.



Overview of the Online Teaching Suite (OTS)

The Online Teaching Suite 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, Try this, Explore! and STEM activities.
- **diagnostic tools**, including ready-made pre- and post-tests and intuitive reporting



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Chapter 1
Being scientific

Chapter introduction

When conducting their experiments and investigations, scientists employ a rigorous and systematic approach, commonly referred to as the scientific method. This year, you will explore potential causal relationships between experimental variables. To establish causation, scientists must substantiate their claims with scientific evidence. The scientific method serves as a reliable guide, enabling scientists to conduct effective experiments while remaining mindful of the ethical implications of their work.

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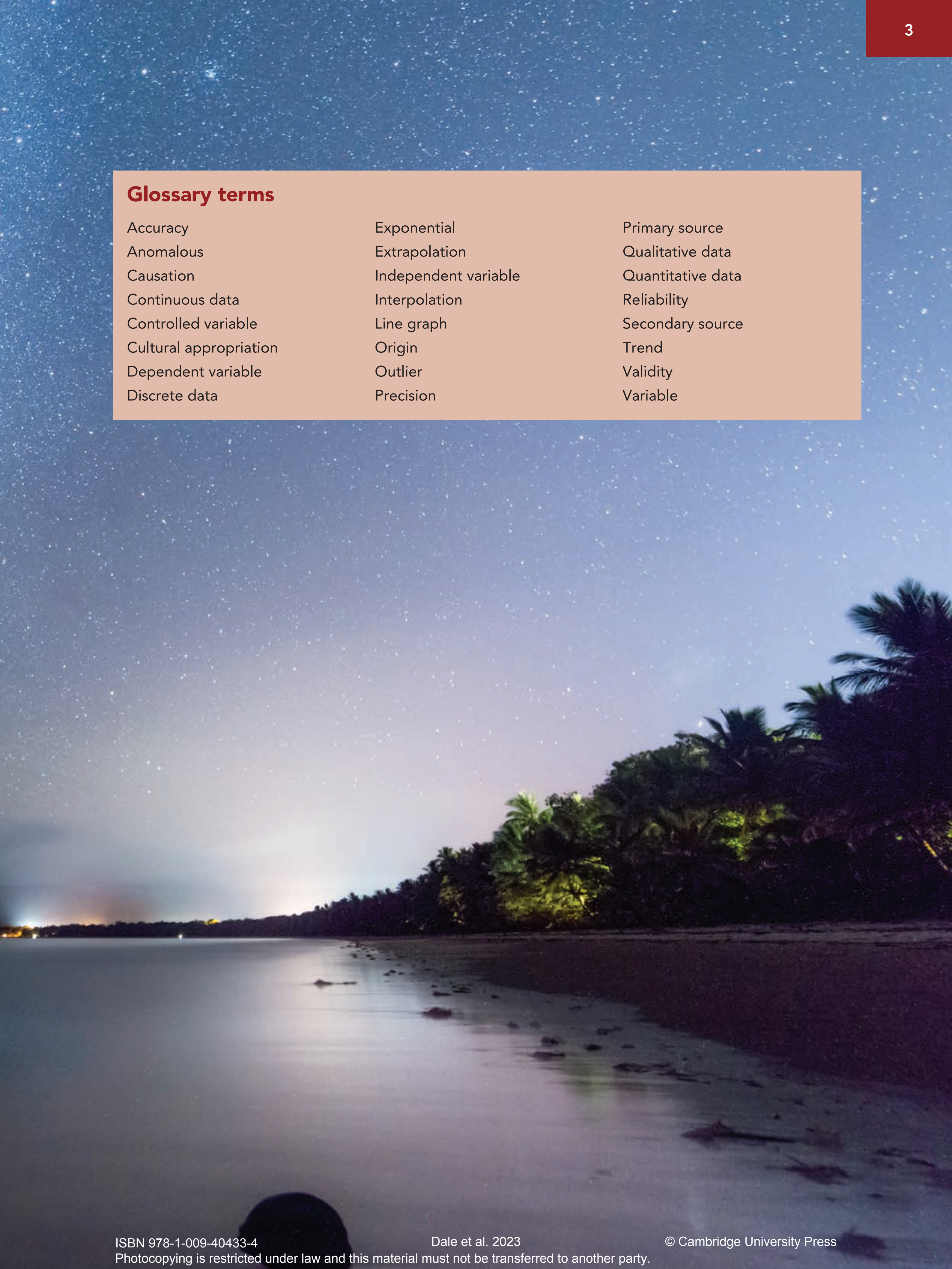

Glossary terms

Accuracy
Anomalous
Causation
Continuous data
Controlled variable
Cultural appropriation
Dependent variable
Discrete data
Exponential
Extrapolation
Independent variable
Interpolation
Line graph
Origin
Outlier
Precision
Primary source
Qualitative data
Quantitative data
Reliability
Secondary source
Trend
Validity
Variable

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1.1 Investigating causal relationships

WORKSHEET
Identifying variables and hypotheses

Learning goals

1. To be able to define primary and secondary sources of information.
2. To be able to write a scientific hypothesis.
3. To be able to write a stepwise experimental method.

A scientific method: review

Scientific methods allow scientists to follow a systematic approach towards experimentation. Here, you will be presented with a common scientific method that you should follow in the scientific investigations that you plan at school.

A scientific method

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

↓

STEP 2: DO BACKGROUND INFORMATION RESEARCH
Find as much information as you can on the question. You should consider the quality and reliability of your sources of information.

↓

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

↓

STEP 4: TEST THE HYPOTHESIS IN AN EXPERIMENT
You will need to write a method that can test a prediction from the hypothesis. It should include the materials and apparatus used and the procedure in easy to follow steps. You should also write a risk assessment.

↓

STEP 5: GATHER DATA
During the experiment, you will collect data. It might be quantitative or qualitative data. You will display these data in a meaningful way, using graphs, tables or diagrams.

↓

STEP 6: ANALYSE THE DATA
Examine the tables and graphs of data. Analysing data can reveal relationships, trends and patterns. Discuss your results in relation to your research hypothesis.

↓

STEP 7: EVALUATE THE DATA
This is a discussion of the reliability and validity of the experimental process, including any improvements you would make or extensions that you would do if you were to repeat the experiment.

↓

STEP 8: MAKE A CONCLUSION
This is an insightful interpretation of the data through a justified conclusion that is linked to the hypothesis.

↓

STEP 9: COMMUNICATE 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 A scientific method

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Background information research

In year 7, you learned about the types of observations and inferences that can be used to formulate questions about the world around you. Once a research question has been decided, it is important that scientists do some background research to identify what similar questions have already been answered by other scientists.

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

Secondary sources of information are more likely to be reviewed in background research, and summarise, analyse or interpret primary sources. When scientists refer to secondary sources of information, they have access to the research and questions that have been answered all over the world. However, when accessing secondary sources of information, particularly those on the internet, it is important that the credibility of sources is evaluated. In year 7, you did this using the CRAAP test.

Making thinking visible 1.1

Name, describe, act: The CRAAP test

The CRAAP test can be used to evaluate the credibility of secondary sources of information.

1 Name the component that each letter stands for in the CRAAP test.
2 Describe what each of the components listed in Question **1** mean.
3 Explain the purpose of each of the components in the CRAAP test. How do each of these relate to the credibility of a source?

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

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

Australian First Nations communities are a fantastic primary source of information on their own traditional and cultural knowledge, practices and history. It is imperative that scientists acknowledge and recognise the cultural importance of the traditional knowledge as well as cultural sites, including ceremonial grounds, traditional quarries and when uncovering artefacts in fieldwork.

Local First Nations Australian leaders and appropriate government agencies should always be contacted when uncovering traditional artefacts or working on culturally significant sites. Moreover, scientists should always work with First Nations Australian leaders when using traditional knowledge, to ensure that they are working within ethical guidelines. When ethics are not considered, traditional knowledge is at risk of **cultural appropriation**, in which cultural knowledge is used without acknowledgement or consent, which often means it is used inappropriately.

primary source a first-hand record or account

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

cultural appropriation use of cultural knowledge or tradition without acknowledgement or consent

Try this 1.1

Traditional knowledge of First Nations Australians

There are some important steps to take when discovering First Nations Australian artefacts as a scientist. What are some key steps that should be taken to ensure that the artefact is not damaged and appropriate persons are notified? Discuss with a partner.

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Causal relationships

When asking a research question, often it will be a question of **causation**. For example, does exposure to sunlight make a seed sprout grow longer? The causal relationship questioned here is whether exposure to sunlight *causes* seed sprouts to grow longer.

causation
one event is caused by another event occurring

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

independent variable
the variable in an experiment that you change or allow to change so it causes change in the dependent variable that you can measure

dependent variable
the variable in an experiment that you measure to see if changes to the independent variable cause it to change

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

To gather evidence that might support or not support this question of causation, experimental factors or conditions must be chosen or controlled (such as amount of sunlight or duration of the growing period) to ensure that only the relationship between the two variables in question is measured.

Variables

All the aspects or factors of an experimental procedure that could change are **variables**. The factor you *do* change (or allow to change) is the **independent variable** and the **dependent variable** is the one that is measured due to the change in the independent variable. All other variables must stay the same to gather evidence on whether the independent variable causes the dependent variable to change. If all other variables are not controlled, then changes to the dependent variable measurements might not be caused by the independent variable! This would not be a fair test. All the variables you keep constant are known as **controlled variables**.

In the seed sprout experiment, the variables are as follows:

Independent variable: sunlight exposure
Dependent variable: length of a seed sprout
Controlled variables: time interval between measurements of length of seed sprout, volume of water given, temperature the seed is being grown at, mass of soil provided

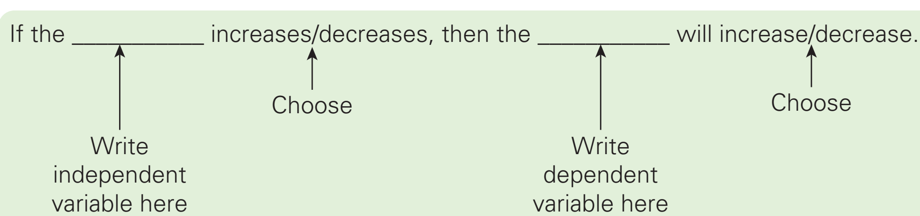
Note that some experiments may consist of collecting data by observation of the independent and dependent variables as they occur naturally in the environment. For example, if the research question is 'Do soldier crabs inhabit rocky shorelines?', the independent variable is the nature of the shoreline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

Writing a hypothesis

Recall that a hypothesis is an if … and then … statement that predicts the causal relationship between an independent and dependent variable.

A few points to remember when writing a hypothesis:

- A hypothesis makes an educated guess about the causal relationship between two variables.
- The hypothesis is a statement that can be tested in an experiment.
- The hypothesis must include the independent and dependent variables.



For example:
If the **temperature in the backyard** (°C) *increases*, then the **time taken for clothes to dry** (seconds) will *decrease*.

Figure 1.2 Setting out a hypothesis

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Quick check 1.1

1 Sequence these steps in the order in which they should be done.
   1 Test the hypothesis in an experiment.
   2 Gather data.
   3 Observe and ask questions.
   4 Do background research.
   5 State a hypothesis.
   6 Analyse the data.
   7 Evaluate the data.
   8 Make a conclusion.
2 Define these terms:
   a independent variable
   b dependent variable
   c controlled variables
3 Recall what a hypothesis must contain.

Writing a method

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

A few points to remember when writing a method for your experiment:

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

DOC WORKSHEET Writing a method

Explore! 1.1

The passive voice

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

For example, a high school student might write:

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

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

- A 100 mL measuring cylinder was filled with water.

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

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. An example is shown in Table 1.1.

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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 1.2 shows some of the information that can be found on the safety data sheet for hydrochloric acid.

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

Table 1.1 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 mol L^{-1})	 Corrosive, irritant	Corrosive to skin and eyes. Vapour or aerosols (droplets in air) may irritate the respiratory tract and lungs. It may also cause serious burns.
Moderate concentrations of hydrochloric acid (2.7 mol L^{-1} – 6.8 mol L^{-1})	 Irritant	May cause irritation of eyes, skin and the respiratory tract.
Dilute hydrochloric acid (<2.7 mol L^{-1})	 Potential irritant, low hazard	May cause irritation of eyes and any existing cuts in the skin.

Measures for reducing risk

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

Emergency response

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

Table 1.2 An example of a simple SDS for hydrochloric acid. Usually, companies will have a much more detailed and extensive SDS accompanying chemical products.

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Selecting appropriate equipment

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

quantitative data data values that are numerical in nature

qualitative data data values that are descriptive or categorical in nature

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

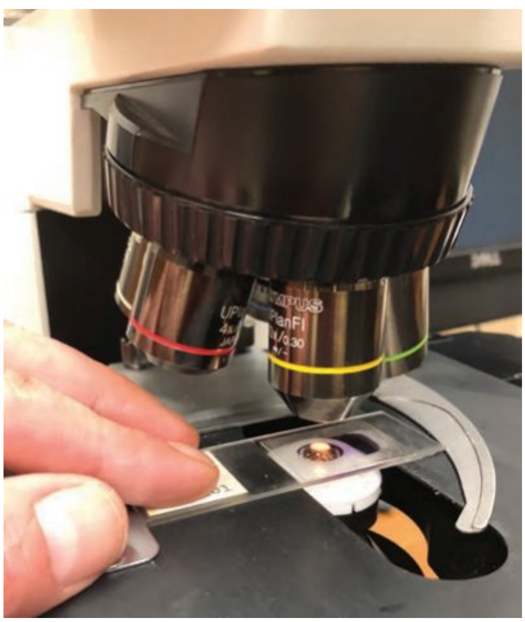

Figure 1.3 When observing cell structures under a microscope, adjusting the magnification to the appropriate level allows specific details to be clearly observed. Recording the magnification used is also necessary for other scientists to replicate the experiment and validate the findings.

Figure 1.4 When measuring liquid volumes, the observer must read the correct position of the meniscus in order to obtain accurate measurements. The meniscus refers to the curved surface of a liquid, and accurately determining its position enables the precise measurement of the liquid volume.

Try this 1.2

Testing the strength of shapes

Background

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

continued …

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... continued

Aim

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

Materials

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

Planning

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

Independent variable	
Dependent variable	
Controlled variable(s)	

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

Method

1 Construct and number your paper stands, each one made from a sheet of A3 paper, and the same height. Use sticky tape if required to hold the shape.

2 Place cardboard horizontally on the first stand.

3 Add 50 g masses until the stand collapses. Record the total mass added that collapses the stand.

4 Repeat three times for each stand (i.e. do three trials).

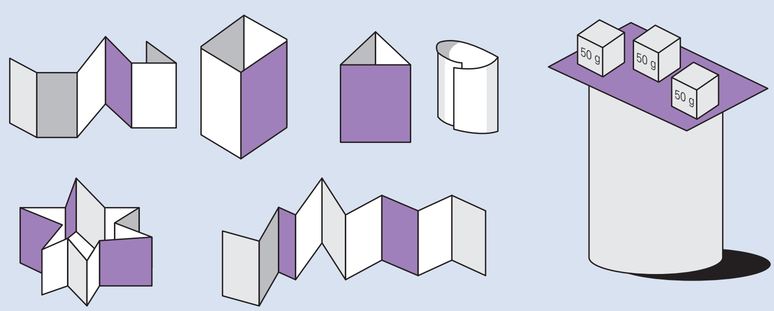

Figure 1.5 Some possible shapes to use (shown on left) and one way to test their strength (shown on right)

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 Were you able to identify a causal relationship between the independent and dependent variables?

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

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

Retrieval

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

Comprehension

2 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

3 **Explain** why variables must be controlled.

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

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

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

Analysis

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

Knowledge utilisation

7 Sanika says her scientific research satisfies a scientific method because she performed all the steps of a method in the flow chart of Figure 1.1. 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 Sanika's claim. Do you agree that she has followed the scientific method? Explain your answer.

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1.2 Presenting and analysing data

Learning goals

1. To be able to calculate the mean, median, mode and range of data.
2. To be able to plot a line graph and a line of best fit.
3. To be able to identify trends present in graphed data.

WORKSHEET
Analysing data

When an experiment or investigation has been carried out, scientists collect observations and data. To find meaning in the data, they should be analysed and presented in ways that allow possible causal relationships between variables to be evaluated. In this section you will learn about calculating measures of central tendency as well as presenting your data in graphs.

The type of analysis that is appropriate depends on the type of data you have collected. Quantitative data is data that is numerical in nature and can be categorised as either **continuous** or **discrete**. Continuous data includes all numerical values within a range, while discrete data only considers integer number (whole number) values. Qualitative data is data that is worded, descriptive or categorical in nature, such as red or blue, and dog or cat.

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

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

Measures of central tendency

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

Consider the following data. Five students were asked: 'How many hours of screen time do you have per day?'

The data was as follows: 2, 2, 4, 5, 8, 9

Measures of central tendency allow scientists to gain further information about the relationship between these data points by calculation of the mean, median, mode and range.

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

$$= \frac{(2+2+4+5+8+9)}{6} = 5$$

Median = 'middle number' when the data is arranged in numerical order. In this case: ~~2, 2,~~ 4, 5, ~~8, 9~~, the middle number is between 4 and 5; median = 4.5

Mode = 'most occurring number' = 2

Range = highest number – lowest number
= 9 – 2 = 7

Measures of central tendency can be great simple ways to gather more information on a data set. For example, often your teacher might calculate the mean of test scores to obtain more information about how well the class is performing as a whole, compared to other classes. However, measures of central tendency must be analysed carefully. For example, in this case the mode is 2, and this does not tell you anything about the spread of data points.

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Try this 1.3

Collecting smartphone usage data

As a class, collect data about the number of hours each student spends on their smartphone per week. Look for the 'Screen Time' or 'Digital Wellbeing' feature. It might be located under the 'Usage' or 'Battery' section. Depending on your device and operating system, you may find a weekly summary or a detailed breakdown of your smartphone usage. You can now collate data from the class to create a summary of this data. Consider the different ways you might want to analyse the data, perhaps based on gender or age or type of phone.

Quick check 1.2

Consider the following data set: 22, 23, 23, 24, 25, 26, 27, 29, 31

For the data, calculate the:

1 mean
2 median
3 mode
4 range

Recording data with precision

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

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

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

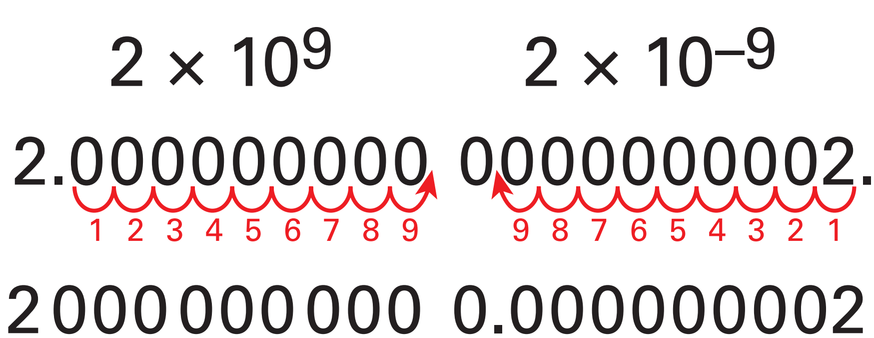

Figure 1.6 Scientific notation helps simplify the presentation of very large or small numbers, making it easier to compare values.

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Displaying data in tables

Presenting data in tables allows information to be organised and effectively communicated. The independent variable's values or categories should be listed in the first column, and the subsequent columns should display the data from the different trials of the dependent variable. Each column should have an appropriate header, including any units of measurement. This helps others understand the scale of the measurements.

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

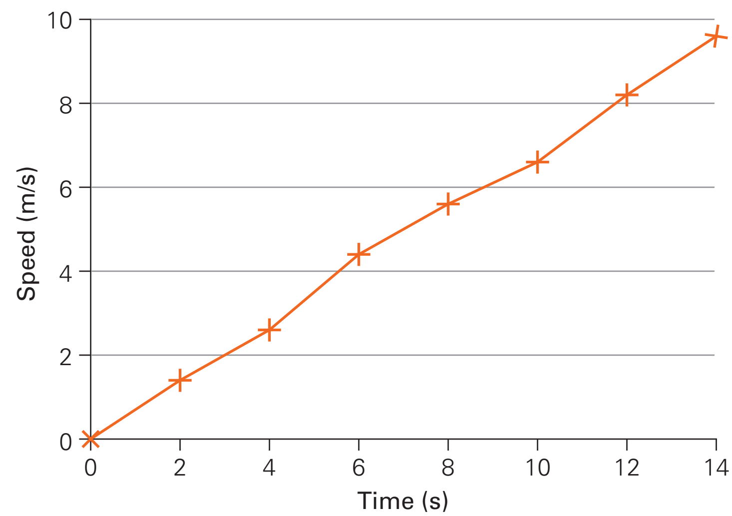

Figure 1.7 Table and figure showing the effect of time on car speed. Note that in the graph representation of this table, very small crosses have been used to mark the data points.

Displaying data in graphs

Quantitative data is usually displayed using a line graph.

Line graphs

A *scatter plot* is a way of displaying how one quantitative variable (the dependant variable) changes in response to another quantitative variable (the independent variable). When the plotted 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 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

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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
- Blu Tack®
- stopwatch
- 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	

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 1.8 on the following page.
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 1.8 on the following page.
5 When the pendulum returns for the third time, stop the stopwatch and divide the time by 3 to get the time for one swing.
6 Record the time for one swing in the results table. Repeat for two more trials.
7 Repeat steps **2–6** for different lengths of string.

Results

Create a results table for your experiment.

Use the mean of all 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).

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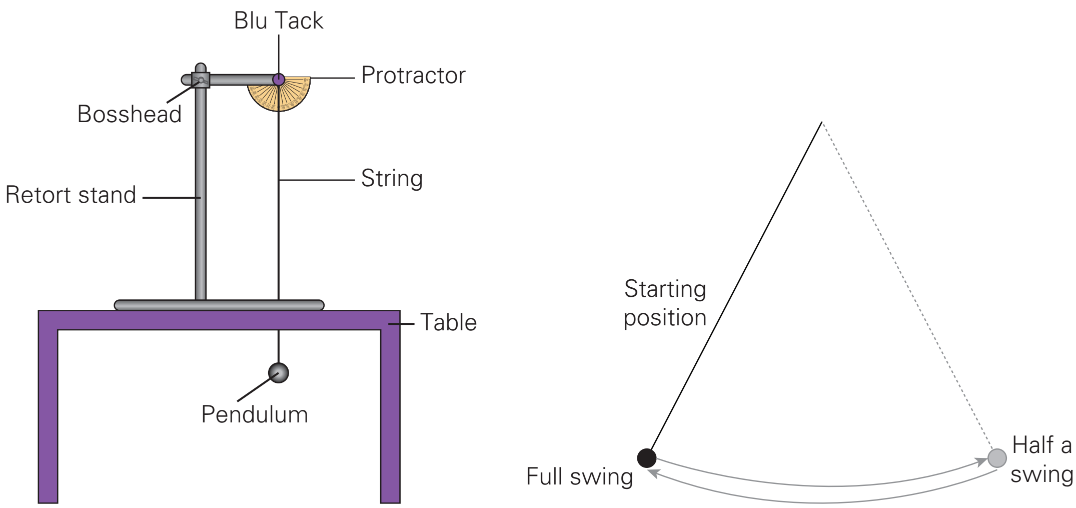

Figure 1.8 Experimental set-up. Left: setting up the pendulum. Right: timing the swing of the pendulum

Analysis

1 Identify any trends you see in your graph.
2 Compare your collected data to data from another group. How do their results compare to yours?
3 Explain whether your results supported or did not support your hypothesis.

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 zero 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 point where the axes meet (0, 0) is called the **origin**.
- 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 zero to 20 in intervals of five 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.
- Circle any **outlier** results, and label them as 'outlier'. These data points are those that are clearly **anomalous** and are likely a result of an error or mistake in recording that data point. Note: you cannot simply remove the point! Scientists must communicate all data including outlier results.
- Write a clear and concise title for the graph, incorporating the independent variable and dependent variable. This should sit below the graph.

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

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

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

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Practical skills 1.2

Insulation of water

Be careful

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

Background information

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

Aim

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

Materials

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

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.

Method

1. Cover the sides of three conical flasks with either cotton wool, paper or foil, and use elastic bands to secure the covers in place. Leave one conical flasks without covering.
2. Place one thermometer in each of the conical flasks.
3. Boil the kettle and carefully pour boiling water into each of the conical flasks up to the 200 ml mark. 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				

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… continued

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

Analysis

1 State whether your results supported or did not support your hypothesis and explain why.
2 Suggest a reason for using a conical flask 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.
3 Can you identify evidence that supports the causal relationship between the independent and dependent variables?

Reporting data

Describing patterns

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

In Figure 1.9, 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'.

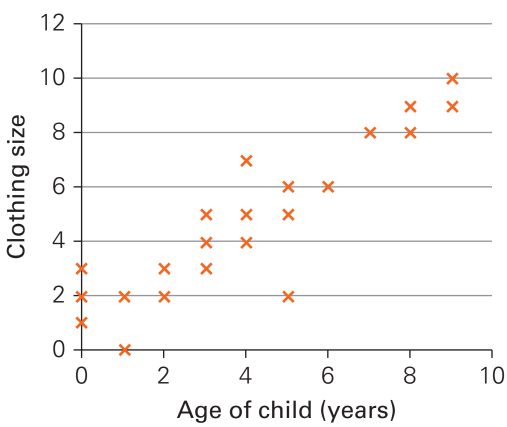

Figure 1.9 The effect of child age on clothing size

In Figure 1.10, the data show a rapid increase in customers that reaches a plateau (flat line) and then remains constant. You would describe this by saying, 'Initially, during approximately the first 60 months, as the number of months increases, the number of customers per month increases rapidly from 0 to 2000. Then, for the next 100 months, the number of customers per month remains constant at around 2000'.

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

DOC
WORKSHEET
Using spreadsheets

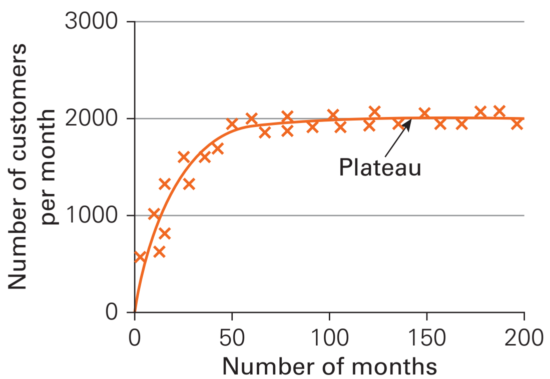

Figure 1.10 The total number of customers per month over 200 months

exponential
a growth or decline that becomes more rapid proportional to the growing number or size

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

The data in Figure 1.11 show an **exponential** increase. You would describe this by saying, 'For the first 10 hours, the number of bacteria increases slowly from 10 000 to 30 000. After 10 hours, the number of bacteria increases more rapidly'.

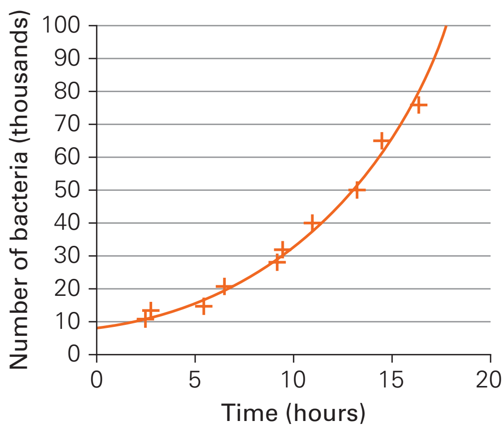

Figure 1.11 The effect of time on the number of bacteria

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

In Figure 1.12, the data do not show a clear pattern. There are seemingly random fluctuations over time. You should still highlight that the data points appear to be scattered or randomly distributed without a clear pattern or correlation.

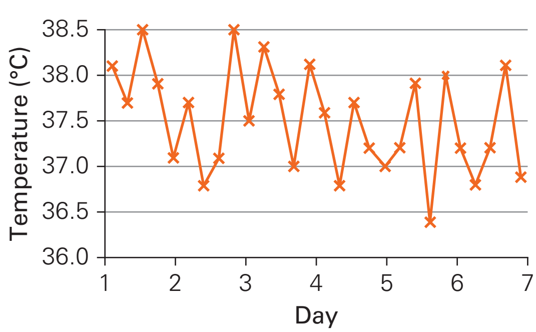

Figure 1.12 Temperature fluctuations over a seven-day period

Drawing a line of best fit

After plotting your data as points, you may notice a pattern or trend, such as lying more or less in a straight line or curve. To highlight this pattern, you can use a curve or line of best fit. While connecting every data point may suggest that there are no errors in the data, a line of best fit approximates the relationship between the two variables more accurately. Additionally, you can use the line of best fit to predict missing measurements. However, if you make predictions within the original data set, this is called **interpolation**, and it may be reliable in certain circumstances, but caution is advised. **Extrapolation**, or making predictions outside the original data set, is less reliable and should be approached with care.

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 averages 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 1.13.
- should not consider any outlier data points when averaging the data points.

Figure 1.13 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.

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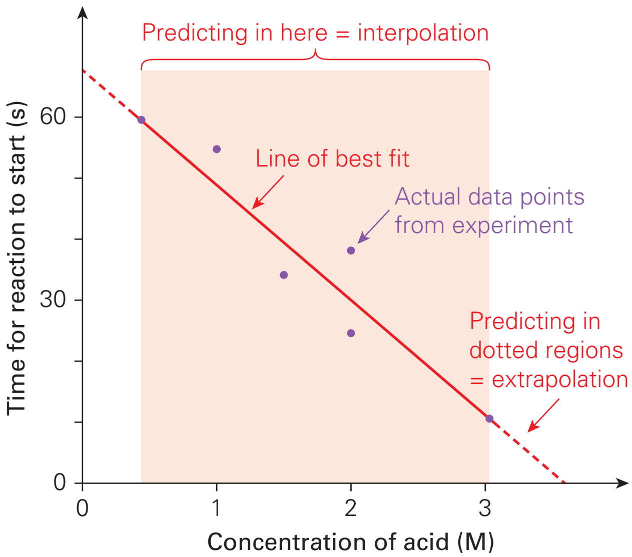

Figure 1.13 The effect of acid concentration on the time taken for a reaction to start

The line of best fit is not always a straight line. The graph in Figure 1.14 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.

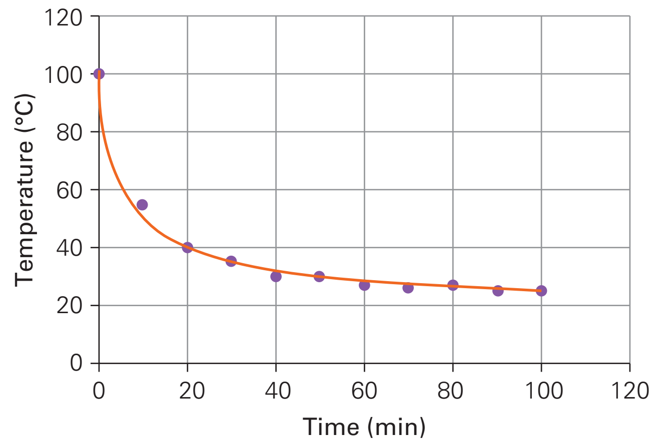

Figure 1.14 The effect of time on the temperature of 100 mL of water

Try this 1.4

Balloon popping

Be careful

Safety glasses must be worn for this practical.

Background information

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

Aim

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

Materials

- balloon
- string
- permanent marker
- ruler

Method

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

continued …

1.3 Evaluating and communicating causal relationships

Learning goals

1. To be able to distinguish between reliability and validity of experimental results.
2. To be able to construct a scientific conclusion using three key ideas.

WORKSHEET Evaluations and conclusions

It is important to note that identifying a trend in data points does not *prove* that one variable had caused another variable to change because there's always a possibility that the trend arose by chance. The data analysed might provide evidence; however, the results and method must be evaluated before making any conclusions or claims of causation! 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 to explain your results.

Evaluation

The evaluation section of your scientific report is where you describe any trends in your collected data, as observed in the analysis of a graph, for example. It is also a section of the report where you would outline any problems you faced during the experiment and offer suggestions for improvements or extensions to the method. This includes possible errors or mistakes encountered in experimentation.

Any suggested improvements should include the following information:

- a brief description of the problem encountered
- a description of how the problem affected the results
- a description of how you could improve the experimental method (e.g. use different equipment or change the order of the steps)
- an explanation of how this would improve the **reliability**, **validity**, **precision** and **accuracy**. Table 1.3 provides more detail on the difference between these four aspects.

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

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

precision
how close measurements repeated under the same conditions 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

Here is an example of how to approach an evaluation.

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

Step 1: Describe a problem that was encountered.

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

Step 2: Describe how the problem affected the results.

It was unclear whether the temperature was staying the same, so the students had to make a judgement about when the boiling point had been reached. This judgement could vary from person to person.

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	Reliability	Validity	Precision	Accuracy
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	The closeness of two or more measurements to each other	How close a measurement is to the correct value
How is it assessed?	By checking the consistency of results across time, across different observers and across parts of the test itself	Was only the independent variable changed and dependent variable measured? Were all variables that should have been controlled actually controlled?	Are the measurements similar every time?	Are the measurements close to a standard measurement?
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 may not be reliable if the conditions of the experiment are not consistently reproducible. A result is considered valid if it is both accurate and precise.	A measurement can be precise but not accurate.	A measurement can be accurate but not precise.

Table 1.3 The difference between reliability, validity, precision and accuracy

Step 3: Explain how it could be improved.

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

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

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

Figure 1.15 By using a pH meter instead of pH paper, more accurate and precise pH measurements can be made.

To finalise your evaluation, things you may consider:

- Did you identify all the variables that needed to be controlled? For example, was the concentration of salt the same each time (same mass of salt added to same volume of water)?
- Were all controlled variables actually controlled in the experiment?
- Were there any errors that are unavoidable in the experiment?

Next time the experiment takes place, it may be appropriate to modify the method. Any modifications should aim to improve the reliability and accuracy of the results. For instance, if the original method involved measuring the pH of a solution using pH paper, a modification could be made to use a pH meter instead. This change would be made because pH paper measurements may introduce errors due to colour interpretation and limited precision.

Another reason for modifying the method could be to address potential sources of error. For example, if the original method required a specific incubation time for a reaction, but it was found that the reaction did not proceed as expected within that time frame, the incubation time could be extended to allow for complete reaction. This modification is based on the recognition of an error in the original method and the need to ensure accurate data collection.

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Writing a conclusion

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

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

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

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

Lee conducted an experiment to see if taking his dog Max for more walks reduces the number of socks Max destroys.

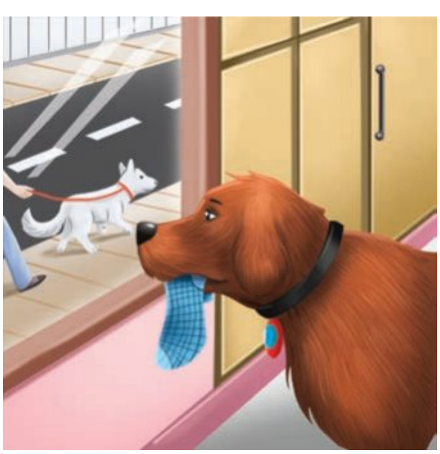
Lee's hypothesis was: 'If Max takes more walks per day, then Max will chew a smaller number of socks'.

Lee put his collected data into a graph and produced a line of best fit, shown in Figure 1.16.

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

Validating a conclusion

Comparing results with other groups or secondary sources is a valuable practice to assess the consistency of your findings. If there are discrepancies or conflicting results, the potential reasons behind them can be analysed, such as differences in methods, sample size or experimental conditions. Such conflicts may lead to further investigation or discussion to understand the underlying factors causing the variations. Sometimes, this comparison may produce additional questions that need to be explored to verify the validity of those claims.



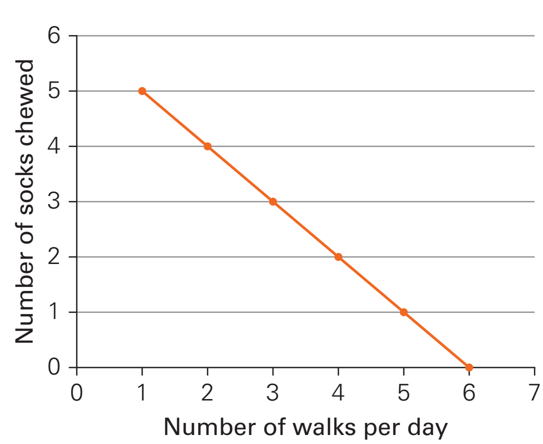


Figure 1.16 The effect of walks on the number of socks chewed

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Remember, when validating any conclusion, it is important to look for facts or ideas that have been taken for granted to be true. Discussing these assumptions with others helps determine if they are reasonable and supported by evidence. This process helps in developing a stronger understanding of the topic and promotes a more thorough examination of the evidence.

Try this 1.5

Writing a conclusion

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

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

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

1 Develop a conclusion based on Gen's results.
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.

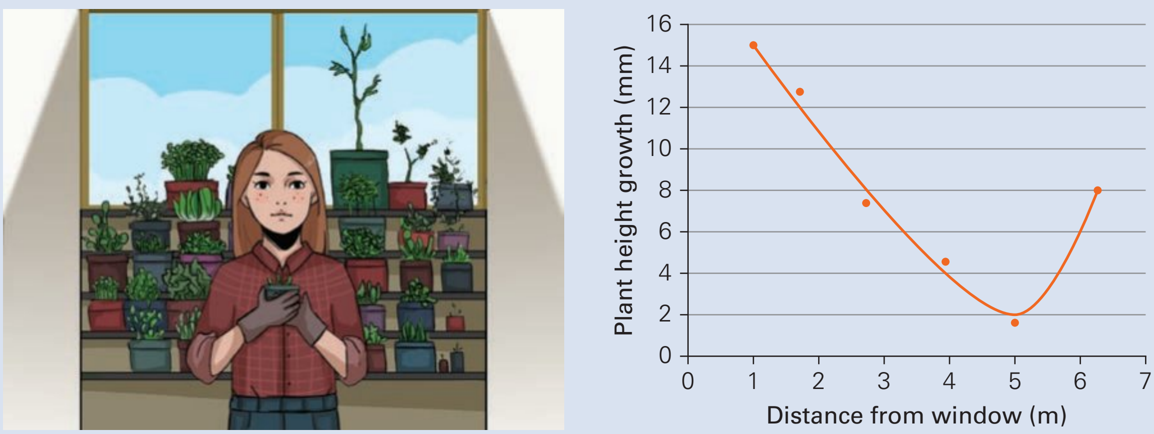

Figure 1.17 How the distance from a window affects plant height growth

Explore! 1.2

Science influencers

When communication of science is done well, scientists have the ability to enthuse and harness the curiosity of the general population. Effective communication can change the mindset of young people toward pursuing careers in the sciences.

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

- Doctor Karl Kruszelnicki
- Professor Lisa Harvey-Smith

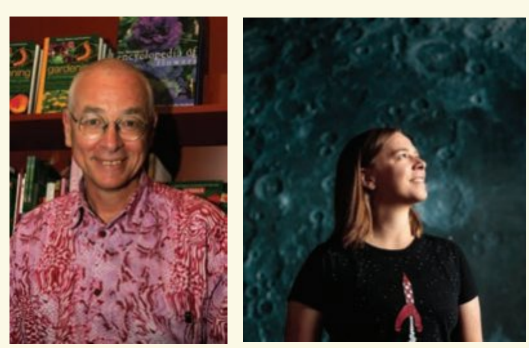

Figure 1.18 Science influencers, Doctor Karl Kruszelnicki (left) and Professor Lisa Harvey-Smith (right)

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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 Use Figure 1.19 to answer the following questions.

a **Identify** the general trend shown.

b **Consider** any potential errors that may be present in the data.

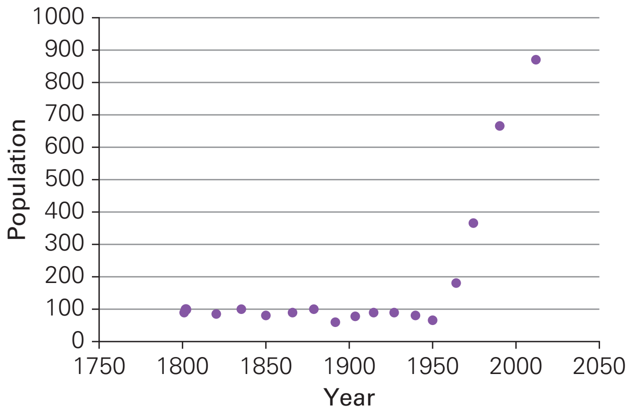

Figure 1.19 Change in population size over time

6 **Identify** the general trend in the graph shown in Figure 1.20.

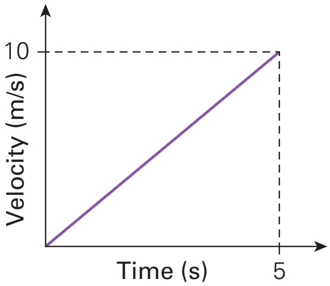

Figure 1.20 Change in velocity over time

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.

e **Evaluate** the data.

f **State** a conclusion for this data.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
1.1	I can define primary and secondary sources of information.	1	
1.1	I can write a scientific hypothesis, including independent and dependent variables.	2	
1.1	I can construct an experimental method.	8	
1.2	I can calculate the mean, median, mode and range of data.	3	
1.2	I can plot a line graph and a line of best fit.	9c	
1.2	I can identify trends present in graphed data.	7d	
1.3	I can distinguish between reliability and validity of experimental results.	5	
1.3	I can construct a scientific conclusion using three key ideas.	9d	

Review questions

SCORCHER

Retrieval

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 **Calculate** the mean, median, mode and range of the following data set: 11, 11, 11, 10, 9, 8, 8, 15

4 The CRAAP test assesses the quality of sources of information. **State** what the letters stand for.

5 **Define** the terms 'reliability' and 'validity'.

Comprehension

6 **Explain** what features a well-constructed graph should have.

7 Several students were timed on how long each spent on chapter review questions, and then the next exam score for each was recorded. The results were graphed and are shown in Figure 1.21.

- **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.

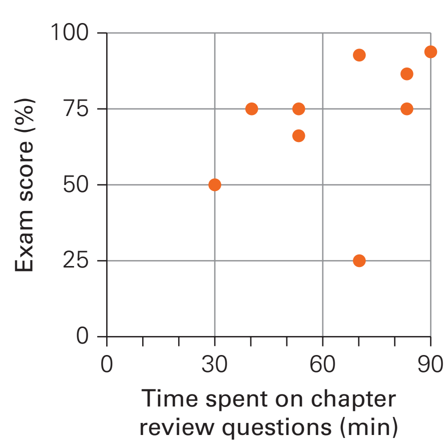

Figure 1.21 How time spent on chapter review questions affects exam scores

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Analysis

8 **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

Knowledge utilisation

9 Answer the following questions using Figure 1.22.
a **Determine** the masses of the two bandicoots captured after three 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 six months.
d **Propose** a reason why there appears to be a trend of increasing mass with time.

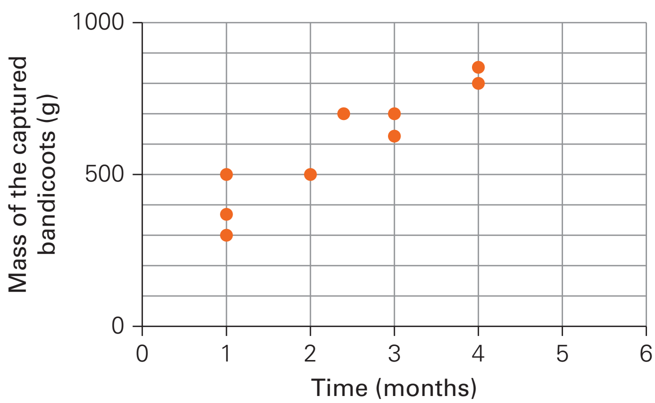
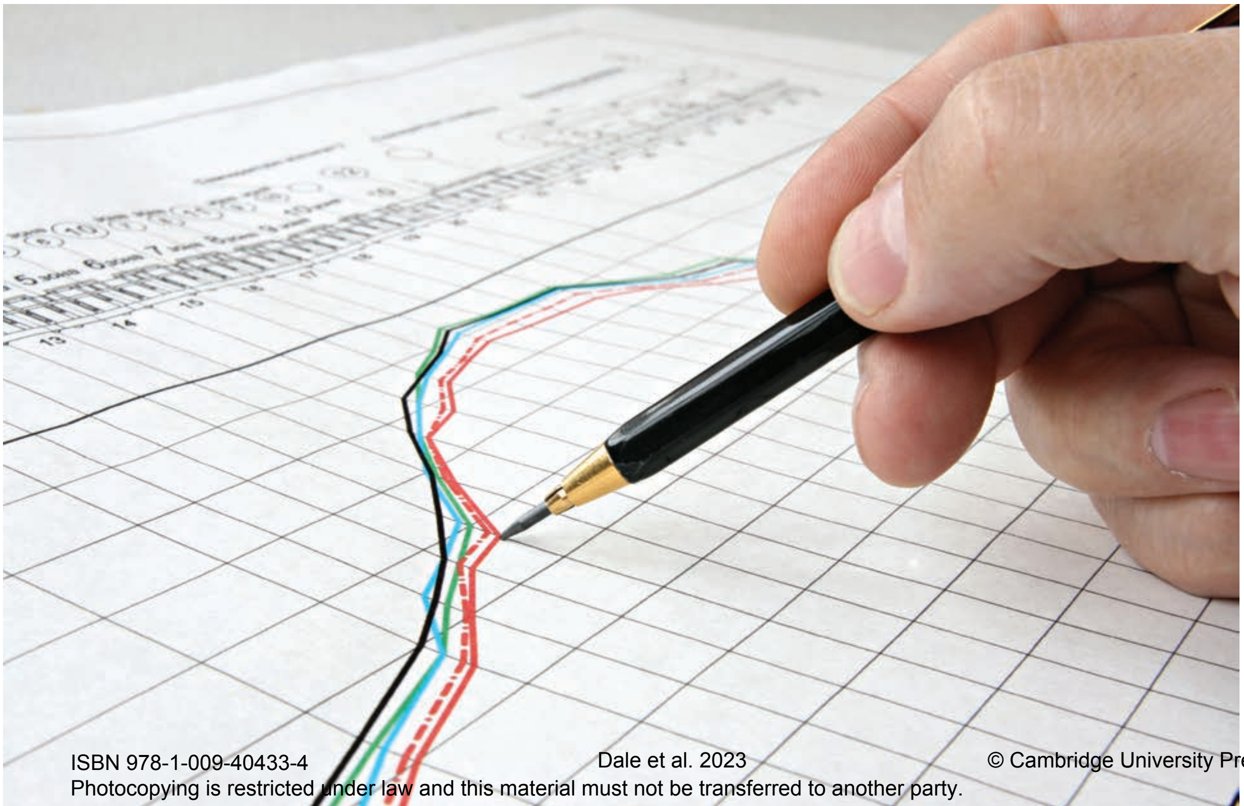


Figure 1.22 How time affects the mass of captured bandicoots



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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).

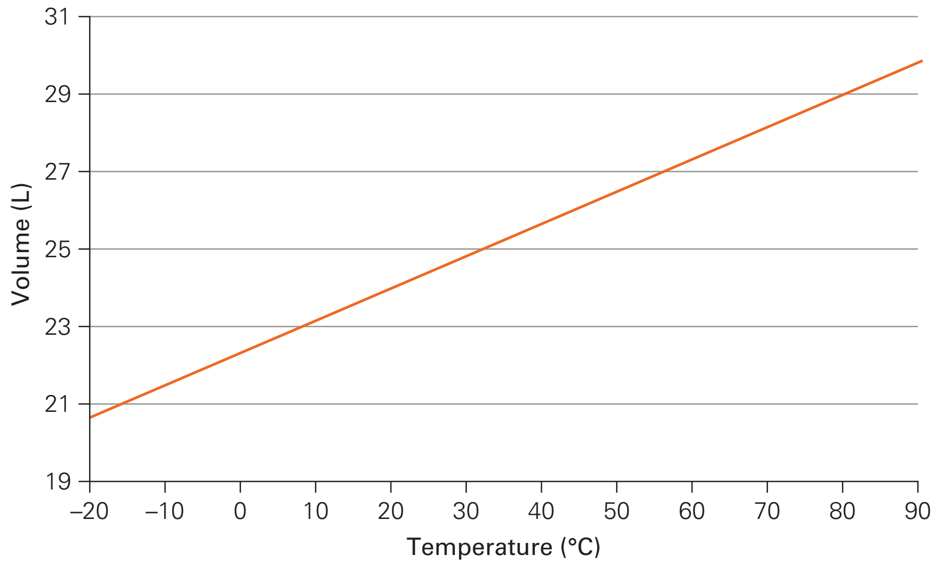

Figure 1.23 Variation of the volume of a gas at atmospheric pressure (P = 101 kPa), when temperature is changed

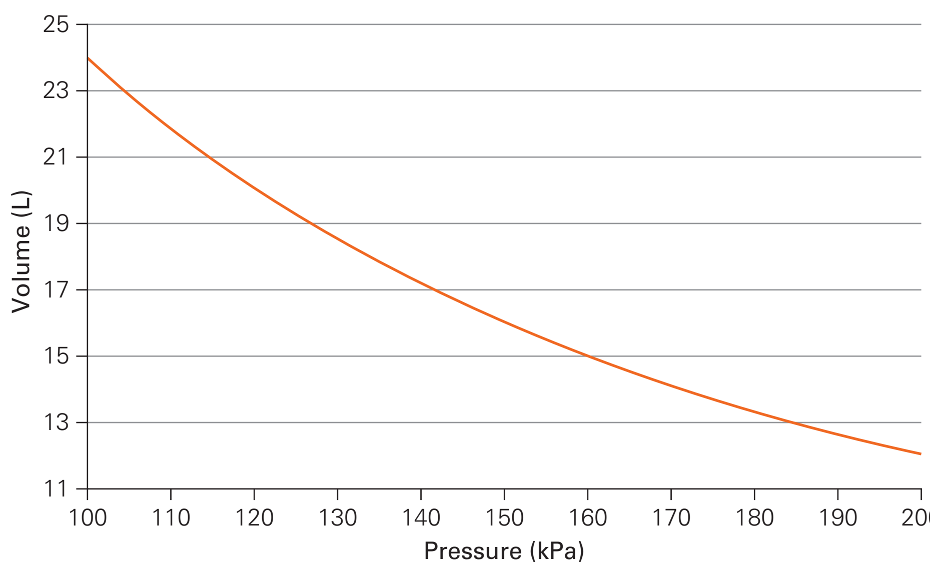

Figure 1.24 Variation of the volume of a gas at ambient temperature (T = 20°C), when pressure is changed

Apply

1 **Identify** the pressure exerted by a volume of 19 L of gas at 20°C, by referring to Figure 1.24.

2 **Identify** the dependent, independent or controlled character of each variable (volume, temperature, pressure) for the data presented in Figure 1.23.

3 **Identify** the volume occupied by a gas at 101 kPa pressure and a temperature of 10°C, by referring to Figure 1.23.

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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 1.23.

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 1.23, **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 1.23 and Figure 1.24 to **deduce** whether an increase in temperature at atmospheric pressure would affect the volume occupied by the gas.

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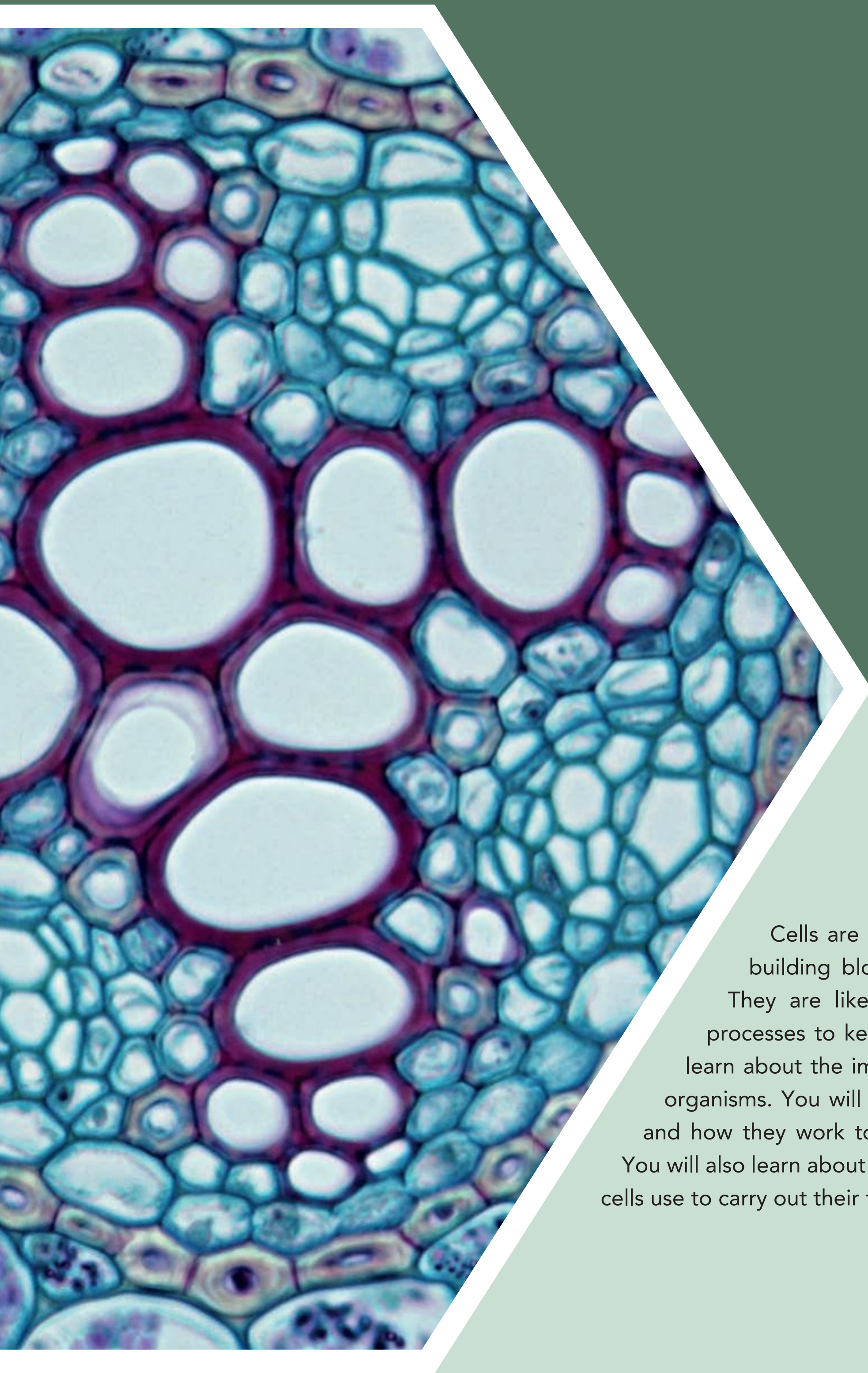
Chapter 2
Cells



Chapter introduction

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

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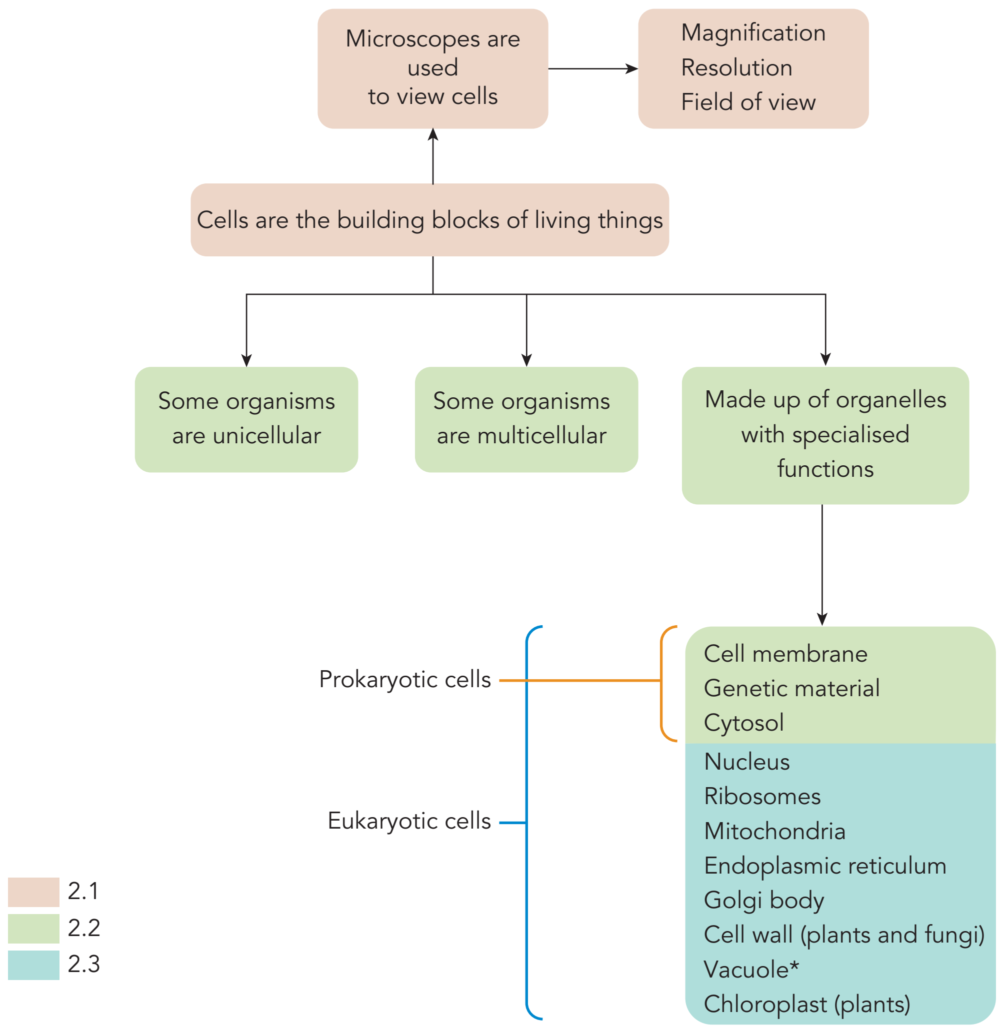
Concept map



*some bacterial, protist and animal cells have vacuoles

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Curriculum

Recognise cells as the basic units of living things, compare plant and animal cells, and describe the functions of specialised cell structures and organelles (AC9S8U01)	
considering how the invention of the microscope has contributed to understanding of cell structure	2.1
examining a variety of cells, including single-celled organisms, using a light microscope, a digital microscope, simulations and photomicrographs	2.1
identifying the structure and function of organelles in cells, including the nucleus, cell membrane, cell wall, cytoplasm, chloroplasts and vacuoles	2.2
exploring an augmented or virtual reality tour of a plant or animal to 'zoom in' and understand the scale of cells	2.3
comparing the similarities and differences of plant cells and animal cells visible with a light microscope and represented in a digital or physical model	2.2, 2.3
designing a physical or digital model of a cell and explaining how the representation models the cell	2.3, STEM activity

Glossary terms

Bacteria
Cell membrane
Cell wall
Chloroplast
Cytosol
Differentiation
Double helix
Embryo
Endoplasmic reticulum
Eukaryote
DNA
Golgi body
Macroscopic
Membrane-bound organelle
Microorganism
Microscopic
Mitochondrion
Multicellular
Nucleus
Organelle
Prokaryote
Protist
Ribosome
Specialised cells
Stem cell
Unicellular
Vacuole
Zygote

2.1 Microscopes and cells

Learning goals

1. To consider how the invention of the microscope has contributed to understanding of cell structure.
2. To be able to label the parts of a microscope.
3. To examine a variety of cells, including single-celled organisms, using a light microscope, a digital microscope, simulations and photomicrographs.

WORKSHEET
Parts of a microscope

The microscope

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

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

Did you know? 2.1

The discovery of microorganisms

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

Figure 2.1 Van Leeuwenhoek viewing what he called animalcules

VIDEO
Leeuwenhoek and his simple microscope

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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.

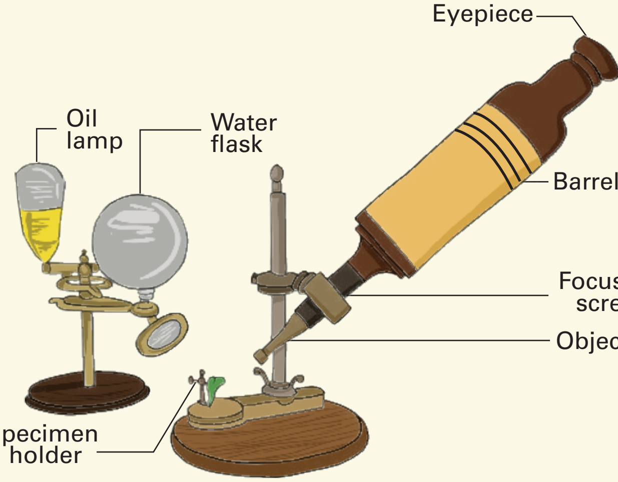

Figure 2.2 The Hooke microscope (circa 1660)

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

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 in Figure 2.3 is for use with one eye. Binocular microscopes can be used with both eyes.

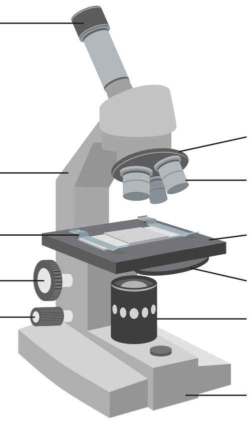

Figure 2.3 The parts of a monocular microscope

Try this 2.1

Parts of the microscope

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

Microscope terms

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

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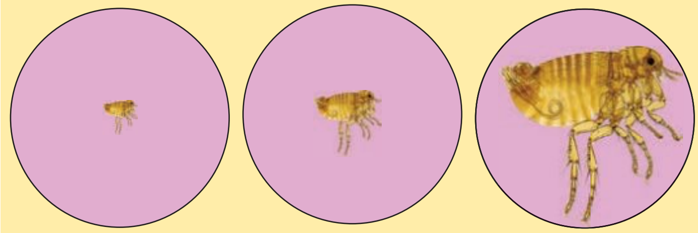
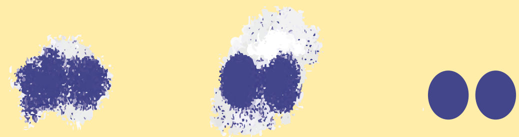
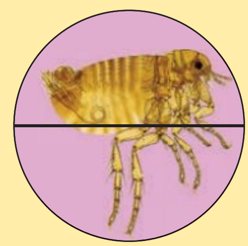
Term	Definition	Image
Magnification	How much the image of the specimen or object is increased in size (i.e. how much you are zooming in)	 Low magnification · Medium magnification · High magnification
Resolution	How detailed and clear the image is (i.e. how easy it is to tell two separate objects apart)	 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

Binocular microscopes have an eyepiece for each eye. There are two types: compound binocular and stereoscopic. Compound 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. There are also trinocular microscopes that have an additional eyepiece that a camera can be attached to.

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 detail.

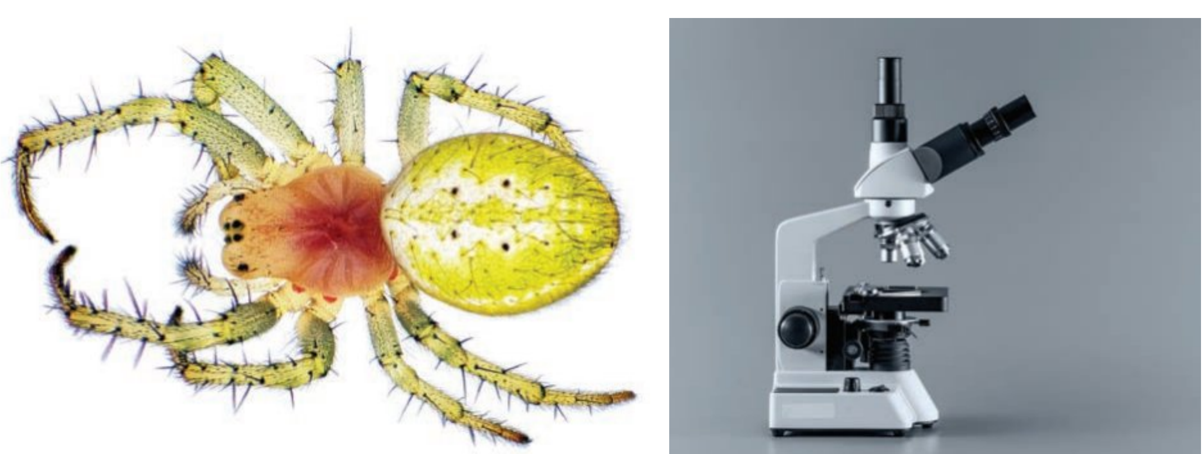


Figure 2.4 An image of a cucumber green spider (left) taken with a camera mounted on a trinocular microscope (right)

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Figure 2.5 Light microscope images taken of the heads of a caterpillar, ant and beetle

VIDEO
Electron microscope

Advances in technology

To observe 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 because images are created from electrons transmitted (passing) through the specimen.
- scanning electron microscope (SEM) – The specimen to be viewed is not sliced, and the external surface can be viewed. Images are created from reflected electrons.

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

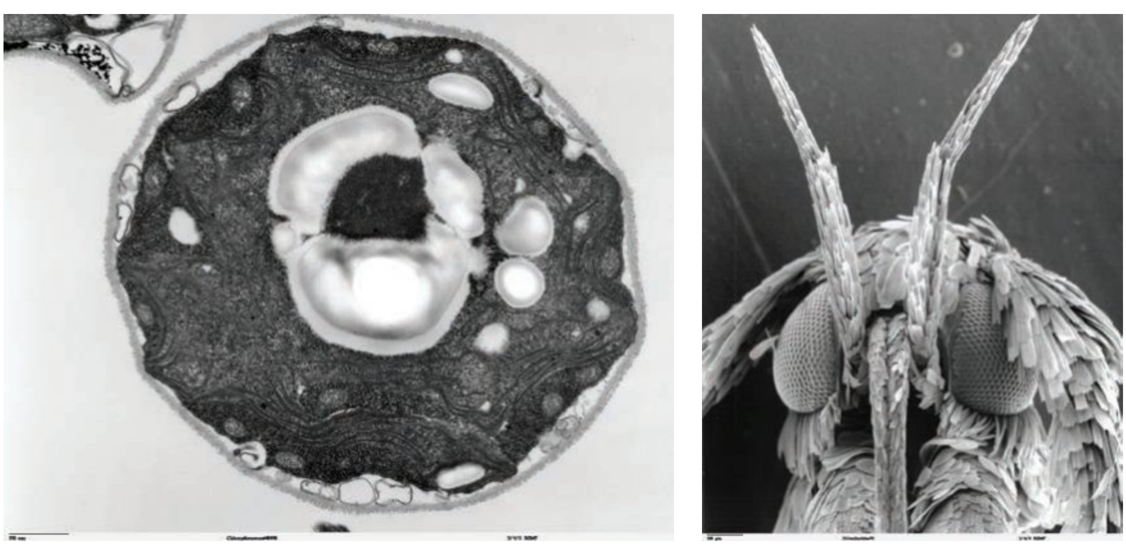

Figure 2.6 Examples of a green algal cell as seen through a TEM (left) and moth head through an SEM (right)

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Explore! 2.2

Types of microscopes

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

Copy and complete the following table.

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

Quick check 2.1

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

Making thinking visible 2.1

See, feel, think, wonder

The following images have been produced from an SEM.

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

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

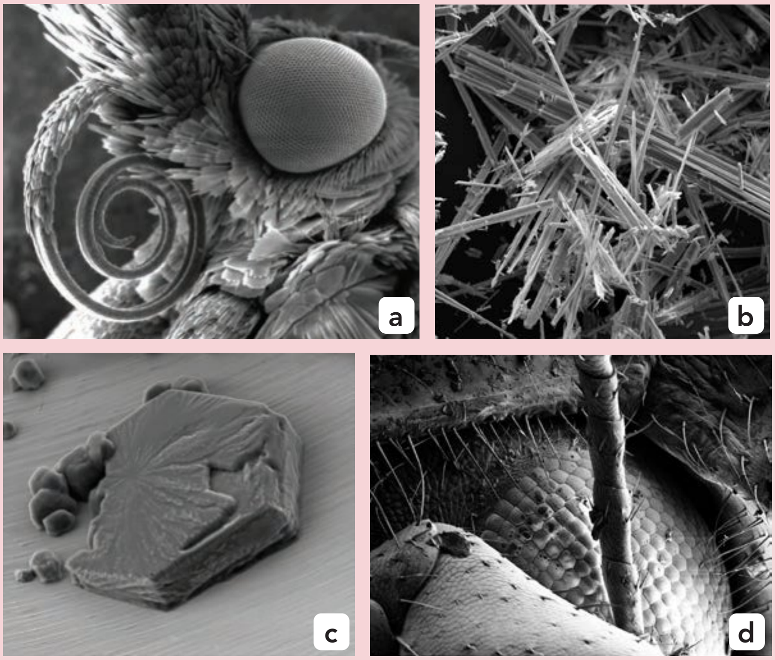

Figure 2.7 a) Head of a moth b) Asbestos c) Partially melted ice crystal d) Ladybird eye

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Science as a human endeavour 2.1

Smartphone disease detection

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

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

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

Practical skills 2.1

Using a microscope

Aim

To become proficient in using a microscope

Materials

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

Be careful

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

Method

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. 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 $10 \times 4 = 40\times$.
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.

continued…

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...continued

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.

Cell theory

Cells are extremely small, and most cells cannot be seen with the naked eye. They are described as being microscopic. It wasn't until 1965, when Robert Hooke built a compound microscope that lit up the specimen he was viewing, that we even knew cells existed. Because of his improvement of the microscope, he was able to observe that a dead cork plant appeared to be made of small blocks. He named these blocks 'cells' because they looked like the small identical 'cells' that monks lived in at the time.

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

This first cell theory stated that:

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

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

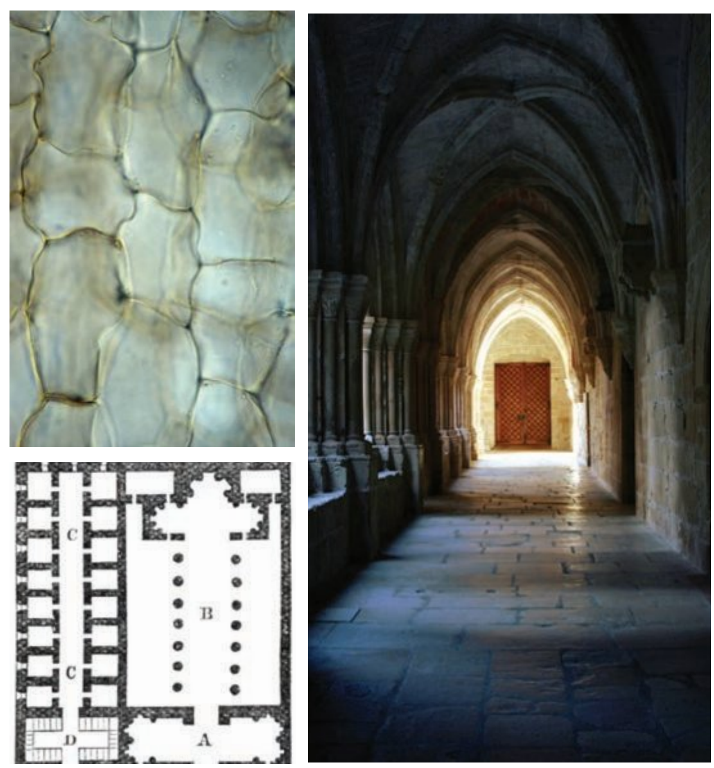

Figure 2.8 The cork cells (top left) Hooke observed looked like the monks' cells in the building plans (bottom left) of monasteries (right)

- 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.

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Did you know? 2.2

Egg cells

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

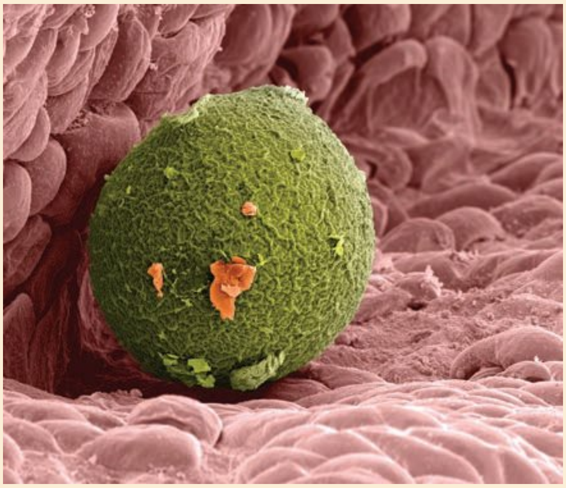

Figure 2.9 A human ovum in the fallopian tube. Ova are 'macro' cells. Macro means 'large-scale', and so they can be seen with the naked eye – that is, without a microscope.

Quick check 2.2

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

Did you know? 2.3

Skin

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

Try this 2.2

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).

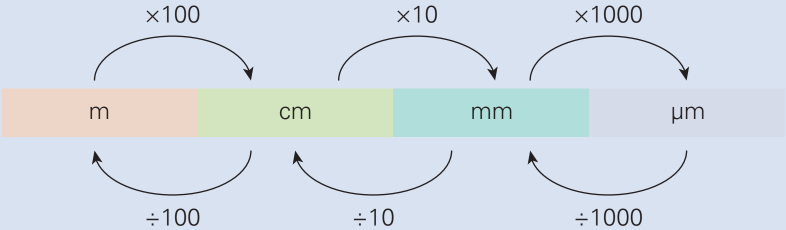

Figure 2.10 Conversions needed for different measurements

continued…

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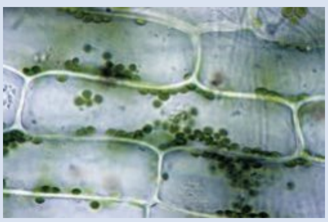
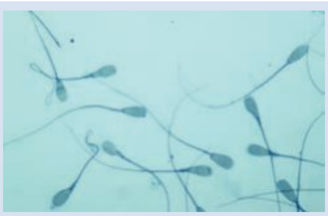
…continued

Using Figure 2.10, convert the cell sizes below into millimetres (mm) or micrometres (μm).

Cell type	Size (mm)	Size (μm)
 **Figure 2.11** Red blood cells	0.0065	
 **Figure 2.12** Plant cells on leaf surface		100
 **Figure 2.13** Sperm cells	0.05	

Section 2.1 questions

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	

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.

QUIZ

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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 advantages of using:

a a monocular light microscope

b a stereo light microscope

10 **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

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

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

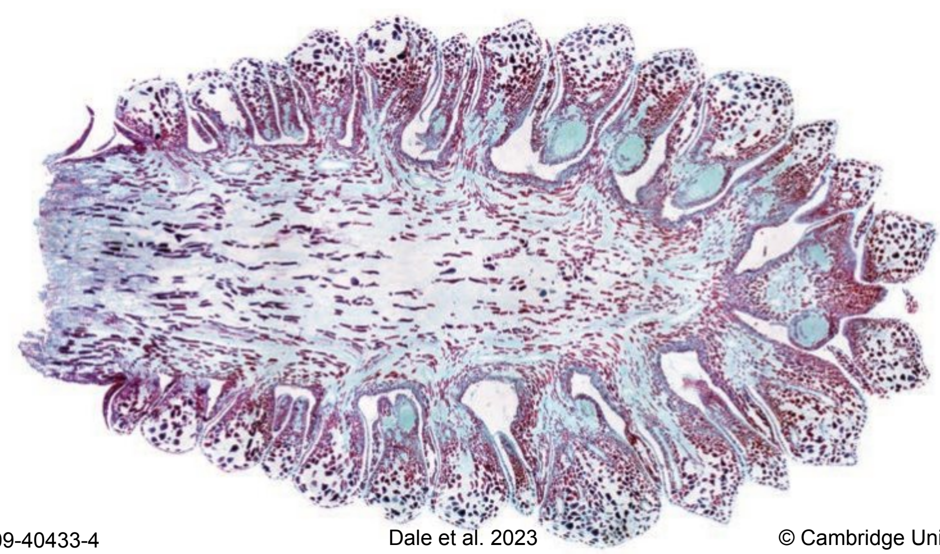
plant cell (100 μm)
frog egg (1 mm)
red blood cell (7 μm)
phytoplankton (2 μm)
chicken egg (50 mm)
virus (35 nm)
bacterium (1 μm)

Knowledge utilisation

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

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

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



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2.2 Organelles

Learning goals

1. To distinguish between prokaryotic and eukaryotic cells.
2. To identify the structure and function of organelles in cells.

WORKSHEET
Cell types and structure

What do all cells have in common?

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 the cells of multicellular organisms are specialised and much more complex.

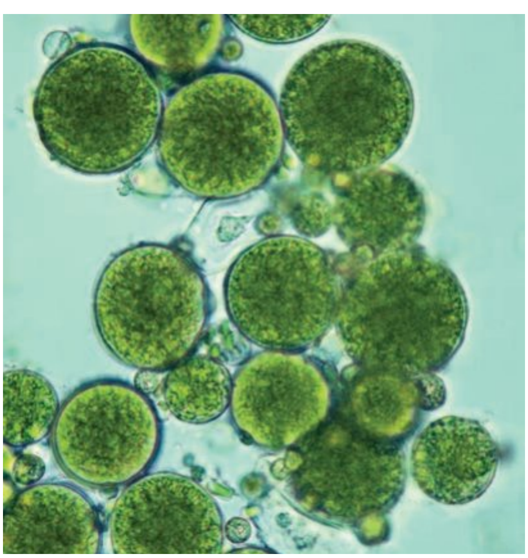

Figure 2.14 Unicellular algae

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

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

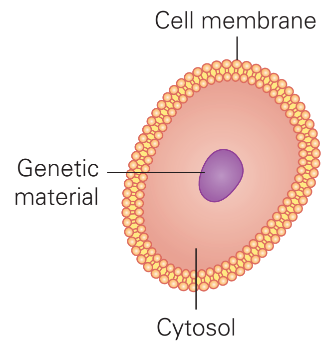

Figure 2.15 All cells, no matter how simple or complex, contain these three components.

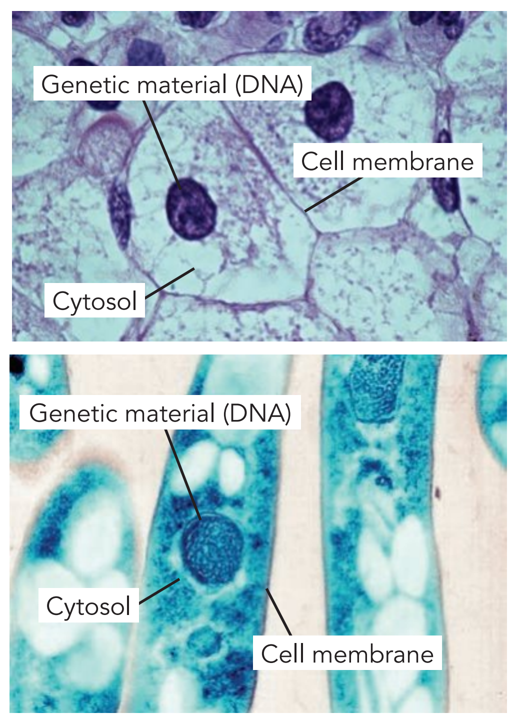

Figure 2.16 Top: Human liver cells. Bottom: *Bacillus anthracis* bacteria, which are unicellular organisms

Quick check 2.3

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

multicellular
made of many cells

unicellular
made of just one cell

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

DNA
the material containing the code that allows 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; many chemical processes that happen within a cell occur in the cytosol

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VIDEO
Cells of living things

prokaryote
a unicellular organism that lacks membrane-bound organelles and a nucleus

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

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

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

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

Simple and complex cells

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 eukaryotes are animals, plants, fungi and protists. The two categories of cell type are based on the structures found inside the cell. All cells have a membrane, cytosol and genetic material, but eukaryotic cells are more complex and also have many **membrane-bound organelles**, including a nucleus, that carry out specific functions. Prokaryotic cells do not have a nucleus or any membrane-bound structures.

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

Try this 2.3

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

Explore! 2.3

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

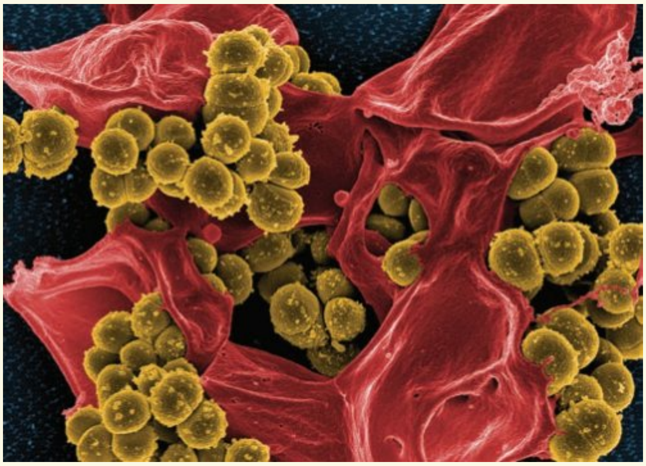

Figure 2.17 Methicillin-resistant *Staphylococcus aureus* bacteria (coloured yellow) and a dead white blood cell (coloured red)

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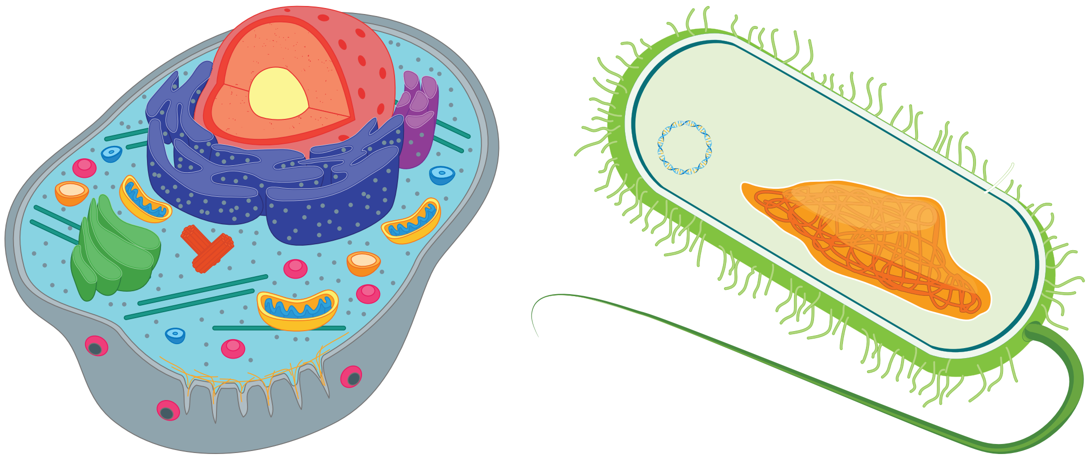

Figure 2.18 3D representations of a eukaryotic cell (left) versus prokaryotic cell (right). Can you identify the cell membrane, genetic material and cytosol in each cell type?

Try this 2.4

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

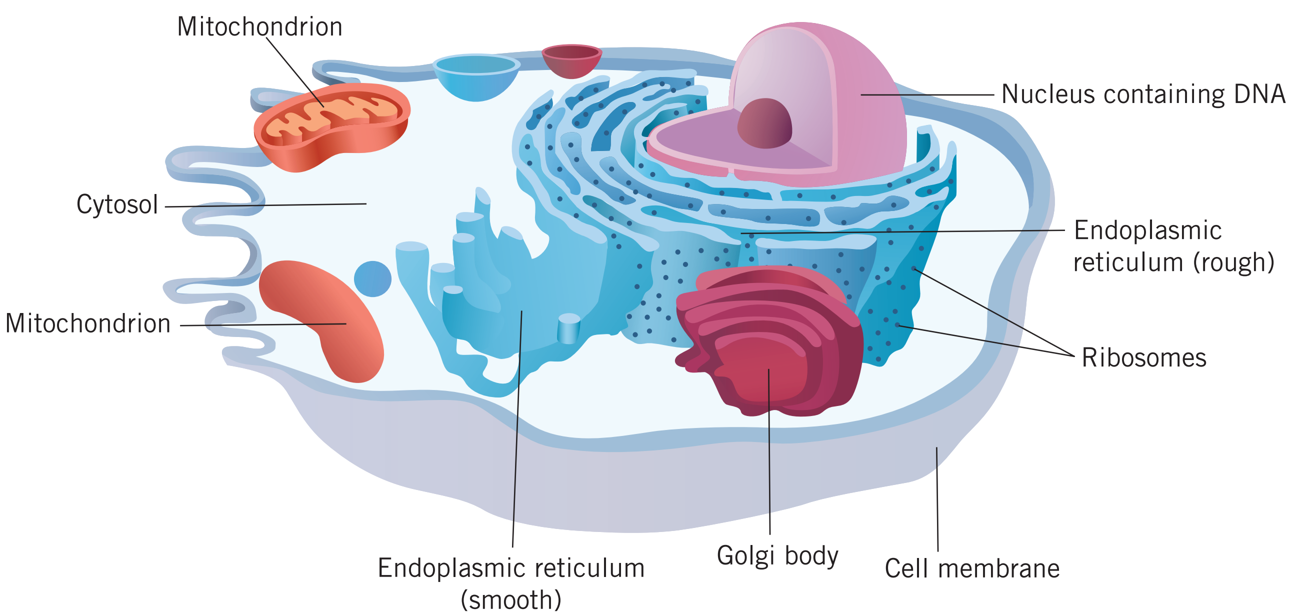

Figure 2.19 A eukaryotic cell with labelled organelles

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nucleus
part of a cell that contains the genetic material

Nucleus

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

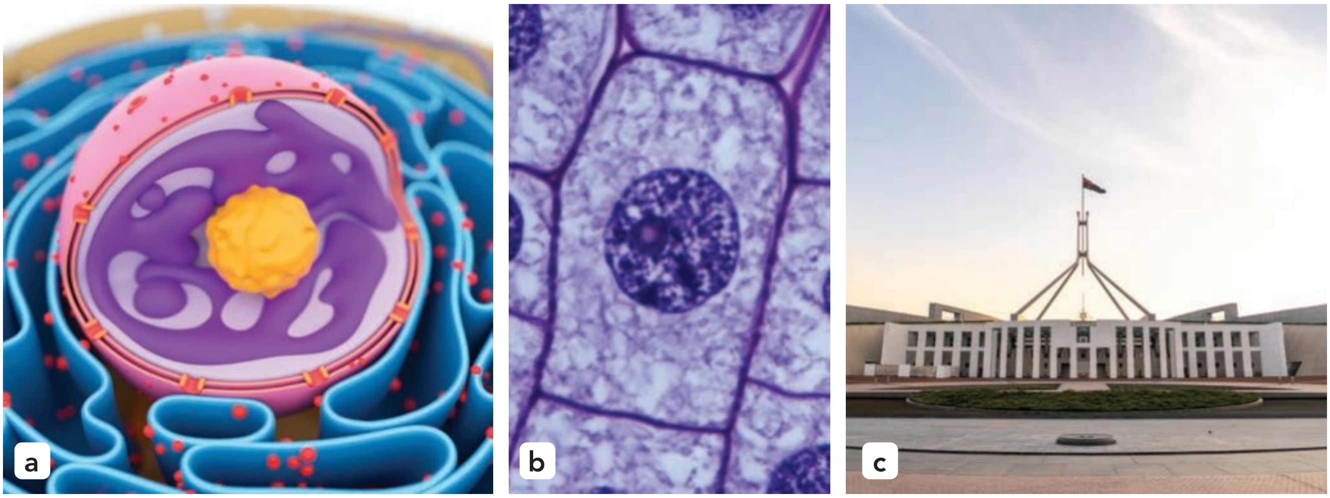

Figure 2.20 **a)** Graphic representation of a nucleus. **b)** An electron microscope image of a nucleus within a plant cell. **c)** Parliament House, Canberra. The nucleus makes all the major decisions for the cell city.

Did you know? 2.4

Missing nucleus

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

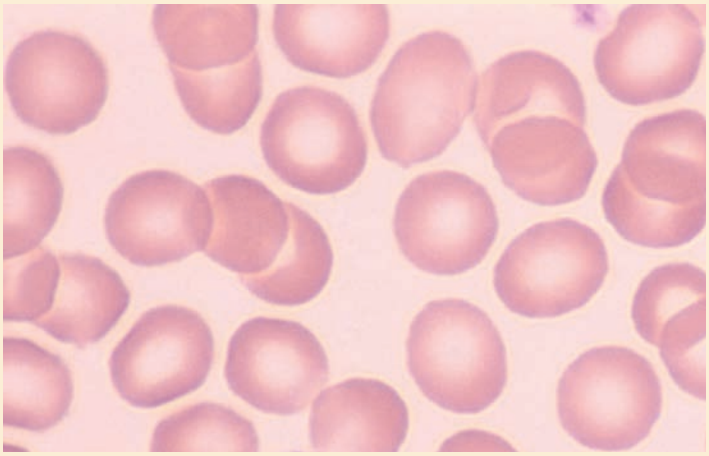

Figure 2.21 Red blood cells lack a nucleus.

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Genetic material

The genetic material found in the nucleus is called deoxyribonucleic acid (DNA). 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 laws that the government (the nucleus) uses to keep everything running smoothly.

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

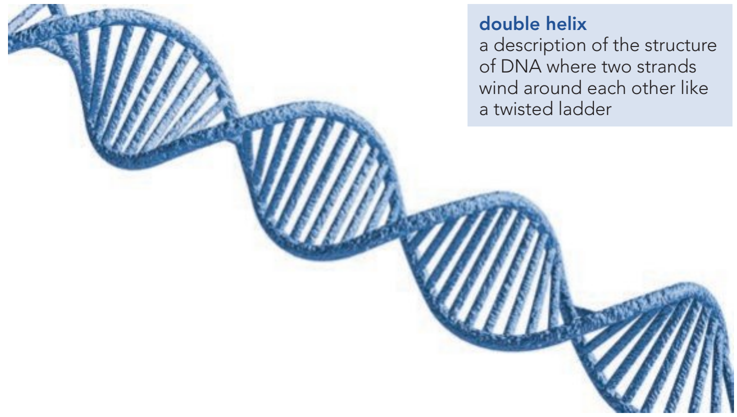

Figure 2.22 Graphic representation of a DNA molecule

Did you know? 2.5

The Moon and back

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

Cell membrane

The cell membrane is a thin double layer that separates the inside of the cell from its external environment. It contains molecules such as fats and proteins that play a role in checking what passes through the membrane. The cell membrane is like a border checkpoint of the cell city, controlling who enters and leaves.

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

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Cytosol

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

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

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

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

Ribosomes

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

Mitochondria

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

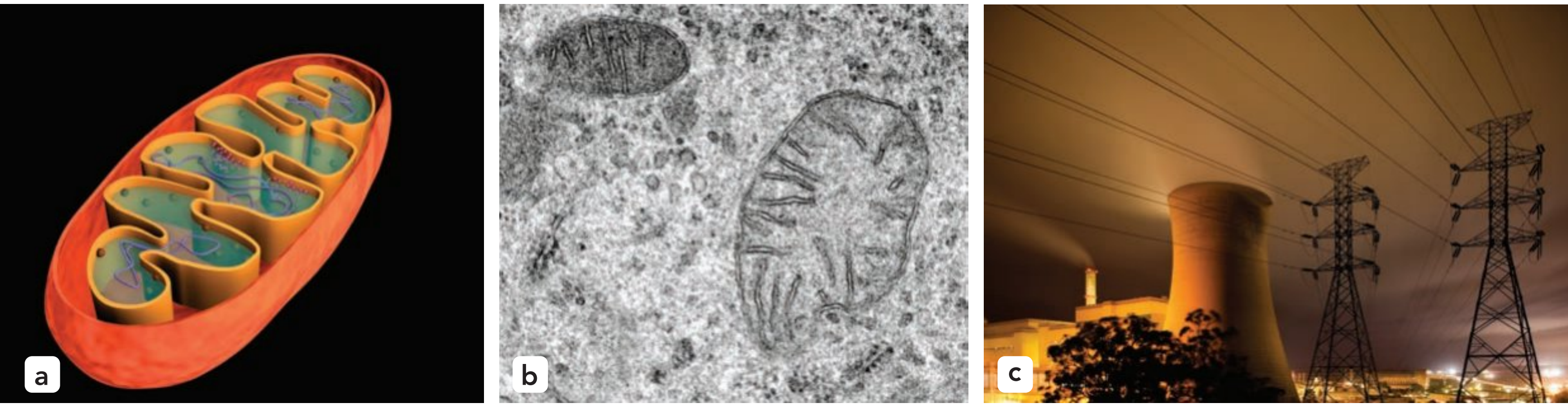

Figure 2.24 a) Graphical representation of the inside of a mitochondrion. **b)** An electron microscope image of mitochondria. **c)** The mitochondria produce energy from food, much like power stations can produce electricity from coal.

Endoplasmic reticulum

The **endoplasmic reticulum** (ER) is a folded membrane attached to the nucleus. The name 'endoplasmic reticulum' is a description of what it does: *endo* (inside), *plasmic* (cytoplasm), *reticulum* (network). There are two types of ER in the cell.

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

The rough ER is where ribosomes are attached, and it is involved in the building and transport of proteins. If no ribosomes are attached, then it is smooth ER, which is involved in the making of carbohydrates and fats. The ER is like a highway that produces, connects and delivers substances to different parts of the cell.

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

Golgi body

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

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

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

Try this 2.5

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.

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Quick check 2.4

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

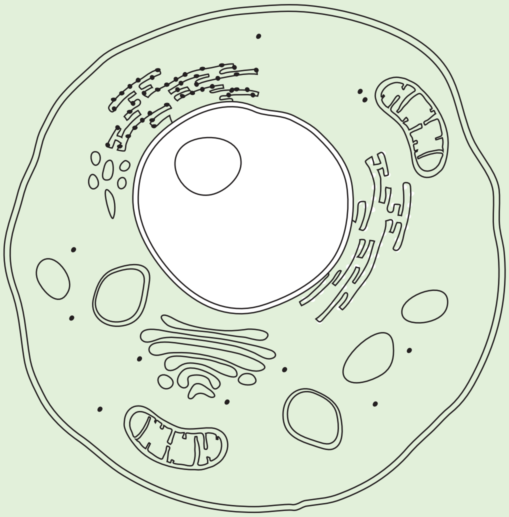

Figure 2.27 Diagram of a eukaryotic cell

Explore! 2.4

The cell's internal scaffolding

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

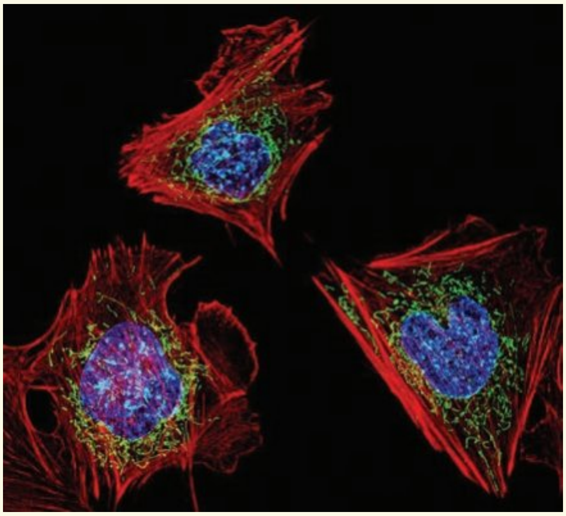

Figure 2.28 Mouse connective tissue cells. DNA in the nucleus is shown in blue, mitochondria are green, and the cytoskeleton is red.

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Science as a human endeavour 2.2

Discovery of a new cell organelle

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

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

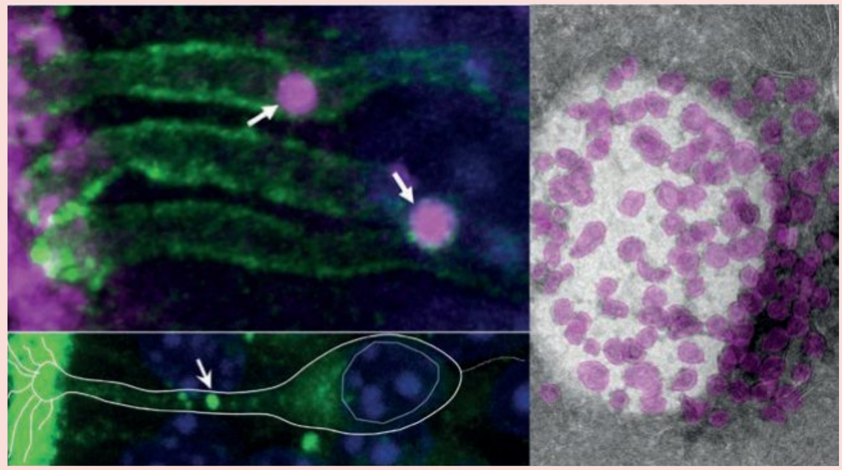

Figure 2.29 The silhouette of an olfactory nerve cell with transducosomes shown with arrows (left). A magnified image of the release of transduction proteins from a transducosome (right).

Section 2.2 questions

QUIZ

Retrieval

1 **State** three organelles found in all cells.

2 **State** three organelles found only in eukaryotic cells.

3 **Identify** the correct organelle from the description.

  a produces energy for cells

  b a barrier between the inside and the outside of cells that controls what enters and leaves

  c a water-based mixture that fills the cell, and where many chemical processes happen

  d makes proteins using the instructions provided by the genetic material of the cell

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 roles 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.

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2.3 Eukaryotic cells

DOC WORKSHEET Plant and animal cells

VIDEO Eukaryotic cells

Learning goals

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

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

Figure 2.30 Plants, animals and fungi living together

Animal cells

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

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

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

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

zygote
a fertilised egg cell

differentiation
the process by which stem cells become specialised

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

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

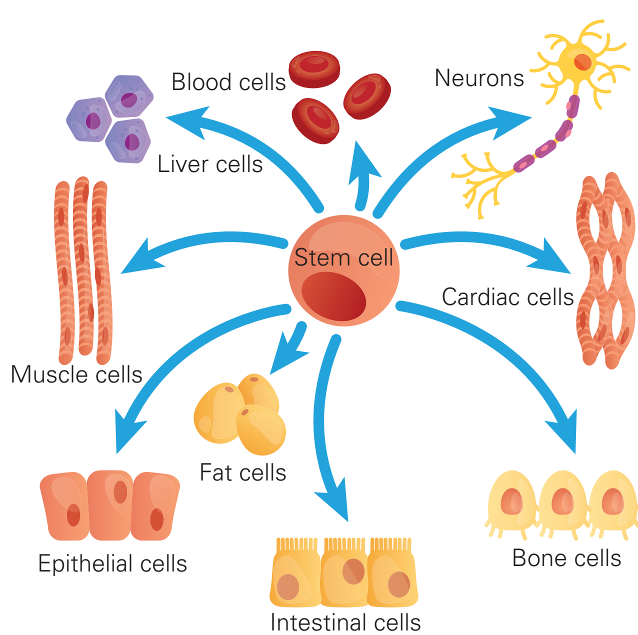

Figure 2.31 Embryonic stem cells can become many types of cells in a process known as cell differentiation.

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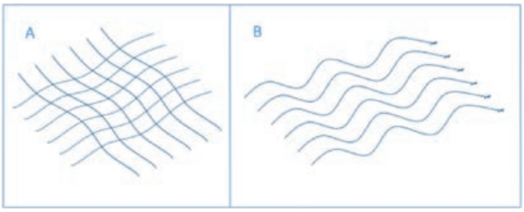
Stem cells don't only exist in embryos. There are still some stem cells in your body today that are ready to turn into any type of cell you need. They can be found in different tissues around your body and are activated by certain triggers, such as an injury. For example, if you cut yourself, stem cells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

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



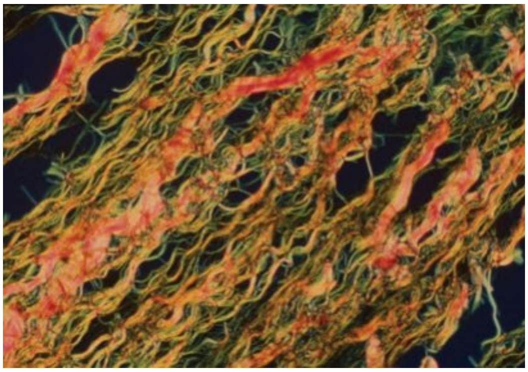


Figure 2.32 Top: collagen fibre structure in normal tissue (A) and scar tissue (B). Bottom: micrograph of collagen fibres in scar tissue

Explore! 2.5

Stem cell therapy

Because stem cells can 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.

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

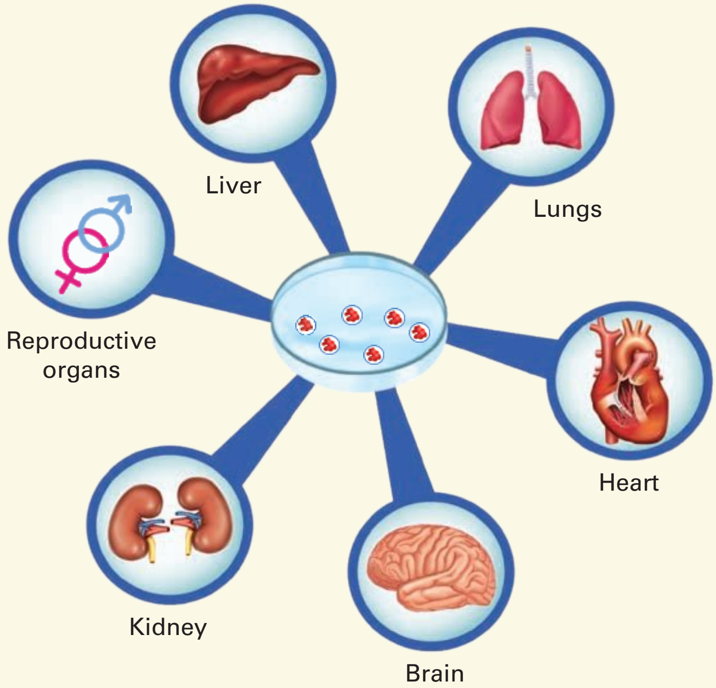


Figure 2.33 A stem cell can replicate and become any one of the 200-plus types of cells in the body.

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Explore! 2.6

Growing synthetic organisms

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

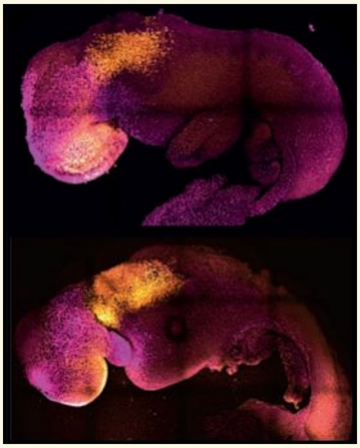

Figure 2.34 A naturally formed mouse embryo (top) compared with a synthetic embryo grown using stem cells (bottom)

Quick check 2.5

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

Plant cells

Plants are different from all other eukaryotic organisms in many ways. Most noticeably, they can make their own food in a 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

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

Chloroplasts contain a green pigment called *chlorophyll*, which captures the Sun's light. It is because of this pigment in chloroplasts that plants appear green.

Chloroplasts are found in plant cells that are exposed to light (e.g. leaf cells) but not in cells of the roots.

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*.

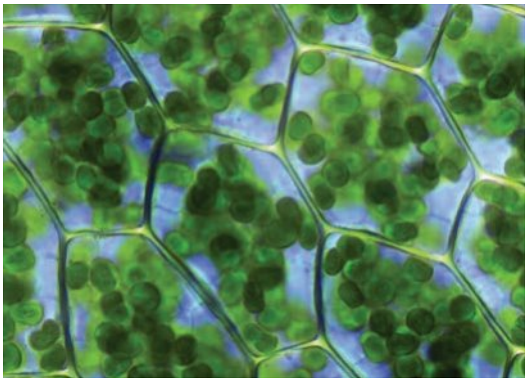

Figure 2.35 Plant cells; the green blobs are chloroplasts. Also note the thick cell wall that surrounds each cell.

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Figure 2.36 Eucalyptus trees grow as tall as they do because of the rigid cell wall that surrounds each of their cells.

Plant cells also contain an organelle called a **vacuole**. This organelle stores water and other nutrients for the plant. It also works with the cell wall to help support the plant and give it shape. If you have ever forgotten to water your plants at home, you might have noticed that they droop and wilt, becoming floppy, and if not watered they will start to die. This is because the vacuoles in each cell lose so much water that the cells become flaccid, and so the plant cannot hold its shape.

Try this 2.6

Cell exploration

Use the internet to find a free online interactive 3D model that will allow you to understand the scale and scope of cells. You may want to consider *the Cell Explorer* by SCoPE or *Cell Size and Scale* by Learn.Genetics.

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.

vacuole
a structure in a cell that stores water and nutrients

Figure 2.37 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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WIDGET
Eukaryotic organelles

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.

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

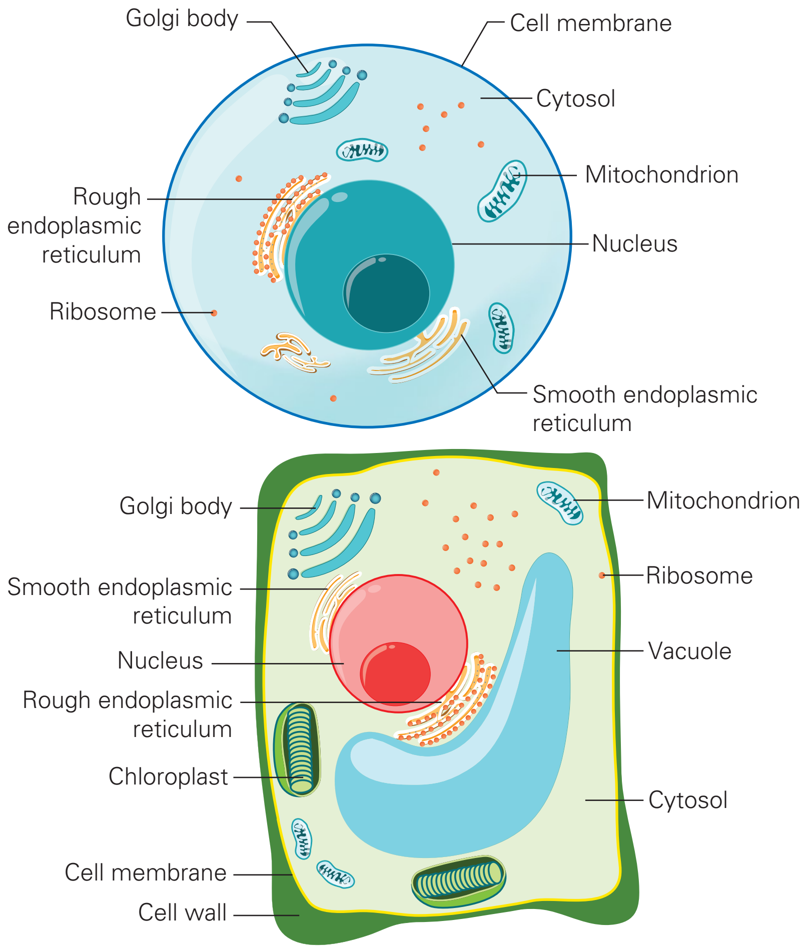

Figure 2.38 Animal cell (top) and plant cell (bottom) showing the major structures and organelles

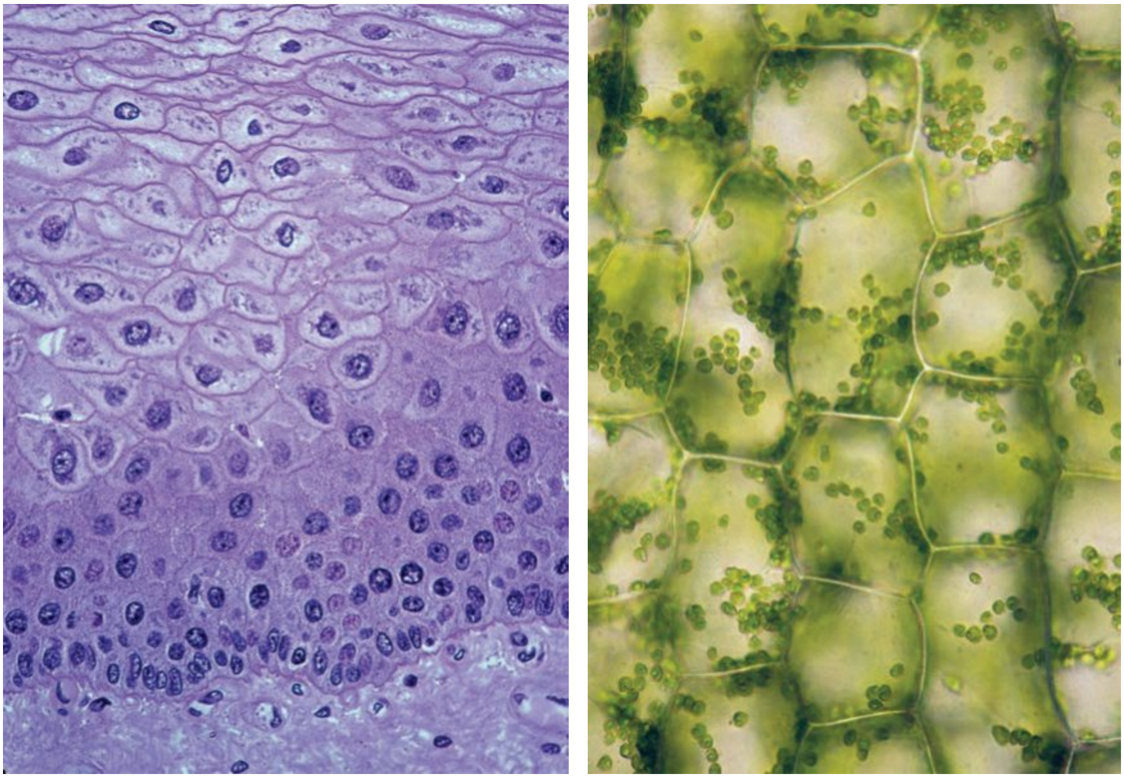

Figure 2.39 Animal (oesophagus) cells at 100× magnification (left). Plant cells at 100× magnification (right)

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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 the organelles named in Question **1**.

Try this 2.7

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 2.40. 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.

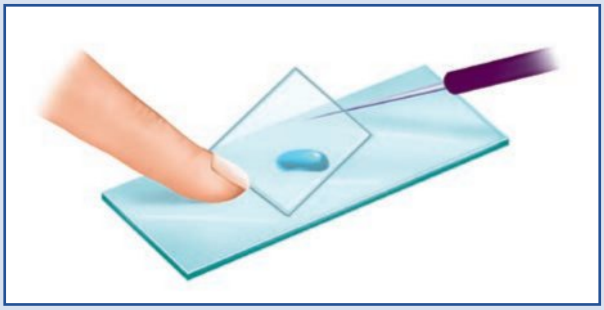
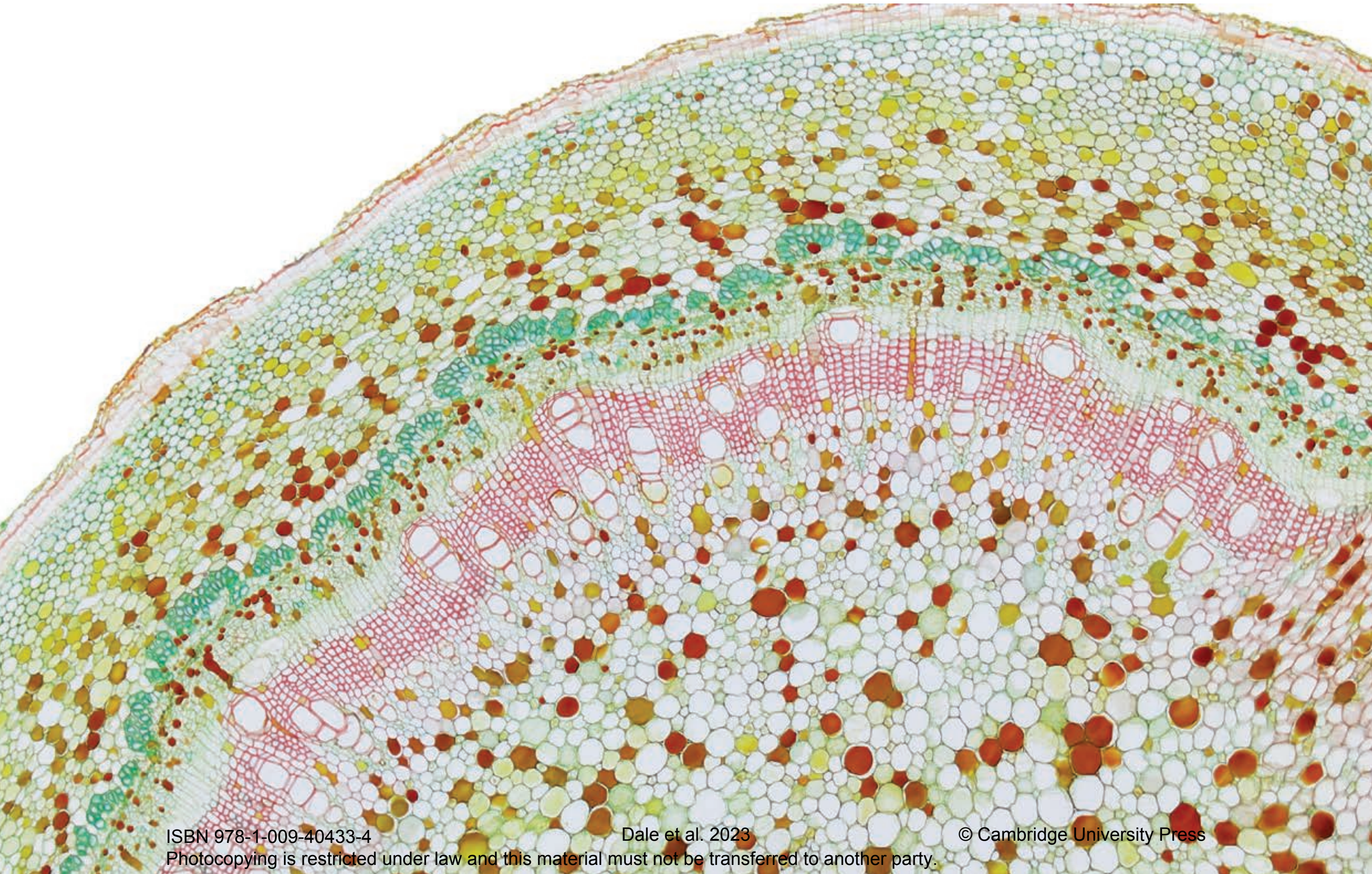


Figure 2.40 Lowering the cover slip slowly is very important when preparing a wet mount.

After laying the cover slip down, use a tissue or blotting paper on the edge of the cover slip to soak up any extra liquid.

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



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Practical skills 2.2

Observing cells under a microscope

Aim

To observe the characteristics of plant and animal cells

Materials

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

Be careful

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

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 your first slide on the stage and focus using the coarse focus knob. Once focused, turn to the next objective lens. Use only the fine focus knob to focus now. 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 of the drawing, 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. Are the plant and animal cells all the same size? If there are differences, can you explain why?

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Try this 2.8

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.

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Fungi

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

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

Did you know? 2.6

Fungi and beetles

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

Figure 2.41 Beetle exoskeletons and fungal cell walls are made of the same substance: chitin.

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

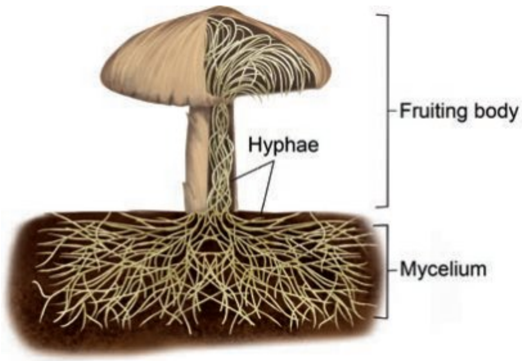

Figure 2.42 Diagram of a fungus

Figure 2.43 Fungi: toadstool (top), chanterelle mushrooms (middle), puffball (bottom)

Quick check 2.7

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

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Investigation 2.1

Fungi-fighting bacteria

Be careful

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

Background information

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

Aim

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

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

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 a separate quadrant and label the agar plate lid. Ensure the drops of different dilutions do not touch each other, as they may mix together and affect your results.
4. Allow time for the drops to be fully absorbed into the agar.
5. Cover the agar plate with the lid and with two to four 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 fungal 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.

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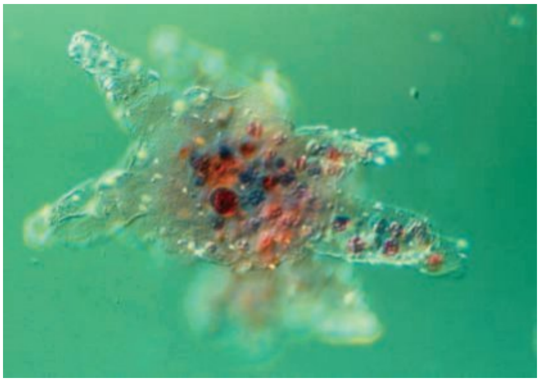
Protists

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* and *Amoeba*. Each of these types of protists is slightly different in structure, depending on its function.

protist
a eukaryotic organism that is part of the kingdom Protista



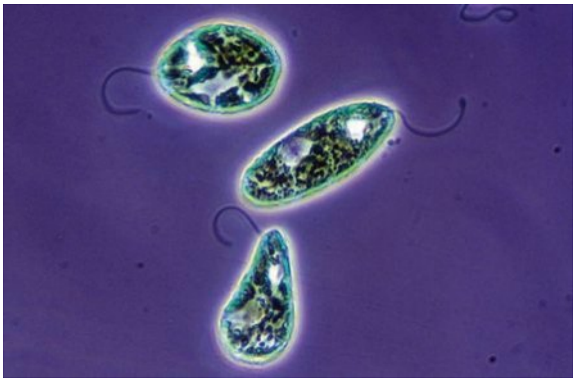


Figure 2.44 Protists: *Amoeba* (left); *Euglena* (right)

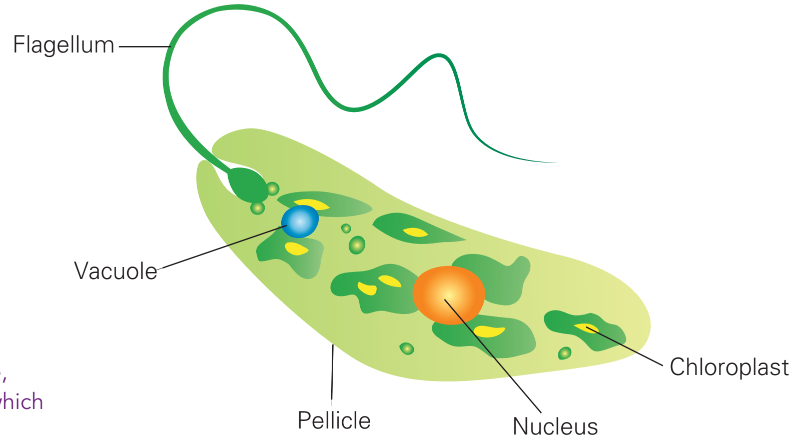


Figure 2.45 *Euglena* have chloroplasts, which are typically considered a plant cell organelle, but they also have a flagellum, which is more typical of an animal cell.

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** two examples of protists.
4 **Define** the term 'specialised cells' and provide examples.

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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 2.46.

b **Identify** the type of cell shown in Figure 2.46. Explain your answer.

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

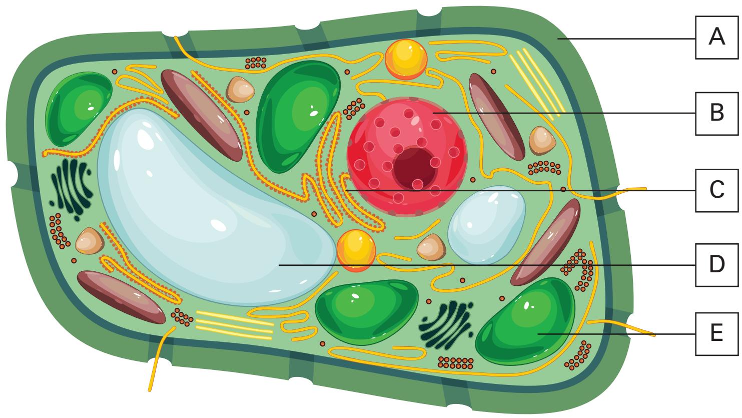

Figure 2.46 Eukaryotic cell

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 significant interest to scientists. **Explain** why this is the case, using what you have learned about their use in therapy and other medicinal applications.

Analysis

11 a Draw a Venn diagram to **compare** an animal cell with a fungal cell in terms of the cell's structure and organelles.

b Draw a Venn diagram to **compare** a plant cell with a fungal cell in terms of the cell's structure and organelles.

12 Yeast are unicellular eukaryotic cells and belong to the 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 one minute.

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

a Using the student's results, **identify** the effect of temperature on yeast function.

b **Identify** the best temperature for yeast activity.

c **Infer** the effect that an even higher temperature, such as 100°C, would have on the yeast being tested.

Knowledge utilisation

13 **Justify** this statement: 'Fungi are all around us, but you can't always see them'.

14 **Propose** reasons why humans need muscles and a skeleton, whereas plants do not.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
2.1	I can describe how the invention of the microscope has contributed to understanding of cell structure.	8, 9	
2.1	I can label the parts of a microscope.	4	
2.2	I can distinguish between prokaryotic and eukaryotic cells.	15	
2.2	I can identify the structure and function of organelles in cells.	5, 6, 11	
2.3	I can compare the similarities and differences of plant, animal, protist and fungi cells.	1, 12, 5c	
2.3	I can design a physical or digital model of a cell and explain how the representation models the cell.	10, 16	

Review questions

SCORCHER

Retrieval

1 Of the four kingdoms – Animal, Plant, Fungi, Protist – **state** which have unicellular organisms and which have multicellular organisms.

2 **Name** two examples of protists.

3 **Name** three types of specialised cells.

4 **Name** the common components of the monocular light microscope.

5 a **Recall** the role of the following organelles in the cell.

Organelle	Role in the cell
Nucleus	
Cytosol	
Golgi body	
Ribosomes	

b Using Figure 2.47, **identify** the organelles listed in part **a**.

c Is the cell shown in Figure 2.47 a plant cell or an animal cell? **Explain** how you know.

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.

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

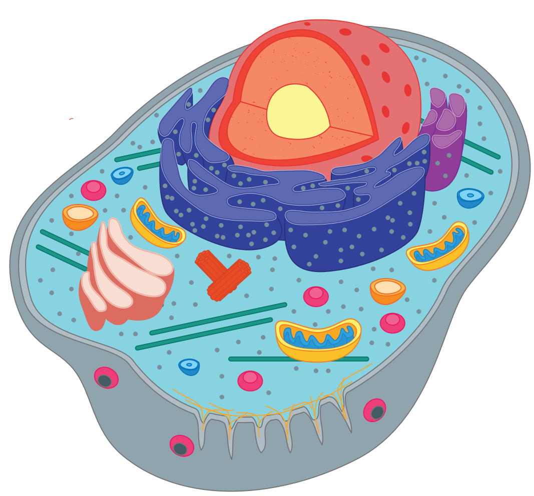

Figure 2.47 Eukaryotic cell

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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 in the table below.

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

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

Knowledge utilisation

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

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Data questions

The human body is composed of trillions of cells that work together to carry out various functions necessary for life. Estimating the total number of cells in an adult human body is a challenging task, but researchers have made significant progress in recent years. By studying individual organs and tissues and using various methods, such as microscopy, scientists have developed estimates for the number of cells in the human body, divided by cell type. These are shown in Figure 2.48.

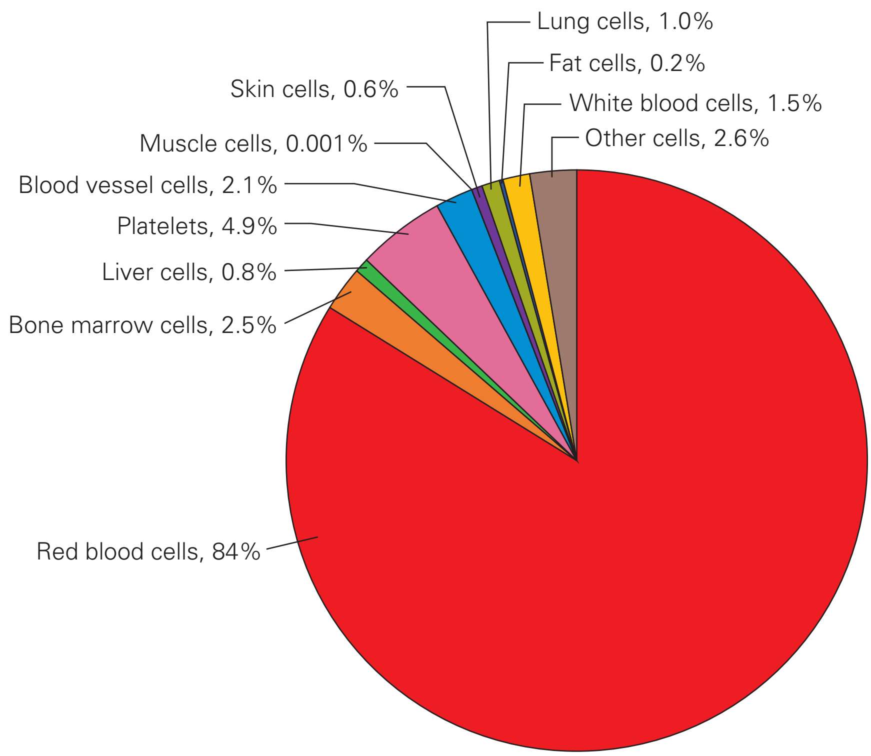

Figure 2.48 Estimated cell numbers in an average adult human, divided by cell type

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

Figure 2.49 on the following page shows the mean lifespan of different cell types and their total mass in an adult human.

Apply

1. **Identify** the most common cell type, using Figure 2.48.
2. **Identify** the least common cell type, using Figure 2.48.
3. If the estimated total number of cells in an adult human is 30 x 10^{12} (30 trillion), **calculate** the total number of red blood cells, using Figure 2.48.
4. **Identify** the cell type that has the highest total cell mass, using Figure 2.49.
5. **Identify** the cell type that has a mass turnover of 0.08 g per day, using Figure 2.49.

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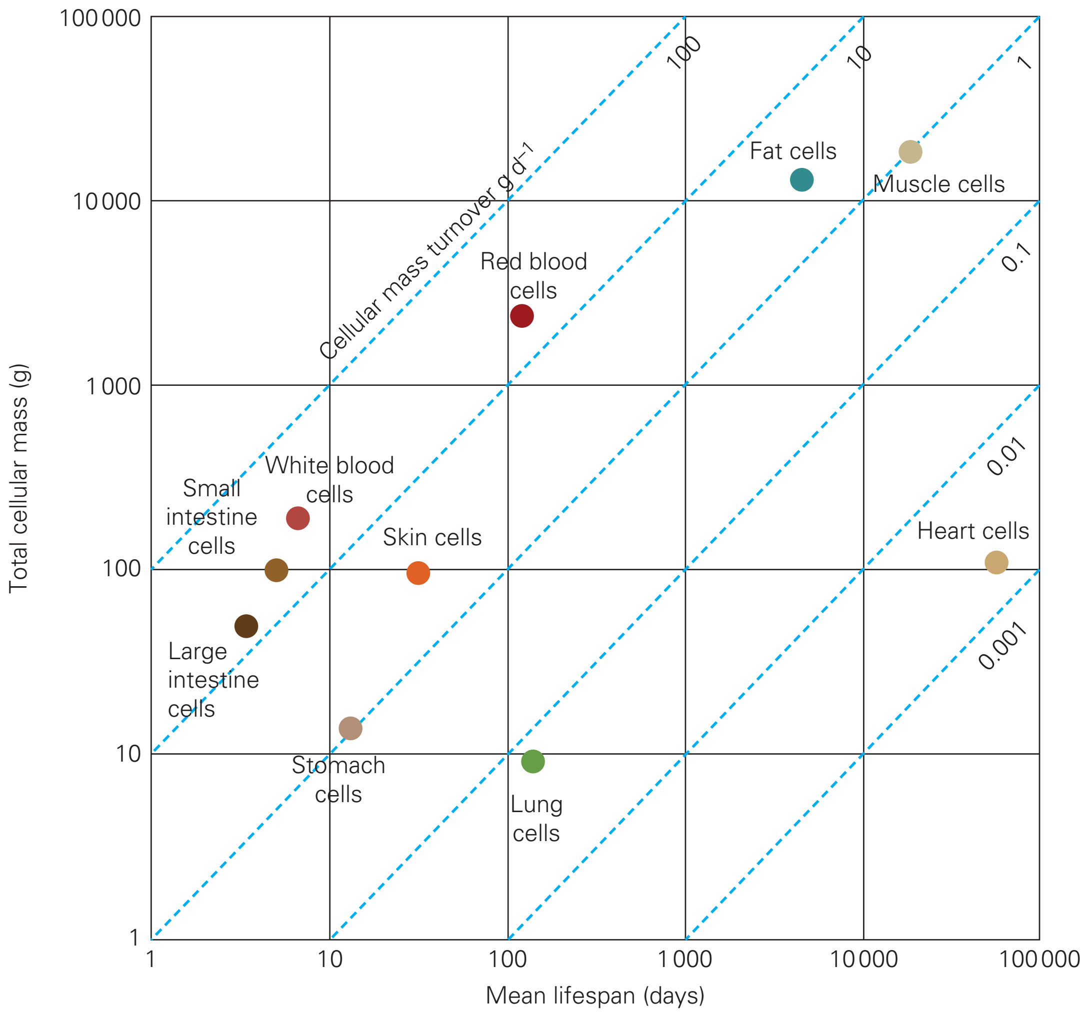


Figure 2.49 The mean lifespan (days) and total cell mass (grams) of different cell types in an adult human. Note that both the *x*-axis and the *y*-axis increase by a factor of 10 at each interval.

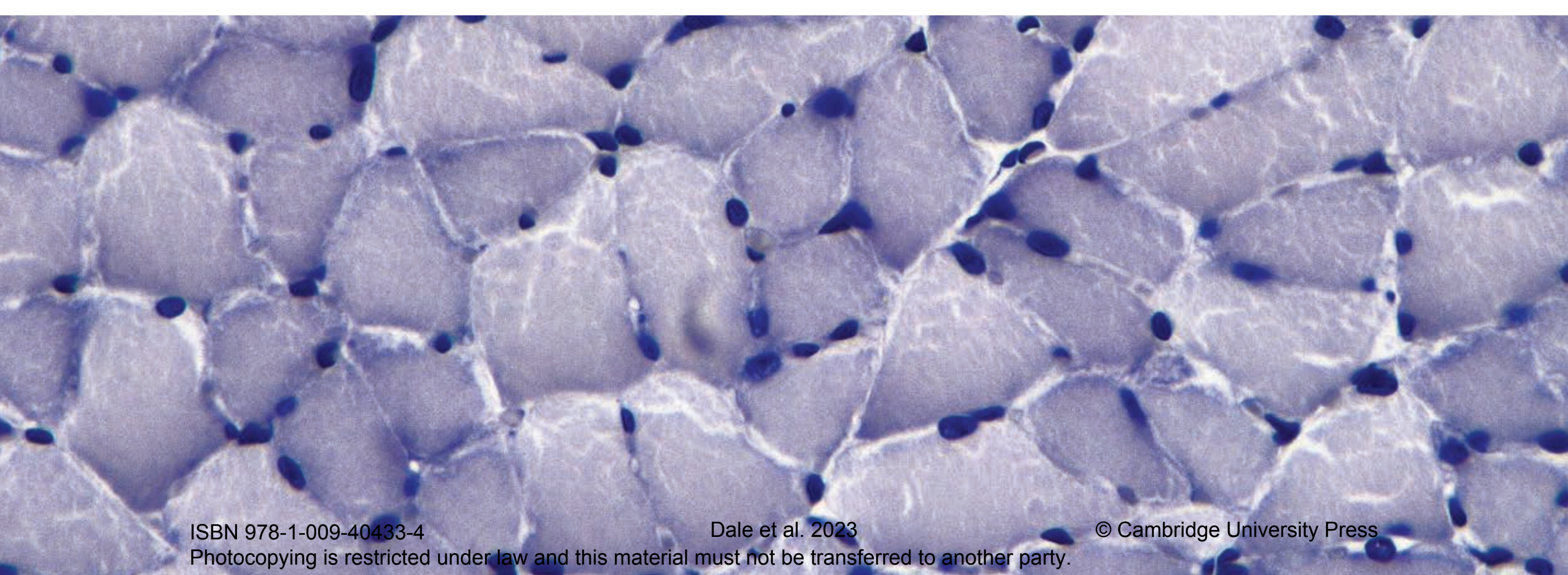
Analyse

6 **Contrast** small and large intestine cells, using Figure 2.49.

7 **Categorise** the following cells as having either a high turnover rate or a low turnover rate, using Figure 2.49: *heart cells, white blood cells, red blood cells, lung cells.*

Interpret

8 **Compare** stomach cells and muscle cells, using Figure 2.49.



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STEM activity: Design a city

Background information

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

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

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

Design brief: Design a city using cells as a model

Activity instructions

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

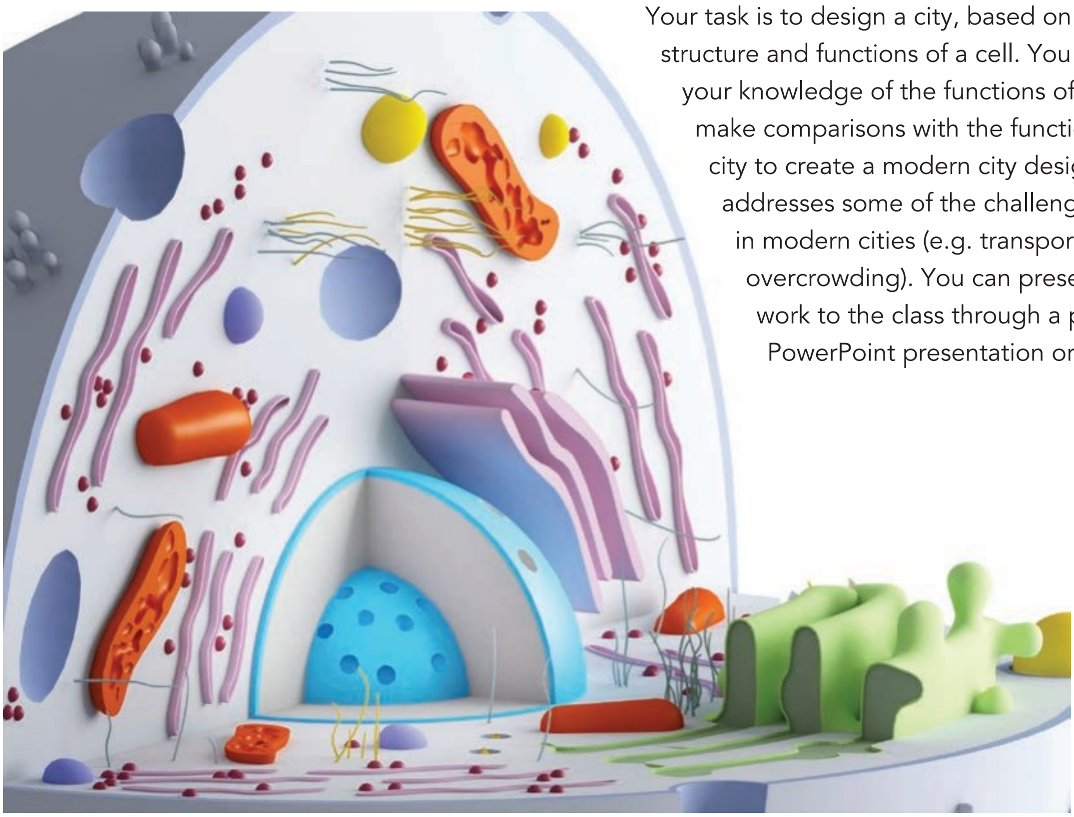

Figure 2.50 3D model of a cell

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Suggested materials/presentation formats

- poster
- PowerPoint
- video

Research and feasibility

1 List all the major organelles and their functions. As a group, research the issues/resources faced by a city such as 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.

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Chapter 3
Organ systems

Chapter introduction

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

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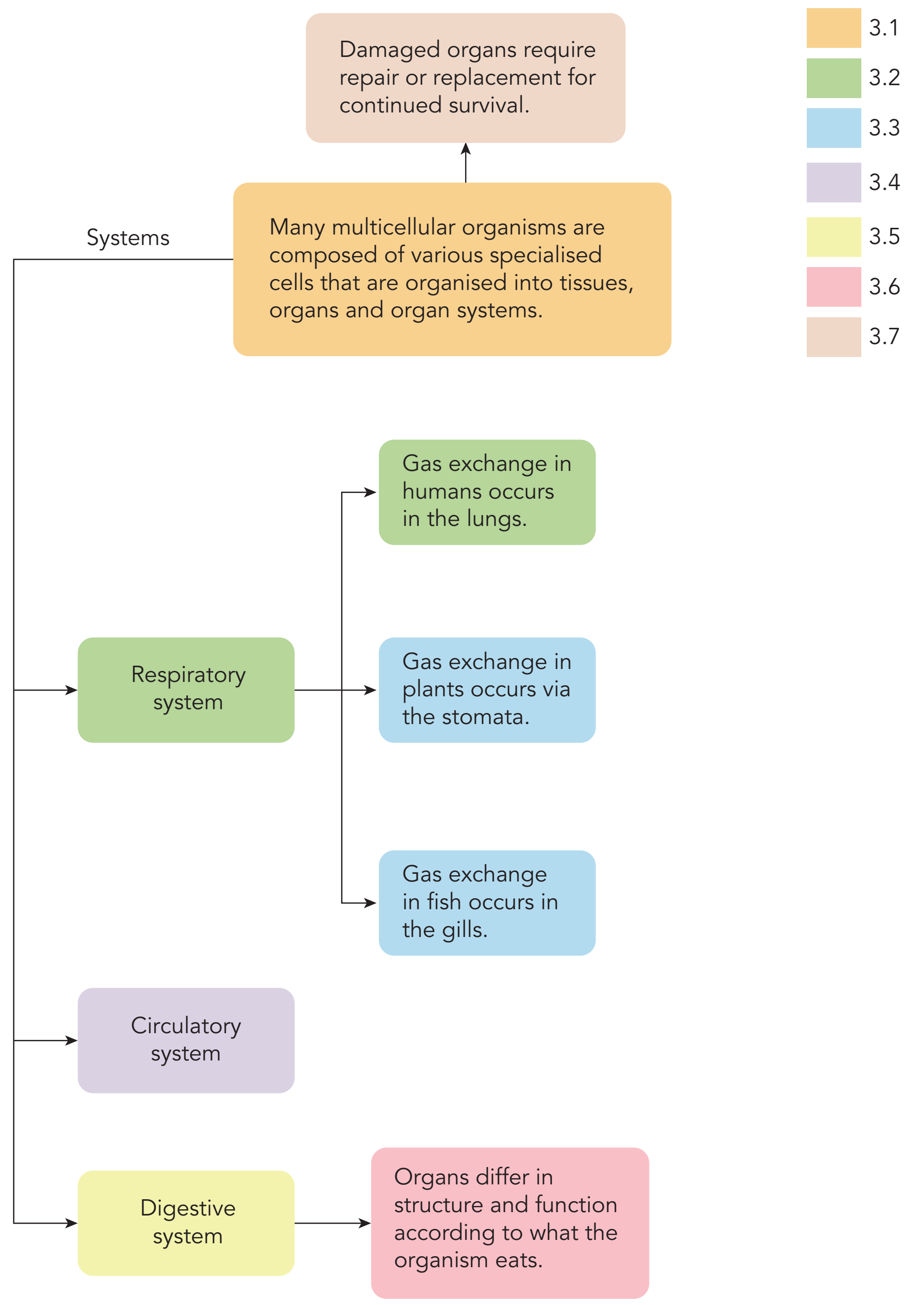
Concept map



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Curriculum

Analyse the relationship between structure and function of cells, tissues and organs in a plant and an animal organ system and explain how these systems enable survival of the individual (AC9S8U02)	
comparing 2-dimensional and 3-dimensional representations of organ systems to understand how organs are positioned within the body	3.1, 3.2, 3.4, 3.5, 3.6
comparing the structure and function of analogous systems in a plant and an animal	3.2, 3.3, 3.4
examining the specialised cells and tissues involved in structure and function of particular organs in an organ system	3.1, 3.2, 3.3, 3.4, 3.5, 3.6
describing the structure of each organ in a system and relating its function to the overall function of the system	3.2, 3.3, 3.4, 3.5, 3.6
researching how a disorder in cells or tissues can affect how an organ functions, such as how hardening of the arteries can lead to poor circulation or heart disease	3.7
investigating how an artificial organ mimics or augments the function or functions of a real organ	3.7

Glossary terms

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

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3.1 Cells to systems

Learning goals

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

DOC WORKSHEET Cells to systems

Cells

A cell is the basic unit of life. Every living organism is made up of at least one cell. Unicellular organisms are made up of only one cell 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. These are known as specialised cells.

Specialised cells

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

structure
a physical part of an object

function
the job that an object does

differentiation
the process by which cells become specialised

All the cell types in your body begin as unspecialised cells called stem cells. As the cells grow and develop, they **differentiate** (change into specialised cells), forming over 200 different types of cells that make up your body. These cells then replicate to produce more copies of each type of specific cell.

Making thinking visible 3.1

Creative hunt: Specialised cells

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

What is the **purpose** of the image?
What are the main **parts** of the image?
What do you think is particularly **creative** about the image?
Who do you think the image in **intended** for?

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

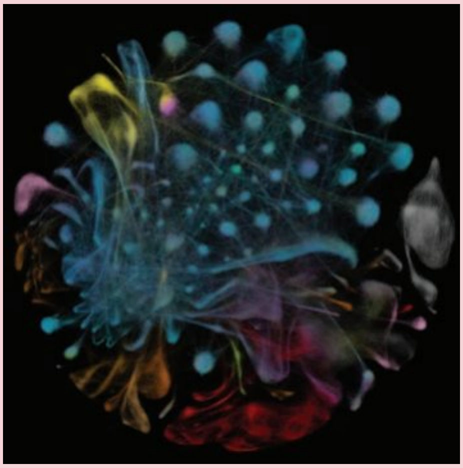

Figure 3.1 A representation of monkey cells. The image won the Wellcome Photography Prize in 2019.

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Neurons

Nerve cells or **neurons** are specialised cells that allow all the parts of your body to work together, by transferring signals to and from your brain to each part of your body through the nervous system. Neurons 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 by their highly branched ends. They have long axons, which are specialised to carry electrical signals over long distances at very fast speeds. The longest nerve cell in your body is your sciatic nerve, which stretches from the bottom of your spine to your big toe.

neuron
a nerve cell

haemoglobin
a protein in red blood cells that binds to oxygen

biconcave
concave on both sides

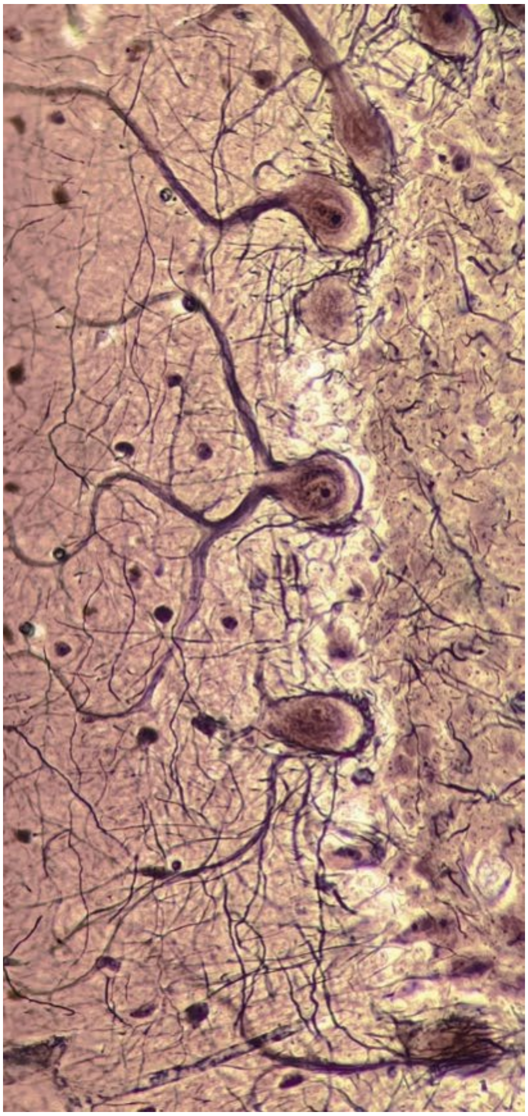

Figure 3.2 Neurons in the brain of a dog

Figure 3.3 Neurons are shown on the left, and on the right is the main organ of the nervous system, the brain.

Red blood cells

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

When they reach maturity, they do not have a nucleus, which allows extra room for haemoglobin to carry oxygen around the body. 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.

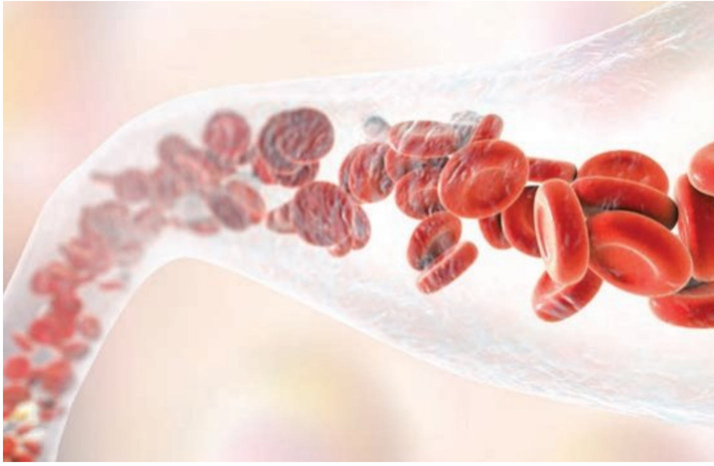

Figure 3.4 Representation of red blood cells travelling through a blood vessel. Note their biconcave shape.

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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 must be able to move to swim to the egg. That is why they have a specialised tail, called a flagellum, which beats in a corkscrew motion and allows the sperm cell to swim. Sperm cells have many mitochondria in their midpiece, to provide energy for fast movement. Their head also contains an acrosome, a sac of digestive enzymes that digest through the membrane of the egg cell, allowing the sperm nucleus to enter.

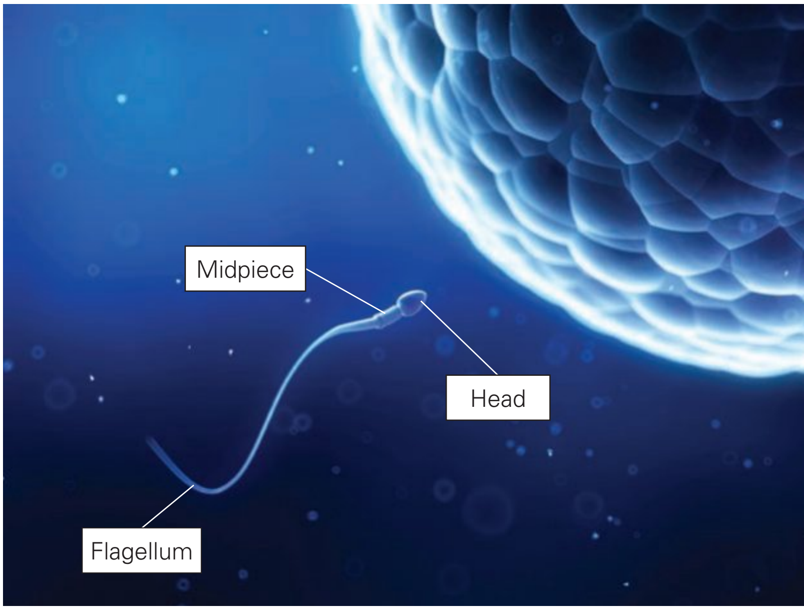

Figure 3.5 A sperm swimming towards an egg. Note its long flagellum.

Quick check 3.1

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

Practical 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.

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**.

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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.

Levels of organisation

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

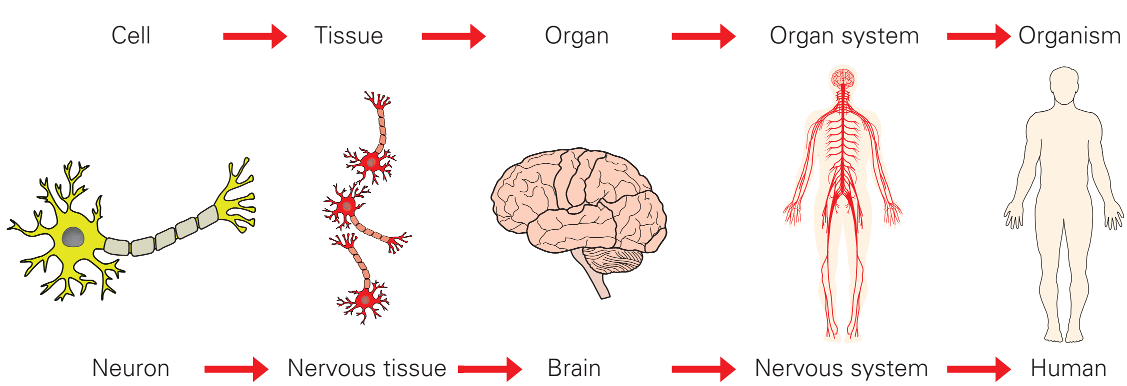

Figure 3.6 The nervous system is an example of cells being organised into an organ system.

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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 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.

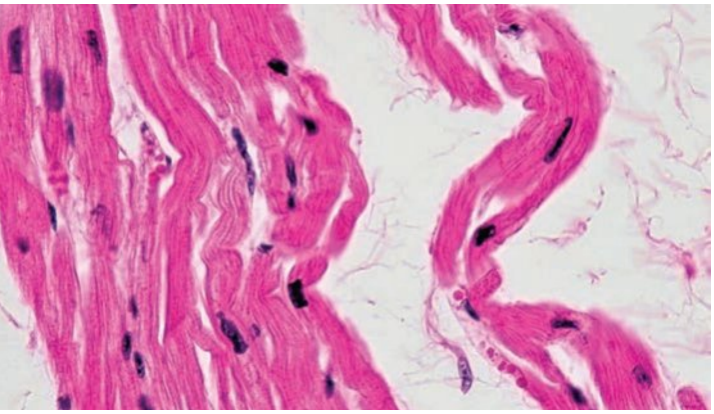

Figure 3.7 A high-magnification photograph of human cardiac (heart) muscle tissue, seen through a light microscope. Each of the long, thin muscle cells has a purple nucleus. Note that a stain has been added to the tissue to make it more visible.

Figure 3.8 Connective tissue in a tendon

Organs

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

tissue
a group of cells performing the same function

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

organ
a group of tissues working together to perform a function

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

Did you know? 3.1

Human skin

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

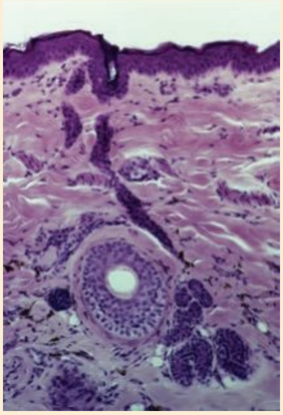

Figure 3.10 A sweat gland and duct on the head

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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. There are 11 organ systems in humans.

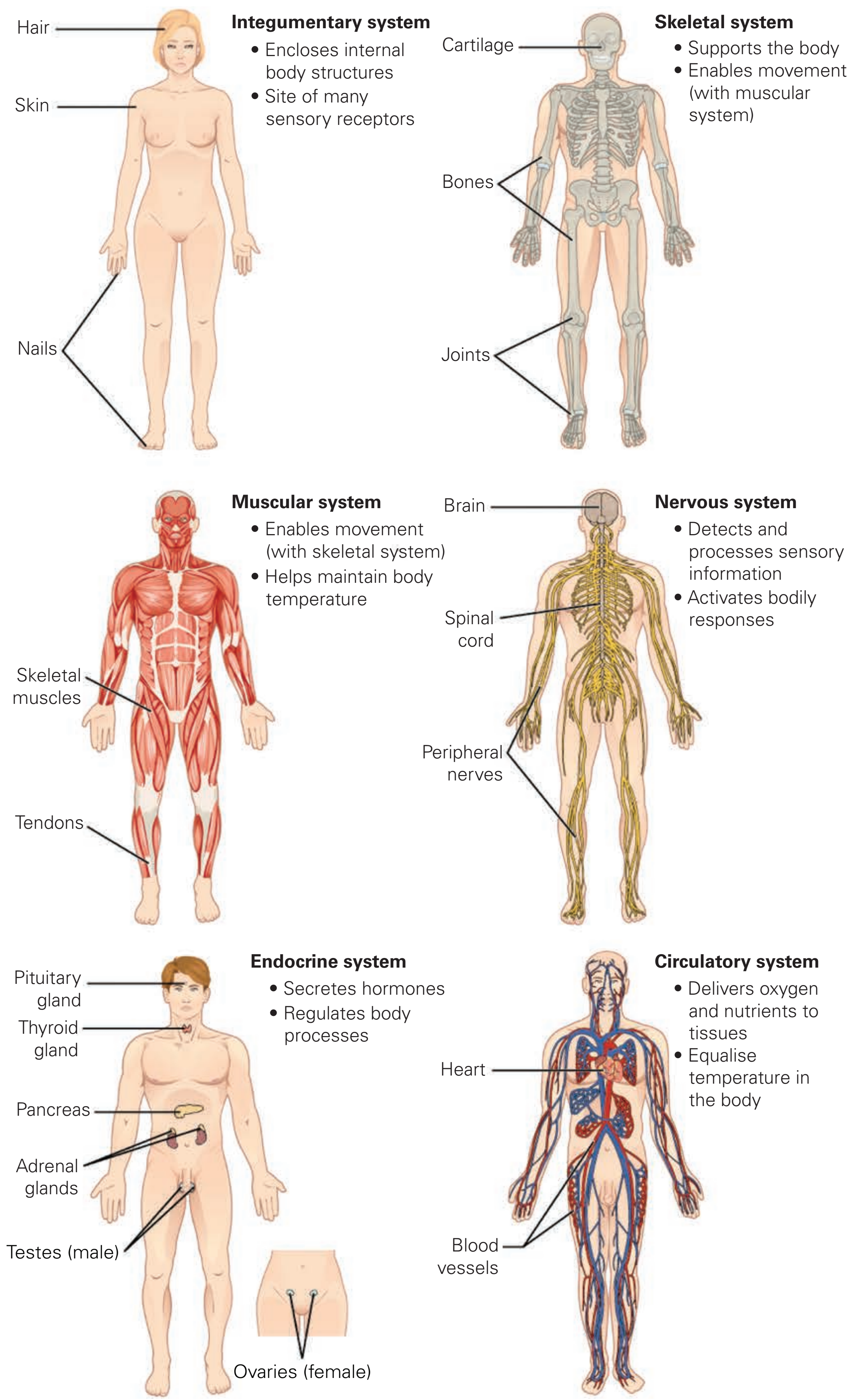

Figure 3.11 The 11 human organ systems (continued on the following page)

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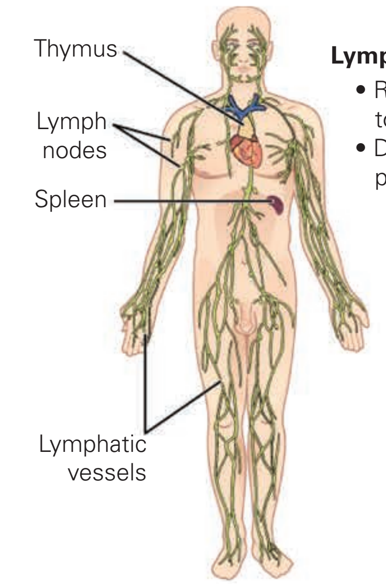
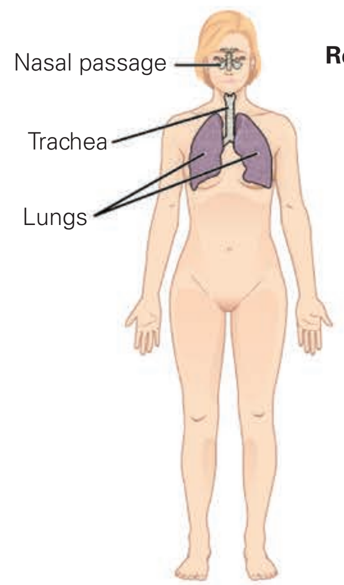
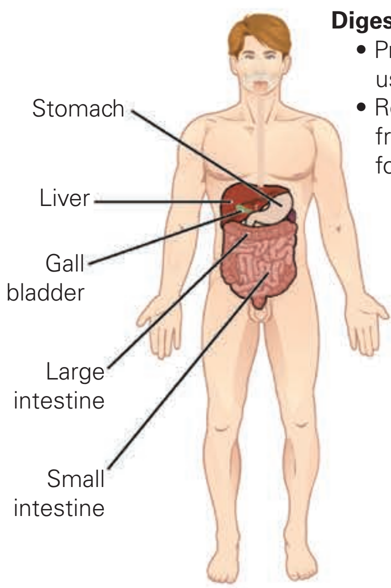


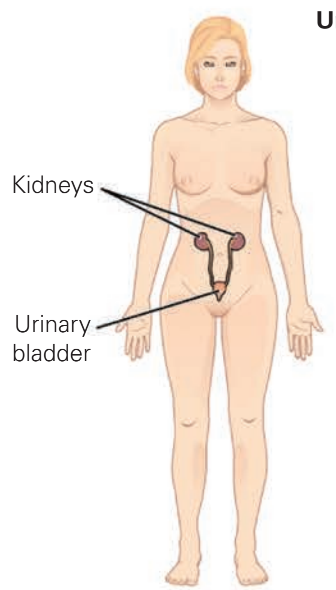
Lymphatic system
- Returns fluid to blood
- Defends against pathogens



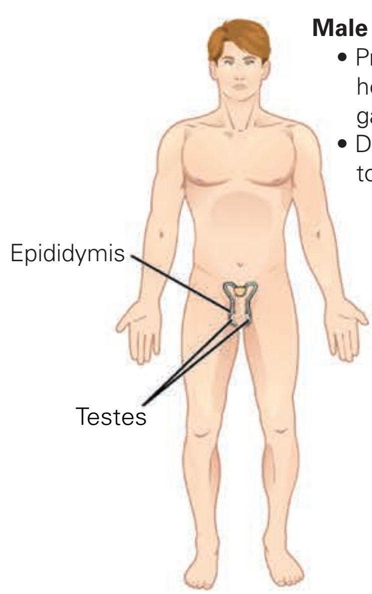
Respiratory system
- Removes carbon dioxide from the body
- Delivers oxygen to blood



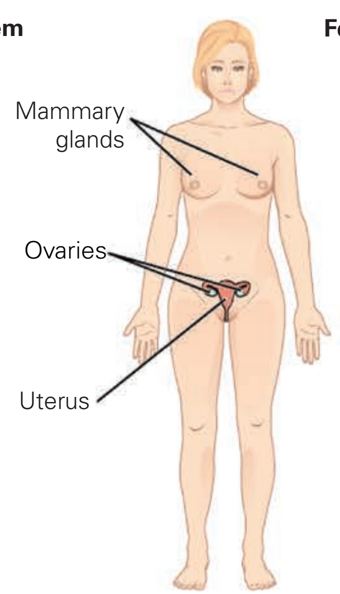
Digestive system
- Processes food for use by the body
- Removes wastes from undigested food



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



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



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

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Science as a human endeavour 3.1

Practice makes perfect

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

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

Figure 3.12 The HaptX Gloves DK2 system being used in 2019 with FundamentalVR's surgeon simulator software. This technology allows trainee surgeons to build their skills before performing a real operation.

VIDEO Seeing a developing organism

Try this 3.1

Three-dimensional organ systems

Use the internet to find an online 3D anatomy site such as ZygoteBody. You should compare the two-dimensional representations in this book with the three-dimensional representations of organ systems online to understand how organs are positioned within the body.

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.

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

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

Quick check 3.2

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

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Explore! 3.1

Plants are complex

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

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.

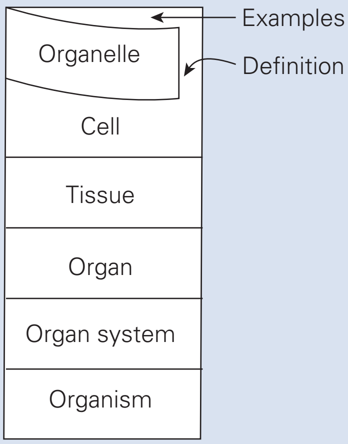
Step 2 Fold it in half vertically – from left to right. You have formed a brochure with four sides or pages.

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.



Did you know? 3.2

Traditional knowledge of internal systems

First Nations Australians have unique ways of communicating their understanding of the internal systems of organisms. Various Peoples often depict the internal features of animals through mediums like X-ray paintings, sculptures or head dresses.

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

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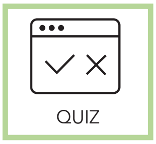
Section 3.1 questions



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 A cell is composed of different types of tissue.

B A tissue is composed of only one type of cell.

C If you look at a tissue under the microscope, you will see many different organs.

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.

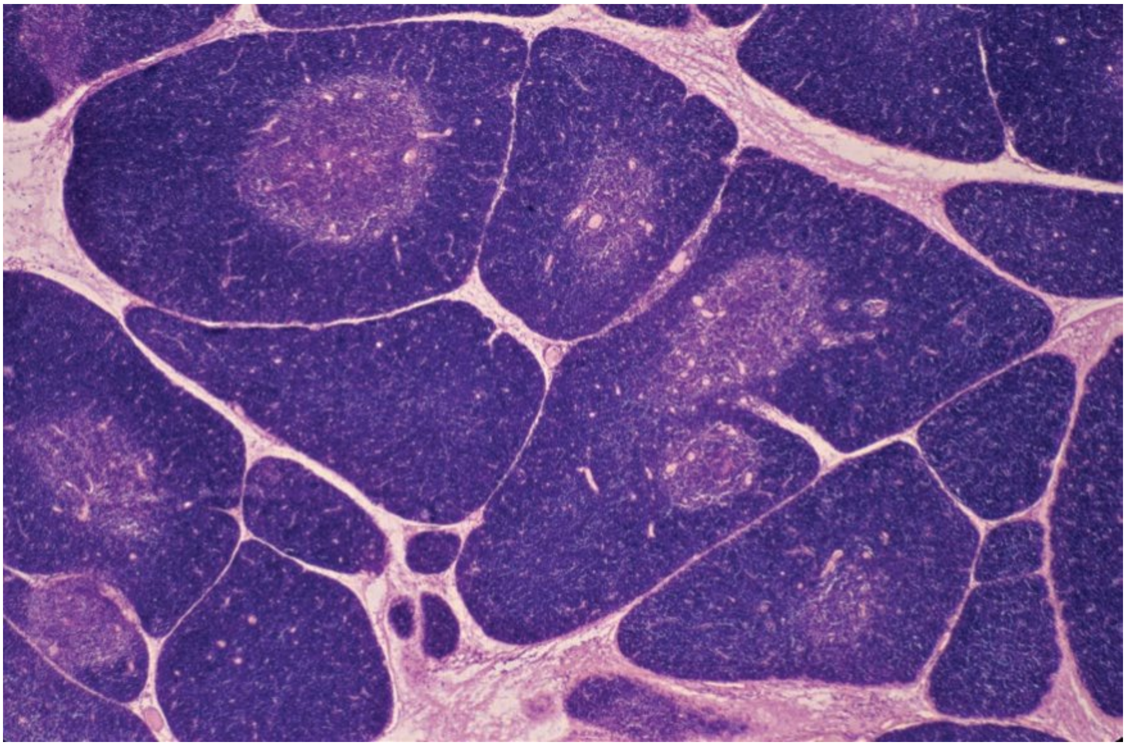
Analysis

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 tree, 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

Learning goal
To describe the structure of each organ in the respiratory system and relate its function to the overall function of the system.

WORKSHEET
Human respiratory system

Breathing versus respiration

You can probably hold your breath for about a minute, maybe two, but after that your body forces you to take a huge gulp of air. This is because the cells in our bodies need a constant supply of fresh oxygen to produce energy and function efficiently. Cellular respiration is the process that happens inside the mitochondria in our cells, which turns glucose and oxygen into useable energy called ATP. The process also produces the waste products of carbon dioxide and water. Breathing, the physical process of inhaling and exhaling, provides your body with oxygen to undertake cellular respiration. If you stop breathing, you are preventing oxygen entering your body and therefore depriving your cells of oxygen, meaning ATP cannot be made.

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

Figure 3.15 When you breathe out on a cold day, you can see your warm breath start to condense in the cold air.

Did you know? 3.3

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

Figure 3.16 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 together transport the oxygen you breathe in and removes the carbon dioxide you breathe out.

Mouth and nose

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

Trachea and bronchi

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

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

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

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

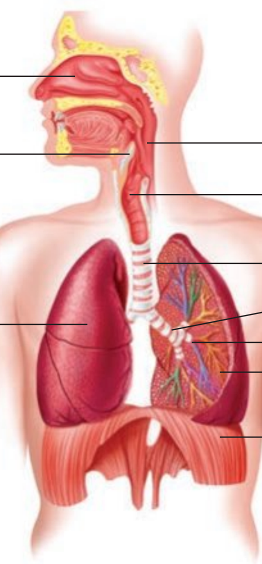

Figure 3.17 Structure of the human respiratory system

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?

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Figure 3.18 A scanning electron micrograph of ciliated cells in the trachea

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

Figure 3.19 This illustration of the lungs shows the blue central trachea dividing into the left and right bronchi. The red bronchi then branch into bronchioles.

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.

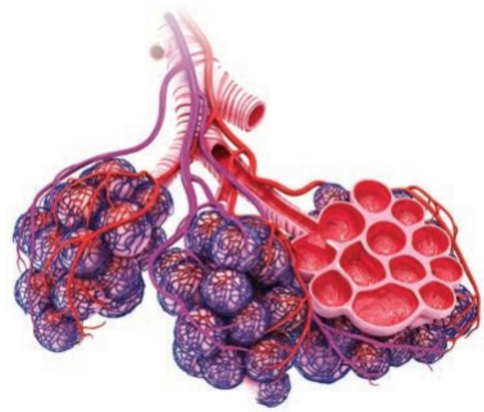

Figure 3.20 Gas exchange occurs between the alveoli and the capillaries. The oxygenated blood is returned to the heart, and the carbon dioxide-rich air is exhaled.

VIDEO
Gas exchange in an alveolus

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.

Big breath in!

When you breathe in (inhale), a large muscle at the base of your ribs, called the **diaphragm**, contracts and pulls down. At the same time, the intercostal muscles between your ribs contract, moving the ribs upwards and outwards. This increases the volume in your chest, drawing air in through your mouth and nose and 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.

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

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

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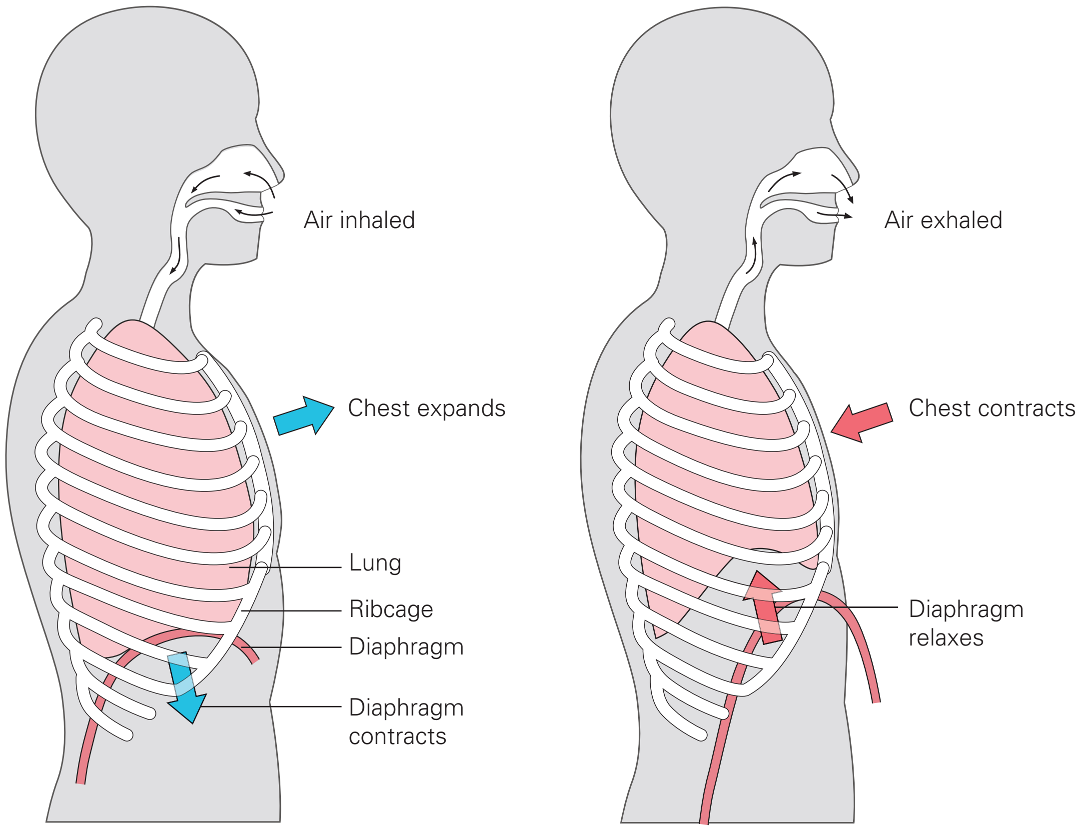

Figure 3.21 The movements of the chest during inhalation and exhalation

Try this 3.3

Pressure changes

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

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

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

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

Making thinking visible 3.2

Parts, purposes, complexities: Respiratory system

Examine Figure 3.17 closely.

What are the different **parts** of the respiratory system?

What is the **purpose** of each of these parts?

What is complicated about the diagram? Do you have any questions about these **complexities**?

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

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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 elastic 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.

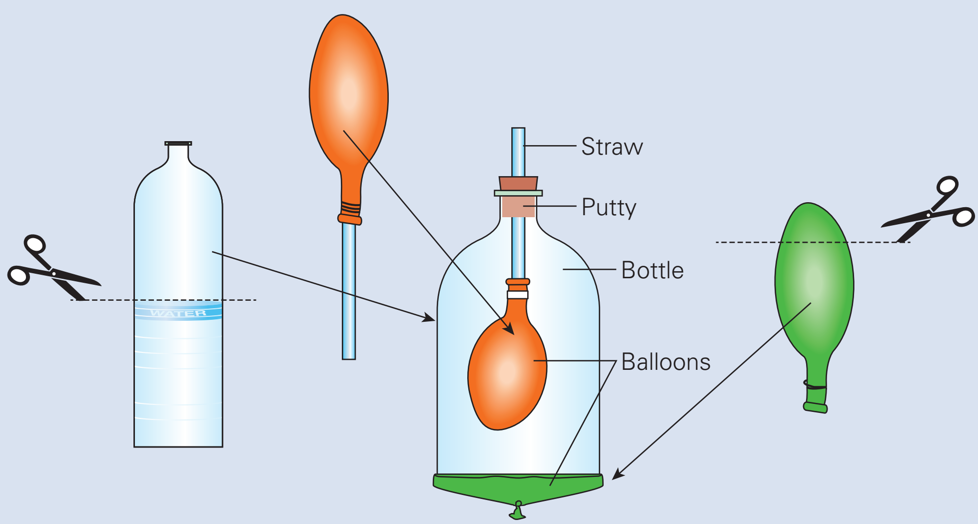

Figure 3.22 Experiment set-up. Breathing in: pressure in the lungs is lower than the atmosphere, so air flows in. Breathing out: pressure in the lungs is greater than the atmosphere, so air flows out.

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.

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Science as a human endeavour 3.2

Thunderstorm asthma

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

Thunderstorms can cause a phenomenon known as thunderstorm asthma, which can affect even those who do not have a history of asthma. The sudden change in weather conditions causes pollen grains to be drawn up into clouds as the storm forms. The moisture in the air causes the pollen grains to swell and then burst, generating tiny fragments of pollen that are pushed back down to the ground by wind. These small particles are then inhaled, leading to symptoms such as coughing, wheezing and shortness of breath.

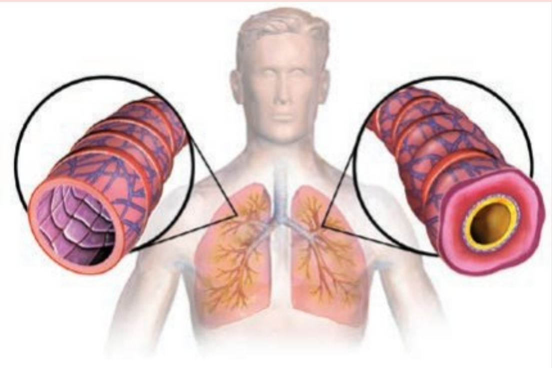

Figure 3.23 Asthma (right) causes a narrowing of the airways.

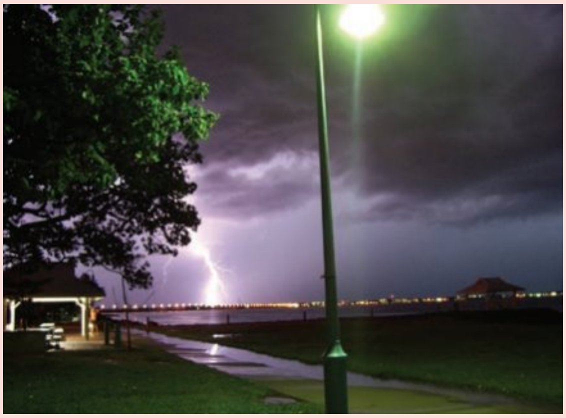

Figure 3.24 The 2016 thunderstorm asthma event in Melbourne was one of the largest and most severe on record, with over 10 000 people affected, placing a significant strain on the healthcare system. The sudden surge in respiratory-related cases overwhelmed emergency departments and resulted in 10 fatalities.

DOC WORKSHEET Asthma

Quick check 3.4

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

Did you know? 3.4

Your lungs float!

Each of your lungs contains around 300 million alveoli, which you can imagine as tiny balloons. When 'inflated', the lungs are the only organ in the human body that can float on water.

Gas exchange in animals

In humans and other animals with lungs, it is the alveoli that are responsible for exchanging gases into and out of the blood. However, there are other members of the animal kingdom that have developed 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:

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- a very large surface area. This is usually achieved by a folded surface, which increases the amount of gas that meets the animal's blood.
- a moist surface that gases dissolve into before they enter or leave the body. This makes the process of diffusion much easier for gases.
- a thin surface and small barrier between the inside and the outside of the body. This means that the gas has to travel a smaller distance.
- a transport system near these structures, such as blood vessels, to transport the gases to all parts of the body.

The 300 million alveoli in our lungs have all of these features, which makes them an extremely efficient gas exchange surface.

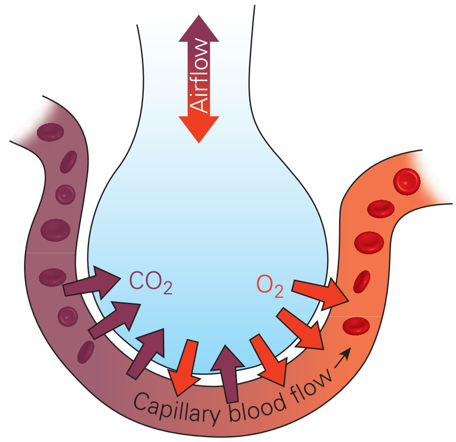

Figure 3.25 Gas exchange between the alveolus and the capillary. Note the direction of diffusion as oxygen enters the bloodstream and carbon dioxide leaves the bloodstream.

Quick check 3.5

1 Recall the site of gas exchange in the lungs.
2 State three other gas exchange structures found in the animal kingdom.
3 Recall the advantage of having a moist surface for gas exchange.

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 blue solution

1 Add 50 mL of water to a conical flask.
2 Add a few drops of bromothymol blue and record the colour in the 'Observations before' column of your results table.
3 Using a pump and a straw, blow air slowly through the solution for 30 seconds.
4 Record your observations in the 'Observations after' column.

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… continued

5 Using your breath and the same straw, blow air slowly through the bromothymol blue solution for 30 seconds, being careful not to suck up any of the solution.

6 Record your results in the 'Observations after' column.

Petri dish

7 Using a pump, blow air directly over the Petri dish.

8 Record any changes in the results table.

Air source	Bromothymol blue solution		Petri dish	
	Observations before	Observations after	Observations before	Observations after
Pump				
Exhaled				

9 Using your breath, exhale directly over the Petri dish.

10 Record any changes in the results table.

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.

Explore! 3.3

Frog business

Billions of years ago, life began in the oceans, and gills were the first form of respiratory organ. As animals began to move onto land, a new gas exchange surface was needed. Evidence of this gradual change from aquatic life to terrestrial (land) life is present in amphibians today. In amphibians such as frogs, newts and salamanders, there are several ways in which gas can be exchanged. Unlike mammals and birds, amphibians are ectotherms, which means they depend on external sources of heat. As a result, their level of respiration can be lower than endothermic animals (those that produce their own body heat), and so their cells need less oxygen to function properly.

1 Tadpoles spend all their time in water. Find out how they get oxygen and explain how the features of gas exchange (thin, moist surface etc.) relate to this process.

2 As tadpoles transition into adults, the process they use to gain oxygen changes. Explain how it changes.

3 Find out what 'cutaneous respiration' is and how it relates to a frog getting oxygen. Link this information to the features that gas exchange surfaces exhibit.

4 Research why frogs must undertake buccal pumping.

Figure 3.26 A frog keeping its nostrils above water to breathe

Figure 3.27 A frog with an extended buccal cavity

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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.

Section 3.2 questions

QUIZ

Retrieval

1 **Name** the gas that is absorbed into the blood by the respiratory system.
2 **Name** the gas that is removed from the blood by the respiratory system.
3 **State** the more biologically correct name for the 'windpipe'.

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 helps with 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 'cellular respiration'.
11 The graph in Figure 3.28 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.

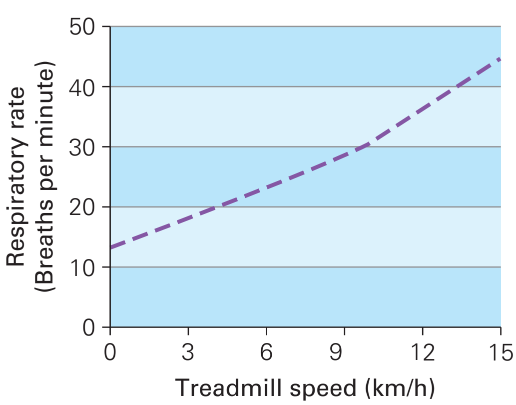

Figure 3.28 Respiratory rate versus treadmill speed

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 that 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

WORKSHEET
Plant respiration

VIDEO
Other respiratory systems

Learning goal
To compare the structure and function of the analogous respiratory systems in plants and animals.

Gas exchange in plants

Gas exchange is important for all living organisms, including plants. Plants carry out both cellular respiration to make energy and photosynthesis to make their own food. Both of these processes require the exchange of oxygen and carbon dioxide between the inside and outside of the plant. This means plants must have organs that allow their internal structures to exchange gases with the environment. The main gas exchange organ in plants is the leaf.

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. Unfortunately, this means that water loss can also occur through stomata. When they are open, gas exchange can happen but water is also lost to the environment.

stomata
tiny pores (holes) in leaves that allow entry/exit of gases such as oxygen and carbon dioxide

guard cells
cells on either side of a plant stoma that control gas exchange by opening and closing the stoma

The guard cells of stomata contain large vacuoles that, when filled with water, hold the stomatal pores open. The vacuoles fill with water when plants are in strong sunlight or high carbon dioxide concentration. However, when the plant begins to dry out in periods without rain, or in high temperatures or low humidity, the vacuoles inside the guard cells empty out and the cells become floppy or flaccid. This closes the stomata 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).

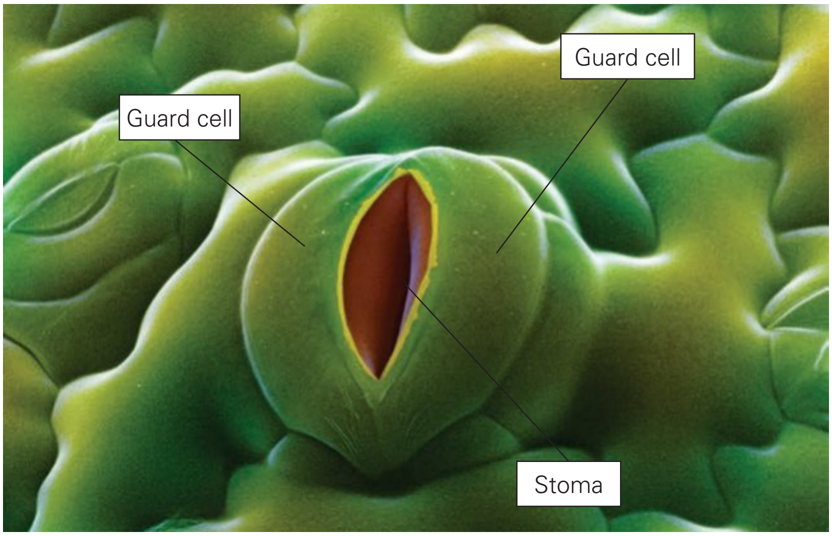

Figure 3.29 Swollen guard cells have forced open this stoma, allowing gases to enter and exit the leaf.

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Try this 3.6

Modelling stomata with a balloon

1 Using a twist balloon, blow it up and fold it in half but do not tie a knot in the end.
2 Keeping the balloon folded, allow some air to escape slowly from the balloon.
3 Notice how the two sides of the balloon begin to come together.

This is like what happens in the stomata as they lose water. By closing the stomata, the plant can limit water evaporation and save water.

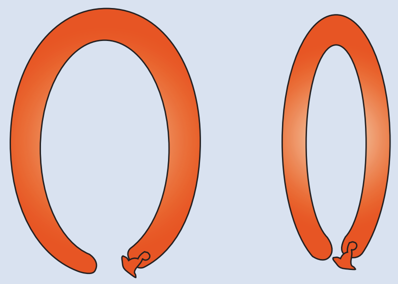

Figure 3.30 A twist balloon can be used to model stomata.

Although the stomata on leaves are very effective at providing gas exchange for the leaves, other parts of the plant need to respire, as well. The thick woody parts of trees, such as the branches, stems and trunks, have structures called **lenticels**. You can often see these in the bark – they look like small dots or stripes. 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 3.31 The small horizontal slits in this tree trunk are lenticels.

Practical skills 3.3

Stomata lab

Aim

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

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.

Materials

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

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.

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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.

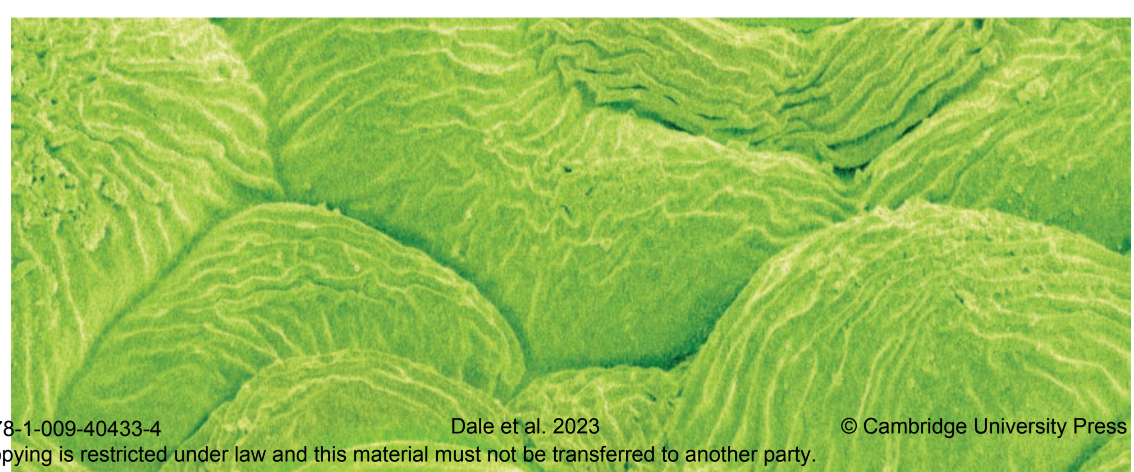
Results

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

Plant	Sketch, magnification and diameter estimate

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.



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Explore! 3.4

Trichomes

Plant hairs, also known as trichomes, can help to prevent water loss in plants. They break up the flow of air across the plant surface in windy regions, reducing water loss. When trichomes are dense, they reflect sunlight and in areas where plants obtain their water from fog, the trichomes allow water droplets to accumulate.

Figure 3.32 Scanning electron micrographs showing a variety of trichomes on different leaves

Quick check 3.6

1. Name the structures in leaves that allow gas exchange.
2. Recall three environmental factors that could cause stomata to close.
3. Explain the process involved in closing the stomata.
4. Identify how plants conduct gas exchange through their trunks.

Respiratory systems in fish

Lungs 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 3.33 The highly folded inside of fish gills maximises the surface area available for gas exchange.

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Explore! 3.5

Counter-current flow

Fish also have another way of increasing the level of diffusion in their gills, known as *counter-current flow*. This process maximises the exchange of gases, because a guiding rule for diffusion is that the bigger the difference between the concentration of a gas in two areas, the faster that diffusion can occur.

1 Research what counter-current flow is and explain how it works.
2 Draw a picture to demonstrate counter-current flow in a fish gill.

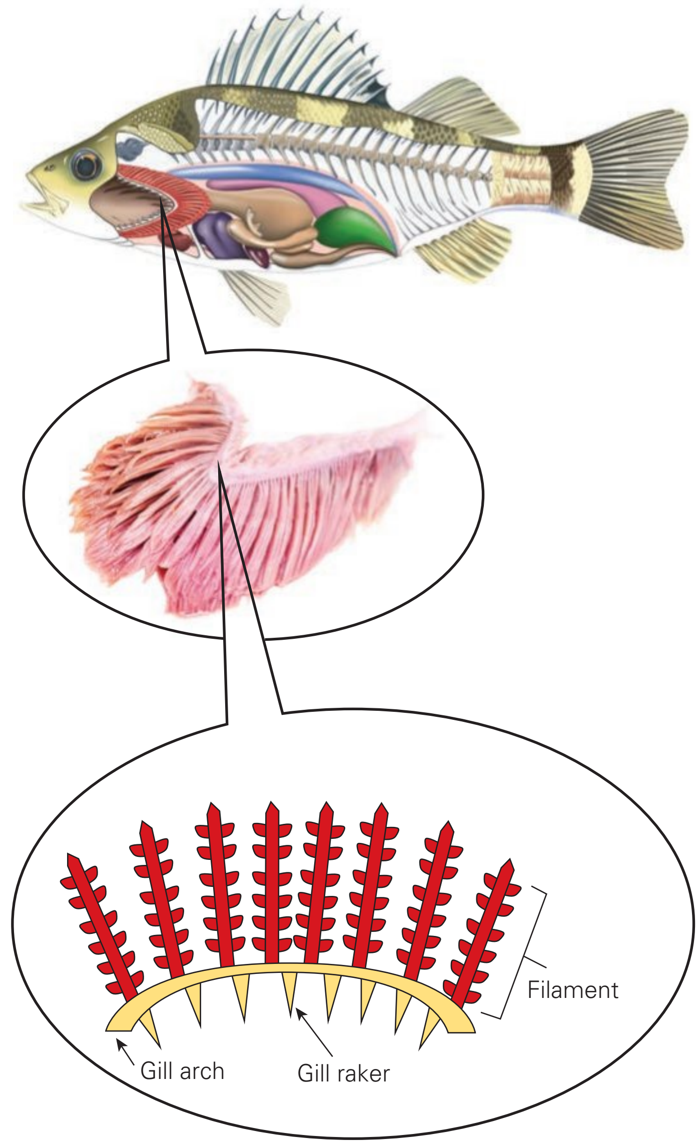

Figure 3.35 The complex structure of fish gills

Did you know? 3.5

Axolotls

Axolotls are neotenic, meaning they keep their juvenile characteristics when they become adults. Axolotls remain aquatic for their entire life, even though they develop fully functional lungs. Instead, they use their feathery gills on their heads to breathe underwater.

Figure 3.34 The gills of an axolotl stick out from the side of its head to maximise gas exchange with the surrounding water.

Quick check 3.7

1 State the gases that fish need to exchange with their environment.
2 Summarise the features of gills that allow efficient gas exchange.
3 Recall three ways in which gills speed up the diffusion of gases into and out of a fish.

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Practical 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 3.36. This will expose the internal anatomy of the fish.

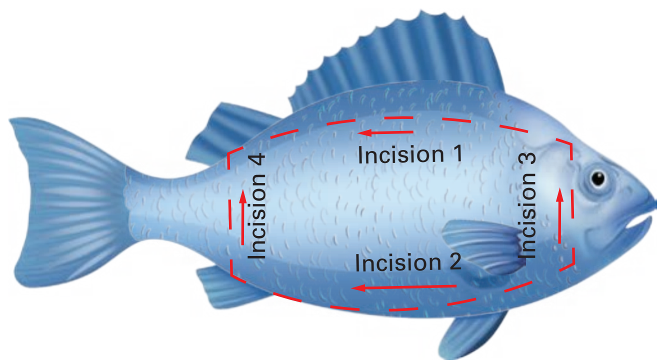

Figure 3.36 External incisions

2 Your teacher will identify the structures shown in Figure 3.37.

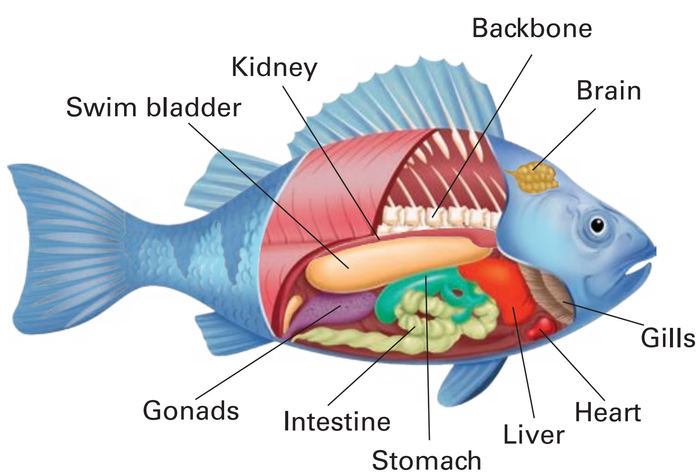

Figure 3.37 Internal organs of the fish

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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. It produces many digestive liquids and stores some vitamins and nutrients.
Gonads	Sex organs, male or female. Some species have both types of gonads in one fish.
Kidneys	Two kidneys, located near the spine, regulate water levels in the body.
Gills	The aquatic version of lungs. Each gill arch holds many hundreds of filaments, which are feather-like structures with a large surface area.

Table 3.1 Structural features of each organ

3 Your teacher will cut open the gill arch to expose the gills. You will be able to see that the gills are stacked on top of each other.
4 Your teacher will cut the gill arches and pass one to each group.

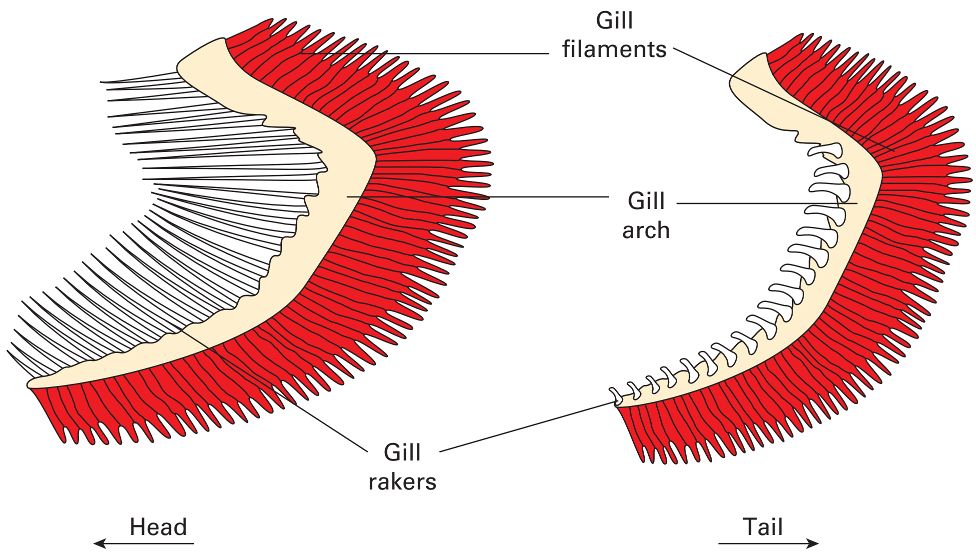

Figure 3.38 Observe the structures: *gill filaments* are the site of gas exchange; *gill rakers* are appendages along the front edge of the gill arch; *gill arches* support the gills.

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 gas regulation in fish.
2 Explain what you observed when you added water to the gill arch.
3 Using your observations, suggest why fish cannot breathe out of water.

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Did you know? 3.6

Insect gas exchange

In insects, gas exchange occurs through a system of tubes called tracheae, which branch into smaller tubes called tracheoles, which eventually reach the individual cells. The tracheae open to the outside of the body through structures called spiracles, which are found on the sides of the insect's thorax and abdomen.

The spiracles can open and close to control the flow of air into and out of the tracheae. When the spiracles are open, air flows into the tracheae and can then diffuse into the individual cells, providing oxygen for respiration. At the same time, carbon dioxide produced by respiration diffuses out of the cells and into the tracheae, where it is expelled from the body through the spiracles.

Figure 3.39 Spiracles

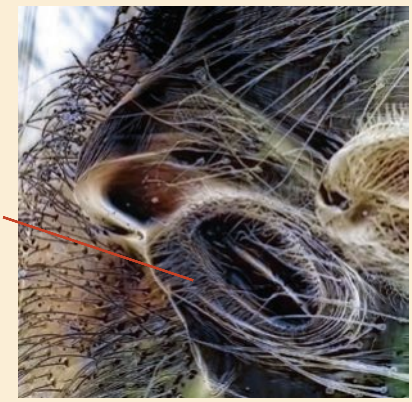

Figure 3.40 A fly spiracle

Section 3.3 questions

QUIZ

Retrieval

1 **Define** the term 'gas exchange'.

2 **State** three gas exchange structures found in eukaryotic organisms.

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

WORKSHEET
Human circulatory system

Learning goal
To be able to describe the structure of each organ in the circulatory system and relate its function to the overall function of the system.

The partner of most of the organ systems in the body is the circulatory system (sometimes referred to as the cardiovascular system). This is a transport system that moves oxygen, nutrients, hormones, immune cells, waste and heat throughout the body, in one continuous loop. Without the circulatory system, none of the other organ systems would be able to function.

Heart

The heart is a powerful muscular pump. It has one job: to maintain pressure in your circulatory system, which moves the blood around your body.

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** (bottom parts of the heart).

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

ventricle
one of the two lower chambers of the heart, the left and right ventricles

sinoatrial node
a natural pacemaker that controls the heartbeat and is located in the wall of the right atrium

atrioventricular node
a natural pacemaker that controls the heartbeat and is located in between the atria and the ventricles

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

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 heart 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 3.43 and Figure 3.45.

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.

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.

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Making thinking visible 3.3

Connect, extend, challenge: Bioprinting

Three-dimensional printing of organs, also known as bioprinting, is an emerging area of research where scientists create functional human organs using 3D-printing technology. The goal is to address the critical shortage of organs for transplantation and create tissue models for drug discovery and testing.

In bioprinting, a 3D printer is used to layer living cells with a supportive material to create functional tissue. The cells can be taken from the patient, reducing the risk of rejection, or they can be sourced from a biobank. Once the tissue has been printed, it is incubated in a controlled environment that allows it to mature and develop into functional tissue.

While the technology is still in the early stages of development, significant progress has been made in bioprinting simple tissues, such as skin and cartilage. However, more complex organs, such as the heart, liver and lungs are much more challenging to bioprint, as they require intricate networks of blood vessels and other structures to support the cells.

Despite the challenges, researchers are optimistic about the potential of bioprinting to revolutionise the field of transplantation and provide a limitless supply of functional organs for patients. Bioprinting also has the potential to advance the field of drug discovery and testing, allowing researchers to test new drugs on functional human tissue before proceeding to clinical trials.

Consider what you have just read about bioprinting, then answer the following questions:

- How are the ideas and information about bioprinting connected to what you already know about organs?
- What new ideas extended your thinking or made you think differently?
- What questions do you have about bioprinting?

Figure 3.41 3D printing of a human heart

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

Try this 3.7

Testing your heart rate

Your heart rate responds to the oxygen requirements of your body. For each of the following test conditions, follow the procedure below and record your heart rate (in beats per minute) in the table. You will need a stopwatch.

Find your pulse by gently pressing two fingers over your radial artery (on the inner side of your wrist, slightly off-centre towards the thumb). Count the number of beats you feel in 15 seconds, using the stopwatch, and then multiply by four 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 three minutes	

Figure 3.42 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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VIDEO
Contraction of heart chambers

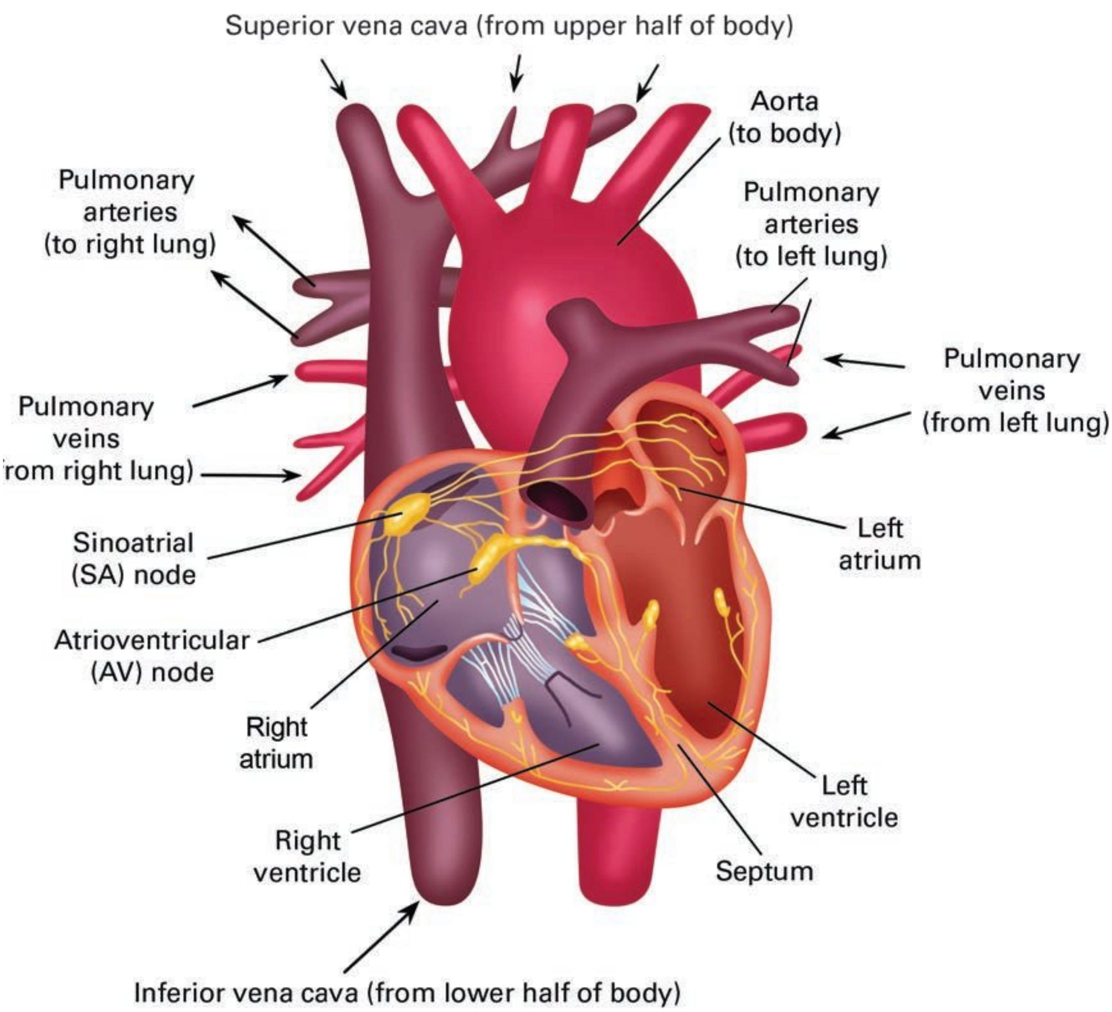

Figure 3.43 The human heart and its major vessels, chambers and valves. The heart is labelled as it sits in your chest, but it is drawn as if it were visible to someone facing you. Therefore, the left ventricle is located on the right-hand side of the diagram.

Did you know? 3.7

Red or blue?

When you look at your wrist, you might be tempted to think that your veins are blue or green, depending on your skin tone. The light passing through our skin makes our veins look blue or green, but this is just an illusion! The appearance of blue veins is due to the interaction of light with the veins and the layers of skin above them. The colours you perceive are determined by the wavelength of light that reaches your eye. Different layers of skin cause the wavelengths to scatter in various ways. In individuals with darker skin tones, veins often appear green, rather than the blue seen in individuals with lighter skin tones. This is because green and blue light have shorter wavelengths compared to red light. Red light can penetrate human tissue better than blue light. As a result, our skin absorbs red wavelengths, while green and blue wavelengths are reflected and scattered back to us, contributing to the colour we observe in veins.

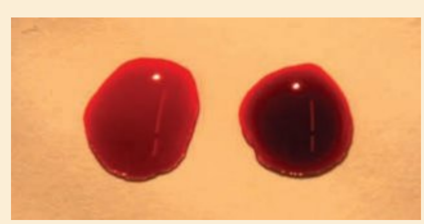

Figure 3.44 Bright-red oxygenated blood (left) and darker deoxygenated blood (right)

continued…

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...continued

Blue veins are particularly noticeable on very pale skin and may have caused the expression 'blue blood' when talking about royalty in some European countries. In the eighteenth century, light-skinned nobility were untanned as they did no manual labour outside, and so their veins would have appeared very blue.

Your veins contain deoxygenated blood (lower levels of oxygen), which is still red, just a darker shade. Some diagrams use blue and red to distinguish deoxygenated blood from oxygenated blood. It is important to remember our blood is always red.

As the blood passes through the lungs, it releases the carbon dioxide it has stored within it and gains oxygen from the alveoli of the lungs.

The oxygenated blood then returns from the lungs through the pulmonary veins into the left atrium. From there, it passes into the left ventricle. The left ventricle pumps the blood out via the **aorta** to all the different parts of the body. This process delivers oxygen to the cells and picks up the waste carbon dioxide.

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

Quick check 3.8

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

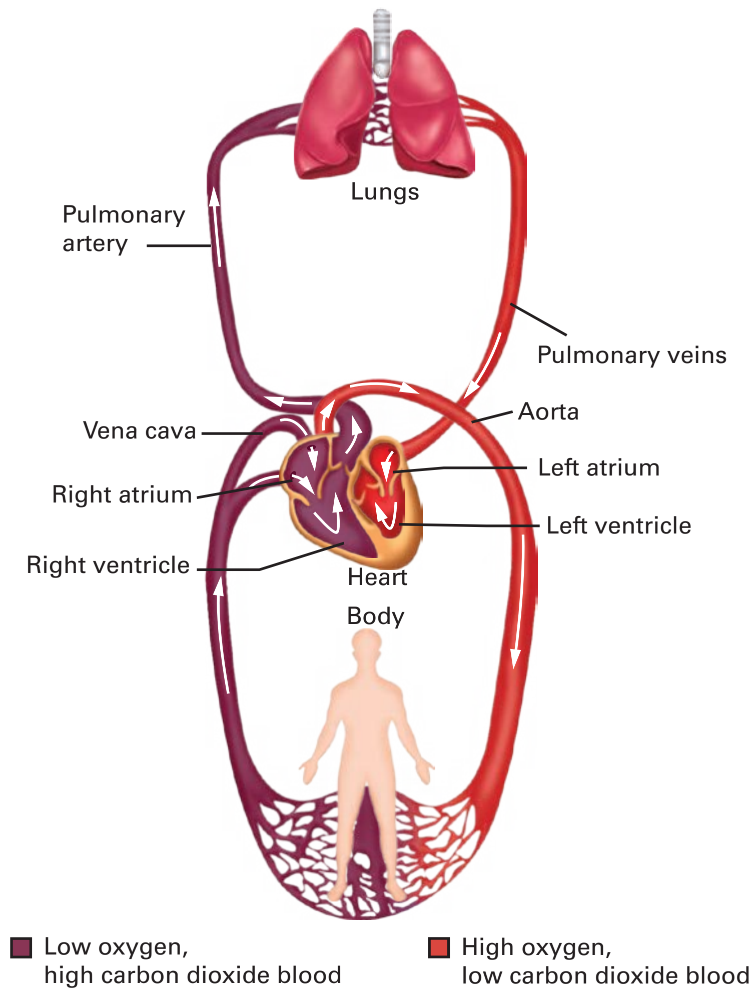

Figure 3.45 Blood flows in the following loop: right atrium ➔ right ventricle ➔ pulmonary artery ➔ lungs ➔ pulmonary vein ➔ left atrium ➔ left ventricle ➔ aorta ➔ body tissues ➔ vena cava ➔ right atrium ... and the loop starts again.

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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 side as the vena cava).
   - pulmonary vein – Place a red pipe cleaner here (representing oxygenated blood, note that this connects to the same side as the aorta).
   - right/left side (Remember, these will be opposite – your left and right).

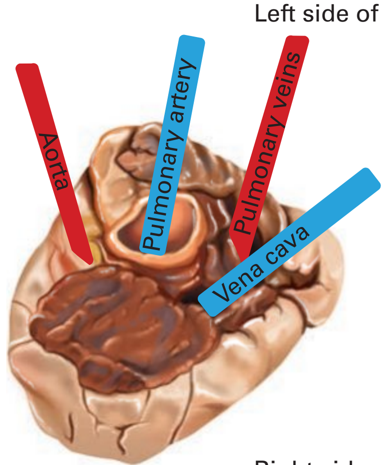

Figure 3.46 Diagram of where you will place the pipe cleaners in the lamb heart

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.

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.

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Science as a human endeavour 3.3

Robot surgeons

Angioplasty is a medical procedure used to treat narrow or blocked arteries, especially those that supply blood to the heart. Coronary angioplasty aims to improve blood flow to the heart and reduce the symptoms of conditions such as angina (chest pain) or a heart attack.

During an angioplasty, a thin, flexible tube called a catheter is inserted into an artery, usually in the groin or arm, and guided to the site of the blockage. A small balloon at the tip of the catheter is then inflated to compress plaque (fatty deposits) against the walls of the artery and widen the opening. In some cases, a small device called a stent may also be inserted to help keep the artery open.

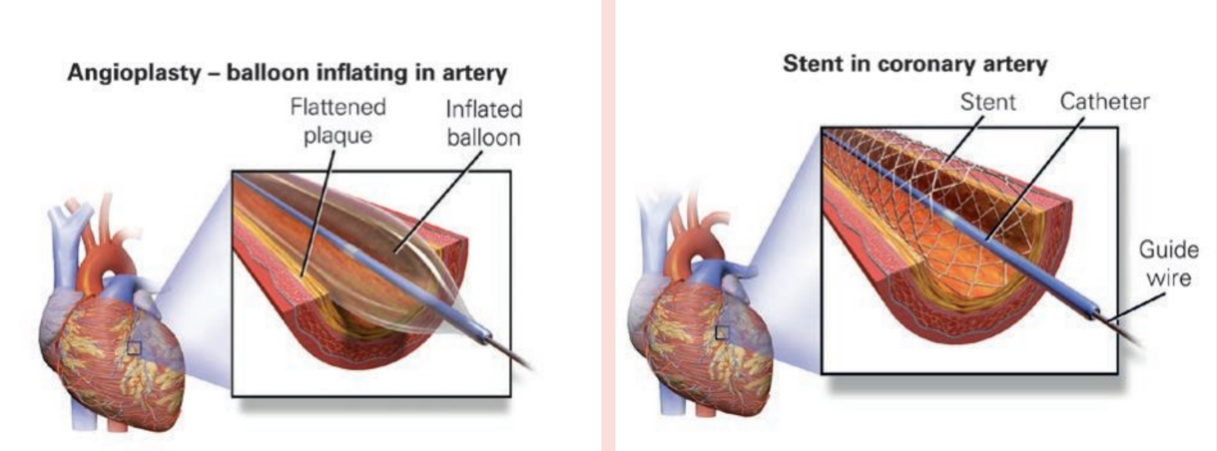

Figure 3.47 Angioplasty procedures

During the procedure, X-ray imaging is often used to guide the catheter to the site of the blockage and to monitor the progress of the procedure. X-ray imaging uses ionising radiation, which can be harmful if a person is exposed to high doses over time. The radiation exposure during angioplasty is relatively low, but it can add up over time for doctors and other medical personnel who perform many procedures. To minimise their exposure to radiation, medical staff usually wear protective clothing, such as lead aprons and thyroid collars, to shield their bodies from the radiation.

Figure 3.48 Using robots to perform angioplasties is not only safer for medical staff but also more accurate.

However, robots are now being used to perform coronary angioplasties. Medical staff can work from a control station shielded against radiation and use joysticks to remotely control the devices needed for the procedure, such as guidewires, balloons and stents. In addition to reducing exposure to radiation, staff do not need to wear heavy lead protective gear during the procedure.

Robot angioplasties have improved the navigation and accuracy of balloon and stent placement due to the millimetre precision of the robotic controls.

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Vessels of the circulatory system

There are three main types of blood vessels in the body: arteries, veins and capillaries.

artery
a thick, muscular elastic vessel that carries blood away from the heart

Arteries

Arteries take blood away from the heart. They carry oxygenated blood to all the cells of the body, with one exception: the pulmonary artery, which carries deoxygenated blood to the lungs. The blood in arteries is pumped out of the heart with a lot of force and this means that the artery walls must be thick, muscular and strong to withstand the pressure being placed upon them.

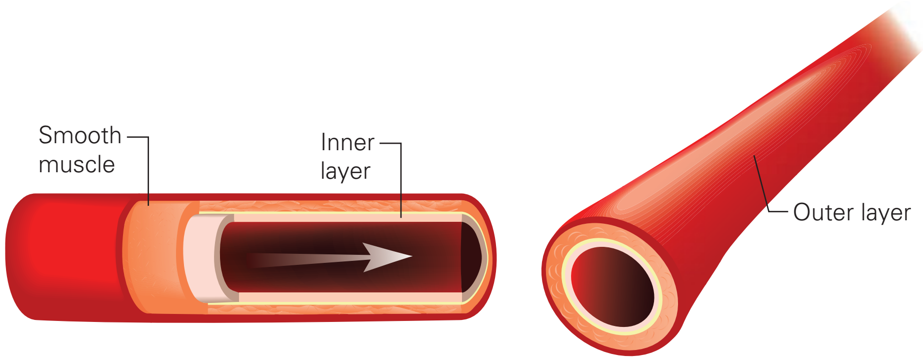

Figure 3.49 The structure of an artery

Capillaries

As the blood travels away from the heart in the arteries, 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.

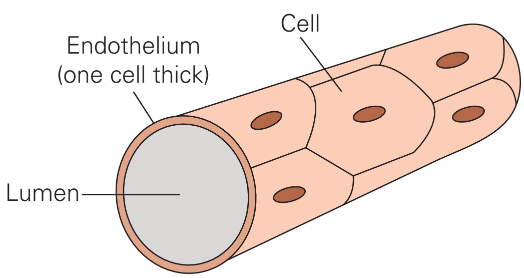

Figure 3.50 The structure of a capillary

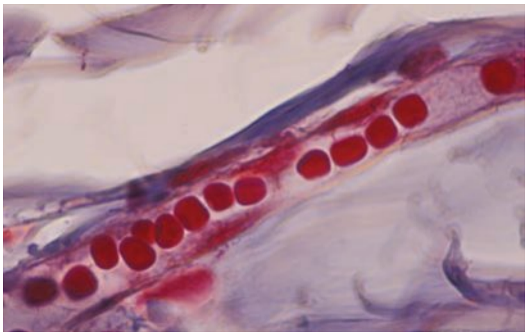

Figure 3.51 A capillary is only slightly wider in diameter than a red blood cell.

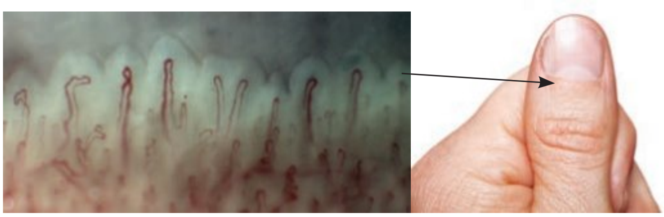

Figure 3.52 Nailfold capillaries (left). The nailfold is located at the base of your fingernail (right).

Veins

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, due to the low flow pressure, the veins need to prevent blood from flowing backwards, and so they have special **valves** that prevent this from happening.

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

valve
a structure that prevents the backward flow of blood

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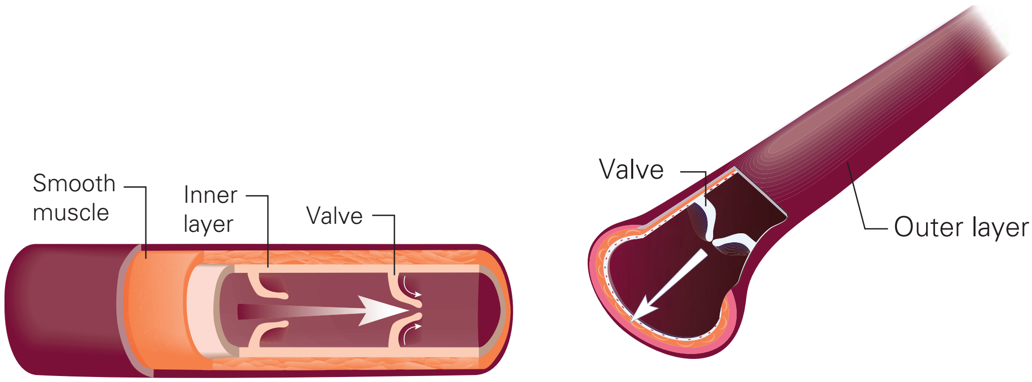

Figure 3.53 The structure of a vein

Quick check 3.9

1. State the vessel type that matches each feature listed below.
   a. thick, muscular walls
   b. diameter one cell wide
   c. valves to prevent backflow of blood
   d. carry oxygenated blood (except for the pulmonary vessel)
2. Explain why arteries carry blood at high pressure.
3. Explain why capillaries need to be one cell thick.

Explore! 3.6

Circulatory system technologies

There are several surgical procedures and devices that can assist people who have malfunctioning hearts, such as when a hardening of the arteries leads to poor circulation or heart disease. Choose one or more of the following to research and answer the questions below.

- automatic external defibrillators
- implanted pacemakers
- mitral valve replacements

1. How does this device or technique work?
2. What problems of the heart does it assist with?

Did you know? 3.8

Bruises

Bruises occur when an impact breaks the capillaries under the skin. As the trapped haemoglobin in the red blood cells breaks down, it changes colour, leading to the colour changes you see in bruises over a couple of weeks.

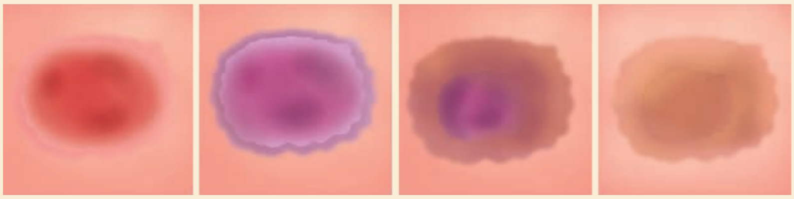

Figure 3.54 From left to right, a stage 1 bruise is red; a stage 2 bruise is purple. At stage 3 it becomes blue, and at stage 4 it becomes more yellow.

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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.

Blood

The human circulatory system is structured around a pumping heart and connected vessels, but the third part is the tissue that is actually circulated: blood.

You have around five litres of blood circulating around your body all the time. This blood contains dissolved nutrients, gases and several types of cells.

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

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

Figure 3.55 Blood plasma

The second-largest component of blood is the red blood cells. These cells contain a molecule called haemoglobin, which gives blood its red colour. Haemoglobin molecules contain iron and can bind with oxygen molecules. Red blood cells are unusual, as they do not have a nucleus. This gives them more space for haemoglobin and hence allow them to carry more oxygen molecules. The biconcave shape provides a greater surface area for gas exchange and allows the cells to be extremely flexible so that they can fit through small capillaries easily.

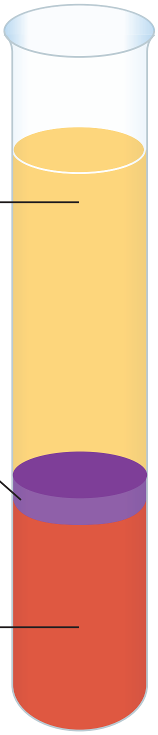

Figure 3.56 The components of blood, separated into layers using a centrifuge

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

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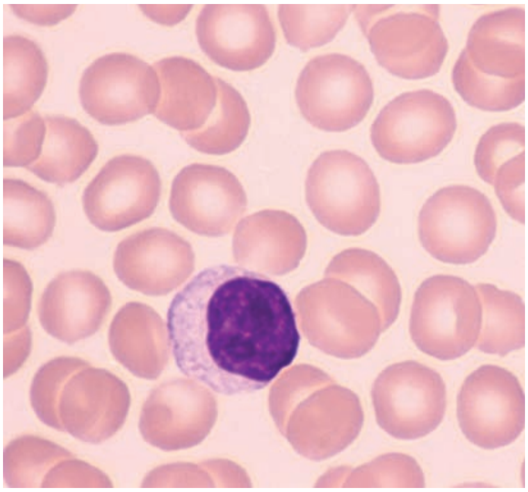

Figure 3.57 An image of a human blood sample (400x magnification). A white blood cell is easily identified due to its size and presence of a nucleus (the nucleus appears dark purple due to a stain being added to the sample). The red blood cells do not have a nucleus and are smaller in size. Their biconcave shape is indicated by the thinner, transparent centre.

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 molecules known as antibodies to destroy the invaders.

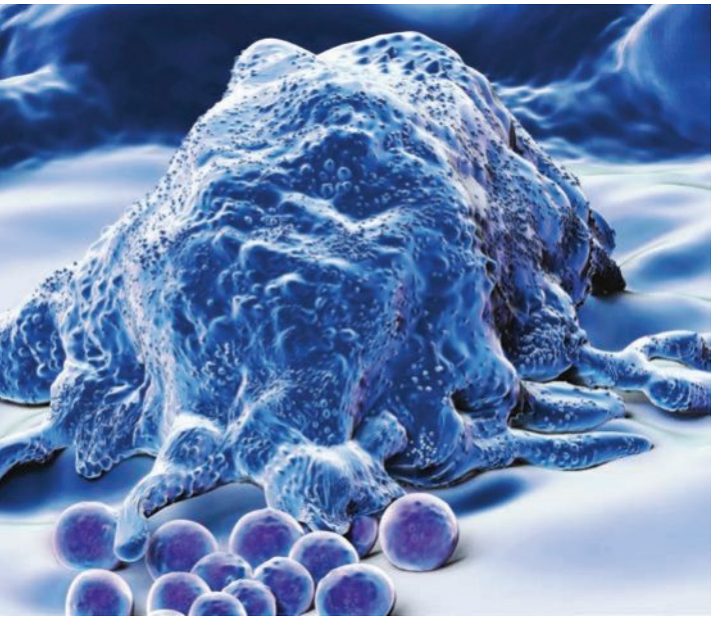

Figure 3.58 A large white blood cell (called a macrophage) engulfing and destroying bacteria

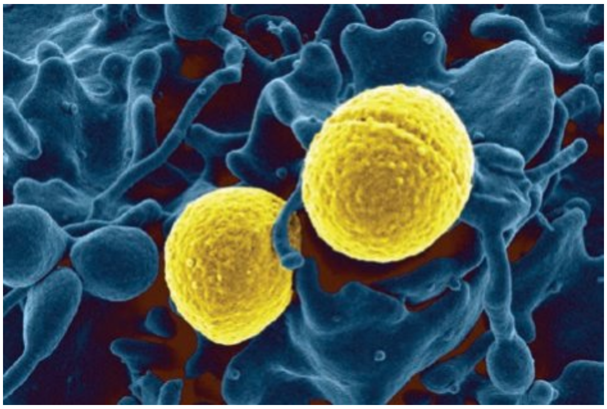

Figure 3.59 A coloured TEM image showing the bacteria *Staphylococcus aureus* (coloured yellow) outside a white blood cell (coloured blue)

platelets
tiny cell fragments that assist with blood clotting

Another component of your blood is the **platelets**. These tiny cell fragments help blood to clot and help scabs form. Platelets are much smaller than red blood cells. If platelets encounter any punctures along the blood vessels, they become activated and change shape. They then release chemicals that produce a thread-like substance called fibrin. 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.

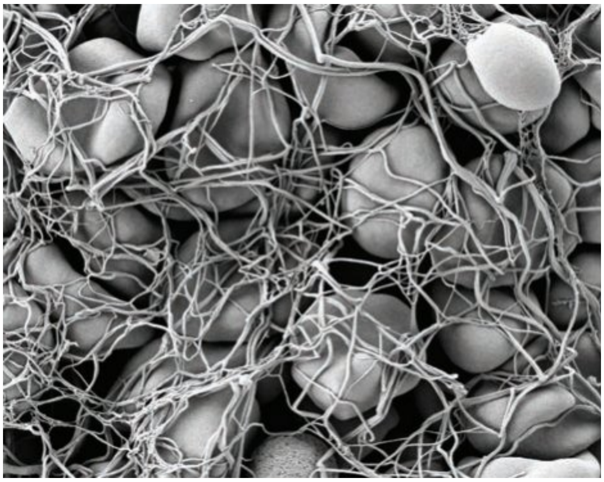

Figure 3.60 Red blood cells trapped in fibrin threads

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Figure 3.61 Platelets help a scab to form over a wound.

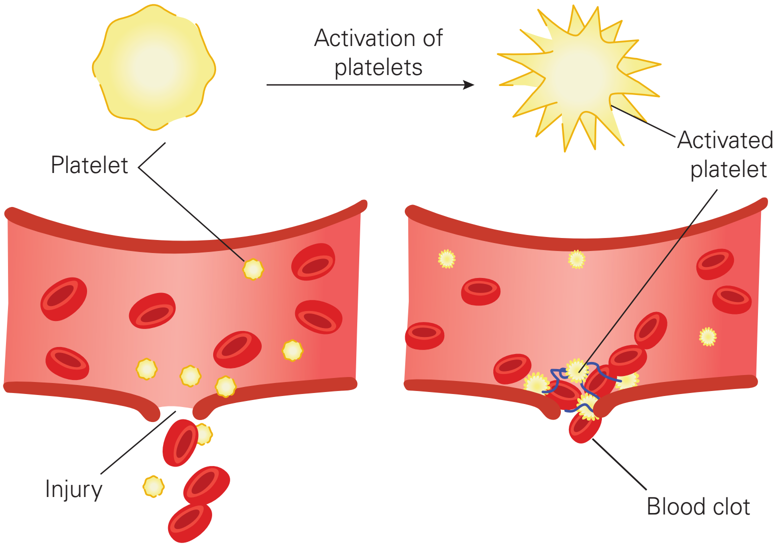

Figure 3.62 Platelets in the blood, sealing a hole in a blood vessel

Did you know? 3.9

Changing blood composition

The composition of your blood can change, depending on many environmental factors. At higher altitudes there is less air, and so there is less available oxygen. People who live at higher altitudes have more red blood cells to cope with this. If you were to go and live on the top of a mountain, after about a week your blood would have adjusted too.

Quick check 3.10

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

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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.
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 3.63 is an ECG readout of a person's heartbeat. The ECG machine captures the electrical signals of the heart. The section between the arrows represents one full cardiac cycle (heartbeat + refilling stage). If the person's heart rate is 120 beats per minute, **calculate** how much time this full cycle takes.

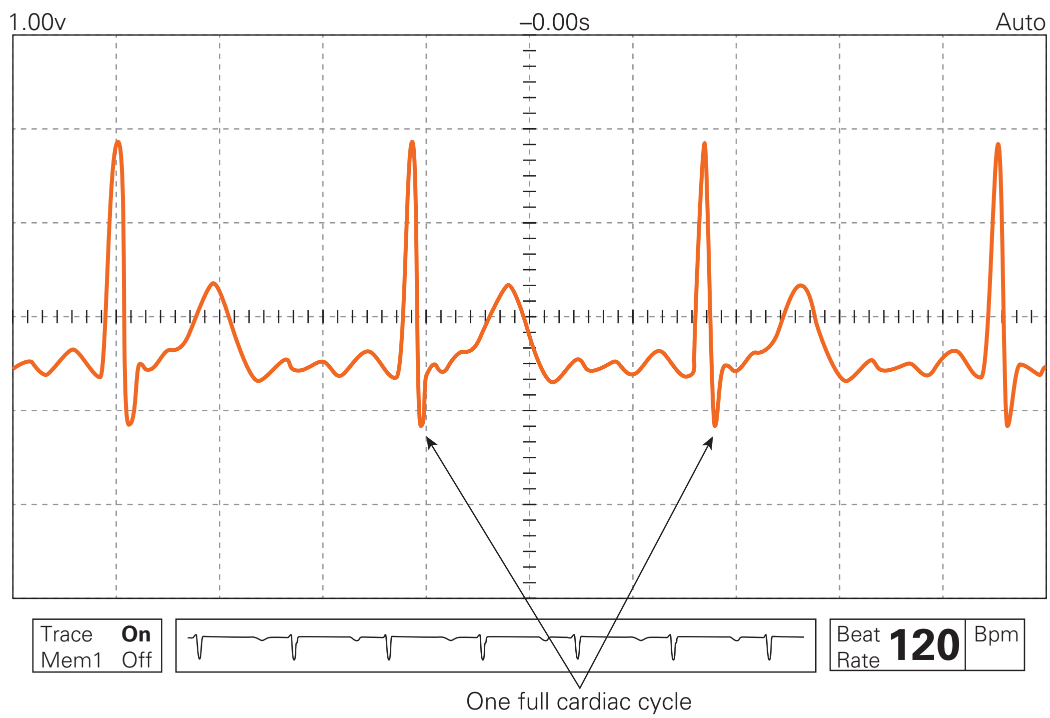

Figure 3.63 ECG printout of a person's heartbeat

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 alveolus 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

WORKSHEET
Human digestive system

Learning goal
To describe the structure of each organ in the digestive system and relate its function to the overall function of the system.

The nutrients we need

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 types of nutrients that humans need can be grouped into four main categories:

heterotroph
any organism that obtains its nutrients by consuming other organisms

- carbohydrates – the main source of energy in the human diet. Bread, pasta, rice and oats are all great sources of carbohydrates. The simplest carbohydrate is glucose.
- proteins – the building blocks of life and the main structural component of most of the living parts of your body. Proteins are needed for growth and repair. Meat, cheese, eggs, seeds, nuts and legumes are great sources of protein.
- lipids – also called fats and oils. Fats transport some vitamins around our bodies, are a good energy source and help protect the delicate organs inside our bodies from shock or impact.
- vitamins and minerals – essential for the efficient functioning of our body. There are many vitamins and minerals that we can't make ourselves, so we must consume them in the food we eat.

Did you know? 3.10

Where does vitamin C come from?
Vitamin C helps the body to absorb more iron, which is required for oxygen-carrying haemoglobin in the blood. It also aids in the production of collagen, which helps heal cuts in your skin.

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

Figure 3.64 All citrus fruits have a high level of vitamin C.

Quick check 3.11

1. Recall the simplest carbohydrate.
2. Recall another name for lipids.
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 involves physical changes – that is, physically breaking food into smaller components but not changing the chemical structure of the food. Examples include breaking food apart with your teeth and tongue when you chew, and 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.

mechanical digestion
a series of mechanical processes that break food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

chemical digestion
a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

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

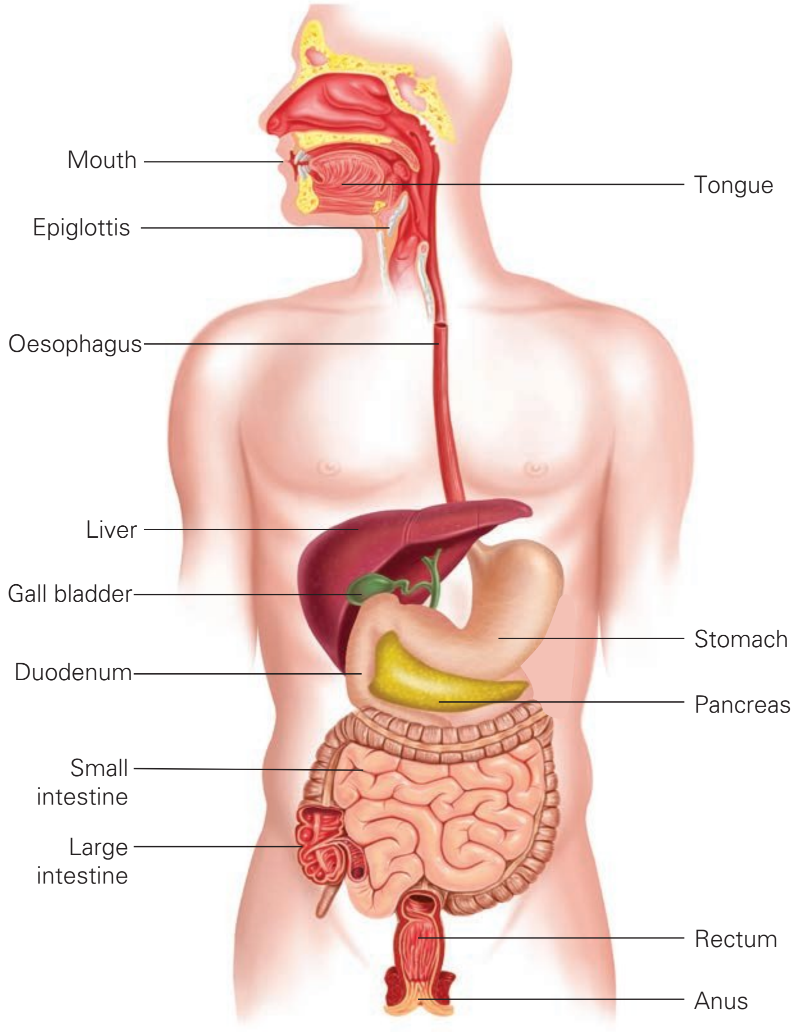

Figure 3.65 The human digestive system

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Mouth and tongue

The mouth has many specialised structures that start the digestive process. First, your teeth cut, tear and grind the food, breaking it into smaller pieces. This increases the surface area of the food, which helps with chemical digestion later. The tongue moves the chewed food around the mouth and coats it in saliva. It forms a lump of partially broken-down food, called a **bolus**.

bolus
a lump of partially digested food

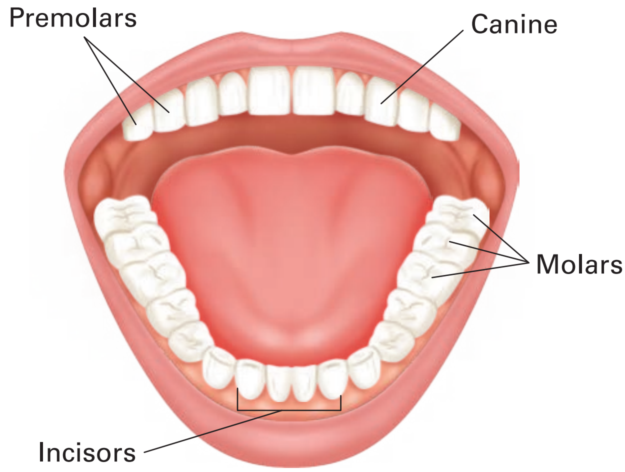

Figure 3.66 The different kinds of adult teeth: incisors for cutting, canines for tearing and molars for grinding

Did you know? 3.11

Taste buds

The average person's tongue is around 8.5 cm long and has 2000–4000 taste buds on it. A quarter of the population has 4000 taste buds and therefore a superior sense of taste. Your taste for certain foods can change throughout your life, because as you age you lose some taste buds and your sense of smell decreases, meaning that you become less sensitive to food. As a teenager, your sense of smell and taste are much stronger than an adult's.

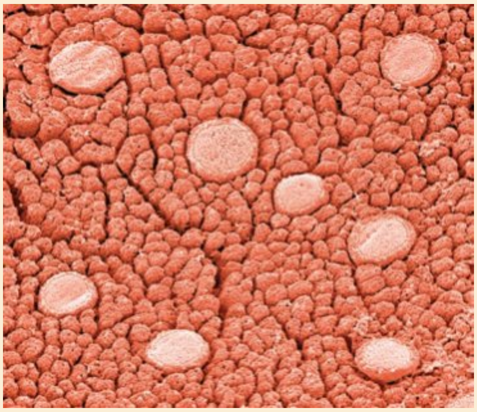

Figure 3.67 The surface of the tongue is covered with a mucous membrane and is also covered with tiny bumps called papillae. The papillae contain taste buds, which are responsible for detecting different tastes, such as sweet, sour, salty, bitter and umami.

saliva
liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

enzyme
a protein that can speed up chemical reactions in living organisms

Saliva lubricates the food to make its movement through your body smoother. It also has a role in chemical digestion because it contains special proteins, called **enzymes**, that begin to break down the food at a molecular level.

The main enzyme found in your saliva is called *amylase* and it begins to break down carbohydrates, such as starch, into maltose in your mouth. Many more enzymes are found along the digestive tract and each is designed to break down a particular food type.

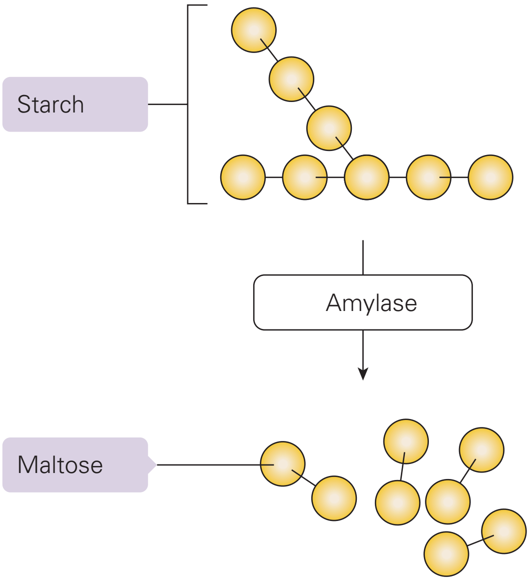

Figure 3.68 Amylase breaks the bonds in starch to form smaller maltose molecules.

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Try this 3.9

Thanks, enzymes!
Place a small piece of bread or a dry savoury cracker on your tongue and leave it to sit there for a while. As the amylase in your saliva begins to break down the carbohydrates, you should be able to taste the sweeter maltose subunits.

Oesophagus

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 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

VIDEO
Peristalsis

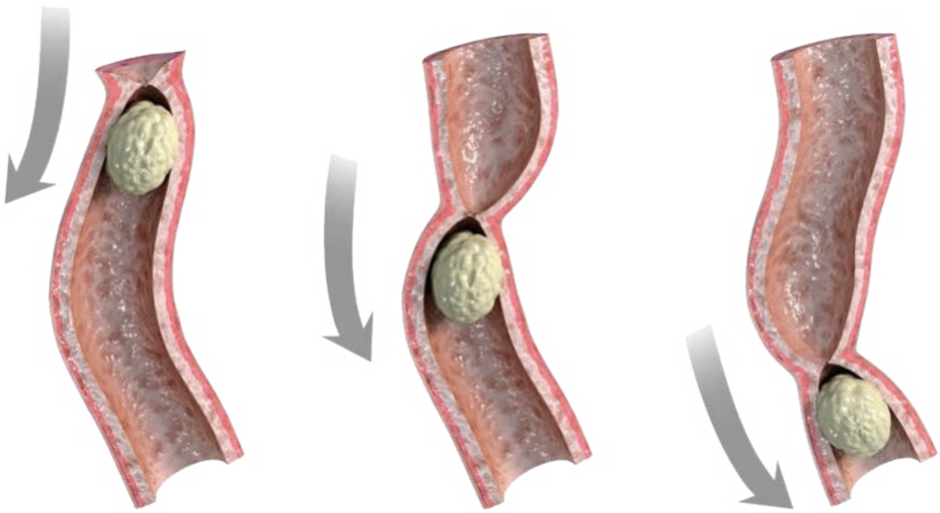

Figure 3.69 Peristalsis moves the bolus of food down the oesophagus.

Try this 3.10

Modelling peristalsis
Find an old nylon stocking and cut off the toe end of the leg. Place a tennis ball at the toe end and gently squeeze behind the tennis ball, to move it along the length of the stocking. This is how the muscles of the oesophagus push a bolus of food along.

Quick check 3.12

1 Describe the function of saliva.
2 Name the enzyme found in saliva.
3 Recall the number of taste buds that an average person has.
4 State if chewing food is an example of mechanical or chemical digestion.
5 Define 'peristalsis'.

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Stomach

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

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 acid reflux or 'heartburn'.

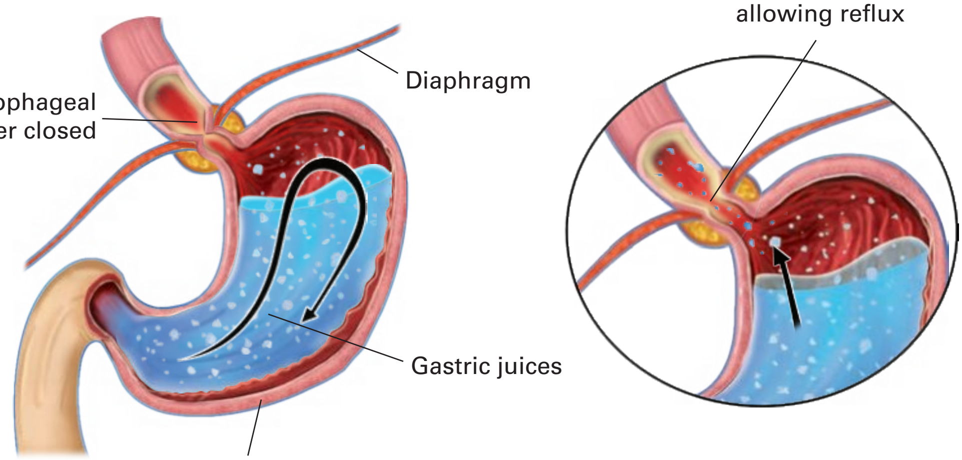

Figure 3.70 When the oesophageal sphincter fails to close, gastric juices can irritate the bottom of the oesophagus.

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. The stomach wall is a mucosal membrane, which produces mucus to protect the stomach tissue from the strong acid.

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.

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, at the base of the stomach, into the small intestine.

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

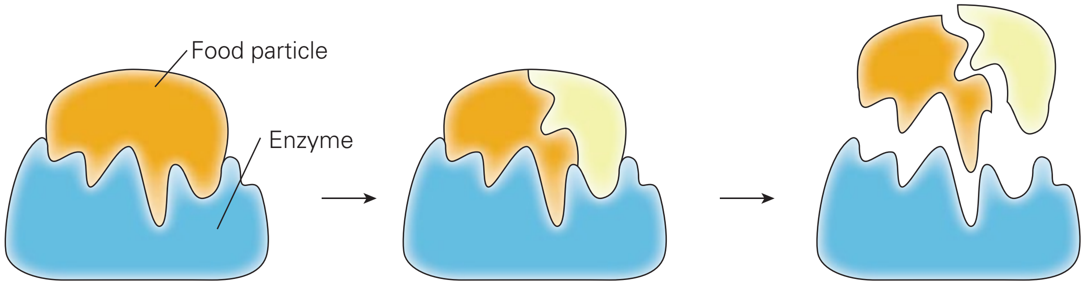

Figure 3.71 Each enzyme fits a specific type of molecule, like a key fitting a lock. An enzyme attaches itself to a food particle and speeds up the chemical reaction that breaks down the food particle, and then it releases the broken-down food particle.

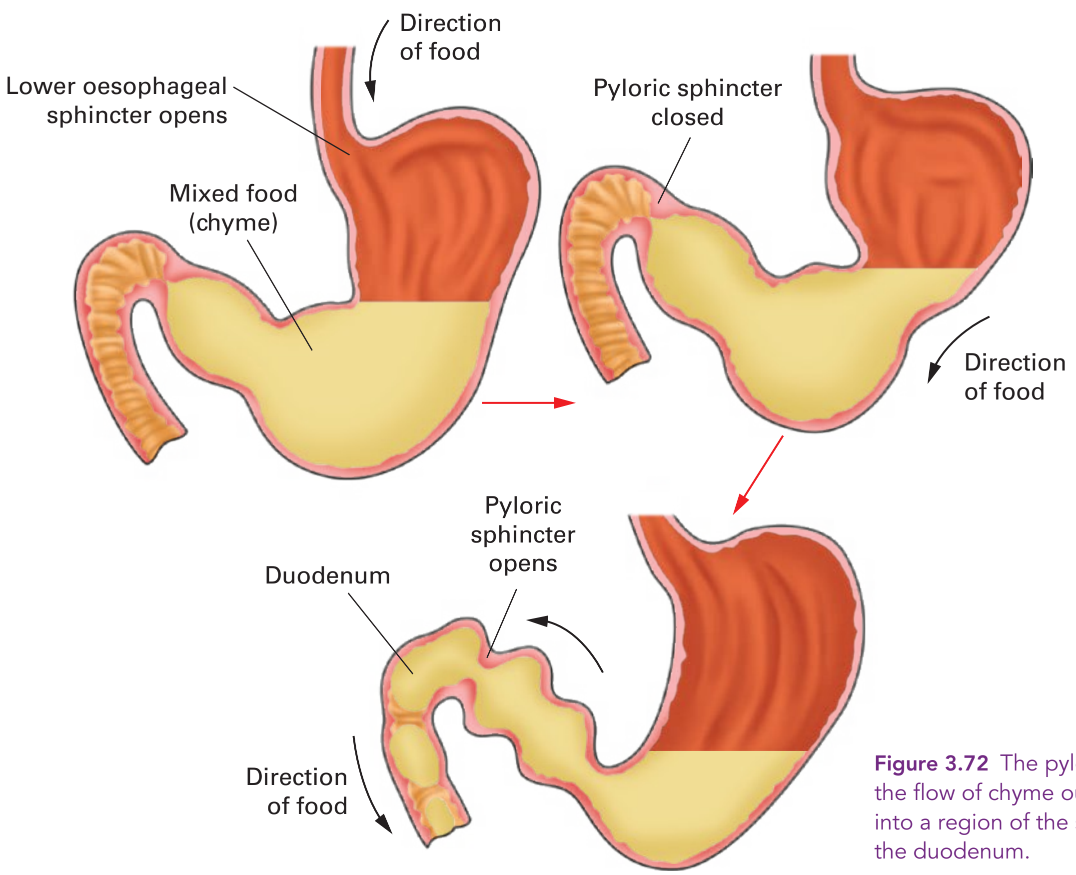

Figure 3.72 The pyloric sphincter controls the flow of chyme out of the stomach and into a region of the small intestine called the duodenum.

Quick check 3.13

1 State two sites of mechanical digestion.
2 Define 'chyme'.
3 Name the enzyme that catalyses the digestion of protein.
4 Explain why the stomach wall is lined with mucus.

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duodenum
the first section of the small intestine where many enzymes are secreted

jejunum
the second section of the small intestine, where food breakdown and nutrient absorption occur

ileum
the third section of the small intestine, where further food breakdown and nutrient absorption occur

liver
a large organ that has many functions, including the production of bile

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

gall bladder
a small organ near the liver that stores bile and secretes it into the duodenum

pancreas
an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

villi
finger-like structures in the digestive system that have a high surface area and rich blood supply for absorption of nutrients

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 also occurs in the small intestine and it propels the chyme forwards and continues all the way along the digestive tract.

The **liver** produces **bile**, which helps to mechanically break down fats or lipids. The bile is stored in the **gall bladder** and is excreted into the duodenum if you eat a fatty meal.

Bile acts like a detergent – it emulsifies or breaks big globs of fats and oils into smaller ones that can be easily moved and broken down further. Bile has the second job of neutralising the 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 good blood supply, which increase 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 intestine is to finish off any absorption of nutrients and to compact the remaining digested food and pass it through into the large intestine.

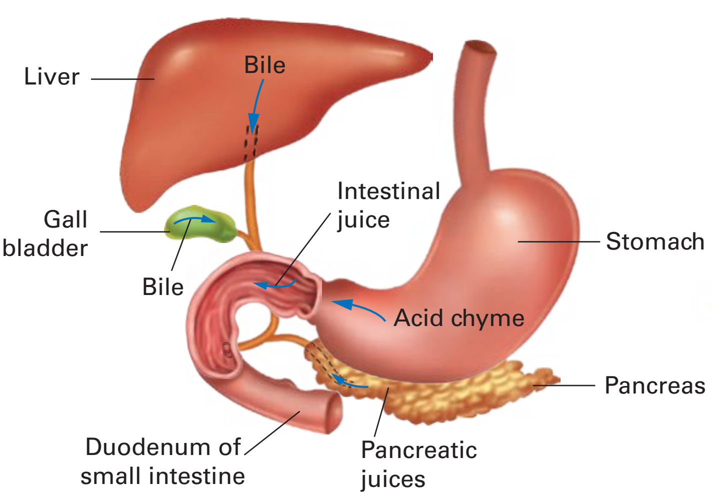

Figure 3.73 The liver, gall bladder and pancreas all contribute to the digestion of food and are connected to the duodenum.

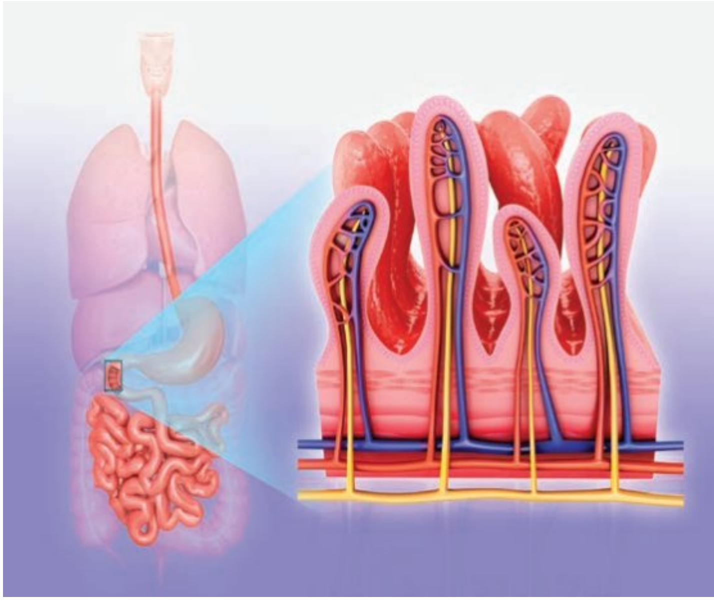

Figure 3.74 Finger-like villi in the intestines are specialised for absorption of nutrients.

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Large intestine

The **large intestine** is one to two metres long and has five parts: caecum, appendix, colon, rectum and anus. Its main function is to absorb water from the material left over from digestion. The large intestine also has large numbers of helpful bacteria that can produce vitamin K and vitamin B for your body to use. In humans, the **caecum** is a pouch at the start of the large intestine, where it joins the small intestine. The caecum helps digest and absorb nutrients, especially plant materials, with the assistance of bacteria. The appendix has long been considered a useless organ that is a remnant of evolution, but there is ongoing debate about what its actual role is. As waste enters the large intestine and passes through the colon, water leaves the waste and is absorbed back into the bloodstream, resulting in a solid mass called faeces remaining in the colon. Faeces are stored in the **rectum** and when the rectum is full, it sends a signal to your brain to tell you to go to the toilet. The faeces then pass out through a sphincter called the **anus**.

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

Figure 3.75 Most bacteria in your body are in the intestine. It is thought that the appendix could be a safe haven for good bacteria that can repopulate the gut after sickness and diarrhoea.

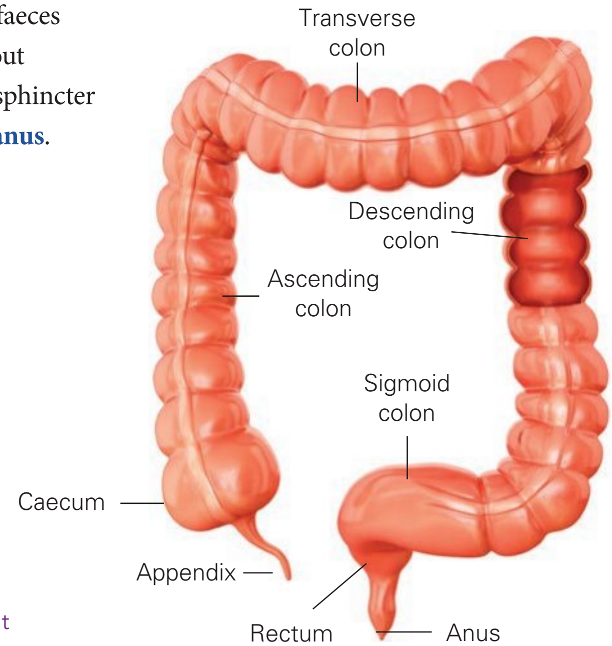

Figure 3.76 The five sections of the large intestine

Explore! 3.7

A lot of you is not you!

The average person's body has around the same number of human cells as bacterial cells.

Until recently, it was thought that the number of bacteria in our bodies outnumbered our own cells 10:1. However, new research suggests that the average person is more likely to have a 1:1 ratio of bacteria and human cells. In any human body there are approximately 30 trillion human cells, but our microbiome is an estimated 39 trillion microbial cells that live on and in us. Despite only making up 1–3% of our body mass, they play an important role in our health and wellbeing.

Three quarters of the types of microbes in you can be traced back to your birth. The bacteria in the vaginal microbiome plays a key role in establishing the gut microbiome in newborns, and babies born via caesarean section are at increased risk of certain health problems later in life such as asthma, allergies and obesity.

Research the role that your microbiome plays in the following:

- digestion
- immune response
- metabolism
- mental health

Figure 3.77 Faecal microbiota transplantation (FMT) is a medical procedure that involves the transfer of gut bacteria from a healthy donor's faeces to the gut of a person with a digestive or immune system disorder.

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Quick check 3.14

1. State the three sections of the small intestine.
2. The liver produces bile, which is stored in the gall bladder. Recall the type of food that bile helps to mechanically digest.
3. Explain how villi improve absorption of nutrients.
4. Organise the following sections of the large intestine in the correct order: rectum, colon, anus, caecum.

Did you know? 3.12

Is your stomach rumbling?

Ever heard those gurgling stomach noises when you are hungry? Well, they are the sounds of hyperactive peristalsis in the intestines and are named *borborygmi*. When the muscles in your stomach and small intestine are pushing everything along, all the food packed inside muffles the sound. But if it's been a while since you've eaten, most of that food is gone (hence why you equate it with being hungry!) and all those gurgling gases are easier to hear.

Digestion gone wrong

Food poisoning

Your body can detect hazardous substances in the food you eat. Sometimes food can be contaminated with toxins or microorganisms that could do harm to your body. If your body senses the presence of these harmful substances, it signals your digestive system to empty quickly. This causes the stomach to contract violently, causing vomiting, and it also causes the intestines to contract, causing diarrhoea. Even though getting sick is never fun, it is your body's way of protecting you by removing the harmful substances.

Digestive disorders

Many people cannot eat certain foods, because of intolerance or allergy. An **intolerance** is when a food cannot be properly broken down by the body and results in an adverse reaction.

intolerance
an inability to eat a food without resulting in adverse effects

One of the most common intolerances in humans is lactose intolerance. Lactose-intolerant people are unable to digest the sugar in milk and dairy products, called lactose. Normally, when somebody eats food containing lactose, the enzyme lactase is released in the small intestine to break down the sugar into more simple sugars. People who are lactose intolerant do not have lactase, and this means that the sugars do not get digested and absorbed. Instead, the bacteria in the intestines break down these sugars, leading to bloating, lots of gas and diarrhoea.

Because humans are mammals, we all drink milk as infants. This means that the enzyme lactase, which breaks down lactose, is found in everybody when we are young. As we grow older and start to eat solid foods, some of us may lose the lactase enzyme. Anyone can become lactose intolerant at any stage in their life, although there are certain groups of people who are more likely to become lactose intolerant. Some examples:

- People of Asian, African, Indigenous and South American backgrounds are more likely to develop lactose intolerance at a young age.

Figure 3.78 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! 3.8

Coeliac disease

Blunted villi are a symptom of coeliac disease, a condition where a person's immune system responds to eating gluten.

Gluten is a protein in wheat, rye and barley-based products such as bread, pasta, pastry, cakes and biscuits. Bread has been a stable part of the human diet for thousands of years, and so many people view gluten intolerance and coeliac disease as new phenomena, but humans have been affected by these conditions throughout history. However, it was not until about 100 years ago that doctors began to diagnose and treat coeliac disease.

In coeliac disease, the immune response to gluten causes inflammation that damages the villi, making them blunted or flattened. This leads to a decrease in the surface area available for absorption of nutrients, which can result in malabsorption and malnutrition.

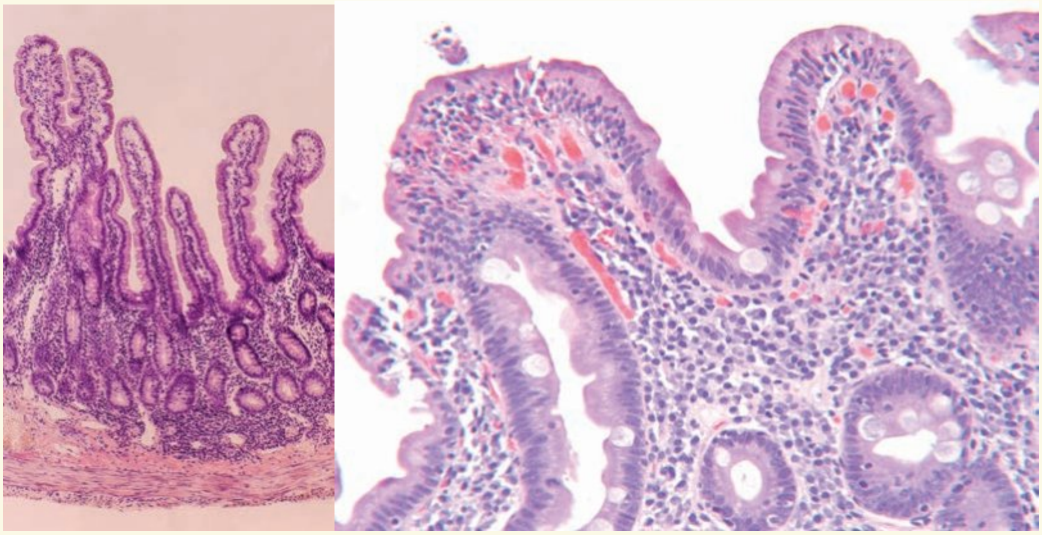

Figure 3.79 Villi in the small intestine of a healthy person (left) compared with blunted villi in a coeliac sufferer (right)

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.

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Science as a human endeavour 3.4

Seeing you from the inside

Capsule endoscopy is a medical procedure that involves swallowing a small camera-equipped capsule that captures images of the digestive system. The capsule travels through the digestive tract and transmits real-time images to a recording device worn by the patient. This procedure allows doctors to visually examine the interior of the small intestine, which is otherwise difficult to access using traditional endoscopic techniques.

Figure 3.80 Camera capsules used to examine the oesophagus (left), small intestine (middle) and large intestine (right)

Capsule endoscopy is used to diagnose and monitor conditions such as Crohn's disease, ulcerative colitis, bleeding in the small intestine and unexplained abdominal pain. It is a non-invasive, painless and well-tolerated procedure for most patients and provides a valuable tool for the diagnosis and treatment of a range of gastrointestinal conditions.

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 break down fats	
Lactase breaking down lactose	

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 gall bladder was removed from the digestive tract.

13 Crohn's disease is a bowel condition that causes flare-ups of inflammation in the ileum, which leads to impaired nutrient absorption. It also causes inflammation of the large intestine. **Propose** what effect this might have on the faeces.

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3.6 Other digestive systems

Learning goal
To be able to compare the structure and function of analogous digestive systems in animals.

WORKSHEET
Comparing skeletal structure and diet

Have you ever had food poisoning after eating undercooked or old food? Food can make you sick when it contains too many bacteria for your body to deal with. But why does that happen to you while some scavenger animals can eat rotten meat and not get sick?

How is it that some animals eat only leaves and still manage to get all the protein, fats and iron they need to be healthy?

The answers to both these questions can be found in their specialised digestive systems.

Carnivores

The human digestive system is designed to process and break down both animal and plant products. However, unlike other animals, we cook our food, which reduces the number of harmful bacteria entering our digestive system.

Figure 3.81 A black vulture eating a dead wood stork

Carnivore and scavenger species, such as vultures, have traits that have evolved that allow them to eat food containing large amounts of bacteria without getting sick.

Digestive system length

Carnivores have a shorter digestive system compared to a **herbivore** or an **omnivore**. Animal cells do not have a cell wall like plants, which makes them easier to digest (cell walls contain cellulose, which is hard to digest). This means the food passes through the animal's digestive system quickly, and harmful bacteria have less chance to grow and cause illness.

carnivore
a consumer (heterotroph) that feeds on animal matter

omnivore
a consumer (heterotroph) that eats a variety of plant and animal matter

herbivore
a consumer (heterotroph) that feeds on plant matter

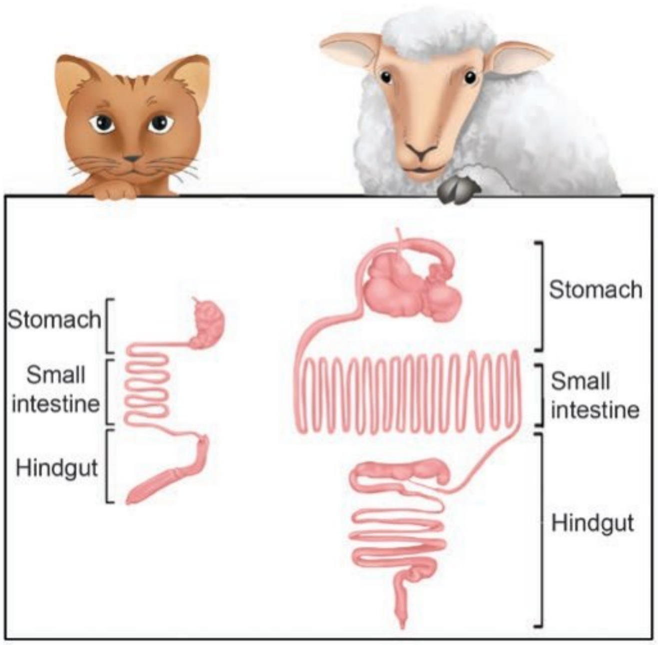

Figure 3.82 Cat (carnivore) and sheep (herbivore) digestive systems

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Stomach acid

The stomach acid in humans is around 1.5 to 3.5 on the pH scale. This is strongly acidic, allowing our bodies to kill many harmful microorganisms, but not all of them. In comparison, a vulture's digestive acid is 0–1 on the pH scale, which is strong enough to dissolve certain metals and so is more than a match for any bacteria.

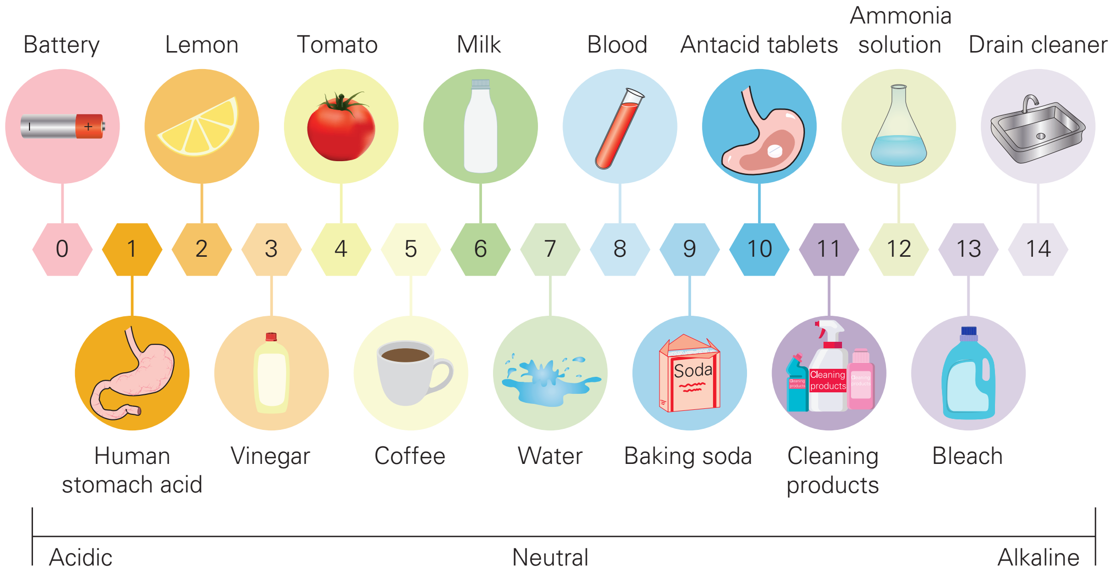

Figure 3.83 The pH scale showing pH of common substances

Did you know? 3.13

Pandas

Giant pandas are technically classified as carnivores due to the presence of carnivorous characteristics, such as sharp teeth, a gastrointestinal tract typical of carnivores and strong jaw muscles. They also do not have the genes for plant-digesting enzymes. Despite this, their diet is mainly bamboo, which makes up over 99% of their daily intake.

Figure 3.84 Despite eating bamboo, giant pandas have digestive systems that are better suited to eating meat.

This means that pandas must consume large quantities of bamboo to extract sufficient nutrients from it. They spend most of their day eating and can consume up to 20 kg of bamboo every day. This is a challenge for their digestive system, as bamboo fibres are difficult to break down, leading to a slow and inefficient digestion process.

It is still unclear what caused them to stop eating meat, but some scientists think it was due to an abundance of bamboo and a lack of available protein sources in their native habitat of central China. Other researchers have suggested that they stopped eating meat at the same time that their gene for the savoury umami taste receptor became inactive.

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Quick check 3.15

1 Contrast a vulture's stomach acid with a human's.
2 State who has a shorter digestive tract: carnivores or herbivores.

Explore! 3.9

Carnivorous plants

Not all plants rely on sunlight and water for their food. Some add meat to their diet to give them a nutrient boost. Most carnivorous plants live in swamps and marshes, where the soil doesn't have many nutrients, especially nitrogen, and so they rely on breaking down insects to absorb nutrients.

Find out about each of the following carnivorous plants and summarise how they catch their prey, the structures they have that allow them to catch their prey, and how they digest their prey.

1 Venus flytrap

Figure 3.85 A Venus fly trap and an unsuspecting fly

2 Sundew

Figure 3.86 A sundew wrapping around an insect

3 Pitcher plant

Figure 3.87 A pitcher plant and its possible prey

Herbivores

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

Koalas are herbivores with adaptations that allow them to obtain the nutrients that they need from eucalyptus leaves. They have a long digestive tract and a very large caecum, around 200 cm long and 10 cm wide, where the cellulose in the cell walls can be digested.

In herbivores, the caecum contains millions of helpful bacteria that are specialised to break down certain plant materials (such as eucalyptus leaves).

Figure 3.88 Grasses and roots make up most of a wombat's diet, but wombats will also feed on the young leaves of eucalyptus trees when available. Their long and slow-moving digestive tract allows them to extract the maximum amount of nutrients from the fibrous matter.

VIDEO
Carnivorous plants

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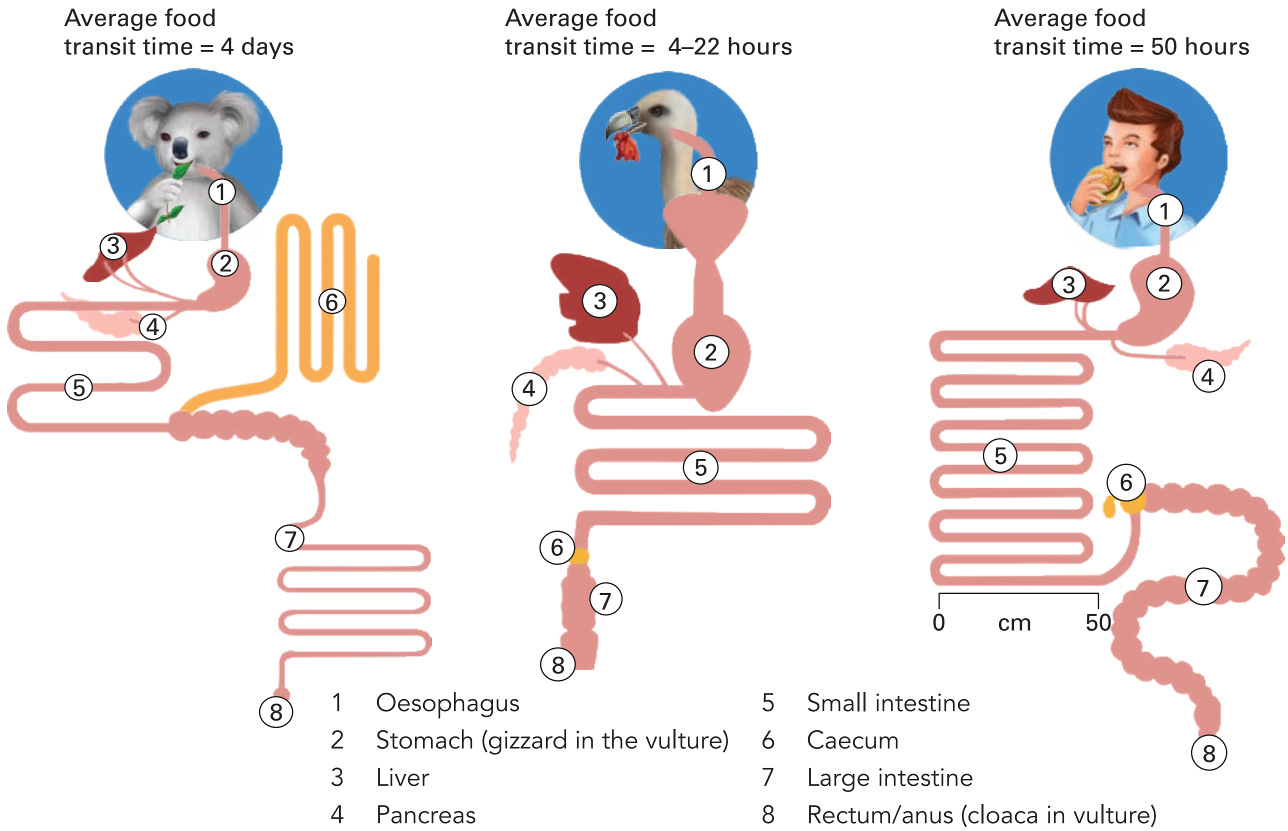

Figure 3.89 Digestive systems and food transit times for koalas, vultures and humans

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 large caecum, koalas need to eat for five hours a day to get enough food to sustain them. They spend most of the rest of their day sleeping, to conserve energy and to allow their bodies to digest their food.

In total, it can take around four whole days for a leaf to pass through a koala's digestive system. This maximises the amount of nutrients and water that is absorbed from the food.

Ruminants

Cows are herbivores, just like koalas, so they need to eat for most of the day to gain as much nutrition from their food as possible. Cows are in a special category of herbivores, called *ruminants*. Ruminants, including antelope, sheep, buffalo and goats, digest their food in a unique way. Figure 3.91 shows the path of food through a ruminant.

Did you know? 3.14

Koala faeces

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

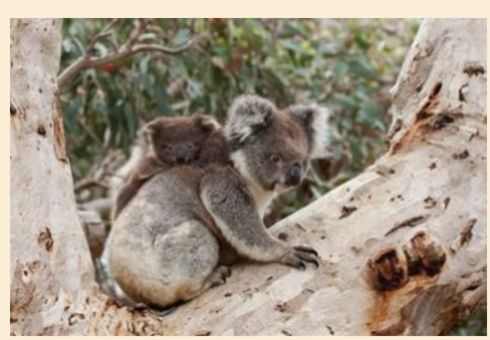

Figure 3.90 A mother and baby koala

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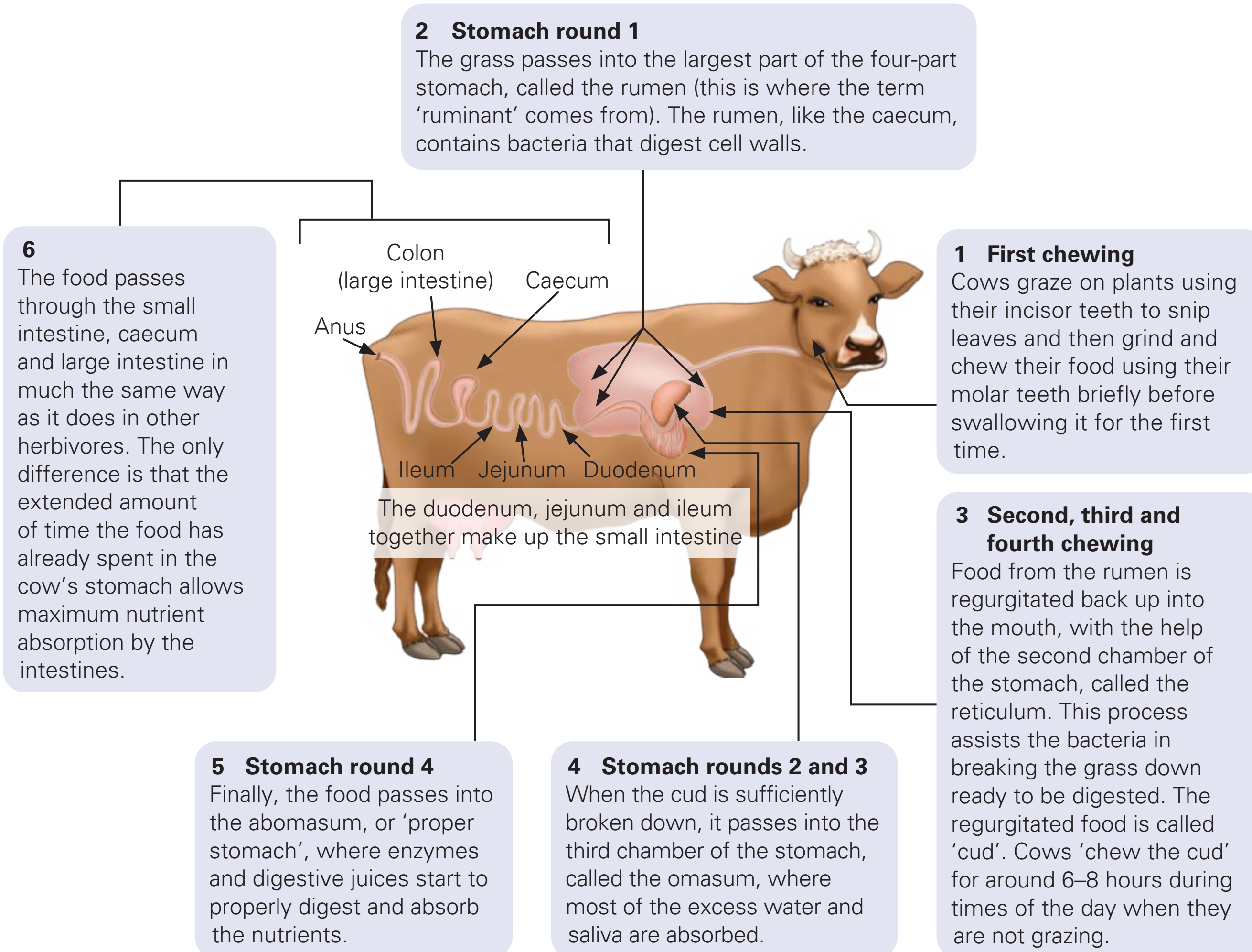

Figure 3.91 The passage of food through a cow's stomach

Quick check 3.16

1. Summarise the role of the caecum in herbivores.
2. Distinguish between the length of a carnivore and a herbivore digestive tract.
3. Describe the way a ruminant digests plant matter.

WIDGET
The mammalian digestive system

Try this 3.12

Digestive flow charts

Construct three flow charts on a poster showing the digestive tracts of a carnivore, a herbivore and a ruminant. Annotate the structures of the digestive tract, showing their specialised functions so that the key differences between these organisms are obvious.

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Section 3.6 questions

QUIZ

Retrieval

1 **Recall** the parts of a herbivore's digestive system.
2 **State** the number of chambers there are in the stomach of a cow.
3 **Name** the substance that plant cells contain, which is difficult for humans to digest and gain nutrients from.
4 **Identify** the words to correctly fill in the gaps: Acids have a _____ pH and bases have a ___________ pH.
5 **Identify** the product in the stomach that kills bacteria.
6 **Identify** two ways in which a vulture's digestive system is different from a human's digestive system.

Comprehension

7 **Explain** how a carnivore can eat meat containing harmful bacteria without becoming sick, while humans cannot.
8 **Describe** how baby koalas gain their gut bacteria.

Analysis

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

Human	Koala

10 Use the images in Figure 3.92 to answer the following questions.

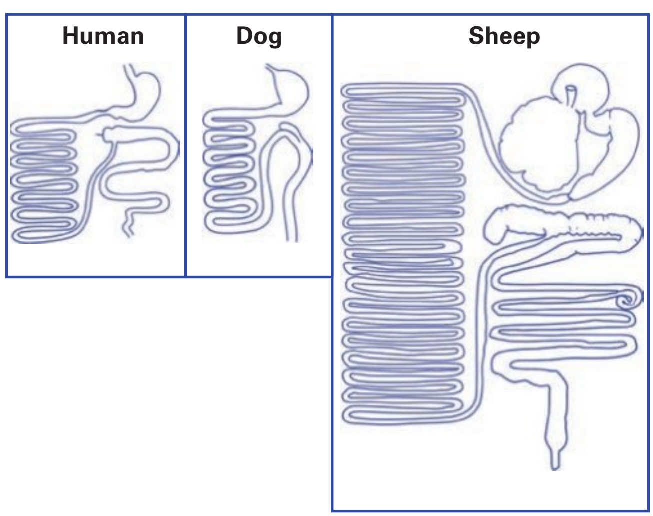

Figure 3.92 Digestive systems of a human, a dog and a sheep

a **Contrast** the digestive system of a dog and a sheep.
b **Identify** which two of the animals in Figure 3.92 probably have a similar diet.

Knowledge utilisation

11 Carnivorous plants tend to prey on small insects or amphibians. **Propose** why attracting larger mammals rather than insects might be a problem for carnivorous plants.

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3.7 Organ disorders

Learning goals

1. To be able to describe how a disorder in cells or tissues can affect how an organ functions.
2. To be able to describe how an artificial organ mimics or augments the function or functions of a real organ.

WORKSHEET
Organ replacement and repair

Each of the organ systems in your body relies on the specialised function of many different organs working together to keep you healthy. But when cells or tissues within an organ become diseased or dysfunctional, it can impact the overall functioning of the organ.

The treatment of an organ that is not functioning properly depends on the specific type of dysfunction and the underlying cause. Common treatments for less severe dysfunction may include medication or lifestyle changes. However, this is sometimes not enough, and the organ may need to be completely replaced.

Explore! 3.10

Medical imaging

Technological advancements in microscopy and medical imaging have significantly contributed to a better understanding of cells and organs. Medical imaging now allows doctors and researchers to non-invasively visualise the inside of the human body. Techniques like MRI (magnetic resonance imaging) and CT (computed tomography) produce detailed images of organs and tissues, while technologies like PET (positron emission tomography) and SPECT (single photon emission computed tomography) can reveal functional information about cellular processes.

Figure 3.93 MRI scan (left) and CT scan (right) of a head

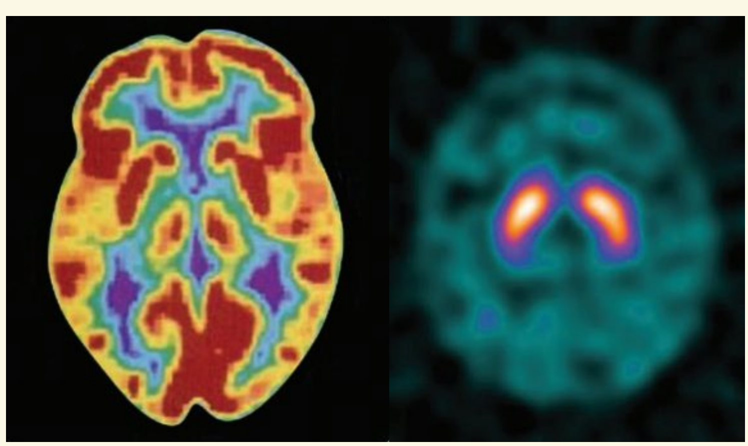

Figure 3.94 PET scan (left) and SPECT scan (right) of a head

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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.

VIDEO Organ transplants

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.

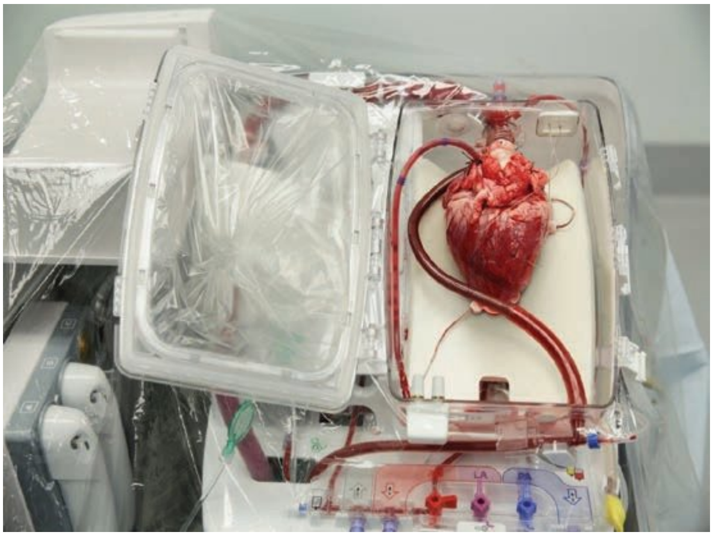

Figure 3.95 A heart being transported ready for transplantation

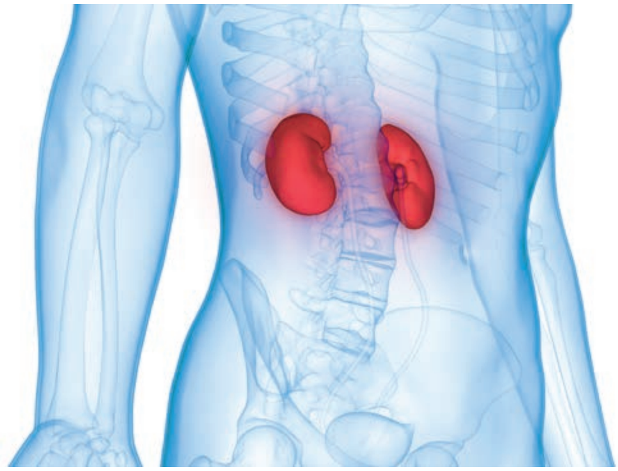

Figure 3.96 Most of us have two healthy kidneys. If they are damaged through disease, one option is a kidney transplant.

Organ donation is sometimes possible when a person dies and has previously indicated that they would like to donate their organs. This donation can save multiple lives, as organs such as the heart, lungs, kidneys, liver, large intestine, pancreas and some tissues, such as skin and corneas from the eye, can all be donated. In 2021, 1174 Australian lives were transformed by 421 deceased and 203 living organ donors and their families.

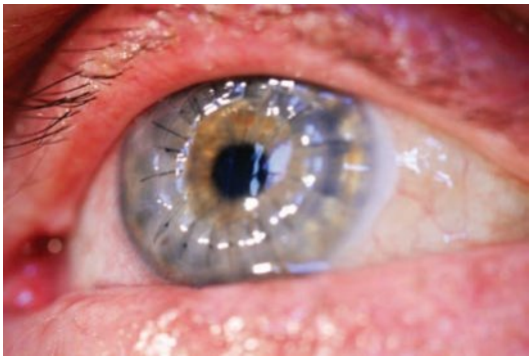

Figure 3.97 A corneal transplant, two weeks after surgery. The sutures are 0.00381 cm thick.

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Not many deaths occur in a way that allows organ donation. In Australia, organ donation typically occurs when a person dies in a hospital setting. This is because the organs need to be removed as soon as possible after death to ensure their viability for transplantation.

Sometimes the families of registered organ donors refuse to give consent. This is why it is very important that people discuss their wishes with their families and consider registering their intentions on the Organ Donor Register.

Quick check 3.17

1 If an organ is damaged, recall the first treatment options before a transplant is considered.
2 Name some of the organs and tissues that can be donated in Australia.
3 Describe what would happen if a transplanted organ came from a donor who was not a good match for the recipient.

Explore! 3.11

Downsizing dialysis

Dialysis is a medical treatment used to remove waste products and excess fluid from the blood of people with kidney failure. The treatment involves patients travelling to a clinic, where they are connected to a large 100 kg machine that filters the blood outside of the body and returns it to the patient. Usually, each treatment lasts about four hours and is done three times per week. This leads to some significant environmental impacts, particularly with regard to water waste as each four-hour session uses 120–180 litres of water.

Many companies are developing alternatives to clinic-based dialysis. Research the benefits of the following new innovations:

- KidneyX
- NextKidney
- automated wearable artificial kidney (AWAK) device
- artificial kidney.

Figure 3.98 An artificial kidney could replace the need for large dialysis machines.

Organ replacement

Because of the high demand but low supply of organs available for transplantation, scientists are developing new ways to overcome this problem. One method is **xenotransplantation**. This is the process of transplanting organs from a different species than the recipient.

Doctors have been transplanting porcine (pig) heart valves into humans since 1965, as pig organs are a similar size and shape to human organs. However, there are two main biological challenges that scientists face with any pig–human transplant procedure:

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

xenotransplantation transplanting organs from one species into another

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In 2022, doctors successfully transplanted a pig heart into an American man, but he sadly died two months after the procedure, possibly due to an infection from the heart.

Later in the year, surgeons successfully transplanted genetically engineered pig hearts into two brain-dead patients in New York. Over three days of monitoring, the new hearts functioned perfectly, and neither body caught any diseases. The hearts were sourced from pigs that had 10 genetic modifications, including four that blocked pig DNA to prevent rejection and abnormal organ growth as well as six human transgenes to improve pig–human compatibility.

Researchers now believe that pig–human transplants will be common within the next few years.

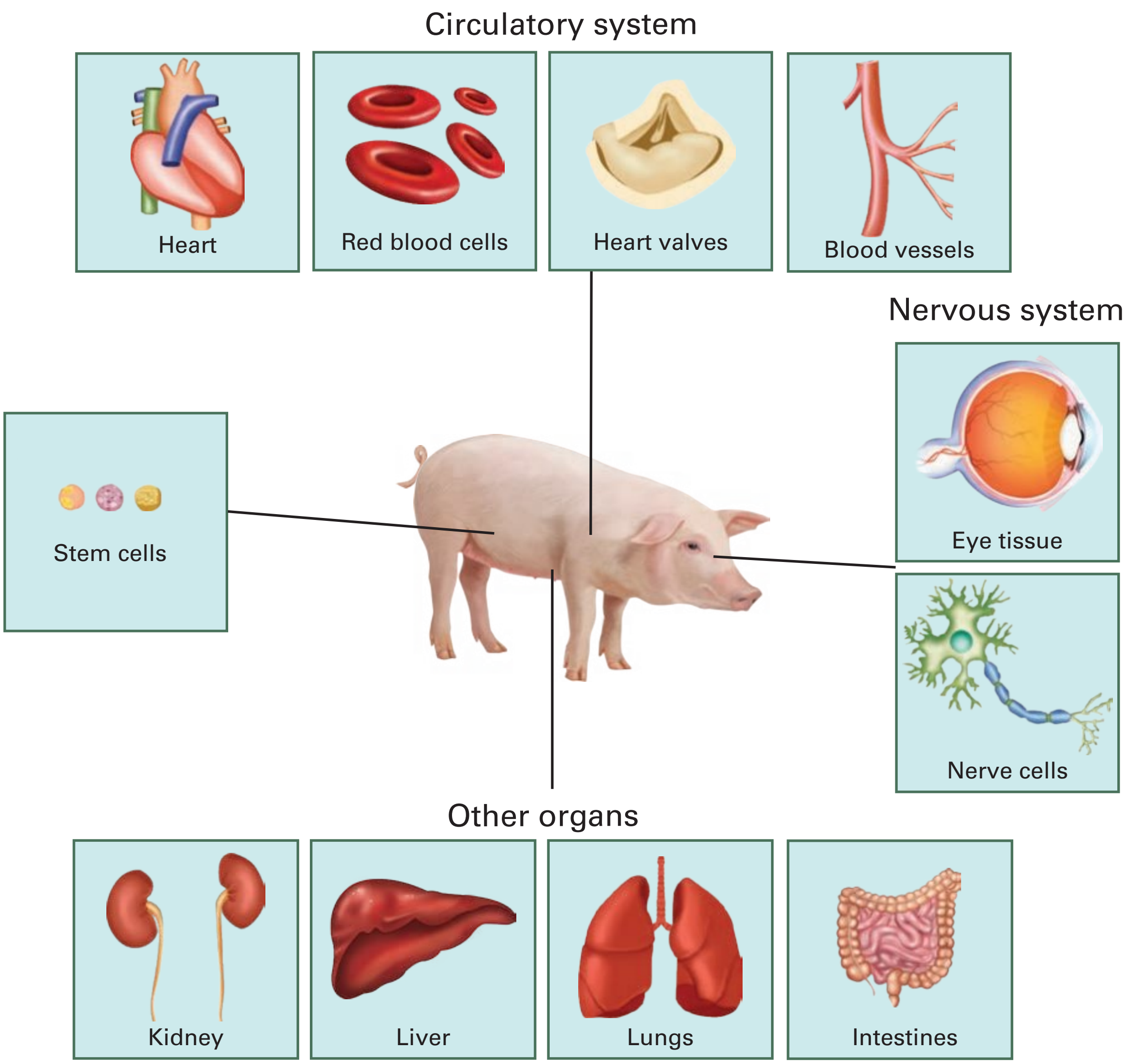

Figure 3.99 Some of the possible transplanted tissues and organs we could get from pigs

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Explore! 3.12

Ethical 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 made to differentiate into specialised cells, such as neurons. These neurons then make connections and begin to behave in a similar way to how they do in a patient's actual brain.

The development of organoids has had a significant impact on using live animals in laboratory research. Many people object to the use of live animals in research, and the use of organoids has the potential to reduce the number of animals used.

Complete some research and discuss how the use of organoids has impacted the ethical, environmental, social and economic issues associated with using live animals in laboratory research.

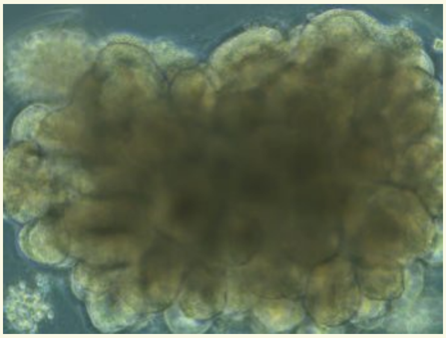

Figure 3.100 Developing human cerebral organoid, made from human brain cells. The organisation, structure and nervous signalling are similar to brain tissue. Organoids are used to study nervous system diseases.

Organ regeneration

The liver is the largest internal organ in your body and the only human organ that can not only repair itself but can regrow dead or damaged areas. It is located just below your ribs, on the right side of your body. The liver is involved in many important processes, such as producing enzymes for digestion, storing vitamins and removing toxins from your blood. If the liver is exposed to too many toxins over a long period of time, it can become damaged and not perform its job properly.

Alcohol is a toxin that the liver filters out of the blood. People who regularly drink too much alcohol can permanently damage their liver. Fatty liver is the earliest stage of liver damage caused by excessive alcohol consumption, occurring when the liver begins to accumulate excess fat.

If the person continues to drink, they can develop alcoholic hepatitis, a condition in which the liver becomes inflamed and damaged, and then fibrosis, where the liver becomes scarred. Cirrhosis is the final stage of liver damage from alcohol consumption, where healthy liver tissue is replaced with fibrous tissue. Cirrhosis can lead to several serious health problems, including liver failure. If caught early enough, a change in lifestyle habits can reverse or limit the damage done to the liver. In severe cases, however, liver transplantation surgery may be necessary.

As you learned earlier in this section, organ transplants come with many risks, and matching donors are hard to find. That is why scientists are working on the ability to regenerate or grow organs from living healthy tissues. This process is called **tissue engineering** and it is a fast-growing area of research. This means that healthy living organ donors can donate part of their liver and 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.

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

If scientists could grow and regenerate organs using the patient's own tissue, then the body would not reject the transplanted organ.

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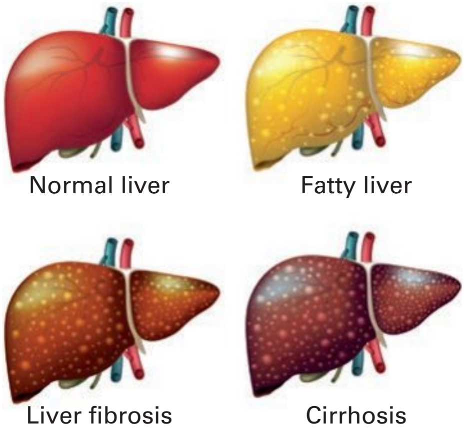

Figure 3.101 The stages of liver disease

Artificial organs

Advances in technologies have enabled the repair and replacement of organs using synthetic materials. An artificial organ can mimic or enhance the function of a real organ in several different ways.

Regardless of their design, artificial organs are constructed using materials that are compatible with the human body. Some artificial organs are also equipped with sensors and other devices that can monitor and adjust their function in real time.

Try this 3.13

The benefits of artificial organs

Research the benefits of using artificial organs and create a persuasive text that influences a specified audience regarding their use. You may want to think about their cost effectiveness, their medical outcomes and the impact on organ donor waiting times.

Quick check 3.18

1. Contrast organ replacement and organ regeneration.
2. Define 'xenotransplantation'.
3. Summarise two potential problems with xenotransplantation.
4. Name two toxins filtered out by the liver.
5. Recall the size of liver that the organ can regrow from.

Purpose	Description
Replacement	Some artificial organs are designed to replace a damaged or failing organ.  **Figure 3.102** An artificial heart can be implanted in a patient with heart failure to help pump blood.
Supplementation	Artificial organs can supplement the function of a real organ.  **Figure 3.103** Dialysis machines and artificial kidneys can be used to filter the blood and remove waste products in patients with kidney failure.
Enhancement	Artificial organs can enhance the function of a real organ.  **Figure 3.104** A cochlear implant can be surgically implanted in the ear to enhance hearing in individuals with hearing loss.
Control	Artificial organs can control the function of a real organ.  **Figure 3.105** A pacemaker can be used to control the heartbeat and regulate the electrical activity of the heart.

Table 3.2 Different purposes of artificial organs

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Investigation 3.1

Investigating the impact of salt on liver function

The liver breaks down hydrogen peroxide, a toxic substance that is produced as a by-product of various metabolic processes in the body. Hydrogen peroxide can cause damage to cells, so it must be quickly broken down into non-toxic products. The liver does this by using the enzyme catalase, which converts hydrogen peroxide into water and oxygen. Some research has suggested that a high salt diet may lead to high risk of liver damage and fibrosis.

Be careful

Safety glasses and gloves must be worn.

Aim

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.

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

- 5 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 solution
- 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 three minutes.
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 **3–5** after combining liver solution and a different salt solution in each of the remaining tubes.

Results

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

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 of salt percentage that you would test in a follow-up investigation.
3. Explain the reason that a test tube containing no salt was included in the experiment.

Conclusion

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

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Ethics of organ transplants

When we discuss organ transplants, we must think about the **ethical** implications of taking an organ from one person and using it in another. 'Ethics' is the term we use to discuss what is right and wrong in society. As there are many different beliefs, cultures and people around the world, ethics can vary from country to country or from person to person. When something is considered right, we say it is ethical, and if it is considered wrong, we say it is unethical.

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

Our laws are linked to the ethical beliefs of a nation and can change over time as people's perception of ethics evolves. However, just because something is considered unethical does not necessarily mean that it is illegal.

Figure 3.106 Judges make decisions based on law, but ethics may also be a consideration in the decision-making process.

Some donated organs, such as kidneys and partial livers, come from living donors. This creates an ethical dilemma for the doctor who is performing the surgery. Should they risk the life of a healthy person to save or improve the life of a patient? Some questions they must consider are:

- Does the living donor know and understand all the risks?
- What if something goes wrong during surgery and puts the donor's life at risk?
- What if the transplant is rejected by the patient and the organ goes to waste?
- What happens if the donor is left with long-term pain, infection or impaired health after the surgery?

The donor may be under a lot of pressure from friends or family, which can make them feel forced into donating.

At any one time, there are around 1600 people on the Australian organ transplant waiting list. There are many rules in place to ensure that organs are allocated to patients in a fair process that is not affected by race, religion, gender, disability, social status or age, unless an adult organ is too large for a child, or a child's organ is too small for an adult, for example.

There is a very limited number of organs available at any one time, and so the wait for an organ could be anywhere from six months to more than four years. As a result of this, several factors are used to decide who gets an organ, such as:

- how long the person has been waiting for a transplant
- how well the organ matches the patient
- how urgent the transplant is for the patient's health
- whether the organ can be brought to the person in time.

Try this 3.14

The pros and cons of organ donation

Create a table showing the possible advantages and disadvantages (risks) for both an organ donor and a recipient.

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Explore! 3.13

Opt in or opt out?

In some countries, such as Wales and Spain, all adults are automatically registered as organ donors. These adults can 'opt out' of the registration if they do not wish to be an organ donor. Many do not opt out. Spain consequently has one of the shortest waiting times for organ transplants in the world.

Research the current percentage of Australians who are registered organ donors and our average waiting list times and compare these with Spain's.

Answer the following questions and justify your opinion with evidence.

1 Do you think Australia would benefit from an 'opt out' organ donation system?
2 What are some of the advantages and disadvantages of an 'opt out' system?
3 Discuss the ethical issues that arise from organ transplantation.

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 internal organ in 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 3.107 shows percentage survival rates for patients on dialysis versus patients who have received a kidney transplant. Use the graph to answer the following questions.

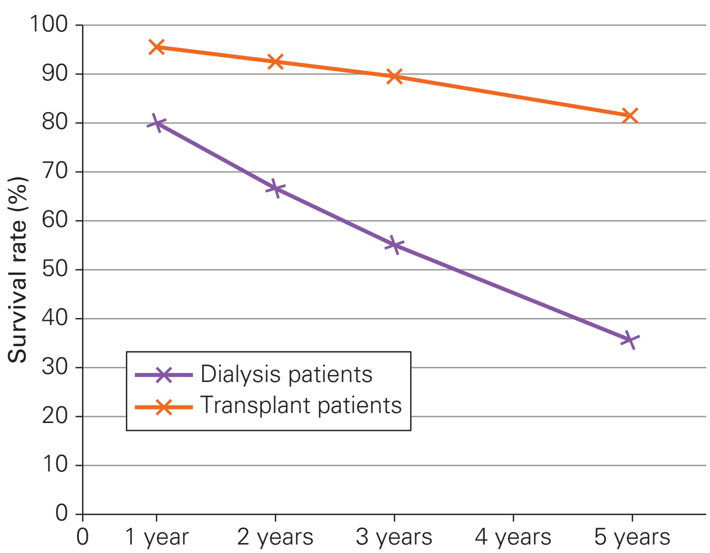

Figure 3.107 Survival rate of patients on dialysis versus patients who have received a kidney transplant

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?

Knowledge utilisation

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

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
3.1	I can describe how a specialised cell's structure is related to its function.	5, 8	
3.1	I can use 2D and 3D representations of organ systems to understand how organs are positioned within the body.	6	
3.2	I can describe the structure of each organ in the respiratory system and relate its function to the overall function of the system	6, 21, 24	
3.3	I can compare the structure and function of the analogous gas exchange systems in plants and animals.	1, 13, 26	
3.4	I can describe the structure of each organ in the circulatory system and relate its function to the overall function of the system.	2, 7, 19, 20, 24	
3.5	I can describe the structure of each organ in the digestive system and relate its function to the overall function of the system.	3, 6, 11, 21, 23	
3.6	I can compare the structure and function of analogous digestive systems in animals.	14, 16	
3.7	I can describe how a disorder in cells or tissues can affect how an organ functions.	8	
3.7	I can describe how an artificial organ mimics or augments the function or functions of a real organ.	9	

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

4 **Define** 'xenotransplantation'.

5 **Recall** the name of the process by which cells become specialised.

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6 **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.

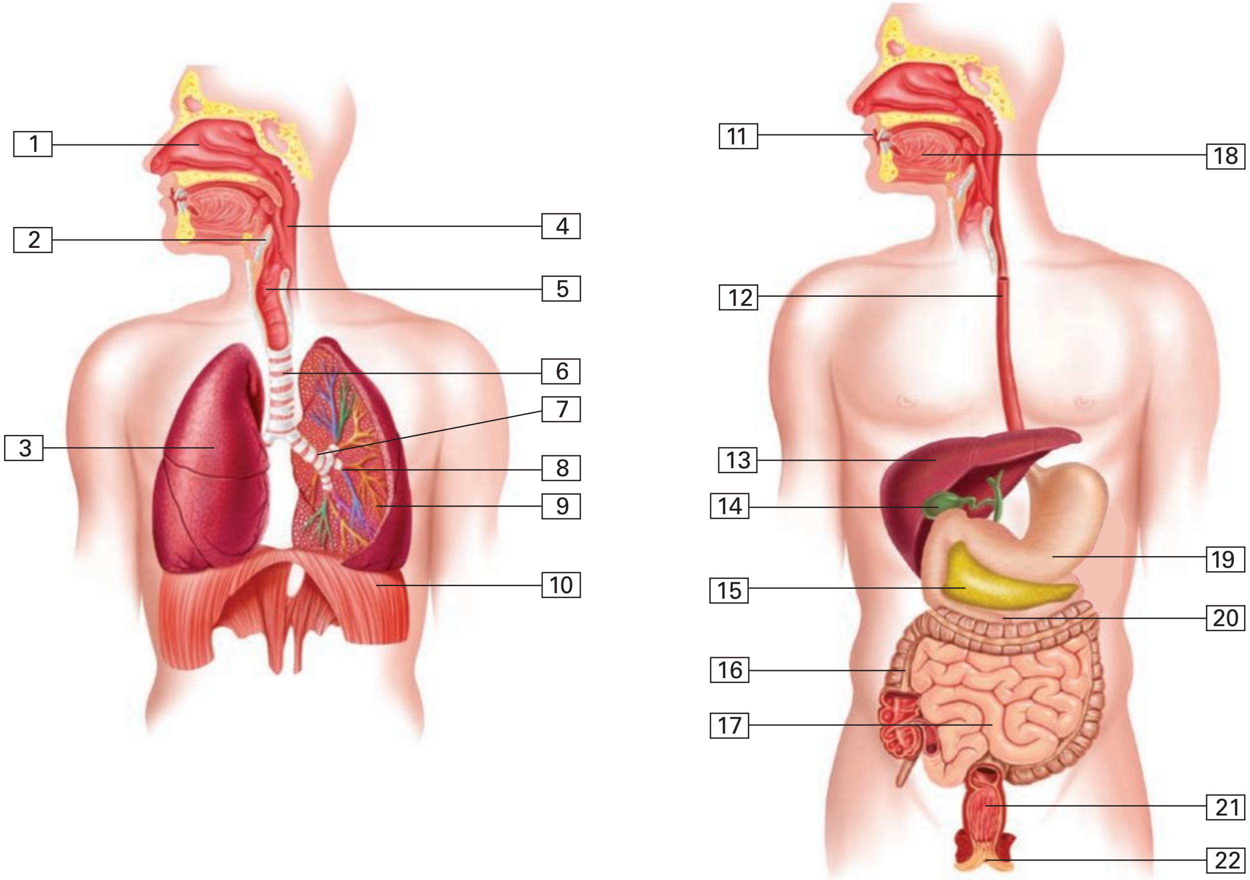

Figure 3.108 Human respiratory (left) and digestive (right) systems

Comprehension

7 **Describe** the different components of blood.
8 **Describe** why a disorder in cells or tissues can affect how an organ functions.
9 **Describe** some of the benefits of using artificial organs.
10 **Explain** the role of enzymes in the digestive system, using examples.
11 **Explain** the function of the liver.
12 **Explain** what is meant by a 'living donor'.
13 **Summarise** three essential features of gills if they are to efficiently exchange gases and act as lungs for fish.
14 **Explain** why it could be harmful to treat a koala with antibiotics for an infection.

Analysis

15 **Sequence** these terms in order of increasing size/complexity: organ, organism, tissue, cell, organ system.
16 **Contrast** the digestive systems of a carnivore and a herbivore.
17 Examine this statement: 'Lactose intolerance should be referred to as lactase deficiency'. **Consider** why this is the case.

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

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

20 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		

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

	Villi	Both	Alveoli
Structure			
Function			

22 Forced vital capacity (FVC) is a measure of how much air a person can blow out in one exhalation. The graph in Figure 3.109 shows the normal values for men (in red) and women (in purple) according to their age. Use the graph to answer the following questions.

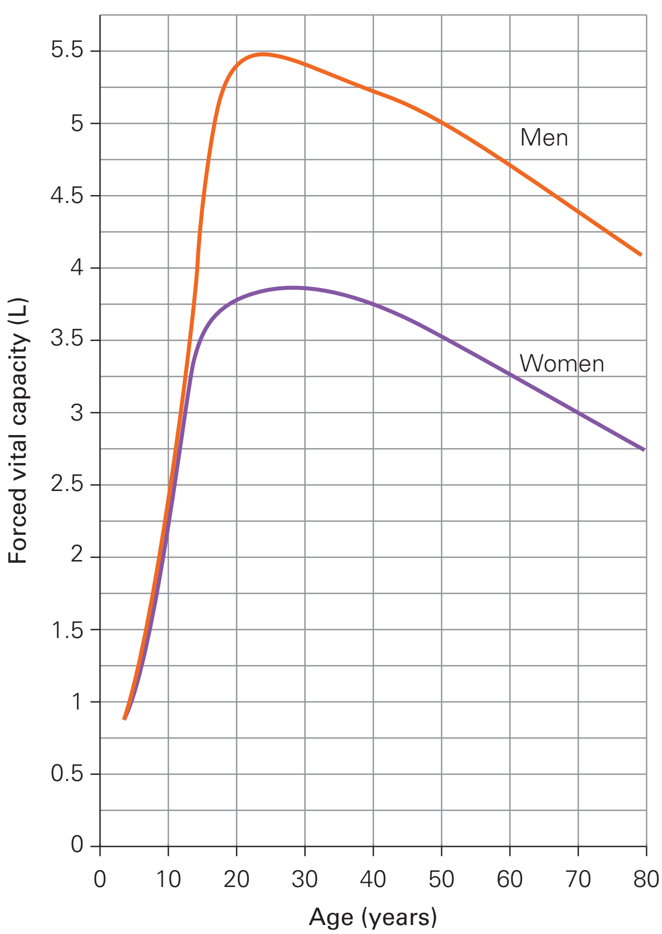

Figure 3.109 Forced vital capacity versus age for men and women

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

23 Other than helping enzymes to break down food, **propose** another function of stomach acid.

24 **Construct** a flow chart or a story that depicts the path taken by a single molecule of oxygen, from when it enters the nose to when it enters a cell and diffuses to the mitochondria to be consumed in cellular respiration. Then show how a molecule of carbon dioxide is produced and follow its story until it is exhaled. Make sure you include all relevant parts of the respiratory and circulatory systems.

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

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

27 A child is diagnosed with a rare and potentially fatal condition, but a bone marrow transplant from a matching donor will likely save their life. Neither of the parents is a match, but they are told by the doctors that a sibling is likely to be a suitable match. The parents decide to have another child, with the intention that when the baby is born, he or she can provide a bone marrow donation to their sibling. Research what is involved in bone marrow transplantation and discuss the ethical dilemma these parents face. **Discuss** the pros and cons of the parents' decision and defend your personal opinion on whether they should or should not have the second sibling.

Data questions

Biathlon is a winter sport whereby an athlete competes by completing three legs of cross-country skiing and two legs of shooting at a target. 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 3.110. The relationship between maximum heart rate (HR_{max}) and age of the athlete is shown in Figure 3.111.

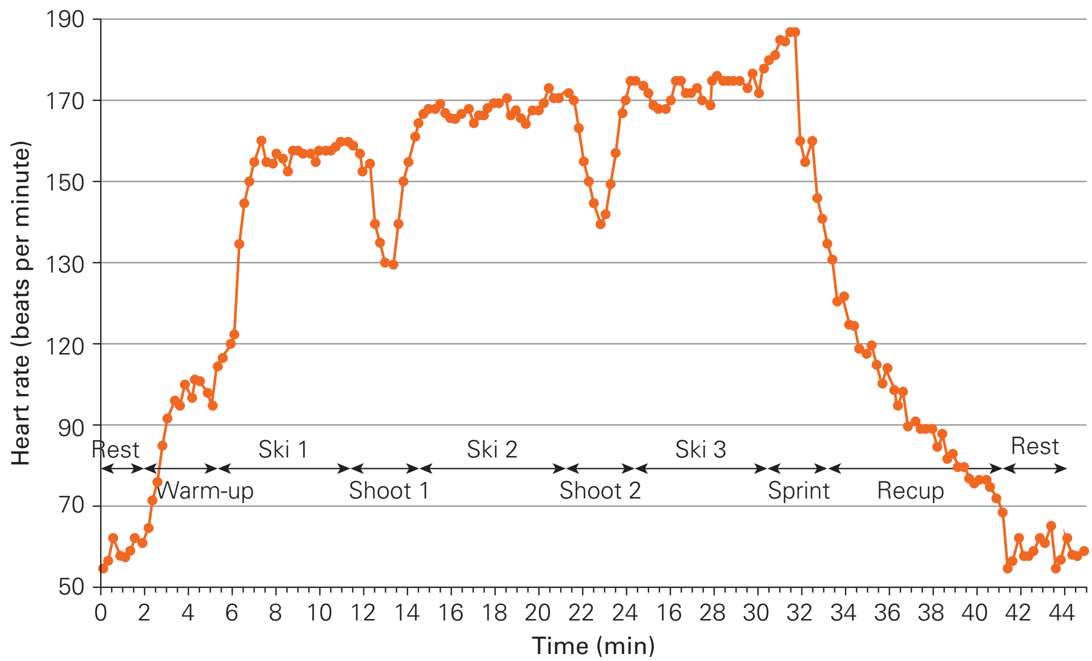

Figure 3.110 Heart rate of an athlete during a biathlon race, including warm-up, three ski phases, two shootings, a final sprint and a recuperation phase

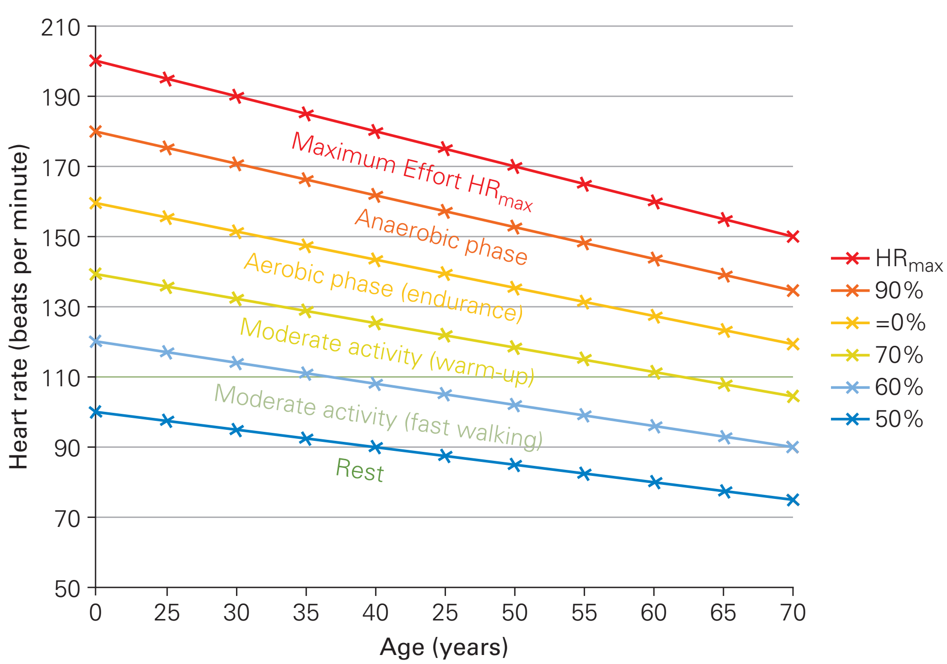

Figure 3.111 Activity intensity linked to the average human heart rate as a function of age (Following the commonly accepted relation HR_{max} = 220 – age)

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

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 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 3.112 and 3.113.

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.

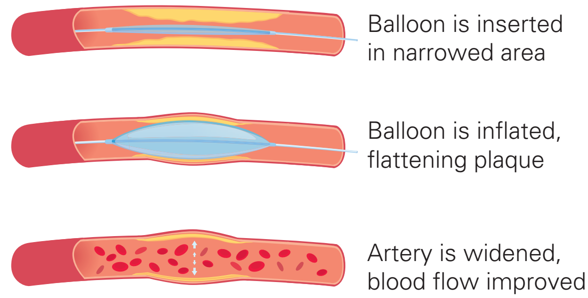

Figure 3.112 In angioplasty, a small 'balloon' is inflated inside the artery, which pushes the plaque aside and widens the vessel.

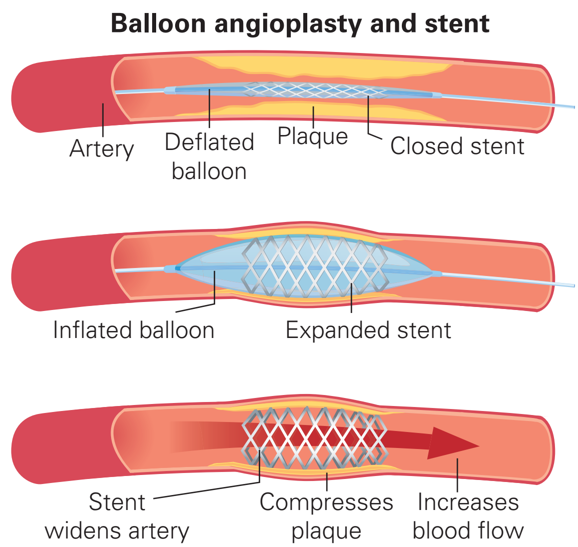

Figure 3.113 Many people also have a stent inserted inside the artery after the artery has been widened by angioplasty. A stent is a small tube made of plastic or metal that is inserted into the artery to prevent it narrowing again.

Design brief: Design a device and a procedure to clear blocked arteries while trapping the dislodged plaque.

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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 3.114).

Figure 3.114 A model of an artery

Suggested materials

- model of a blocked artery, created using a tube or a toilet roll tube and play dough
- paper clips
- string
- popsicle sticks
- cloth
- glue
- tape
- cardboard
- paper

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/s to the design brief and then share as a group. Annotate each group member's sketches and together sketch your preferred model, making note of annotations for your design.

Create

5 As a group, build the model agreed upon by the group and then test for effectiveness. You may wish to create a table such as the one below.

	Prototype 1	Prototype 2
Time taken for 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 for.

Evaluate and modify

7 For each model that you created, discuss how effectively the model performed. Consider how long the procedure was and how difficult it was to carry out. Evaluate how effective the 'trap' was at catching the dislodged pieces – how much of the plaque did it catch?

8 Imagine you had to do this procedure on a real patient. Discuss the limitations of your model of a blocked artery and how your device and procedure might need to be modified to better reflect real life.

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Chapter 4
Our changing Earth

Chapter introduction

Earth is constantly being reshaped by natural forces, including those created by the movement of tectonic plates. Over the course of billions of years, these forces have created and destroyed landforms and reshaped coastlines. In this chapter, you will explore the changing nature of our planet, examining the evidence for plate tectonics and the mechanisms behind plate movement. You will also consider the ways in which plate tectonics can contribute to natural disasters and the strategies that scientists and policymakers are using to predict and manage these events.

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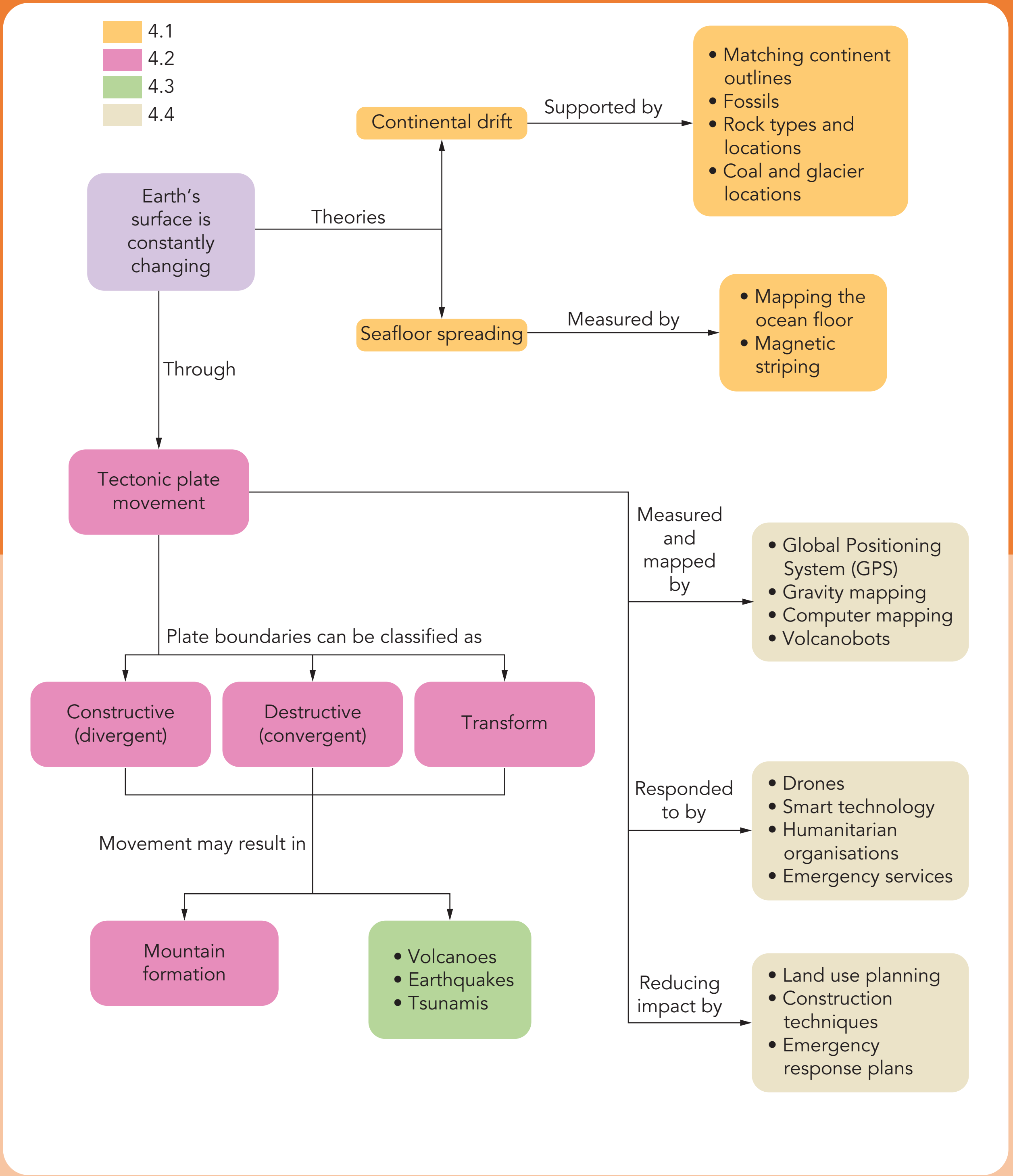
Concept map



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Curriculum

Investigate tectonic activity, including the formation of geological features at divergent, convergent and transform plate boundaries and describe the scientific evidence for the theory of plate tectonics (AC9S8U03)	
constructing a timeline of evidence to show the development of the theory of plate tectonics	4.1, 4.2
modelling interactions at plate boundaries	4.2
investigating the relative significance of different forces involved in tectonic plate movement, including slab pull, ridge push and convection	4.2
exploring how geologist and oceanographic cartographer Marie Tharp's topographic maps of the Atlantic Ocean floor provided support for the acceptance of the theory of plate tectonics	4.2
examining patterns of earthquake and volcanic activity over time and proposing explanations	4.3
relating the extreme age and stability of a large part of the Australian continent to its plate tectonic history	4.3
researching First Nations Australians' cultural accounts that provide evidence of earthquakes and volcanoes	4.3
evaluating the impact of tectonic events on human populations and examining engineering solutions designed to reduce the impact	4.4

Glossary terms

Asthenosphere
Constructive (divergent)
Continental drift
Convection currents
Core
Craton
Crust
Destructive (convergent)
Epicentre
Focus
Geoid
Geosphere
GPS
Hotspot
Lag time
Lava
Lithosphere
Magma
Mantle
Pangaea
Plate boundaries
Plate tectonics
Pyroclastic
Richter scale
Ridge push
Rift valley
Seafloor spreading
Seismic wave
Seismogram
Seismometer
Slab pull
Subduction
Subduction zone
Tectonic plates
Transform
Tsunami

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4.1 Continent movement theories

Learning goal
To be able to describe the evidence for the theory of continental drift.

WORKSHEET
The theory of continental drift

VIDEO
Alfred Wegener

For centuries, scientists have been fascinated by Earth's continents and the puzzle of how they came to be distributed across the planet's surface. The concept of continental drift, or the idea that the continents have moved over time, is not a recent discovery. In fact, it dates to the late sixteenth century when early map-makers noticed that the coastlines of South America and Africa appeared to fit together like puzzle pieces.

Over the centuries, various scientists made contributions to the understanding of the theory of continental drift, and in this section you will explore the historical evolution of the theory of continental drift, from its earliest speculations to the present-day understanding of plate tectonics.

Alfred Wegener – continental drift

In 1912, Alfred Wegener, a German geophysicist and meteorologist, proposed his theory of **continental drift**.

Figure 4.1 Alfred Wegener

Wegener hypothesised that Earth's continents were once part of a giant land mass, which he called **Pangaea**.

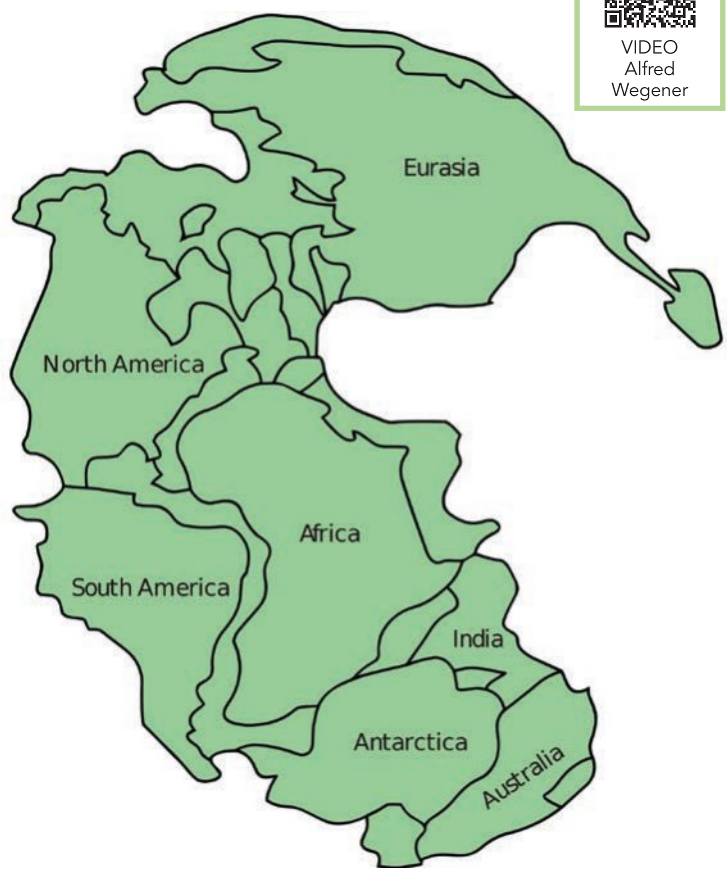

Figure 4.2 Wegener proposed that all the continents were once together in a giant land mass called Pangaea.

Over time, this giant land mass broke up and drifted apart to form the continents as they are found today. Figure 4.3 shows how the continents have moved over millions of years. Follow the movement of Australia to see how far it has moved in that time.

continental drift
the theory of how the continents on Earth have moved over millions of years

Pangaea
the supercontinent that has since broken into pieces and drifted apart

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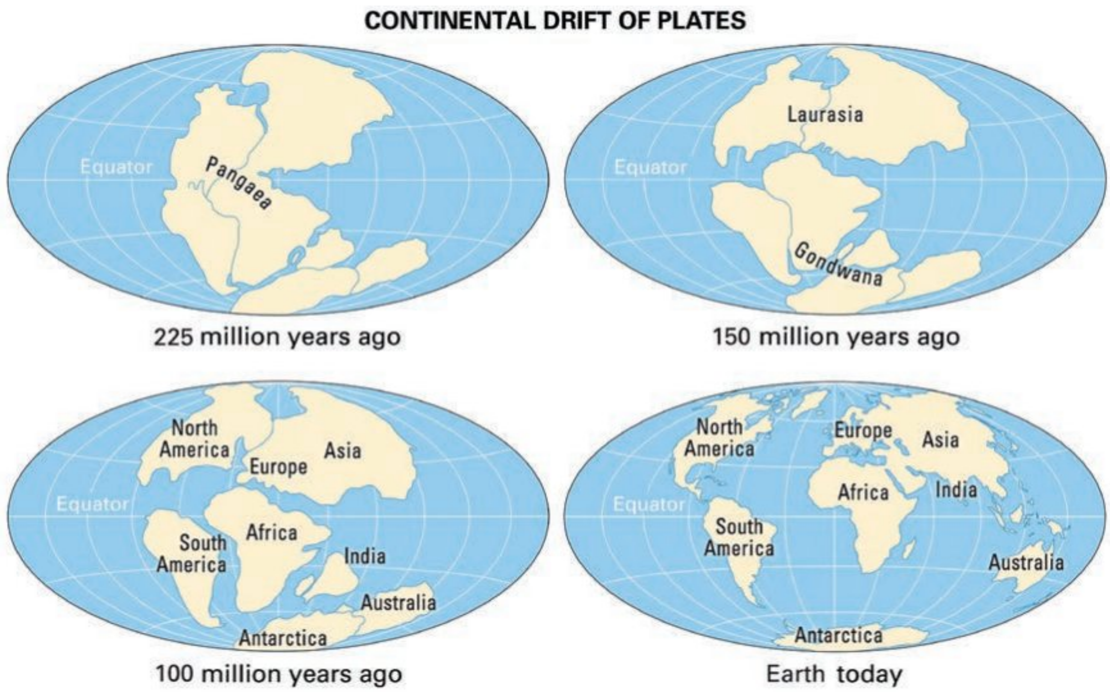

Figure 4.3 The movement of the continents from a single land mass (Pangaea) to their current locations

A scientific theory must be based on evidence. So how did Wegener justify his theory to the scientific community? He put forward four different pieces of evidence to support his theory.

1 Continental outlines matched

You can see from Figure 4.4 that, when put together, some of the existing continents look like they fit into each other – just like pieces of a jigsaw puzzle. This observation was not lost on early map-makers, but you could argue that this is just a coincidence, so Wegener needed more evidence to back up his theory.

Figure 4.4 The outlines of Africa and South America fit together like pieces in a jigsaw puzzle.

2 Similar fossils were found on different continents

When observing the types of fossils on different continents, Wegener found examples of the same prehistoric land-based creatures on continents that are now separated by oceans. He stated that the land masses must have been together at some stage (as shown in Figure 4.5) because these animals could not swim from one continent to another. Opposing geologists argued that land bridges could have existed in the past when ocean levels were lower. These land bridges would have allowed the fauna and flora to cross between continents.

3 Rock types on different continents matched each other

Wegener found rocks of the same type and age on both sides of the ocean, which he claimed was evidence they were formed together and later separated.

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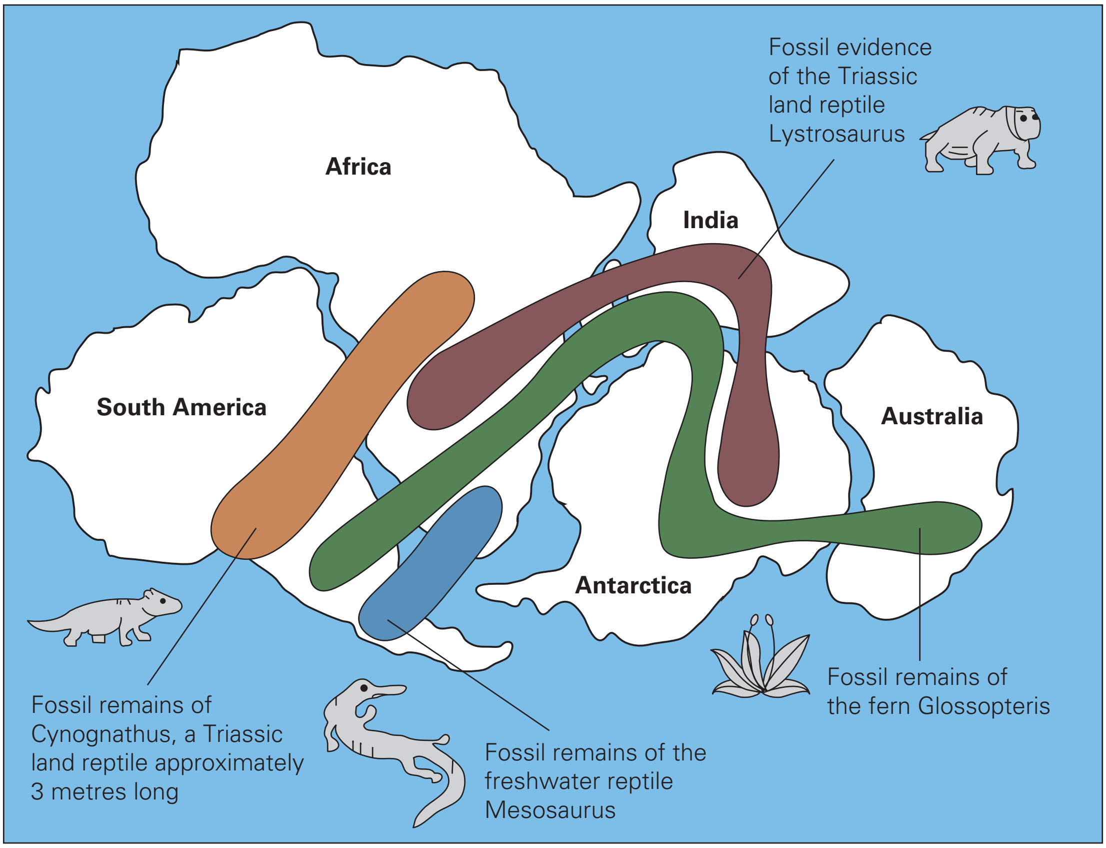

Figure 4.5 Wegener found that fossils on different continents matched up, supporting his theory of continental drift.

4 Coal was found in cold areas and evidence of glaciers was found in the tropics

Coal only forms in hot and humid climates, and glaciers only form in cold climates, so how could there be coal in cold areas and evidence of past glaciers in regions that are now hot? Wegener concluded that continents have moved over time to a different location.

Despite all the evidence compiled by Wegener, he was unable to convince the scientific community at the time of the validity of his hypothesis. Alternative theories (like the land bridges) were proposed, and geologists questioned his credibility because he was a meteorologist and geophysicist known for polar climate research and not a geologist. However, the main flaw of Wegener's hypothesis was that he had no explanation for the mechanism behind the movement of the continents.

Figure 4.6 Coal only forms in hot, swampy areas; glaciers only form in cold areas.

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Unfortunately, in 1930, Alfred Wegener and another team member were caught in a blizzard on an expedition in Greenland and did not survive. At the time of his death, his theory was still not accepted by the scientific community.

Quick check 4.1

1. Recall the name of the scientist who proposed and gave evidence for the theory of continental drift.
2. List the four different pieces of evidence he used to support his theory.
3. Outline why his theory was not accepted at the time.

Harry Hess – seafloor spreading

Around 30 years after the death of Alfred Wegener, new evidence came to light that appeared to support the theory of continental drift. Harry Hess, a professor of geology at Princeton University in the United States, first became interested in the ocean floor while serving in the US Navy during World War II. During this time, he had access to sonar that allowed him to create a map of the ocean floor. Sonar works by sending sound waves into the ocean; when they bounce back they are picked up as an echo. The time they take to bounce back indicates the depth of that part of the ocean.

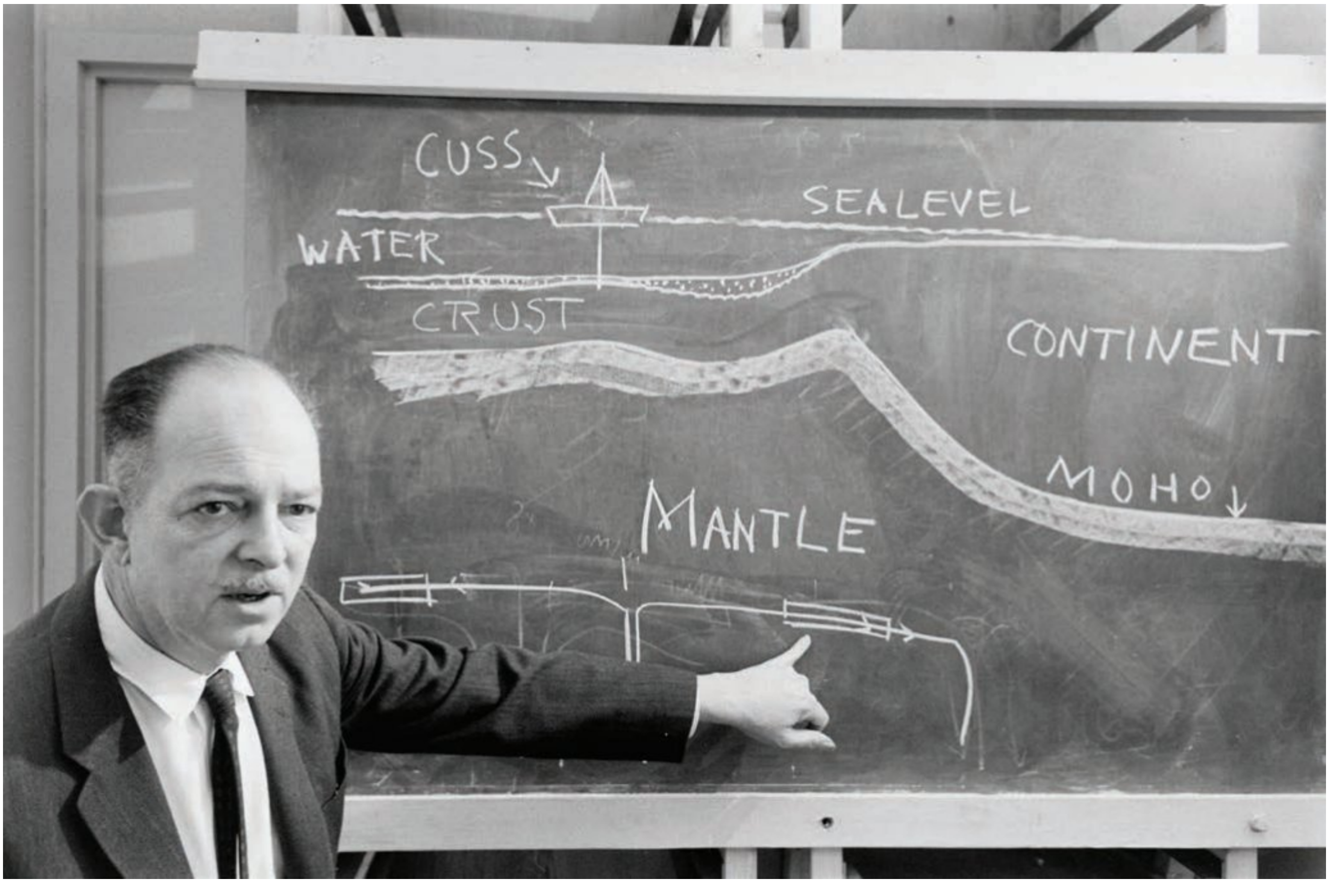

Figure 4.7 Harry Hess, a professor of geology who mapped the ocean floor

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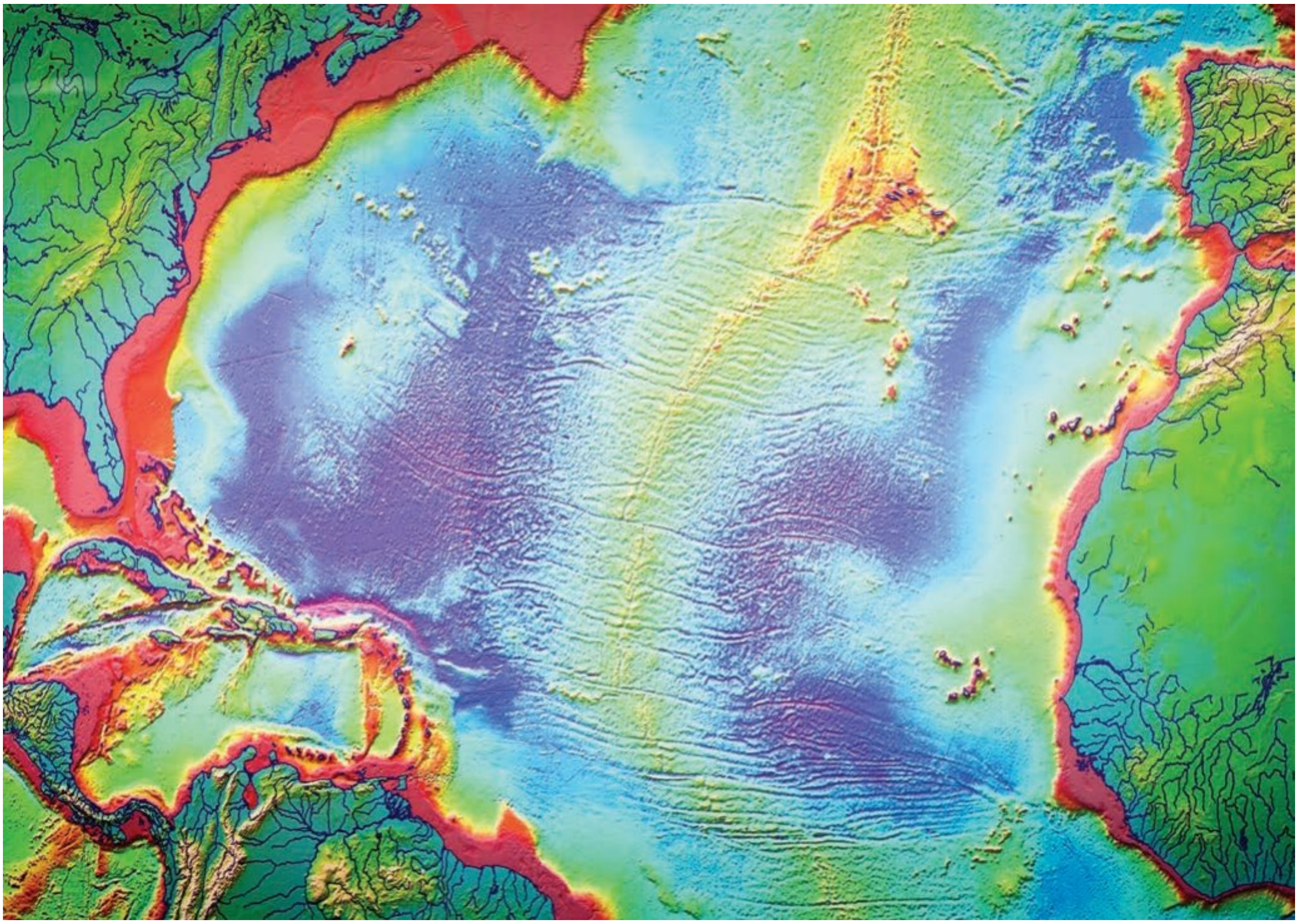

Figure 4.8 A map of the Mid-Atlantic Ridge and its volcanoes running down the middle of the Atlantic Ocean

seafloor spreading
a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

subduction
when the denser oceanic plate sinks underneath a less dense continental plate

Most people at that time thought that the ocean floor was flat. However, when Hess mapped the ocean floor, he found it contained deep trenches, underwater mountain ranges and volcanoes. What surprised Hess the most was that his findings appeared to show that the ocean floor was changing. He discovered mid-ocean ridges that were raised about 1.5 km above the flat sea floor.

In his book *The History of Ocean Basins*, Hess wrote that volcanoes found along the line of the ocean ridges bring up molten rock from beneath Earth's crust. This molten rock cools and forms new oceanic rock. As more and more oceanic rock is produced, the sea floor moves away from the ridges. Hess called this process **seafloor spreading**. This was a crucial piece of evidence to support Wegener's theory. If oceans are moving away from one another, then continents on either side of the ocean must be doing the same. Hess also proposed that if the ocean floor was moving towards a continent it would sink in a process called **subduction**, forming ocean trenches (as shown in Figure 4.9). You will look at subduction in more detail in the next section.

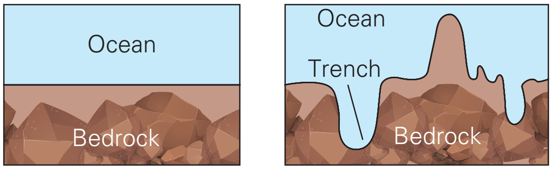

Figure 4.9 The ocean floor was previously thought to be flat (left). Harry Hess's map of the ocean floor (right) indicated otherwise.

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Explore! 4.1

Journey to the bottom of the sea

Victor Vescovo's Five Deeps Expedition was an ambitious project that aimed to explore the deepest points of each of the world's five oceans. Over the course of several years, Vescovo and his team used a specially designed submarine to dive to the bottom of the Atlantic, Southern, Indian, Arctic and Pacific Oceans. The expedition not only provided new insights into the geology and biology of the ocean depths, but it also set several new records.

One of the most significant records broken was the deepest manned descent in history, as Vescovo's team reached a depth of nearly 10 925 m in the Pacific Ocean's Mariana Trench. In addition to this, the expedition also set a record for the deepest dive in the Atlantic, Southern and Indian Oceans. The expedition made the first manned descent to the bottom of the Arctic Ocean.

In June 2023, a submersible vessel owned and operated by the American company, OceanGate, suffered a catastrophic implosion while attempting to explore the wreck of the Titanic, instantaneously killing all passengers and crew. Discuss whether deep ocean expeditions should be manned and why people choose to ignore the risks associated with such trips.

Figure 4.10 Dr Dawn Wright and Victor Vescovo inside the control capsule of the submersible deep-submergence vehicle (DSV) *Limiting Factor*

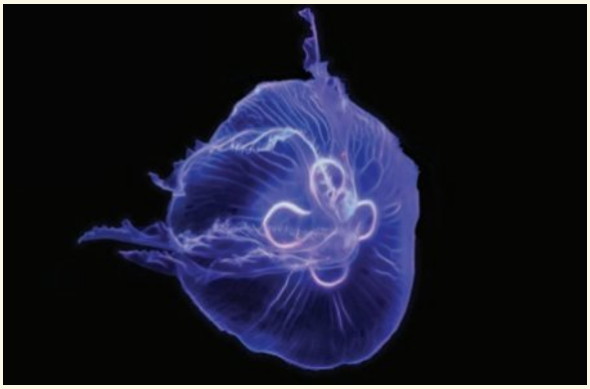

Figure 4.11 The only light that can be observed in the ocean depths is created by the animals that live there. This is called bioluminescence.

Making thinking visible 4.1

See, think, wonder: Vomiting shrimp

The following images show a deep-sea pandalid shrimp, *Heterocarpus ensifer*, and the same animal 'vomiting' light from glands located near its mouth.

Can you describe what is visible in the photos?
What thoughts come to your mind when you observe them?
Are there any questions that arise from your observations?

Figure 4.12 *Heterocarpus ensifer*

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

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Did you know? 4.1

Extreme exploration

On a 2020 crewed expedition to the Challenger Deep, some records were set by passengers who accompanied Victor Vescovo on his dives. Former NASA astronaut Doctor Kathryn Sullivan became the first person to both walk in space and descend to the deepest known point on Earth; and Vanessa O'Brien became the first woman to reach Earth's highest (Mt Everest) and lowest points. She was also the first person to reach nearest to and farthest from Earth's core (Challenger Deep and the summit of Chimborazo).

Figure 4.13 Vanessa O'Brien

Quick check 4.2

1 Name the ridge located in the Atlantic Ocean.
2 Recall the name of the technique Harry Hess used to map the ocean floor.
3 Describe the results and major discovery of Harry Hess's ocean-floor mapping.

Frederick Vine, Drummond Matthews and Lawrence Morley – reading the ocean floor

In the 1960s, further evidence was discovered to support Hess's theory. Frederick Vine and Drummond Matthews were British geologists who first worked together when Vine was a PhD student under Matthews at the University of Cambridge. Earlier work using magnetometers (which measure the direction of magnetic fields) showed that the sea floor has bands of alternating normal and reverse magnetism, running parallel to the mid-ocean ridges. At about the same time, Canadian geologist Lawrence Morley was independently working on the same idea and his results agreed with those of Vine and Matthews.

WORKSHEET
Magnetic striping

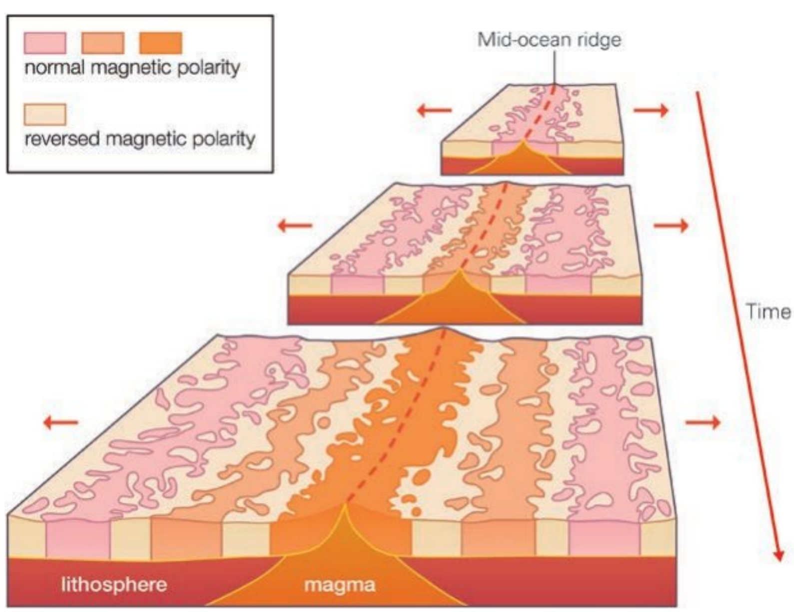

Figure 4.14 The pattern of magnetic stripes on the ocean floor

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Vine and Matthews knew that the new molten rock produced by the ocean ridges contained magnetite, a magnetic mineral. While the molten rock cooled and solidified, the magnetite aligned with Earth's own magnetic field, with its magnetic poles matching Earth's magnetic poles. Earth's magnetic field reverses direction approximately every 300 000 years, and the cooling rock preserves the record of Earth's polarity at that time. For rocks to have their magnetic minerals aligned in different directions, they must have formed at different times. As the pattern of magnetic stripes leading away from the mid-ocean ridges is symmetrical, this led Vine and Matthews to conclude that new sea floor was being added equally to each side of the ridge. Morley also saw the significance of the changes in Earth's magnetic field, magnetism of new oceanic crust and seafloor spreading as a mechanism for continental drift. That is why it is often called the Vine–Matthews–Morley hypothesis.

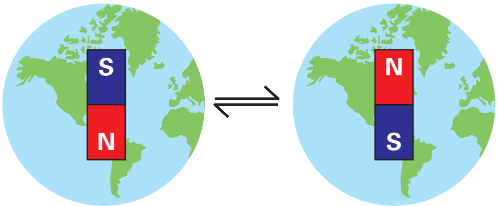

Figure 4.15 According to paleomagnetic records, Earth's magnetic poles have experienced approximately 183 reversals in the last 83 million years and have undergone at least several hundred reversals over the past 160 million years.

Explore! 4.2

Earth's magnetic field

On average, Earth's polarity switches approximately every 300 000 years. The last time Earth's poles reversed was 780 000 years ago. This means that at any time there could be a reversal in Earth's magnetic field. Interestingly the Sun is a lot less magnetically stable; its magnetic field reverses approximately every 11 years.

1. On average, how long does it take for Earth to complete a full reversal?
2. If you were using a compass to navigate at the time when Earth's poles were reversing, how would this affect the direction you were taking?
3. Research and describe how nature uses Earth's magnetic field.
4. Research and discuss the consequences of Earth's magnetic field weakening for a significant period when it reverses.

Figure 4.16 The next switching of Earth's magnetic field is overdue.

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Making thinking visible 4.2

Connect, extend, challenge: The auroras

The upper atmosphere of the Sun generates a stream of charged particles called the solar wind.

The Aurora Borealis and Aurora Australis are natural phenomena that occur when charged particles from the Sun, also known as solar wind, interact with Earth's magnetic field and atmosphere. These interactions cause particles in the atmosphere to emit light, creating the colourful displays that we know as the Northern Lights and Southern Lights.

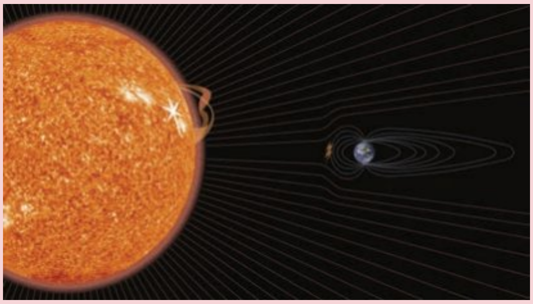

Figure 4.17 Solar wind interacting with Earth's magnetic field

These lights are typically visible in the high-latitude regions near Earth's magnetic poles, including northern Scandinavia, Alaska, Canada and Russia for the Aurora Borealis, and southern Australia, New Zealand and Antarctica for the Aurora Australis. However, during particularly intense geomagnetic storms, the lights can sometimes be seen at lower latitudes as well.

The colours of the auroras depend on the altitude of the aurora, the gas that is being excited and the energy of the particles in the solar wind. Green is the most common colour. Other colours that can be seen include pink, red, yellow, blue and purple.

Consider what you have just read and answer the following questions:

- How do the concepts and details connect to your existing knowledge about auroras?
- Which new insights did you gain from the text that extended your understanding or encouraged you to consider new perspectives?
- What questions do you have after thinking about this information?

Figure 4.18 The Aurora Borealis

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

Further evidence to support the notion of seafloor spreading comes from the age of the rocks on the sea floor. If new rock is forming at the ridge and spreading out equally in opposite directions, you would expect that as you move further away from the ridge, the rock would increase in age. This is exactly what Vine, Matthews and Morley found.

Quick check 4.3

1 Identify the name of the mineral in molten rock that is magnetic.
2 Discuss what happens to this magnetic mineral when the molten rock cools.
3 How did the presence of magnetic stripes in rocks parallel to ocean ridges prove that the sea floor was spreading?
4 What other piece of evidence supports Hess's theory of seafloor spreading?

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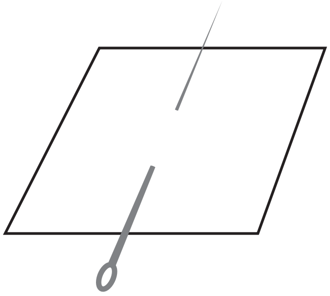
Practical skills 4.1

Making a compass



Aim

To make a simple compass

Materials

- 250 mL beaker half full of water
- needle
- small square of paper
- bar magnet

Method

1. Draw the results table below.
2. Thread the needle through the small square piece of paper as shown above.
3. Stroke the needle 20 times with the bar magnet. You must stroke in **one** direction only and with one end of the magnet only.
4. Put the piece of paper with the needle into the water, making sure that it floats.
5. Record in the results table the direction that the needle points.
6. Turn the beaker 90° and record the direction that the needle points in the results table.
7. Turn the beaker a further 90° and again record the direction in the results table.

Results

	First position	Rotated 90°	Rotated a further 90°
Direction			

Analysis

1. Describe what happened to the magnetised needle when the beaker of water was rotated.
2. Explain the role of the paper in this experiment.
3. The needle in this experiment is acting as a temporary magnet. What is a temporary magnet and how does it differ from a permanent magnet?
4. Discuss the importance of having the needle magnetised only in one direction.

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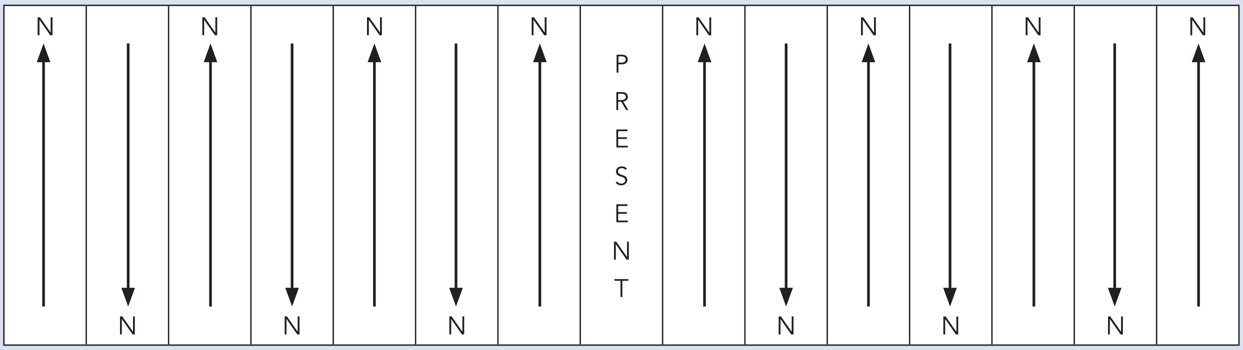
Try this 4.1

Modelling seafloor spreading

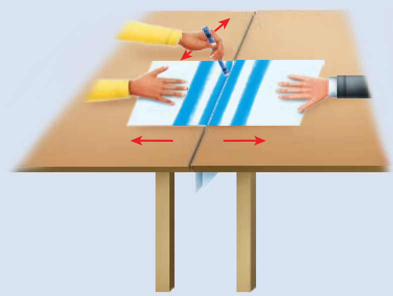
1 Get a piece of paper and re-create the diagram below, which shows Earth's magnetic field changing over time from the present (centre) to the distant past (left and right edges).



2 Fold the paper in half in the middle of the section labelled 'Present'.

3 Put the paper into a gap between two tables with the two short ends of the paper on the tables' edges and the remainder of the paper dropping down into the gap. Push the tables together so that the gap is closed and most of the paper cannot be seen.

4 Pull apart the ends of paper to show the movement of the sea floor away from an ocean ridge.



You have just modelled seafloor spreading!

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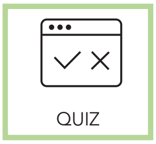
Section 4.1 questions



Retrieval

1 **Name** the theory proposed by each of the following scientists.
  a Alfred Wegener
  b Harry Hess
2 **Recall** the piece of evidence that supported Harry Hess's theory.

Comprehension

3 **Describe** one piece of evidence that Wegener used to back up his theory.
4 **Explain** why Wegener's theory was not accepted during his lifetime.
5 **Communicate** using labelled diagrams the results of Harry Hess's mapping of the ocean floor.
6 **Describe** how sonar works in relation to ocean-floor mapping.
7 **Summarise** the evidence that supports Harry Hess's theory of seafloor spreading.

Analysis

8 **Organise** these major discoveries (A–E) on the movement of continents into chronological order (the earliest first).
  A Harry Hess states that the sea floor is spreading outwards from mid-ocean ridges.
  B Alfred Wegener outlines his theory of continental drift, stating that all the continents were once part of a large land mass, which has split up and drifted apart.
  C The age of rock confirms that new rock is forming at mid-ocean ridges.
  D Magnetic striping patterns in the ocean rock confirm that new rock is constantly forming.
  E Harry Hess maps the ocean floor and confirms that it contains deep trenches, mountains and volcanoes.
9 **Distinguish** between magnetic striping and magnetic field reversal.
10 **Compare** the properties of oceanic rock as you move away from a mid-ocean ridge.
11 **Classify** the following as theory or evidence.
  a The sea floor spreads away from a mid-ocean ridge.
  b The rock is older the further away it is from a ridge.
  c The continents drifted away from one another.
  d Rock types on different continents match up with one another.

Knowledge utilisation

12 **Deduce** what would happen to a compass if Earth's magnetic field was to change direction now.
13 **Justify** by use of a diagram that Earth's magnetic field has switched over time.
14 With the examples of Alfred Wegener and Harry Hess, **evaluate** the impact of currently accepted scientific ideas on the willingness to adopt new theories.

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4.2 Plate tectonics and plate movement

Learning goals

1. To construct a timeline of evidence to show the development of the theory of plate tectonics.
2. To explore how Marie Tharp's topographic maps provided support for the acceptance of the theory of plate tectonics.
3. To investigate the relative significance of different forces involved in tectonic plate movement.
4. To be able to describe the consequence of three types of plate boundaries.
5. To model interactions at plate boundaries.

WORKSHEET Convection currents

VIDEO Plate tectonics

With the help of Harry Hess, Frederick Vine, Drummond Matthews and Lawrence Morley, evidence for Wegener's theory of continental drift was mounting. But in order to explain how the continents moved, scientists needed to understand more about the structure of Earth.

Earth's **geosphere** is made up of four layers: the **crust**, **mantle**, outer **core** and inner core. The mantle is divided into a lower and upper mantle. The **lithosphere** consists of the topmost layer of the upper mantle, which is solid, and the crust. The **asthenosphere** is the softer layer of rock in the upper mantle, under the lithosphere.

The inner core is made up of heavy metals like iron and nickel. Even though the temperatures in the inner core are hotter than the surface of the Sun, these metals are in solid form due to the intense pressure from all the layers above. The outer core is completely liquid and, like the inner core, contains heavy metals. The mantle is mostly made of semi-molten rock and is quite dense, though not as dense as the metal core. The crust is the thinnest layer and supports all the life on Earth. It is made of two different types: oceanic and continental crust. Oceanic crust is much thinner and denser than continental crust and supports the world's oceans. The continents and continental shelves make up the continental crust.

geosphere
the parts of Earth that are solid (like the mantle and crust)

crust
the solid, outer layer of Earth that supports all life on Earth

mantle
the layer of Earth underneath the crust that is made up of solid and semi-molten rock and surrounds the outer core

core
the inner part of Earth's structure

lithosphere
the solid outer layer of Earth consisting of the crust and top layer of the upper mantle; It is split into giant slabs called tectonic plates

asthenosphere
the softer layer of rock under the lithosphere

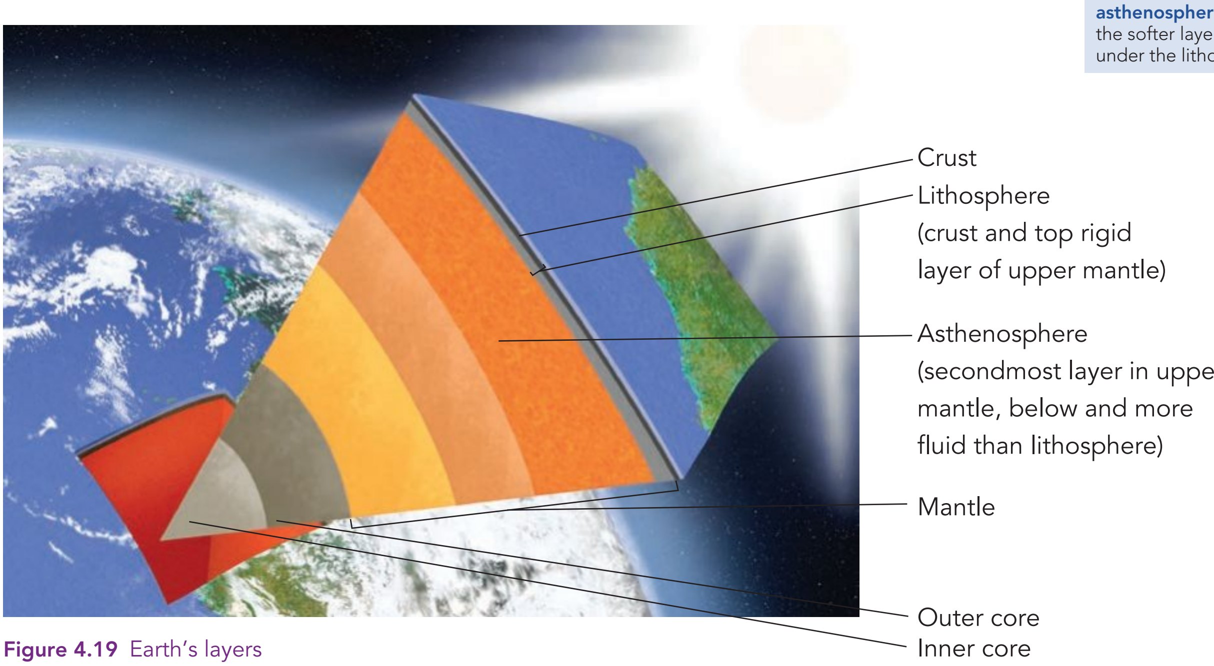

Figure 4.19 Earth's layers

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Did you know? 4.2

The innermost inner core

In 2023, scientists also proposed a fifth layer, the innermost inner core. Geoscientists first hypothesised that Earth's core might have an additional layer twenty years ago, but new research has finally provided evidence. The new layer was detected using data collected by measuring the seismic waves of earthquakes as they passed through Earth's centre.

plate tectonics the theory that Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

tectonic plates giant slabs of rigid rock that float on the partially molten rock below Earth's surface and make up the lithosphere

Scientists need to focus on Earth's lithosphere to explain how continents move. Scientists first proposed the theory of **plate tectonics** in the late 1950s and early 1960s. They said that Earth's surface is composed of **tectonic plates**, gigantic slabs of rigid rock, which float on the partially molten rock below Earth's surface.

Quick check 4.4

1 List the layers of Earth from the surface to the centre of Earth.
2 State the name given to the giant slabs of rock that make up Earth's lithosphere.
3 Describe the differences between oceanic and continental crusts.

Tectonic plates

Tectonic plates are massive pieces of Earth's lithosphere, which is the outermost and rigid layer of the planet. The lithosphere is divided into several large plates that float on the partially molten rock below. Tectonic plate movement is driven by several forces, including slab pull, ridge push and convection in Earth's mantle.

As you can see from Figure 4.20, the major tectonic plates are named after the continents that lie on them. Australia is situated in the middle of the Australian Plate, which is largely the reason why Australia does not experience significant geological activity. You will find out more about this in the next section. There are a few major plates and dozens of smaller or minor plates. No matter how small, every tectonic plate plays a role in shaping Earth. One of the smallest plates, the Juan de Fuca Plate located off the eastern coast of North America, is largely responsible for the volcanic activity there.

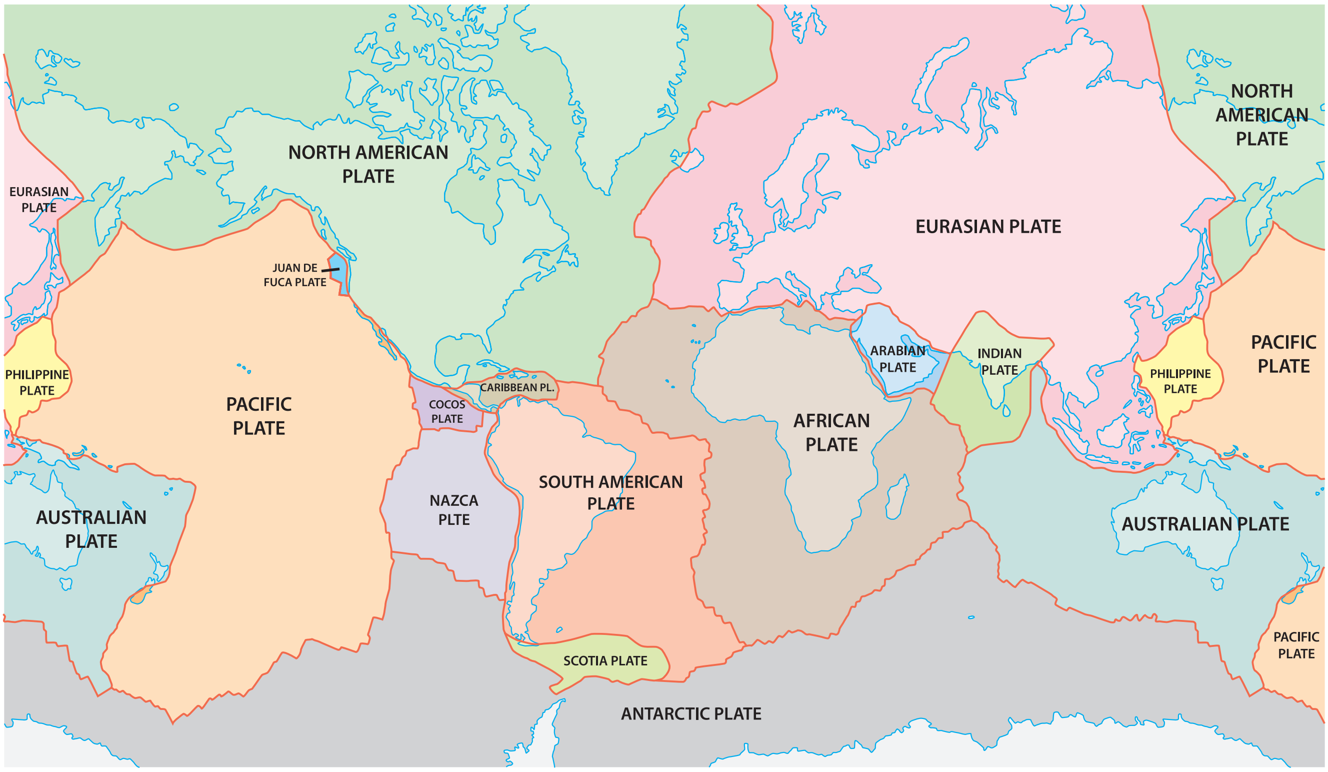

Figure 4.20 The major and some minor tectonic plates on Earth's surface

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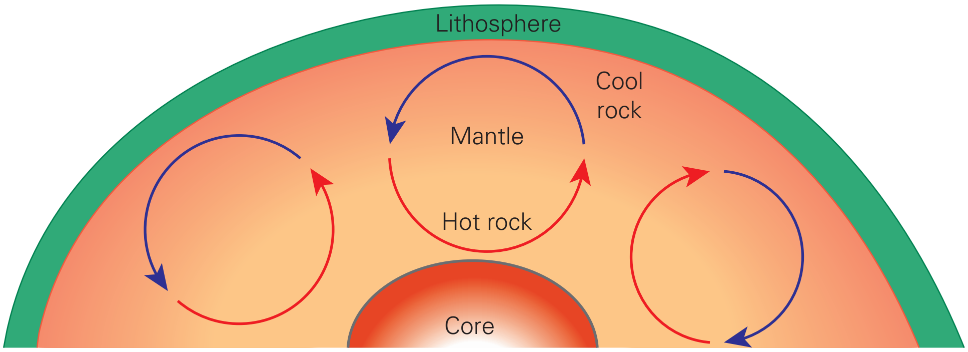

Figure 4.21 Convection currents in Earth's mantle drive the movement of the tectonic plates.

How do the plates move?

Slab pull is the force that results from the sinking of a dense oceanic tectonic plate into the mantle at a **subduction zone**, an area where one plate sinks into the mantle. This sinking motion generates a pulling force on the rest of the plate, causing it to move towards the subduction zone.

Ridge push is the force that results from the elevated position of the oceanic ridges. As new magma rises to fill the gap created by the separating plates, the ridge pushes the plate away from it.

slab pull
the pulling force exerted by a cold, dense oceanic plate plunging into the mantle due to its own weight

subduction zone
the area where a collision between two of Earth's tectonic plates causes one plate to sink into the mantle underneath the other plate

ridge push
a force that causes a plate to move away from the crest of an ocean ridge and into a subduction zone

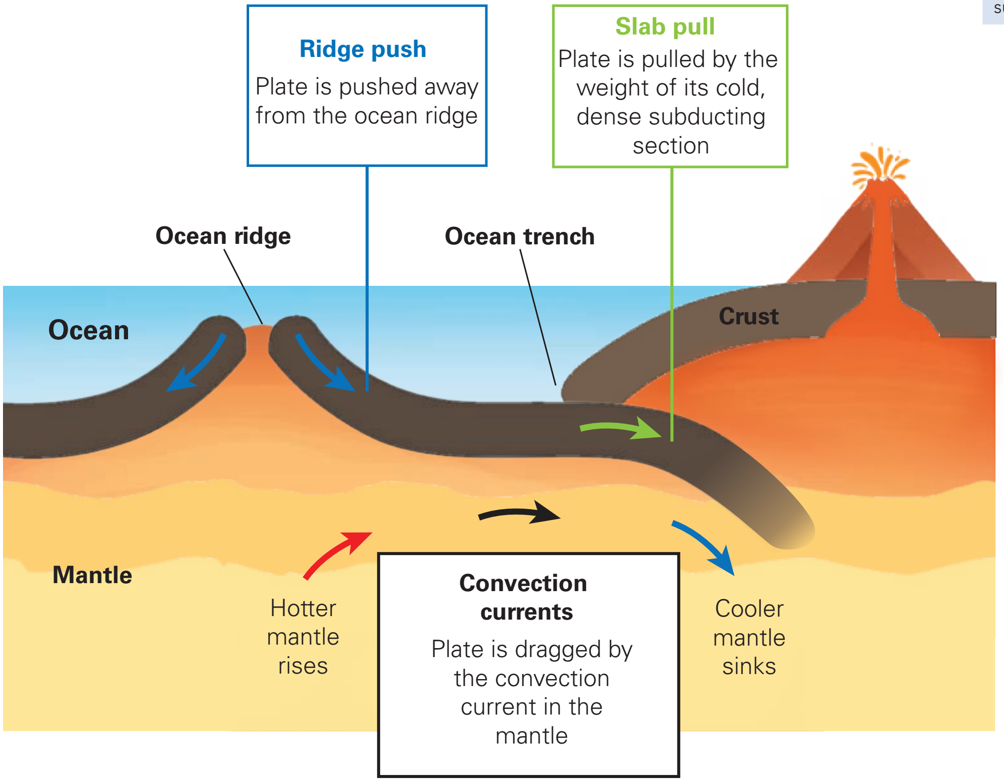

Figure 4.22 Slab pull, ridge push and convection currents all cause tectonic plates to move.

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convection currents the transfer of heat due to temperature differences between the upper and lower layers of Earth's mantle, causing movement of rocks within the mantle

Convection in the mantle is the process by which heat is transferred from Earth's interior to the surface. The temperature increases as you move down through the mantle and get closer to the core. The core is thousands of degrees hotter than the surface of Earth. The heat is generated by radioactivity in the core and heats the rock in the lower mantle, causing it to become less dense and rise towards the crust. As it rises towards the cooler surface, it begins to cool down and become denser. It is pushed aside by the hot rock that is still rising below it and eventually falls back towards the core, as shown in Figure 4.21. This cycle of hot rock rising and cooler rock sinking is called a convection cycle and creates **convection currents** in Earth's lower mantle.

Quick check 4.5

1. What are the major tectonic plates named after?
2. Describe the differences in structure between the rocks in the upper and lower mantle.
3. Explain why hot rock rises.
4. Describe how this movement of rocks in the mantle drives the movement of tectonic plates.

Practical skills 4.2

Observing convection currents

Aim

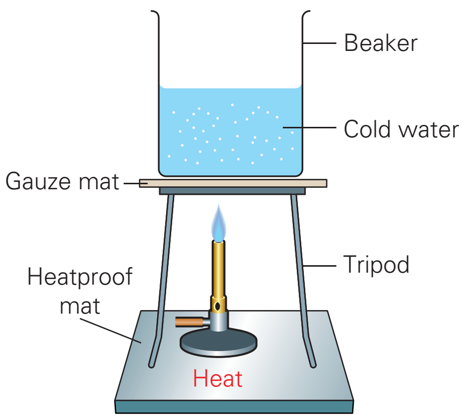
To observe convection currents

Materials

- dark food colouring
- cold water
- 250 mL beaker
- ice cube trays
- Bunsen burner
- gauze mat
- tripod
- heatproof mat

Method

1. Mix 100 mL of water with some food colouring in a beaker (the darker the coloured water the better).
2. Pour this mixture into the ice cube trays and place the trays in a freezer until the water has frozen.
3. Half fill a 250 mL beaker with cold water.
4. Set up your equipment as shown in the diagram.
5. Set the Bunsen burner to a blue flame and concentrate the heat on one corner of the beaker.
6. Drop an ice cube into the beaker and observe the water.



Results

Record your observations.

Analysis

1. Describe what happened to the ice cube when it hit the warm water.
2. Describe the distribution of the coloured water from the ice cube just after it had melted.
3. Explain what you observed.
4. Discuss what happened to the distribution of the coloured water from the ice cube as the Bunsen burner heated up the water.
5. Explain what you observed.
6. Describe and explain the appearance of the water at the end of the experiment.
7. Draw a labelled diagram to show what was happening to the water in the beaker.

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How fast is Australia moving?

Australia is situated in the middle of the Australian Plate. Since the last adjustment was made to Global Positioning System (**GPS**) coordinates in 1994, the continent has moved 1.5 m. That's about seven centimetres a year. In contrast, the North American Plate has been moving roughly 2.5 cm a year. This means that maps drawn after 1994, but still using the pre-1994 data, do not show Australia in its correct position for the time the map was drawn, let alone today. Older maps are even more out in their placement of Australia. Corrections to its geographical location have been made four times over the past 50 years. However, because continents move so slowly, most maps do not need to be updated for continental drift. Look at the map in Figure 4.23 and you will see that 1.5 m would make little observable difference to its location on the map. It is only important to the mapping systems, such as the GPS used worldwide for navigation, and other applications that rely on very accurate mapping, such as traffic signal timing and synchronisation of mobile phone base stations.

GPS
Global Positioning System, a radio navigation system that allows land, sea and airborne users to determine their exact location, velocity and time

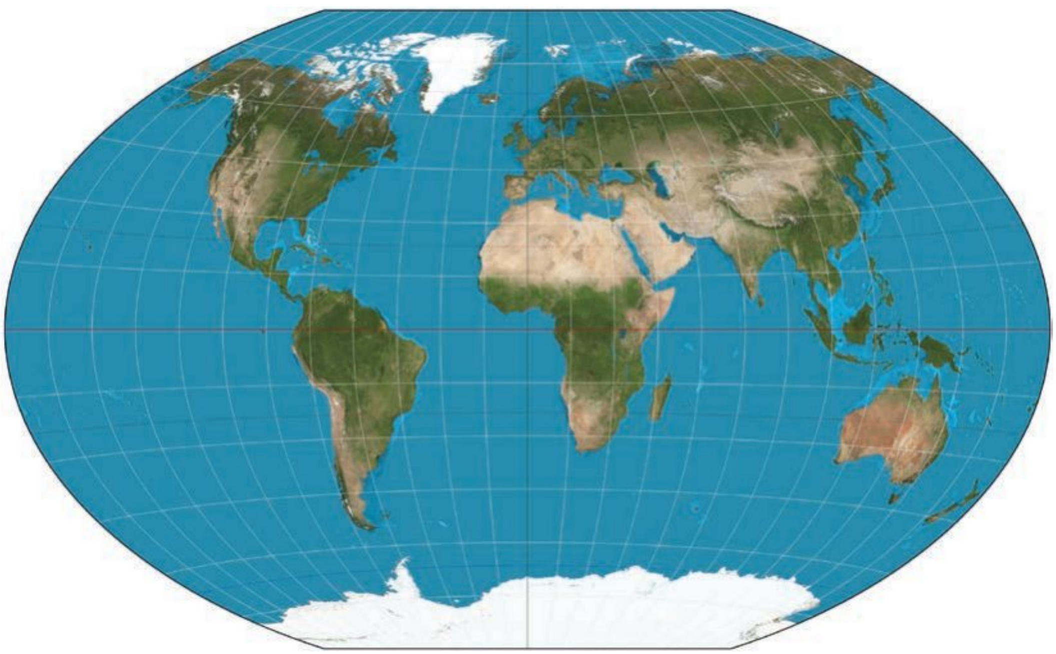

Figure 4.23 Maps drawn using GPS data from before 1994 do not show Australia in its correct geographical location due to the relatively fast movement of the Australian Plate.

Explore! 4.3

Marie Tharp

Marie Tharp was a geologist and oceanographic cartographer who played a pivotal role in the development and acceptance of the theory of plate tectonics in the mid-twentieth century. Tharp's work focused on mapping the topography of the Atlantic Ocean floor, which provided crucial evidence for the theory of plate tectonics.

At the time Tharp began her work in the 1950s, the view among scientists was that the ocean floor was flat and featureless. However, Tharp's research challenged this view by creating the first detailed, three-dimensional maps of the ocean floor. Working with Bruce Heezen, she used data collected from echo soundings to create accurate and detailed maps of the seafloor topography.

Figure 4.24 Marie Tharp and Bruce Heezen

continued …

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… continued

One of the most significant discoveries that Tharp made was the presence of a large underwater mountain range that runs along the centre of the Atlantic Ocean floor, known as the Mid-Atlantic Ridge. Tharp's 1977 maps revealed that the ridge was not a simple continuous structure but was instead a series of interconnected segments with deep valleys running between them. This discovery was a breakthrough for the theory of plate tectonics, as it provided evidence of the process of seafloor spreading.

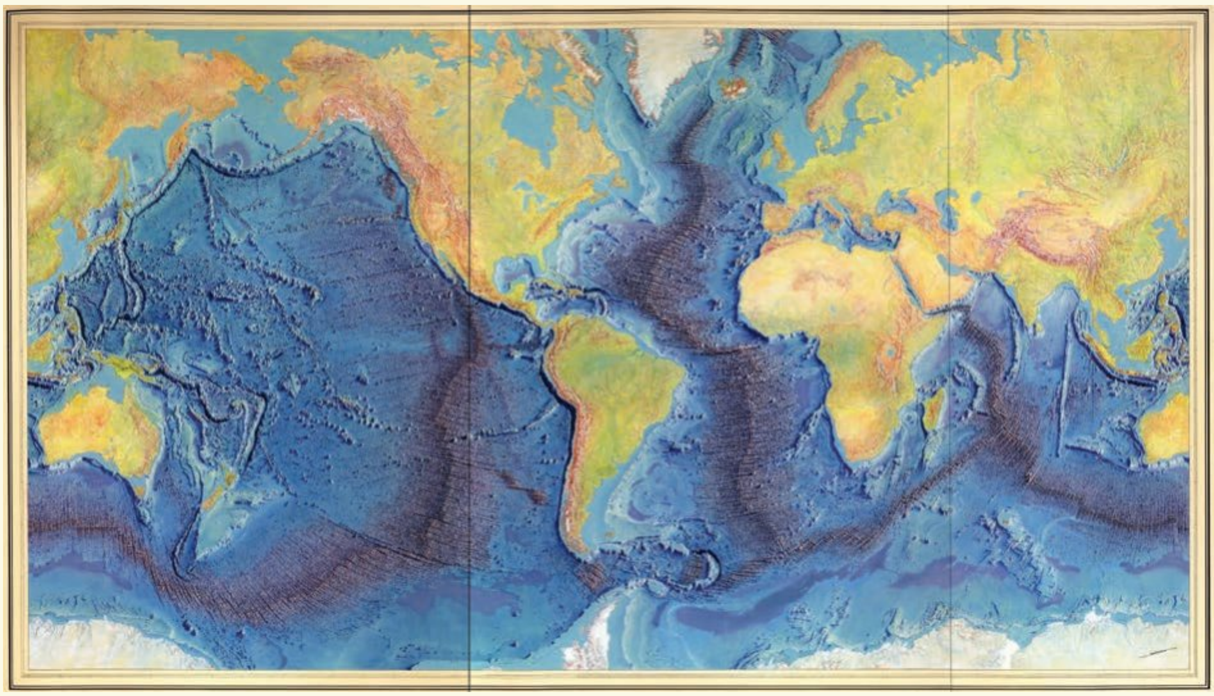

Figure 4.25 A painting of the Heezen-Tharp ocean-floor map

Seafloor spreading is the process by which new oceanic crust is created at the Mid-Atlantic Ridge and then moves away from the ridge, eventually being subducted back into Earth's mantle at deep ocean trenches. Tharp's maps showed that the Mid-Atlantic Ridge is not a static feature but is an active boundary where two plates are moving apart. This provided support for the theory of plate tectonics, which had only recently been proposed.

Tharp's work was initially met with scepticism by many scientists, who found it difficult to accept the idea of such huge movements of Earth's crust. However, as more evidence emerged in support of plate tectonics, Tharp's maps became widely accepted as a key piece of evidence. In 1977, Tharp was awarded the National Geographic Society's Hubbard Medal, the first time the award had been given to a woman.

Try this 4.2

Constructing a timeline

Construct a timeline of evidence to show the development of the theory of plate tectonics.

plate boundaries the edges where two tectonic plates meet

DOC WORKSHEET Plate boundaries

What happens at plate boundaries?

You have learned that convection currents in Earth's mantle cause the tectonic plates floating on top to move in different directions. The direction of plate movement causes different types of **plate boundaries** to form. Figure 4.26 shows the major tectonic plates and the direction they are travelling. There are three types of plate boundaries: destructive (convergent, plates move towards each other), constructive (divergent, plates move away from each other) and transform (conservative, plates slide past each other).

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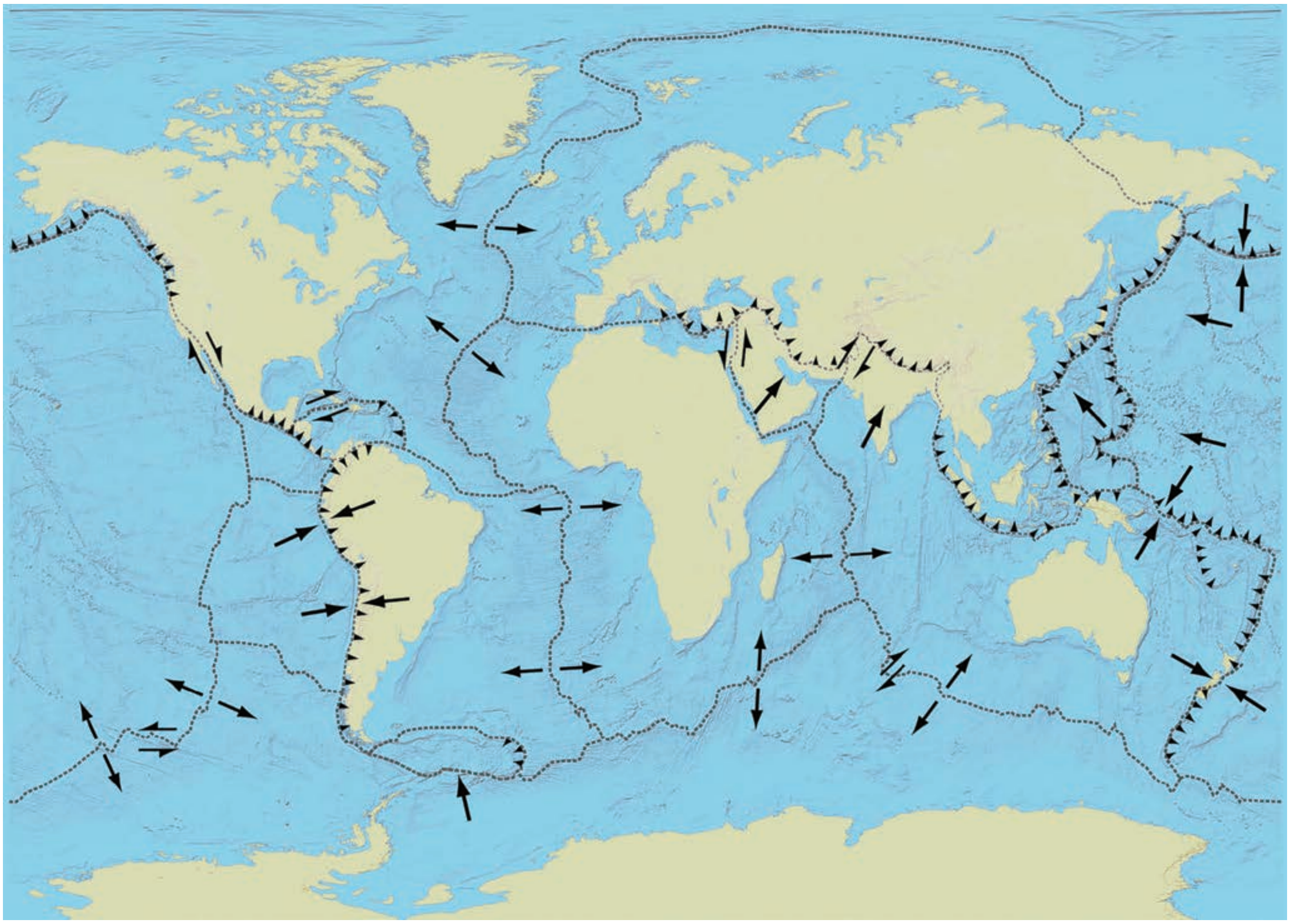

Figure 4.26 The major tectonic plates and their direction of travel. The small triangles on the lines indicate a convergent plate boundary.

Explore! 4.4

The Chile Triple Junction

The Chile Triple Junction is located on the sea floor of the Pacific Ocean off the southern coast of Chile. Use the internet to answer the following questions.

1 List which three major tectonic plates meet at the Chile Triple Junction.

2 Discuss why the triple junction is unusual.

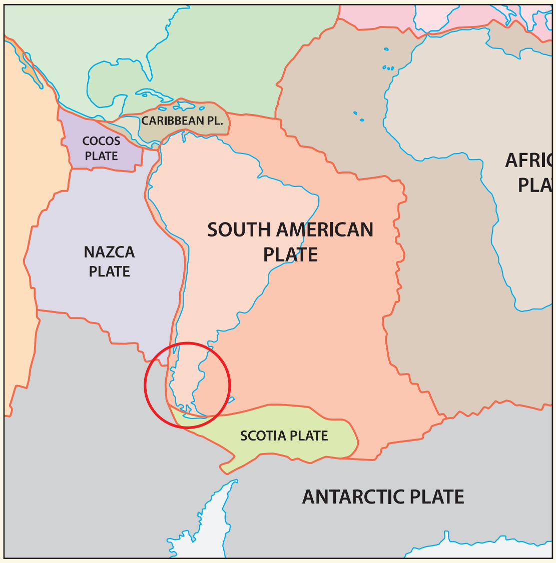

Figure 4.27 The Chile Triple Junction

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Destructive boundaries

A **destructive** plate boundary occurs when plates are moving towards each other. The plates are colliding, so they are also called **convergent** plate boundaries. The effects and the features that form at these boundaries depend on what the two plates are made from. You have already learned that there are two types of crust: oceanic and continental. Oceanic crust is thin and dense; in comparison, continental crust is thicker and less dense. So, what happens when plates with two different types of crust on top of the upper mantle collide?

destructive (convergent)
a type of plate boundary that occurs when plates move towards one another

magma
hot liquid rock found just below the surface of Earth

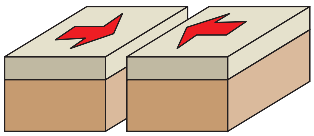

Figure 4.28 A destructive, or convergent, plate boundary

Quick check 4.6

1 Describe the movement of plates at a destructive plate boundary.
2 What affects the features that form at this type of plate boundary?

When an oceanic plate meets a continental plate

The rocks in the oceanic crust are denser than the rocks in the continental crust, so when they collide, the denser oceanic plate will sink beneath the continental plate in a process called subduction. As the oceanic plate moves down into the mantle, it begins to melt, forming **magma**. This magma can rise up through the continental plate to form volcanoes.

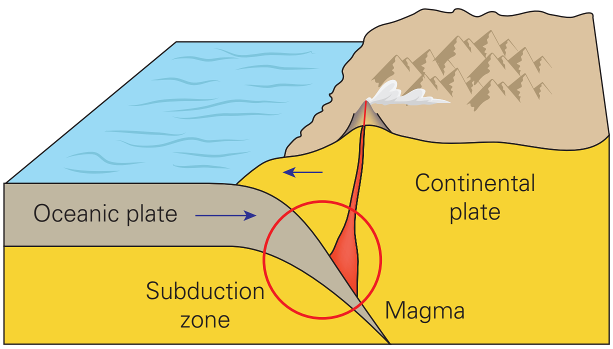

Figure 4.29 A subduction zone forms when the denser oceanic plate subducts underneath the less dense continental plate.

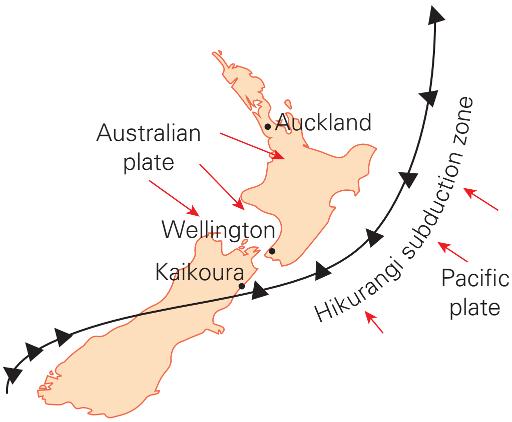

Figure 4.30 The Hikurangi subduction zone is located off the coast of New Zealand's North Island.

The Hikurangi subduction zone located off the east coast of the North Island of New Zealand has formed because of the subduction of the Pacific Plate underneath the Australian Plate. It poses the largest threat of earthquakes and tsunamis to the residents of New Zealand.

Figure 4.31 The Andes Mountains in South America formed due to the subduction of the Nazca Plate underneath the South American Plate.

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Mountains and deep ocean trenches form at a convergent or destructive boundary. For example, the Andes Mountains on the west coast of South America continue to grow in size because the Nazca oceanic plate is subducting beneath the South American continental plate.

When two continental plates meet

In this case, both plates have the same density, so when they collide, subduction does not take place. Instead, the pressure of the collision tends to force the crust upwards from both plates. Mountains are formed but without volcanoes, as is the case for subduction.

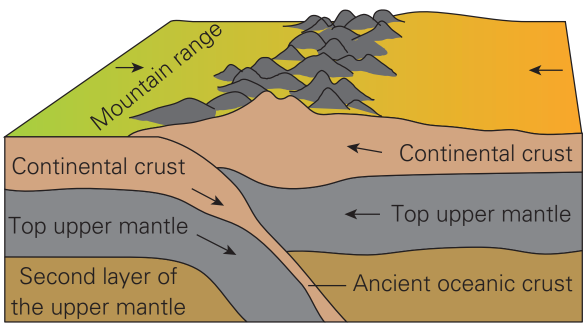

Figure 4.32 The formation of mountains when two continental plates collide

The Indian Plate and the Eurasian Plate are colliding in this type of boundary. These plates collided over 50 million years ago,

Figure 4.33 The Himalayan Mountain range, the highest in the world, was formed and is continuing to form at a destructive plate boundary.

causing a huge uplift of the land and forming the Himalayan Mountain range, the highest mountain range in the world.

When two oceanic plates meet

Several things may happen when two oceanic plates meet. If one plate is less dense than the other, a subduction zone will be created. If they are equal in density, the collision may create a ridge instead, potentially forming islands.

Quick check 4.7

1. State the term that describes the action of one plate sinking underneath another.
2. List some of the features that can form at destructive plate boundaries.
3. Discuss why subduction does not take place when two continental plates collide.

Did you know? 4.3

Mount Everest is getting taller

As the Eurasian and Indian plates are constantly moving towards each other, Mount Everest – the highest mountain in the world at 8849 m tall – is actually getting taller each year, by four millimetres in fact. If your ambition is to climb Mount Everest, then you had better do it sooner, rather than later, if you do not want to have to climb even further!

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Practical skills 4.3

How dense are different rocks?

Aim

To compare the densities of different rock types

Materials

- 4 different types of rock (basalt, granite, sandstone and chalk)
- 10 mL measuring cylinder
- displacement can
- balance

Method

1. Draw the results table below.
2. Measure the mass of each rock type and record in your results table.
3. Fill the displacement can with water.
4. Holding the 10 mL measuring cylinder at the spout of the displacement can, gently drop in one of the rocks.
5. Record the volume of water expelled in cubic centimetres (cm^3) in the results table. (Note: 1 mL = 1 cm^3)
6. Repeat twice more with the same piece of rock, refilling the can before each procedure.
7. Following the same procedure, repeat for the other rock types.
8. Calculate the average volume of water expelled from the displacement can.
9. Using the formula below, calculate the density of each rock type.

$$\text{density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

Results

Type of rock	Mass (g)	Volume of water expelled (cm^3)			Mean volume (cm^3)	Density (g/cm^3)
		1	2	3		
Basalt						
Granite						
Sandstone						
Chalk						

Analysis

1. Organise the rocks from most dense to least dense.
2. Using your results, explain why oceanic crust made of basalt subducts underneath continental crust made predominantly of granite at destructive plate boundaries.

Evaluation

1. Explain why the experiment was conducted three times for each rock type.
2. Explain why you should always measure at the bottom of the meniscus when measuring water levels.
3. Compare the density of each rock that you calculated to densities obtained from secondary sources on the internet. How close were you to those values?

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Constructive boundaries

Plates moving away from one another are called **constructive** plate boundaries. They are also more widely known as **divergent** plate boundaries and can occur beneath the ocean or on land.

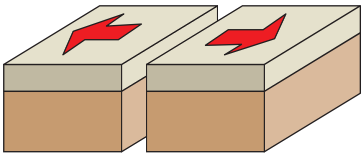

Figure 4.34 At constructive plate boundaries, plates move apart.

In the ocean

When plates move apart in the ocean, magma (molten rock) rises to fill the gap. As it reaches the colder surface, the magma cools, forming igneous rock and gradually building more oceanic crust. The Mid-Atlantic Ridge, a series of underwater volcanoes running down the Atlantic Ocean between Africa and America, is an example of this type of plate boundary. Here, the North American and South American plates are moving away from the Eurasian and African plates.

Figure 4.35 A volcanic crater of basalt rocks near Portugal

On land

Constructive plate boundaries that occur on land form **rift valleys**. An active rift valley is currently separating the Horn of Africa from the rest of Africa. This rift valley will eventually be filled with water when it drops below sea level, creating a new island. It is already having damaging effects, with major roads in cities cracking and caving under the strain. Scientists think the rift valley is moving so fast due to a superplume. A superplume occurs when heat from Earth's core rises up through the mantle, intensifying the convection currents and causing the plates to separate much faster.

constructive (divergent) a type of plate boundary that occurs when plates move away from one another

Figure 4.36 The Laki crater row in Iceland that opened during the eruptive period of 1783–1784 is part of a volcanic fissure running through the country, which is situated on the tectonic plate boundaries of the Mid-Atlantic Ridge.

Quick check 4.8

1 Describe the movement of plates at a constructive plate boundary.
2 List some of the features that can form at this type of boundary.
3 Why are constructive plate boundaries also known as divergent boundaries?

Transform boundaries

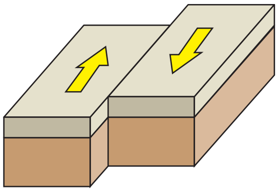

Figure 4.37 At transform plate boundaries, plates slide past one another.

At **transform** plate boundaries, plates are moving parallel to one another, but in opposite directions.

rift valley an elongated depression in Earth's surface formed by the separation of tectonic plates

transform (conservative) a type of plate boundary that occurs when plates move parallel to one another

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VIDEO
Causes of earthquakes

Crust is neither created nor destroyed, so they are sometimes called conservative plate boundaries. When plates move in this way, a tremendous amount of pressure can build up due to friction, which stops the plates from moving. When the force of the plate movement overcomes the friction, the pressure is released and an earthquake occurs as the plates move suddenly. An example of a transform plate boundary is the San Andreas Fault, which runs down the east coast of North America through California. Here, the North American Plate and the Pacific Plate are sliding past each other.

Figure 4.38 The San Andreas Fault is the boundary between the North American and Pacific plates.

Figure 4.39 Earthquakes occur at transform boundaries. The earthquake that occurred at the San Andreas Fault in 1906 caused this fence to separate by a huge distance.

Try this 4.3

Making a documentary

Film a documentary on the dynamic nature of the geosphere to engage a specific audience, making sure you have selected appropriate language, models or analogies.

WIDGET
Plate movement at boundaries

Quick check 4.9

1 Describe the movement of plates at a transform plate boundary.
2 List one of the characteristics of this type of boundary.
3 Why are transform plate boundaries also known as conservative boundaries?

Try this 4.4

Tectonic plate simulations

Use the internet to navigate to *Tectonic Explorer* by The Concord Consortium. This is a computer model of a plate system on a fictional Earth-like planet. Use it to simulate multiple plate system scenarios and observe the different types of plate interactions responsible for patterns of events and landforms observed on Earth's surface.

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Table 4.1 summarises each type of plate boundary.

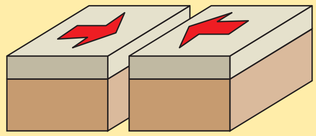
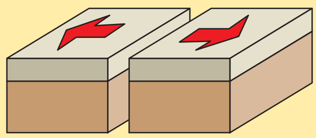
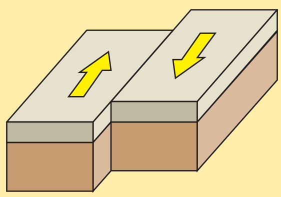
Type of boundary interaction	Diagram	Type of movement	What happens to the crust?	Key features
Destructive (convergent)		Plates move towards each other	Destroyed	Mountains Trenches Subduction zones Volcanoes Earthquakes
Constructive (divergent)		Plates move away from each other	Created	Volcanoes Rift valleys Ocean ridges
Transform (conservative)		Plates move parallel to each other in opposite directions	Conserved	Earthquakes

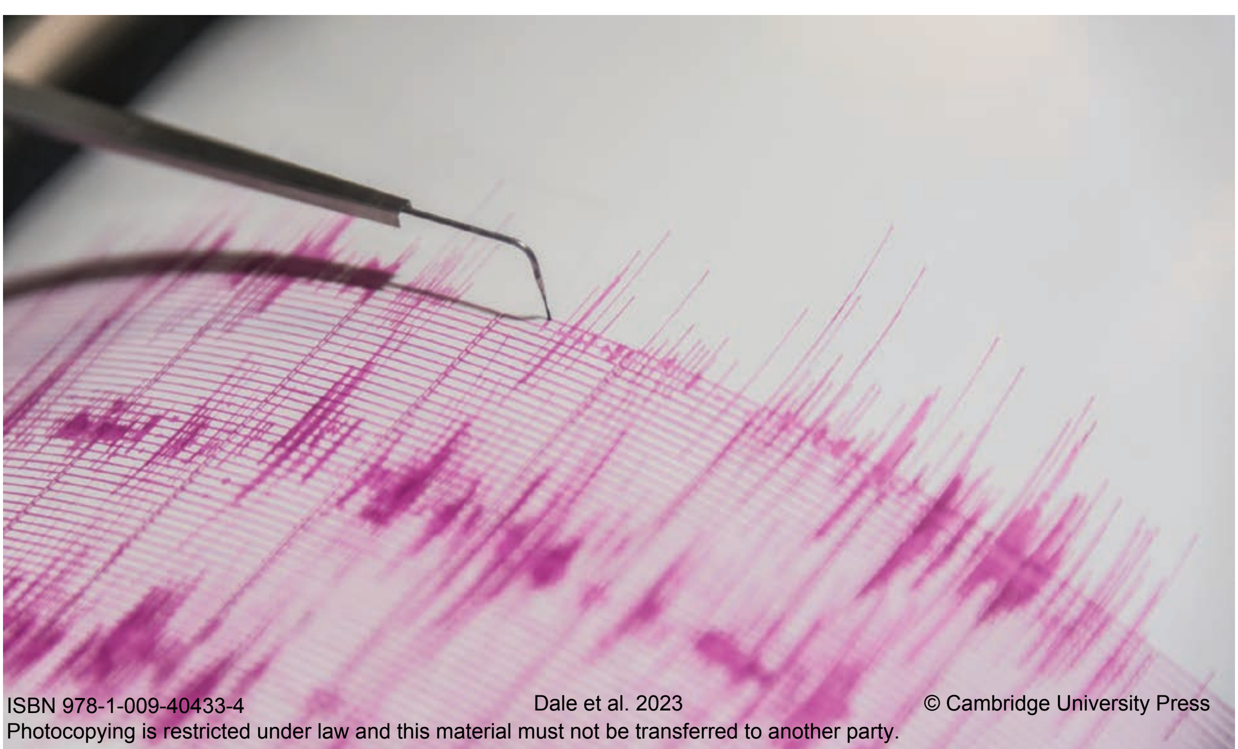
Table 4.1 A summary of each type of plate boundary

Try this 4.5

Modelling plate boundaries

You can model plate boundaries in different ways. Your teacher can provide you with a range of materials for you to explore modelling interactions at plate boundaries.

Figure 4.40 How might crème-filled cookies be used to model each of the different boundary interactions?



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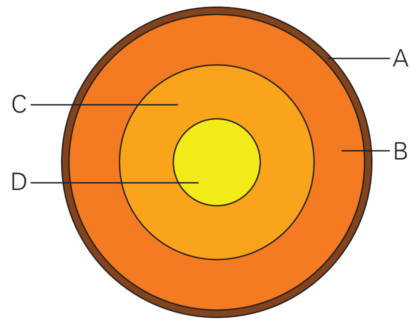
Section 4.2 questions

QUIZ

Retrieval

1 **Name** the three types of plate boundaries.
2 **State** the name of the mechanism that causes tectonic plates to move.
3 **Select** the correct words to label the following diagram of the structure of Earth.



4 **Name** a real-life example of each of the three types of plate boundaries.
5 **Name** two types of crust.
6 **Identify** the type of plate boundary where the following features would occur.
- a trenches
- b mountains
- c earthquakes
- d volcanoes
- e ridges
- f rift valleys
- g subduction zones

Comprehension

7 **Describe** how temperature affects the structure of rocks in the mantle.
8 **Explain** why the physical states of the inner and outer core differ.
9 At destructive plate boundaries, crust is destroyed. **Explain** why the overall amount of crust on Earth has stayed the same despite this destruction.
10 **Summarise** how magma forms at a subduction zone.

Analysis

11 **Compare** oceanic and continental crusts.

Knowledge utilisation

12 **Propose** why mountains and trenches continue to increase in size.
13 **Construct** a labelled diagram to show an oceanic plate subducting underneath a continental plate.
14 **Propose** reasons why countries like Australia do not experience significant amounts of geological activity.
15 **Discuss** why tectonic plates move across the surface of Earth.
16 **Propose** your own reasons why some tectonic plates move faster than others.
17 **Discuss** the evidence that led to the acceptance of the theory of plate tectonics as a development of the earlier idea of continental drift.
18 **Discuss** the role that Marie Tharp's maps had in the theory of plate tectonics.

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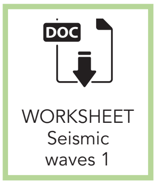
4.3 The effects of plate movement

Learning goals

1. To be able to describe how volcanoes, earthquakes and tsunamis form.
2. To distinguish between S and P waves and the information they provide about earthquakes.
3. To examine patterns of earthquake and volcanic activity over time and propose explanations.
4. To be able to relate the extreme age and stability of a large part of the Australian continent to its plate tectonic history.
5. To research First Nations Australians' cultural accounts that provide evidence of earthquakes and volcanoes.



If you live near a plate boundary, you are at risk of experiencing some of the geological activity discussed. In this section, you will examine the reasons for, and effects of, three types of natural disasters that can occur at plate boundaries.

Volcanoes

Where do volcanoes form?

Volcanoes can form at two types of plate boundaries. When two plates move apart at a constructive plate boundary, magma rises and seeps into the gap, as in Figure 4.41.

At a destructive boundary (particularly at subduction zones), friction caused by one plate subducting underneath another produces intense heat. This heat is enough to melt the rock of the subducting plate, forming magma. As the magma rises to the surface, it will form volcanoes.

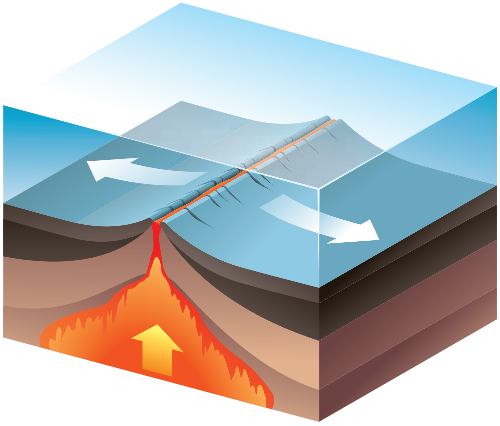


Figure 4.41 A volcano forms at a constructive plate boundary where magma rises to fill the gap when the plates move apart.

When this magma erupts at the bottom of the sea it can make a chain of volcanoes called island arcs. Figure 4.42 shows the island arc of the Aleutian Islands in the northern Pacific Ocean. They are made up of a long chain of volcanoes associated with the Aleutian Trench.

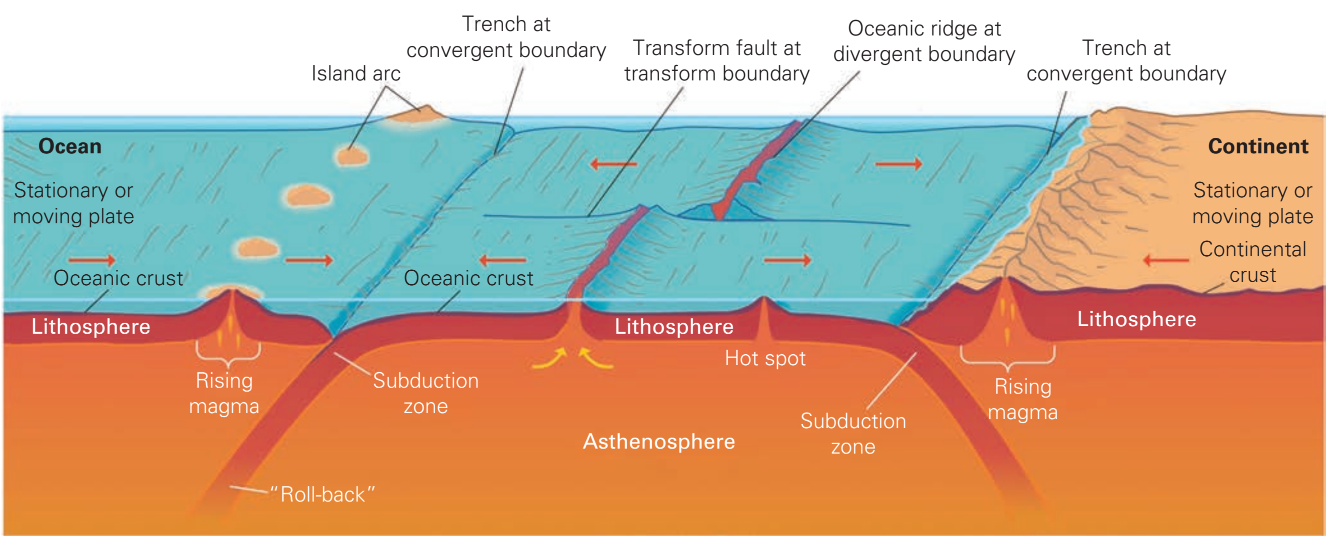


Figure 4.42 Volcanoes can form at destructive (convergent) and constructive (divergent) plate boundaries.

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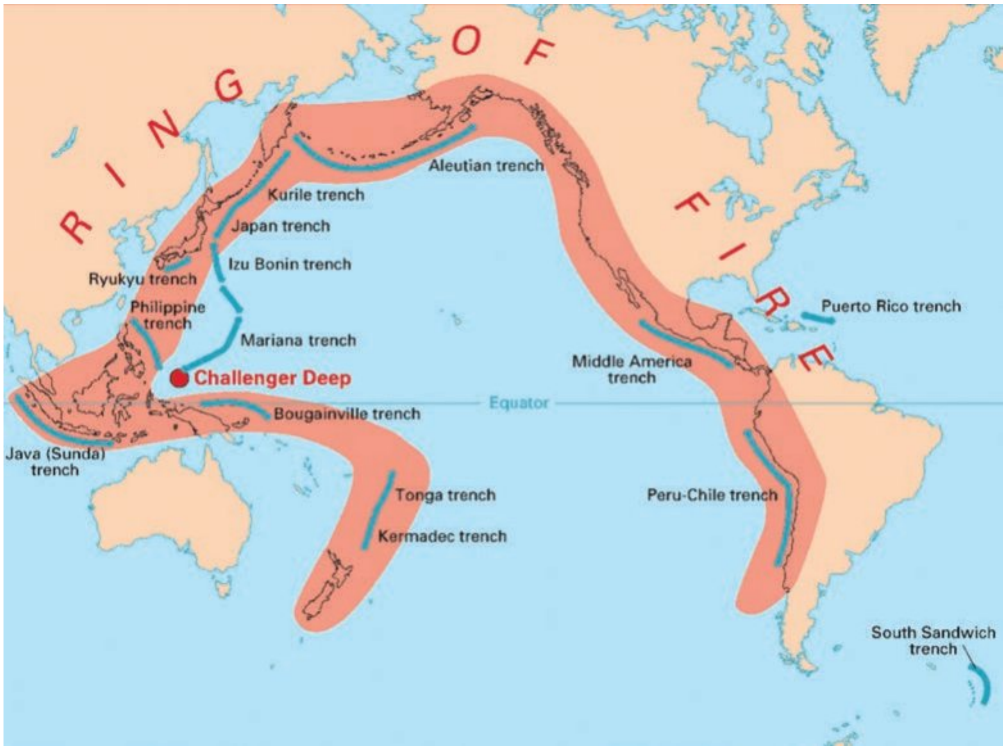

Figure 4.43 The Ring of Fire is an active area of many subduction zones around the Pacific Ocean.

VIDEO
Island hotspots

hotspot a pocket of magma that sits just underneath the crust

Over three quarters of the world's active volcanoes can be found in an area called the Pacific Ring of Fire, the shape of which can be seen in Figure 4.43.

Volcanoes are unique geological features in that they do not always occur where two plates meet. They can form anywhere that a **hotspot** exists. A hotspot is a pocket of magma that sits just underneath the crust. It has the potential to erupt at any time, forming volcanoes. As the tectonic plate above the hotspot moves, the volcano created by the hotspot also moves, allowing for another hotspot volcano to form. Chains of volcanic islands like the Hawaiian Islands have been made in this way.

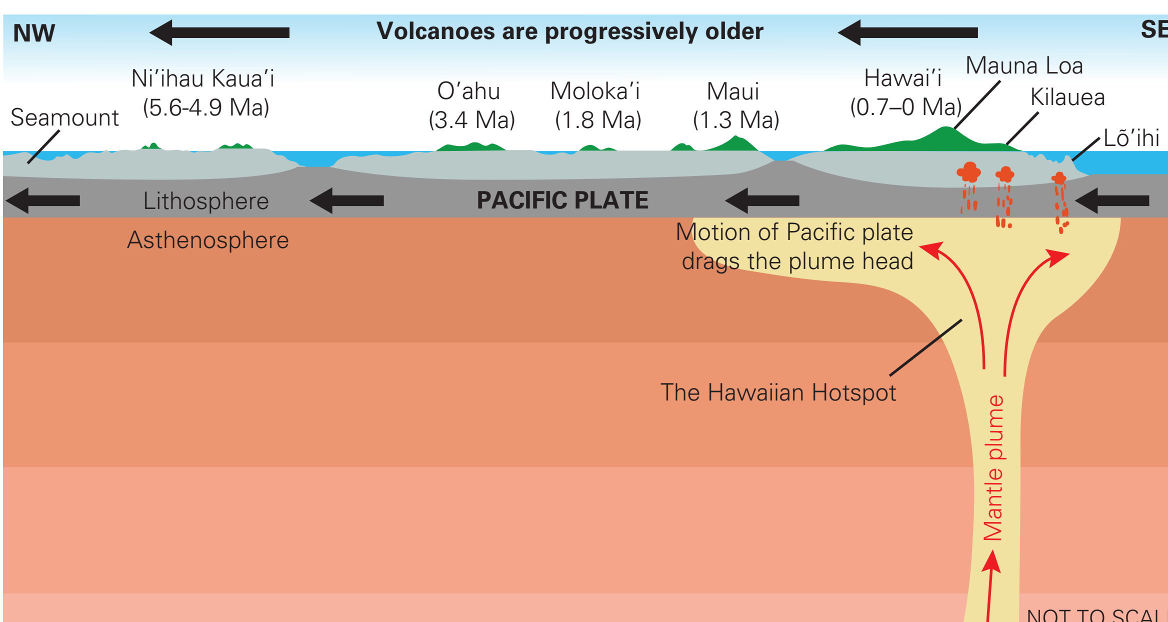

Figure 4.44 The Hawaiian island chain formed as the Pacific Plate moves across a hotspot. The oldest island, Ni'ihau, formed around 5.6 million years ago (Ma) and the top of the newest volcano, Lō'ihi, is less than 1000 m below the sea surface.

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Quick check 4.10

1. At what type of plate boundaries do volcanoes occur?
2. What is the name of the area of the world that contains the greatest number of active volcanoes?
3. Discuss what hotspot volcanoes are and how they differ from volcanoes formed in other ways.

What happens during a volcanic eruption?

When the pressure of the magma rising to the surface increases quickly, a volcano can erupt. When magma reaches the surface, it is called **lava**. The type of lava produced by a volcano makes a huge difference to the effects of a volcanic eruption. Lava with large amounts of silica is viscous (thick and sticky) like golden syrup. Air pockets can build up in viscous lava leading to a very explosive eruption.

Lava that contains a small amount of silica is less viscous, but it will travel further from an eruption, putting larger areas at risk.

lava
molten rock from inside Earth (magma) that has reached the surface

pyroclastic
consisting of or relating to small pieces of rock from a volcano

Lava is not the only hazard of a volcanic eruption. Gas and ash clouds, acidic gas causing acid rain and **pyroclastic** flows, as shown in Figure 4.46, made up of hot gas and rock can also cause major damage, not only to the surrounding areas but across the world.

Figure 4.45 The viscosity of the lava has a huge effect on the damage caused by a volcanic eruption.

Figure 4.46 Pyroclastic flows from the eruption of the Sinabung volcano in Indonesia in October 2017

Quick check 4.11

1. Distinguish between magma and lava.
2. Explain how the viscosity of lava affects a volcanic eruption.

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Explore! 4.5

Oral traditions about earth movements

First Nations Australians have a deep and rich cultural history that includes detailed oral traditions and songs that are passed down unbroken from generation to generation. Many of these accounts provide evidence of earthquakes and volcanoes that have occurred in Australia over thousands of years.

According to oral traditions of the Gunditjmara People, in ancient times, four enormous giants arrived in the south-eastern region of Australia. While three of them departed to other parts of the continent, the fourth remained still and transformed into a volcano that came to be known as Budj Bim. The lava that spewed forth from the volcano was formed from the giant's teeth.

Figure 4.47 A nineteenth century drawing of the lake in the crater at the top of Budj Bim

Recent scientific findings have uncovered evidence to support the timing of this account, which is passed down through generations by the Gunditjmara people. The evidence indicates that Budj Bim, along with another nearby volcano, emerged roughly 37 000 years ago because of a swift succession of eruptions. This discovery suggests that the oral tradition could be the oldest story still in circulation today.

Figure 4.48 For thousands of years, the Gugu Badhun People have lived in the upper Burdekin River valley in Northern Queensland.

Research the scientific basis of the Gugu Badhun oral traditions that recount 'the earth being on fire along watercourses' and 'a time when a witchdoctor made a pit in the ground and lots of dust in the air, causing people to get lost in the dust and die'.

Explore! 4.6

The Hunga Tonga-Hunga Ha'apai volcanic eruption in 2022

In January 2022, the Hunga Tonga-Hunga Ha'apai volcano erupted underwater with a force that caused a 15 m tsunami that demolished homes and killed at least three people in Tonga.

The eruption also damaged undersea communication cables, cutting Tonga off from the rest of the world for weeks and delaying efforts to help the victims.

Complete some research and answer the questions on the following page.

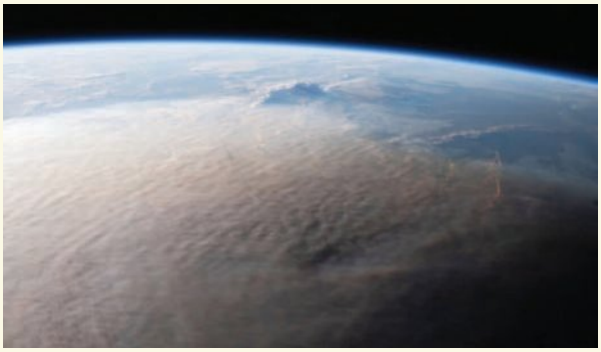

Figure 4.49 This satellite image shows the volcanic ash thrown out of Hunga Tonga-Hunga Ha'apai volcano in 2022, from the force of the eruption.

continued …

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... continued

1 What did the eruption rate on the Volcanic Explosivity Index?
2 The eruption was equivalent to a historical volcanic eruption that took place in 1883. Where did this occur?
3 What records were broken by the volcanic eruption?
4 Explain whether volcanic eruptions only affect the surrounding area. Use this case study as an example in your answer.
5 Using the tsunami travel time map shown in Figure 4.50, determine the tsunami travel time to the East Coast of Australia.

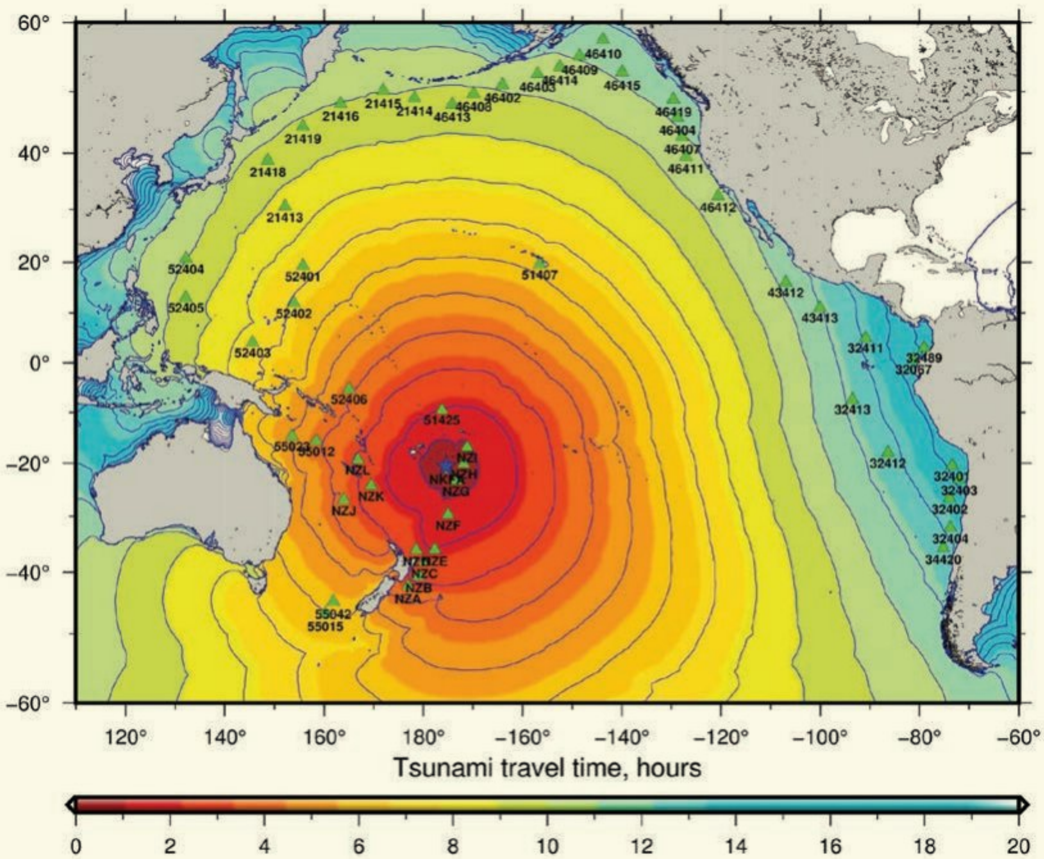

Figure 4.50 Tsunami travel time map of the Hunga Tonga-Hunga Ha'apai volcano eruption and tsunami, 15 January 2022

Earthquakes

Where do earthquakes occur?

Earthquakes occur when there is a sudden movement of land. This can happen at a transform, constructive (divergent) or destructive (convergent) plate boundary. Friction between two plates must be overcome before the plates can slide past each other. When the driving force is strong enough to overcome this friction, the two plates will suddenly move, sending out waves of energy called **seismic waves**. The exact point under Earth where the earthquake occurs is called the **focus**. The point directly above the focus, on the surface of Earth is called the **epicentre**.

seismic wave
a wave that moves through Earth during an earthquake

focus
the exact point under the surface of Earth where the earthquake occurs

epicentre
the location on Earth's surface directly above the focus of an earthquake

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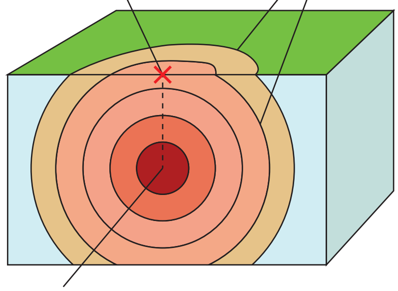

Figure 4.51 A diagram showing the location of an earthquake's focus and epicentre

WORKSHEET
Seismic waves 2

How are earthquakes detected?

Earthquakes are detected using an instrument called a **seismometer**. A simple seismometer is shown in Figure 4.52. Its basic structure uses a weight hanging from a spring suspended from a frame that moves along with the motion of Earth. A rotating drum is attached to the frame and a pen is attached to the weight.

When the land moves from side to side, the base remains fixed to the ground and moves with it, but the mass on the end of the spring stays in its original position. It is not affected by the movement of the ground. The pen attached to the mass records the movement of the box in relation to the stationary mass. The resulting pattern is called a **seismogram**. Note that digital seismometers are also available for many smartphones.

seismometer
an instrument that measures the intensity and duration of seismic waves during an earthquake

seismogram
the pattern produced when seismic activity is recorded by a seismometer

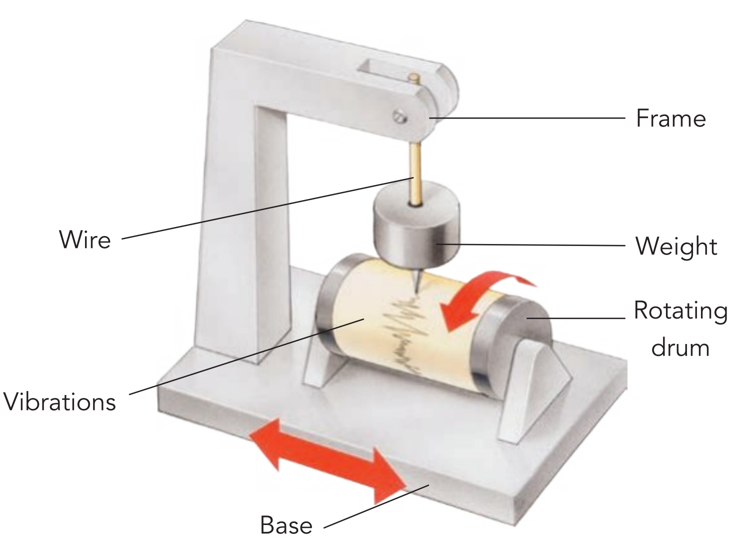

Figure 4.52 A simple seismometer

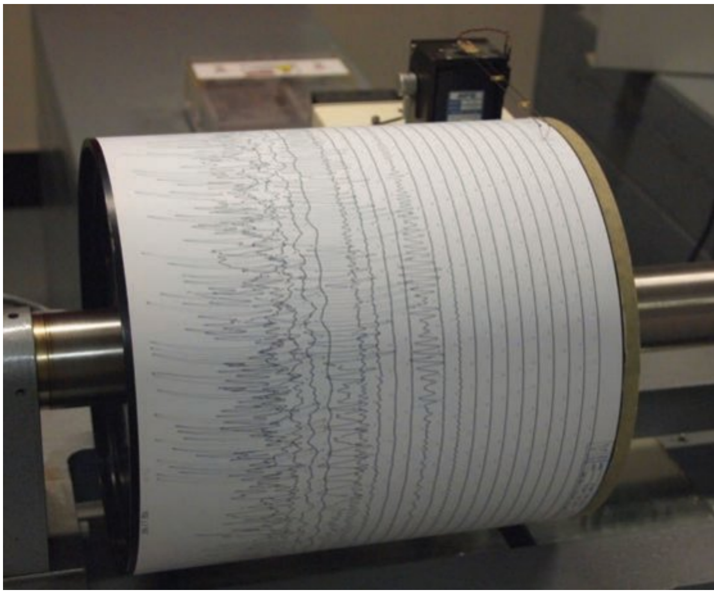

Figure 4.53 A seismogram

The two main types of seismic waves produced by an earthquake are primary (P) waves and secondary (S) waves (see Figure 4.54). The properties of these waves are summarised in Table 4.2.

	P waves	S waves
Name	Primary	Secondary
Speed	Fast	Slow
Movement	Longitudinal (back and forth)	Transverse (side to side or up and down)
Materials they can travel through	Liquids and solids	Solids only
Level of damage caused	Minimal damage caused	Very destructive due to side-to-side movements

Table 4.2 The properties of P and S waves

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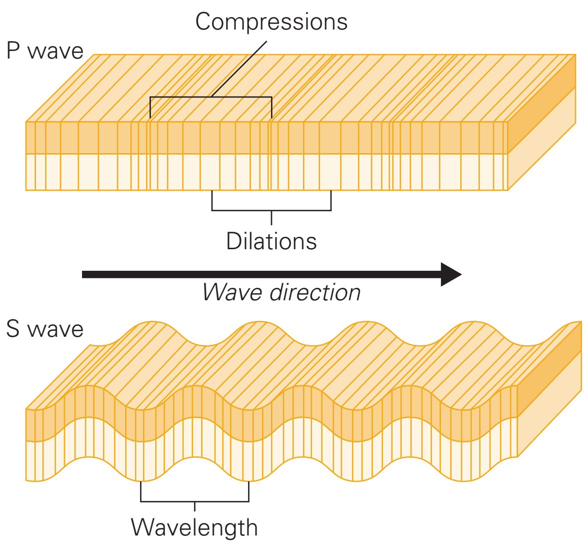

Figure 4.54 P and S waves travelling through Earth

As P waves are the faster of the two waves, they are detected by the seismometer first. The first seismic activity detected by the seismometer on the seismogram in Figure 4.55 is the P wave. The S waves are slower and so arrive second. S waves are also the most intense and so register larger movements on the seismogram.

lag time the time between the arrival of the P and S waves

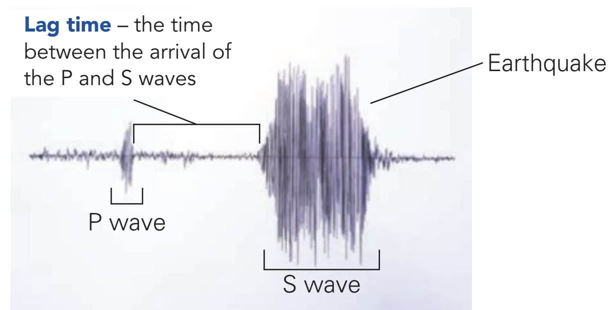

Figure 4.55 A seismogram of seismic activity within Earth

Quick check 4.12

1 Identify the two plate boundaries at which earthquakes occur.
2 Why do they occur at these boundaries?
3 Recall the name given to the part of Earth where the earthquake is generated.
4 What is the name of the equipment used to detect seismic activity?
5 Which type of seismic wave is faster and therefore first to arrive during an earthquake?

Explore! 4.7

How do P and S waves give us evidence for the structure of Earth?

The properties of P waves and S waves generated by an earthquake can be used to determine the properties of the layers of Earth. In 1936, Danish scientist Inge Lehmann discovered that Earth has a solid inner core inside a molten outer core after she analysed data from seismic stations around the world. She noticed some irregularities in the data that disproved the accepted idea that the core was entirely molten. It wasn't until 1970 that her theory was confirmed!

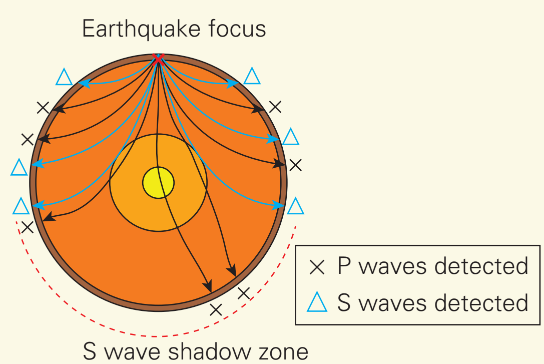

Figure 4.56 The pattern of seismic activity away from an earthquake's focus

Figure 4.57 Inge Lehmann

1 What can you conclude about the movements of P and S waves through Earth using the diagram in Figure 4.56?
2 Interpret the properties of the seismic waves listed in Table 4.2 to make conclusions about the physical properties of the outer core and the mantle.
3 When P waves travel through the inner core and outer core they appear to bend. Discuss why you think this is.
4 What is the S wave shadow zone? Deduce why it occurs.

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The effects of earthquakes

Richter scale
a system used to measure the strength of an earthquake

tsunami
a great wave produced by an earthquake or volcanic eruption in the ocean

The severity of an earthquake is measured using the **Richter scale**: the more severe the earthquake, the higher the number on the Richter scale. The Richter scale is a logarithmic scale. This means that an earthquake measured as four on this scale is *ten times* more severe than an earthquake measured at three.

Did you know? 4.4

The largest earthquake on record
The largest earthquake ever recorded occurred in Chile on 22 May 1960. It was recorded at 9.5 on the Richter scale. The earthquake killed 1655 people and displaced more than two million people from their homes.

Tsunamis

A **tsunami** is a devastating natural disaster that can cause massive destruction to coastal areas. The primary cause of a tsunami is an underwater earthquake or volcanic eruption that generates a large amount of energy, resulting in massive waves. The movement of Earth's tectonic plates can cause an underwater earthquake, which can displace large amounts of water and create a series of waves that can travel long distances. Similarly, a volcanic eruption can cause an underwater landslide or an explosive release of gas, which can trigger a tsunami.

Figure 4.58 A tsunami breaching the embankments after an earthquake measuring 9.0 on the Richter scale occurred off the coast of northern Japan in 2011.

On Boxing Day 2004, an earthquake was measured in the Indian Ocean at 9.1 on the Richter scale. The tsunami waves produced following this earthquake reached up to 15 m high in some places near to land and affected more than 14 different countries. A quarter of a million people died, and two million people were left homeless.

Figure 4.59 An aerial view of the devastation caused by the Boxing Day tsunami in 2004

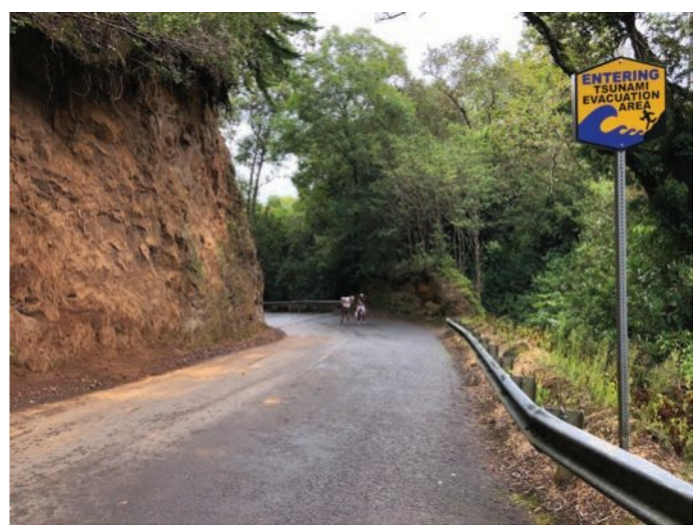

Figure 4.60 A Hawaiian tsunami evacuation zone, located 260 m above sea level

Quick check 4.13

1. How many times more intense is a magnitude 7.0 earthquake compared to a magnitude 5.0 earthquake on the Richter scale?
2. Explain what a tsunami is and how it forms.

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Is Australia at risk?

The extreme age and stability of a large part of the Australian continent can be attributed to its plate tectonic history. Unlike other continents, such as the Americas, Africa and Europe, Australia is in the centre of a tectonic plate, the Australian Plate, which means that it is not affected by the boundary interactions of multiple plates and not directly at risk from major earthquakes and volcanoes.

The Australian Plate, which encompasses the entire continent and parts of the surrounding ocean, has been relatively stable for hundreds of millions of years. The Australian Plate is surrounded by several relatively inactive plates, including the Antarctic Plate, the Pacific Plate and the African Plate.

The age of the Australian continent is also a contributing factor to its stability. Much of the continent is made up of ancient **cratons**, which are large areas of stable, ancient rocks that have not been affected by tectonic activity for billions of years. These cratons make up the core of the continent and have provided a stable foundation for the younger sedimentary rocks and soils that cover much of the continent.

The Australian Plate is moving and colliding with the plates at its northern boundary. This results in a significant amount of pressure building up, which can cause earthquakes in Australia. As a result, although Australia is more stable than other continents, it still has more earthquakes than other regions that sit in the middle of tectonic plates.

Figure 4.61 Rescue workers trying to find survivors under the rubble beneath the Kent Hotel in Hamilton, Newcastle, NSW, after the 1989 magnitude 5.6 earthquake that killed 13 people

craton
the stable interior portion of a continent

The Glass House Mountains are a group of 11 volcanic peaks located in the Sunshine Coast region of Queensland, Australia. The mountains are formed from volcanic plugs, which are solidified magma that hardened within the vents of active volcanoes. They are estimated to have formed between 26 and 27 million years ago during the Oligocene period. The volcanic activity that formed these mountains is believed to have been caused by the movement of the Australian Plate over a hotspot in Earth's mantle.

Figure 4.62 The Glass House Mountains are culturally significant to the Gubbi Gubbi people, who have lived in the region for thousands of years.

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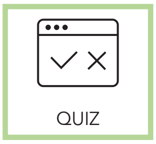
Figure 4.63 The last significant volcanic activity on the Australian continent occurred over 4000 years ago, at Mount Gambier in South Australia.

Section 4.3 questions



Retrieval

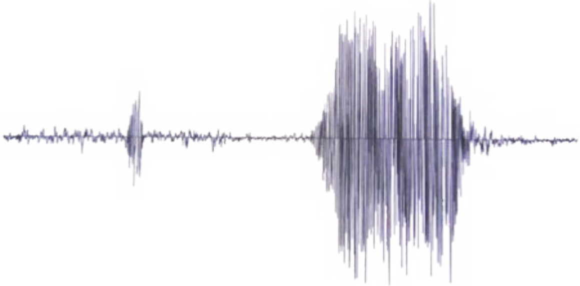
1 **Recall** the name for the volcanic hazard that produces hot, fast-moving gas and rocks.
2 **Name** the equipment used to measure the seismic activity of Earth.
3 **Name** the scale used to measure the magnitude of an earthquake.
4 **Name** the point on Earth's surface directly above the focus of an earthquake.

Comprehension

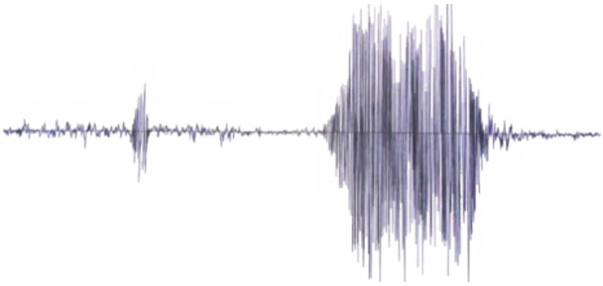
5 **Describe** how earthquakes cause tsunamis.
6 **Explain** why plates at a transform or destructive plate boundary do not slide past each other all the time.
7 **Explain** how the silica content of lava can affect the outcome of a volcanic eruption.
8 **Summarise** the reasons why the Ring of Fire in the Pacific is so volcanically active.

Analysis

9 On the seismogram below, **identify** which is the P wave and which is the S wave.



10 **Identify** the lag time on the seismogram below.



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11 **Compare** the properties of P waves and S waves.

12 **Contrast** magma and lava.

Knowledge utilisation

13 Hannah says that volcanoes only affect the people who live in the country of the eruption. Rounak thinks that volcanic eruptions can affect many countries. **Decide** who is right and give reasons why.

14 There are many different types of volcanoes. **Deduce** definitions for the following types of volcanoes.

- **a** dormant
- **b** extinct
- **c** active

15 **Decide** whether more geological activity is experienced by countries in the middle of a plate or by countries on a plate boundary. Outline your reasoning.

16 **Discuss** the intensity and frequency of geological activity in Australia.

17 **Evaluate** the following hypothesis: 'An earthquake of greater magnitude will cause more damage because there is more energy transferred'.

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4.4 Predicting and responding to natural disasters

WORKSHEET
Investigating tectonic plate movement

Learning goals

1. To be able to list methods that can be used to map or predict plate movements.
2. To evaluate the impact of tectonic events on human populations and examine engineering solutions designed to reduce the impact.

As technology improves, we can use it to improve our understanding of geological patterns and changes. This greater understanding has allowed scientists to predict the movement of tectonic plates. It also assists governments and aid organisations to respond quickly and more effectively when plate movements result in natural disasters.

Measuring and mapping change

Global Positioning System (GPS)

Forecasting the movements of tectonic plates has become an important area of geology. To do this, geologists use GPS and small base stations on the surface of Earth. GPS relies on two dozen satellites that orbit Earth as well as GPS receivers on the ground that detect the radio signals from the satellites. To determine precise locations on Earth, the GPS receiver must receive signals from at least four different satellites. GPS receivers used for plate boundary observation can determine their location to a precision equal to the size of a grain of rice.

geoid
a model of Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

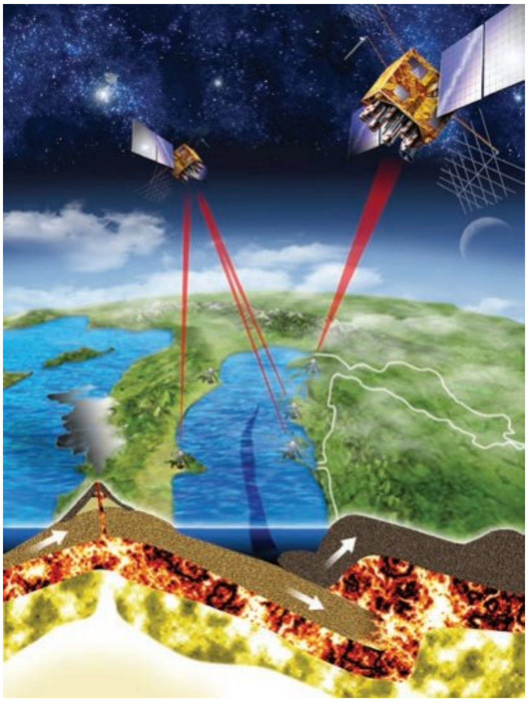

Figure 4.64 GPS is used to measure position and therefore the rate of movement of tectonic plates.

Gravity mapping

Gravity can be stronger and weaker at different points of Earth's surface. Earth's surface is very uneven due to mountains and ocean trenches, both of which affect gravity. Where rocks are denser the gravity is stronger, and where they are less dense it is weaker. The internal structure of Earth can also affect gravity as the materials within the interior do not have a uniform distribution. Scientists can create a gravitational map of Earth, called a **geoid**, using these gravitational measurements.

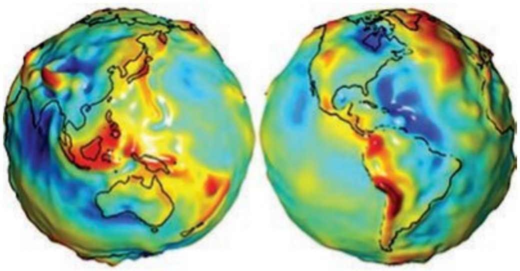

Figure 4.65 A geoid of Earth

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Geoids are not typically used to directly show tectonic movement but changes in Earth's gravity field can indirectly provide information on tectonic movement. For example, if tectonic plates shift or collide with each other, this can cause changes in the density and thickness of Earth's crust, which can in turn alter the gravity field. By measuring and mapping these changes in the gravity field, scientists can infer the movement of tectonic plates.

Satellite gravity mapping can help to create detailed 3D models of Earth's interior structure, which can provide insight into the movement of tectonic plates and the processes that drive them.

Computer modelling

Computer models that simulate the way tectonic plates move are becoming more and more accurate. A new model built by scientists in 2012 was found to be highly accurate in predicting plate motion and the way in which plate boundaries deform. The model focuses on the mantle and it allows for variations in the physical properties of the mantle that can either speed up or resist plate movement.

Figure 4.66 3D visualisation and geological modelling suite being used by geologists to interpret seismic data from an oilfield

The Earthquake Commission (EQC) is funding a new modelling technique pioneered in New Zealand that has the potential to enhance the seismic resilience of buildings worldwide. Researchers at the University of Canterbury are developing a ground-motion simulation model that can predict earthquake damage based on the soil beneath buildings, thereby providing valuable information to engineers and improving the resilience of structures against large earthquakes.

Try this 4.6

Investigating earthquakes

Use the internet to navigate to *Seismic Explorer* by The Concord Consortium. This is a data visualisation tool that shows real-world earthquake, volcanic and plate motion data. Use *Seismic Explorer* to investigate earthquake and volcanic eruption distribution patterns and make connections between the natural disasters and plate boundaries. You can also use cross-sections to investigate earthquake depth patterns.

Quick check 4.14

1. List two pieces of technology used in predicting plate movements.
2. What did the computer model constructed in 2012 allow for so that plate movement could be modelled more accurately?

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Explore! 4.8

Sharing information

Seismic data is collected and shared between governments across the Asia-Pacific region through various regional and international networks and organisations. These organisations work to collect data from seismometers and other monitoring equipment located throughout the region to provide information to government agencies responsible for earthquake and tsunami monitoring and warning.

Research the following key organisations and complete the table to describe their role in seismic data collection and sharing in the Asia-Pacific region.

Organisation	How does it monitor risk?
Pacific Tsunami Warning Center (PTWC)	
Indian Ocean Tsunami Warning System (IOTWS)	
International Seismological Centre (ISC)	
Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES)	

Figure 4.67 DART® (Deep-ocean Assessment and Reporting of Tsunamis) real-time tsunami monitoring systems are positioned throughout the ocean and play a critical role in forecasting tsunamis.

Once seismic data is collected and shared, governments in the Asia-Pacific region use this information in various ways, including for tsunami alerts. When an earthquake is detected, government agencies responsible for earthquake and tsunami monitoring use this data to assess the risk of a tsunami and issue warnings to coastal communities in the affected areas. This may involve sending out alerts through various channels, including radio, television and social media, and mobilising emergency response teams to evacuate coastal areas if necessary.

Volcanobots

Studying active volcanoes is dangerous. Volcanologists (scientists who study volcanoes) use robots that can go into crevices in volcanoes that no human could access. *VolcanoBot 1* (Figure 4.68), built by NASA's Jet Propulsion Laboratory, reached a depth of 25 m in a volcano in Hawaii and was able to put together a 3D map of a volcanic fissure (crack). This enabled scientists to understand the path that magma takes from the mantle to the surface during an eruption.

In 2022, an unmanned surface vehicle (USV) called *Maxlimer* which was developed by a British company called SEA-KIT International, was used to survey the Hunga Tonga-Hunga Ha'apai volcano in Tonga. The robot boat is remotely controlled from the UK and uses instruments that can be deployed at depths of up to 300 m to collect data from the entire water column. The use of the robot boat for this type of survey is important because it allows scientists to collect data from dangerous and hard-to-reach locations without risking human life.


Figure 4.68 Robots like *VolcanoBot 1* are enabling researchers to safely explore volcanoes.

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Responding to natural disasters

Natural disasters strike unexpectedly and cause widespread destruction, injury and loss of life. Responding to natural disasters requires a coordinated effort at local, state and federal levels, and new advances in technology are helping to support this.

Drones

Drones have become increasingly important in responding to natural disasters due to their ability to reach remote or inaccessible areas quickly and efficiently. In disaster response operations, drones can be used to gather real-time images and data that can help emergency responders assess damage, identify survivors and plan rescue operations.

In the aftermath of a disaster, drones can be used to conduct rapid assessments of affected areas and identify potential hazards, such as blocked roads or damaged infrastructure. This information can then be used to prioritise response efforts and allocate resources more effectively.

Drones equipped with thermal cameras can also be used to locate survivors and assess their condition. Survivors who are given assistance quickly after a natural disaster have the highest chance of survival. Drones are also useful for getting medical aid into areas that have been blocked off by landslides or collapsed buildings.

Artificial Intelligence (AI)

xView2 is an AI disaster response system sponsored and developed by the US Pentagon's Defense Innovation Unit and Carnegie Mellon University's Software Engineering Institute. The project has collaborated with organisations such as Microsoft. xView2 uses machine learning algorithms on satellite imagery to categorise damage in a disaster area at a faster rate than other existing methods.

Figure 4.69 Members of a British charity called Serve On used drones to help identify areas that were worst affected by an earthquake in Nepal.

VIDEO
Responding to natural disasters

The system has been deployed in response to wildfires in California and during recovery efforts after flooding in Nepal. In the 2023 Turkey earthquake, the AI system was used by at least two different ground teams for search and rescue.

The xView2 system uses semantic segmentation, a technique similar to object recognition, to analyse each individual pixel of a satellite image and highlight damage in red. This method is more efficient than relying on eyewitness accounts or using drones to assess damage. However, the system is currently reliant on daytime satellite imagery and can be hindered by cloud coverage. Despite this, the xView2 system has the potential to save many lives in disaster response operations.

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FINDERs

In the aftermath of the 2023 earthquake in Turkey, disaster relief teams utilised NASA-developed technology capable of detecting the smallest body movements associated with vital life processes. The technology, known as FINDERs or Finding Individuals for Disaster Emergency Response, operates using microwave radar sensors to remotely detect the heartbeat of survivors trapped under rubble or in avalanches.

Figure 4.70 The FINDER device uses microwave radar sensors to remotely detect heartbeats and locate survivors.

Quick check 4.15

1. State the name given to scientists who study volcanoes.
2. Give one use of drones after an earthquake.
3. What is the benefit of using AI when assessing a natural disaster?

Reducing vulnerability

Natural disasters can have devastating impacts on communities and their infrastructure. It is crucial to have effective strategies in place to reduce vulnerability to these hazards. These strategies involve a range of actions, such as structural engineering designs, land-use planning, and emergency preparedness and response plans.

Land-use planning

Land-use planning can reduce vulnerability to natural disasters by ensuring that development occurs in areas with minimal risk and that appropriate measures are taken to protect people and property. Land planners will consider where to locate critical infrastructure, such as hospitals, schools and emergency response centres, and where to restrict development in high-risk areas.

Land-use planning can also include requirements for building codes and standards that increase the resilience of structures to natural hazards. For example, buildings in earthquake-prone areas may require reinforced foundations and walls, while structures in flood-prone areas may need to be elevated above the flood plain.

Construction techniques

Most buildings are designed to support vertical forces; for example, the walls support the roof. However, earthquakes also produce sideways or horizontal forces, which is why many buildings struggle to withstand high-magnitude earthquakes. A building can be made 'earthquake proof' in three ways:

- base isolation – Buildings do not sit directly on the ground, but are supported by ball bearings and springs, which act like shock absorbers.
- vibration control – Mass dampers are built to sway in the opposite direction to the building's sway during an earthquake.
- seismic resistance – The walls, roof and foundations are tied together into a rigid box that holds together when shaken by an earthquake.

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Earthquake-resistant house

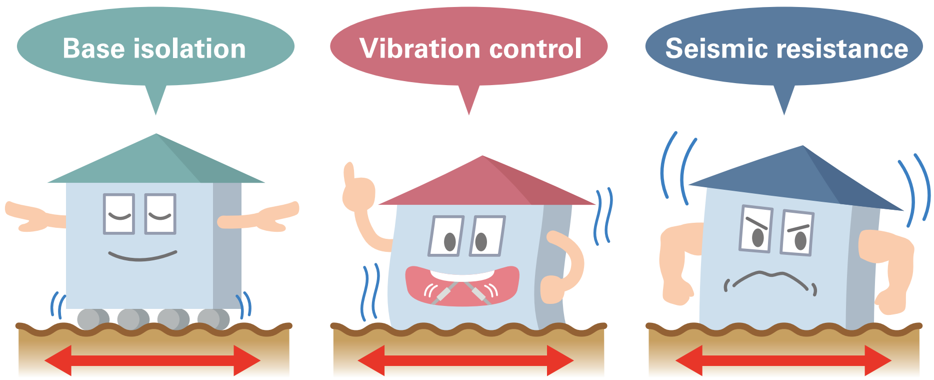

Figure 4.71 Buildings can be made earthquake-proof by three different methods.

Quick check 4.16

1. Give one way in which a building can be earthquake proofed.
2. Discuss why many existing buildings are not able to withstand high-magnitude earthquakes.

Explore! 4.9

Cultural building techniques

Cultural building techniques in construction have led to the development of structures and materials that are better able to withstand the effects of earthquakes. Bamboo has been used for centuries as a building material in earthquake-prone regions, such as South-East Asia, South Asia and Latin America. It is flexible and resilient, which allows it to withstand the forces of an earthquake, and as it is lightweight, making it less vulnerable to damage. Builders have incorporated some bamboo properties, such as the ability to bend without breaking, into modern earthquake-resistant building designs. Researchers have also developed bamboo-reinforced concrete, which is a combination of bamboo and concrete that is more resistant to breaking during an earthquake.

Figure 4.72 A certified earthquake- and cyclone-resistant bamboo house being built in Martinique

Adobe is a technique that involves making bricks from a mixture of clay, sand and straw, and then allowing them to dry in the sun. Adobe structures have been used for centuries in earthquake-prone areas of Latin America, but traditional adobe construction responds poorly during earthquakes. Research how adobe techniques have been refined over time to improve their earthquake resistance.

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Investigation 4.1

Investigating how high-frequency earthquakes affect buildings

Aim

To investigate how high-frequency earthquakes affect buildings of different heights

Planning

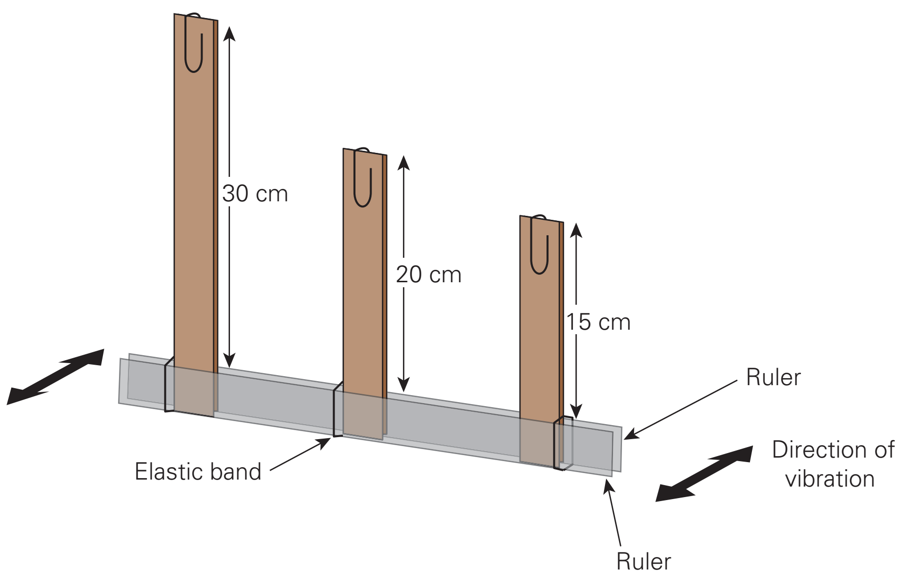
Complete some research and write a rationale about the effects of earthquakes on buildings of different heights. Hint: research the 1985 Mexico City earthquake.

Materials

- 2 rulers
- elastic bands
- pieces of card
- paper clips

Method

1 Draw the results table below.
2 Set up the experiment as shown in the diagram below. Each 'tower' is made of four card strips held together at the top by a paper clip and two rulers at the bottom. The rulers are held in place using elastic bands.



3 Vibrate the rulers in a slow and gentle way in the direction shown in the diagram.
4 Slowly increase the rate of vibration until the cardboard strips begin to resonate (start to regularly and strongly vibrate). Note: This simulates a high-frequency earthquake. The results would differ for low-frequency earthquakes.
5 Count the number of complete vibrations that occur in 10 seconds.
6 Continue to vibrate the rulers until you have recorded the three trials for each strip in your results table.

Results

Height of strip (cm)	Number of vibrations in 10 seconds			Mean number of vibrations	Frequency (vibrations per second)
	1	2	3		

continued …

… continued

Data processing

1 Calculate the frequency by dividing the mean number of vibrations by 10.
2 Plot a graph of height of strip against frequency of vibrations.

Analysis

1 Identify any trends, patterns or relationships in your results.
2 Determine the height of buildings that would be damaged most by high-frequency earthquakes.

Evaluation

Limitations

1 Identify any potential sources of error in this experiment.

Improvements

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

Conclusion

Draw a conclusion from this experiment regarding building height and high-frequency earthquake damage. Justify your answer with data.

Emergency response plans

Emergency response plans are designed to ensure that communities are ready to respond quickly and effectively in the event of a disaster. These plans may include completing risk assessments, using early warning systems, undertaking evacuation planning and providing training and education programs that help residents plan and prepare for disasters.

Figure 4.73 A tsunami evacuation route sign in San Francisco

Explore! 4.10

Reducing natural disaster impacts

Countries located near plate boundaries in the Asia-Pacific region, such as Japan, Indonesia and New Zealand, are particularly vulnerable to geological hazards such as earthquakes, volcanic eruptions and tsunamis. However, scientific responses have helped to support these communities and reduce the impact of these natural disasters.

Produce a presentation on either the use of new building materials, improved predictions or early warning systems to show how the impact of natural disasters can be reduced.

Figure 4.74 To make concrete more suitable for seismic activity, engineers add steel (in the form of rebar), which is much more flexible.

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Practical skills 4.4

Using a shake table to design earthquake-proof building bases

Aim

To observe the effect of base isolation on damage to buildings during an earthquake

Materials

- 100 g masses
- plastic or paper straws
- masking tape
- cardboard
- string
- wooden block
- wooden dowels or pens

Planning

Research base isolation. Propose if base isolation will create more or less damage to a building during an earthquake.

Method

1 Using the equipment provided, except for the wooden block, dowels and pens, design and build two identical earthquake-proof buildings. (You may want to refer to the STEM activity at the end of this chapter for the building creation.)
2 Draw the results table below.
3 Put your finished design on a table and shake the table for 20 seconds. Record what happened in your results table.
4 Now lay the pens or the wooden dowels on the table so they align.
5 Place the wooden block on top of the pens or dowels and put your second building on top.
6 Shake the table again for 20 seconds and record what happened in your results table.

Results

	Observations
Without base isolation (just on the table)	
With base isolation (on the pens and wooden block)	

Analysis

1 Identify which structure was the most earthquake resistant and why.
2 Discuss how base isolation helps the building survive an earthquake.
3 Discuss how design and construction decisions make the building more earthquake resistant.
4 Recommend what you would do differently next time in the construction of your building. Explain why.

Evaluating the impact

Evaluating the impact of natural disasters on human populations involves examining the degree and extent of damage caused by the event, including the number of casualties, injuries and homes destroyed.

The socio-economic impact of the event must also be assessed, including the disruption to local infrastructure, the impact on essential services and the cost of recovery and reconstruction efforts. These assessments can help to inform policy decisions and emergency response strategies, as well as guide the allocation of resources to affected communities.

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Figure 4.75 The February 2023 earthquake in Turkey, which killed more than 43 000 people, will cost the Turkish economy more than US$50 billion.

Section 4.4 questions

QUIZ

Retrieval

1 **Recall** what GPS stands for.

2 **Name** the three methods of earthquake proofing buildings.

3 **Identify** the name of NASA's first robot used to explore volcanoes.

Comprehension

4 **Explain** why scientists need to study the inside of volcanoes.

5 **Explain** how GPS can map the position of tectonic plates.

6 **Summarise** the advantages of using drones after an earthquake.

Analysis

7 **Compare** the three methods of protecting buildings from earthquakes.

Knowledge utilisation

8 **Propose** reasons why humans cannot enter some parts of volcanoes.

9 **Discuss** the benefits and shortcomings of using technologies to map plate movement and Earth's geology, using examples.

10 Recall the various earthquake-proofing methods you have learned about. **Propose** which earthquake-proofing method you would choose and justify your choice.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
4.1	I can describe the evidence for the theory of continental drift.	13	
4.2	I can construct a timeline of evidence to show the development of the theory of plate tectonics.	10, 13, 14, 17, 19	
4.2	I can describe how Marie Tharp's topographic maps provided support for the acceptance of the theory of plate tectonics.	17	
4.2	I can describe the consequence of three types of plate boundaries.	11, 12, 21, 22	
4.2	I can model interactions at plate boundaries.	16	
4.2	I can describe the different forces involved in tectonic plate movement.	3, 7	
4.3	I can describe how volcanoes, earthquakes and tsunamis form.	18, 29	
4.3	I can distinguish between S and P waves and the information they provide about earthquakes.	8, 15, 24	
4.3	I can examine patterns of earthquake and volcanic activity over time and propose explanations.	29	
4.3	I can relate the extreme age and stability of a large part of the Australian continent to its plate tectonic history.	28	
4.3	I can describe First Nations Australians' cultural accounts that provide evidence of earthquakes and volcanoes.	9	
4.4	I can list methods that can be used to map or predict plate movements.	1	
4.4	I can evaluate the impact of tectonic events on human populations and examine engineering solutions designed to reduce the impact.	23	

Review questions

SCORCHER

Retrieval

1 **State** the name of one piece of technology used to measure plate movements.
2 **Name** the tectonic plate that contains Australia.
3 **Name** one mechanism in Earth's mantle that causes tectonic plates to move.

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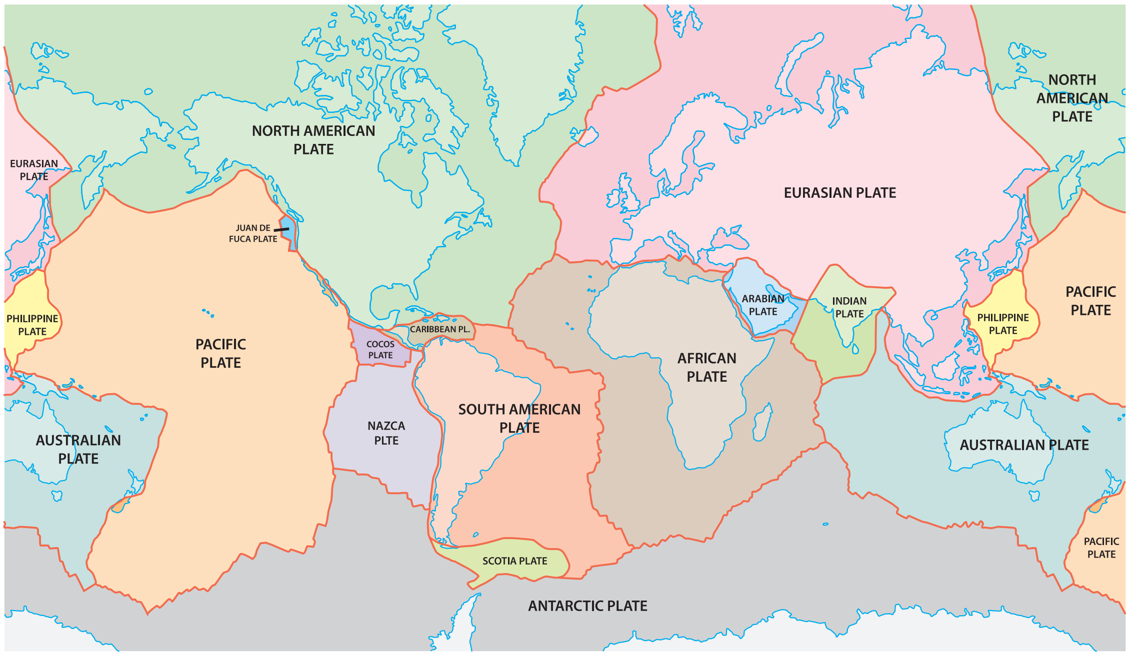
4 **Identify** five major tectonic plates using the image below.



5 **Match** the layer of Earth (A–D) to its physical properties (1–4).

A Crust	**1** Made of metals (iron and nickel) Very hot temperatures Under intense pressure from the layers above so is a solid structure
B Mantle	**2** Made of dense solid rock that flows in hot temperatures
C Outer core	**3** Thinnest layer Supports all the life on Earth
D Inner core	**4** Made of metals (iron and nickel) Very hot temperatures Liquid

6 **Identify** the continental and oceanic plates (A and B) at the subduction zone in the diagram in Figure 4.76.

7 **Identify** the source of heat causing convection currents in Earth's mantle.

8 **Identify** the type of seismic wave from the description.

a a transverse wave that cannot travel through liquids

b a longitudinal wave that can be detected on the opposite side of Earth to the epicentre of an earthquake

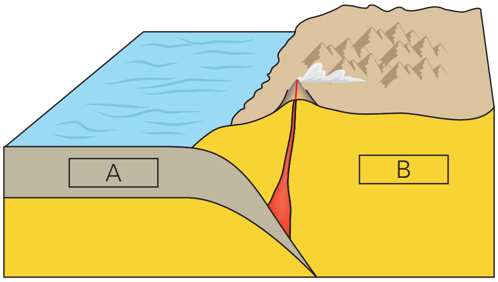


Figure 4.76

9 In Gunditjmara oral traditions, **recall** what the lava that came from the Budj Bim volcano was formed from.

10 **List** the following scientists in order of when they were involved in the development of the theory of plate tectonics: Marie Tharp, Harry Hess, Alfred Wegener, Frederick Vine, Drummond Matthews, Lawrence Morley.

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Comprehension

11 **Describe** the three types of plate boundaries and how they affect the amount of crust present.

12 **Explain** how mid-ocean ridges form.

13 **Summarise** the evidence proposed by Alfred Wegener for his continental drift theory.

14 **Explain** why the rocks in the sea floor are magnetised and how this supports Hess's theory of seafloor spreading.

15 **Describe** how a seismometer works.

16 Using the diagram in Figure 4.77, **model** how convection currents in the mantle move tectonic plates.

17 **Describe** how Marie Tharp's topographic maps provided support for the acceptance of the theory of plate tectonics.

18 **Describe** how a tsunami forms.

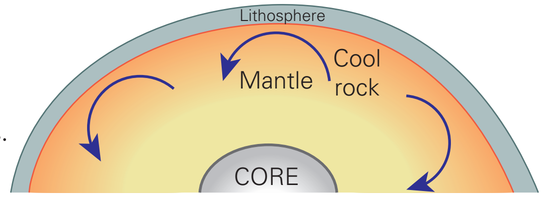

Figure 4.77

Analysis

19 **Examine** the results from Harry Hess's mapping of the sea floor. How did this account for movements of tectonic plates?

20 **Compare** the two types of destructive plate boundaries.

21 **Infer** whether the following effects indicate a constructive, destructive or transform plate boundary.

- a no mountains form
- b island arcs
- c crust is conserved

22 **Classify** the following as constructive, destructive or transform plate boundaries.

- a The Himalayas
- b Mid-Atlantic Ridge
- c Mariana Trench

23 **Analyse** what evidence would be necessary to support the conclusion that all buildings in an earthquake area should be made of bamboo.

24 **Contrast** P and S waves.

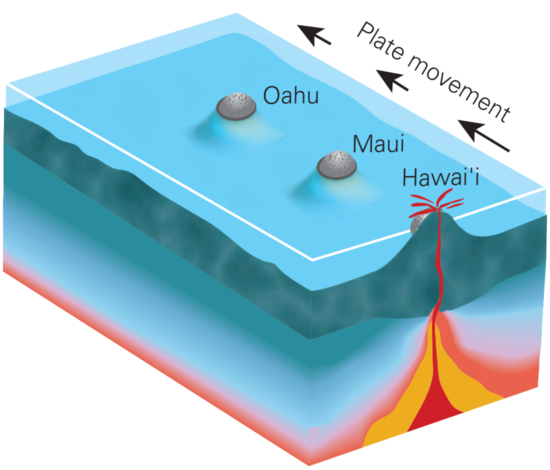

Figure 4.78

Knowledge utilisation

25 At the East African Rift zone, the plates are moving away from each other. **Predict** what will happen to the continent of Africa in the next million years.

26 **Determine** which island is the oldest from the diagram in Figure 4.78. What type of volcano is shown in the diagram?

27 **Predict** what you think will happen to Earth's continents in the next 100 million years.

28 **Discuss** why Australia is considered to be tectonically stable.

29 **Propose** an explanation for the locations of global earthquake and volcanic activity shown in the map in Figure 4.79.


Figure 4.79

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Data questions

New Zealand is a country that lies very close to a fault boundary and consequently experiences thousands of earthquakes a year. Earthquakes are categorised using the Richter scale, which measures earthquake magnitude on a scale of 0 to 10 (see Table 4.3). The magnitudes of 10 New Zealand earthquakes from 2010 to 2019 are presented in Table 4.4.

Richter scale	Observation
0.0–2.9	Not felt by humans
3.0–4.9	Felt by humans and not damaging
5.0–5.9	Small risk of damage to buildings
6.0–6.9	Moderate risk of damage to buildings
7.0–7.9	High risk of damage to buildings
8.0+	High probability of severe destruction

Table 4.3 Severity of earthquake observed with Richter scale value

Earthquake reference	Magnitude (Richter scale)
1	4.1
2	7.8
3	4.3
4	2.9
5	5.1
6	6.6
7	2.3
8	6.1
9	1.1
10	7.6

Table 4.4 The magnitude on the Richter scale of 10 earthquakes that occurred in New Zealand between 2010 and 2019

Apply

1 **Identify** the most severe earthquake recorded in Table 4.4.
2 **Determine** the earthquakes that had a high risk of damage to buildings.
3 The media are reporting a new earthquake in New Zealand that measures 6.5 on the Richter scale. **Identify** the likely observations relating to buildings in the area.

Analyse

4 **Categorise** the earthquakes presented in Table 4.4 as 'not felt' or 'felt'.
5 **Identify** a trend in the Richter scale and severity of earthquakes.

Interpret

6 Based only on the 10 earthquakes presented, **infer** whether there is a higher chance that an earthquake in New Zealand would not be felt or would damage buildings.
7 There are over 10 000 earthquakes a year in New Zealand. **Justify** whether your answer to Question **6** would be reliable.
8 The largest magnitude earthquake ever recorded in New Zealand was 8.2 on the Richter scale, while the largest in Japan was 9.0. **Justify** whether it is possible to suggest that Japan is more at risk than New Zealand for severe earthquakes?
9 The media in New Zealand are reporting a mild earthquake that caused a tremor that did not damage buildings but moved furniture in buildings in the area. **Deduce** the magnitude of this earthquake on the Richter scale.

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STEM activity: Earthquake-proof structures

Background information

In this chapter, you have gained an insight on the inner workings of our planet. You learned that, contrary to appearances, our planet has been very active for over four billion years. Our planet is constantly changing via many important geological processes over eons, and some of the movements produce earthquakes.

Unfortunately, poorer countries have been greatly affected by earthquakes over the centuries, as whole populations live in earthquake-prone areas (for example, the Pacific Ring of Fire and the Andes). Experts have demonstrated that most deaths in earthquakes occur because buildings and dwellings collapse due to poor construction.

Papua New Guinea (PNG) is located in the Australasia 'ecozone', which includes Australia, New Zealand, eastern Indonesia and several Pacific island groups, such as the Solomon Islands and Vanuatu. PNG is one of the poorest countries in the world and is severely affected by earthquakes. Earthquakes are particularly severe in PNG because of a combination of factors – steep terrain, poor infrastructure and housing, lack of roads and extensive seasonal rains – all of which create an environment that is prone to collapse after an earthquake.

Knowledge has the power to improve people's lives. How can you use technology and your knowledge of geology to improve the lives of people living in these high-risk areas?

Design brief: Design and test building designs to improve durability in earthquake risk zones and present this information in a format that would be useful to a small PNG community.

Figure 4.80 (a–c) Damage caused by earthquakes in Papua New Guinea. Earthquakes occur all over the world, in developed and underdeveloped countries. They have the power to destroy whole cities, move entire mountains and lift or drop the ground by many metres. (d) Scientists analyse data collected during an earthquake.

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Activity instructions

In groups (maximum of four people), you will investigate how housing design can affect the stability of a building, by building a series of small structures and testing their durability on a shaker table. It will be useful to allocate roles for this activity: project manager, engineer, builder and presenter.

Role	Responsibility
Project manager	Making sure the project is on time and within a budget. The project manager is responsible for all of the parts of the project.
Engineer	Conducting research on the current models, finding new ways to improve and drawing a sketch of the proposed design
Builder	Creating the proposed design and checking that the design is functional
Presenter	Researching information on cultural awareness of the local community and how to present in the most effective way, and creating a presentation to match this

Together, the group members need to manage their time and help each other through each stage.

Suggested materials

- wooden sticks
- sticky tape
- glue
- mobile phone or video recording equipment for vlog (if chosen as mode to communicate ideas)
- software for creating a presentation
- software for video editing

Research and feasibility

1 Research current house design in villages and list the features, including types of materials used.

2 Discuss and research as a group how a structure's strength can be improved.

3 Research social and cultural information about PNG communities.

Design and sustainability

4 As a group, discuss some design features you could use in a model house structure and make multiple sketches with ideas.

5 Decide as a group which design will be the most sustainable and suitable to build, with the PNG communities in mind.

6 Decide on and design the format you will use for your presentation for the PNG community.

Create

7 Construct your design using allowable materials.

8 Test your design by performing the following tests. Draw a results table.

A **Shake test:** Place your design on a table and secure it using tape. Shake the table forwards and backwards four times. Describe how successful your design was. Did it fail? And if so, where and why?

B **Weight test:** Your design has survived the shake test! Now, it is time to compare how it behaves when 0.5 kg masses are placed on top of it. Describe how your design behaved under the weights.

C **Combination test:** Your design is still standing – that is great! Now, repeat tests **A** and **B** at the same time. Describe what happened.

9 Reflect and, if there is time, create and test another design.

10 Create the presentation while building and testing your design.

Evaluate and modify

11 Take time to think about the investment required to change the lives of villagers. Imagine that a 10 cm wooden stick used to build your model costs around $10 to purchase and that the piece that joins them costs $2. Calculate the current cost of building a house using cubes.

12 Evaluate the effectiveness of your design. It is important to remember who your target audience is throughout this project.

13 Give your presentation to the class and reflect on how it demonstrates cultural awareness and how well it communicates effective building methods.

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Chapter 5
Rocks

Chapter introduction

Rocks are all around us, from the stones in our gardens to the mountains that tower over us. They come in many different shapes, sizes and colours and are made up of a variety of different materials. But what exactly are rocks and how do they form? In this chapter, you will learn about Earth's crust and the rocks that make up its composition. You will learn about the three types of rock – igneous, metamorphic and sedimentary – and how rocks can change from one form to another via the rock cycle. You will also learn about the mining industry and how resources contained in the rocks are extracted to make useful materials, such as metals for technology, and glass and cement for building.

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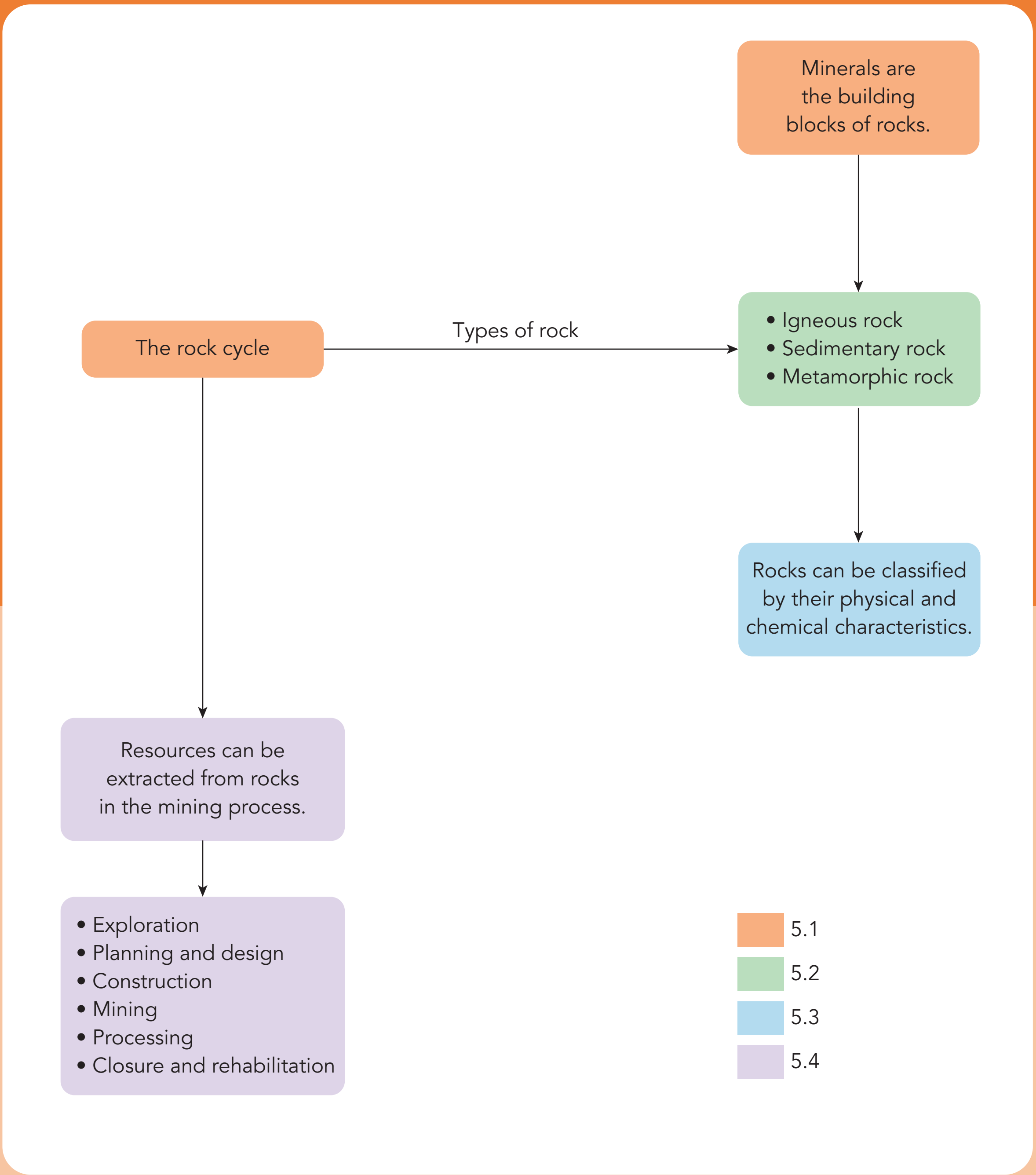
Concept map



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Curriculum

Describe the key processes of the rock cycle, including the timescales over which they occur, and examine how the properties of sedimentary, igneous and metamorphic rocks reflect their formation and influence their use (AC9S8U04)	
analysing the role of forces and heat energy in the formation of different types of rocks and comparing how quickly or slowly different processes can occur	5.1, 5.2
exploring the major processes of the rock cycle, including weathering, erosion, deposition, melting, crystallisation, uplift, heat and pressure in the formation of different types of rocks	5.1
examining fossil evidence, such as body, trace or opalised fossils, to predict how and when a rock was formed	5.2
comparing the observable properties of different types of rocks and identifying them using a provided dichotomous key	5.3
explaining the uses of different types of rocks with reference to their properties and formation	5.3
exploring the traditional geological knowledges of First Nations Australians that are used in the selection of different rock types for different purposes	5.3
exploring how the mining of ores and minerals impacts on local environments and examining environmental rehabilitation initiatives	5.4
investigating how First Nations Australians have used quarrying to access rocks for use as, or production of, everyday objects, such as grindstones, hammerstones, anvils and cutting tools	5.4

Glossary terms

Biological weathering
Breccia
Cementation
Chemical weathering
Clasts
Cleavage
Compaction
Conglomerate
Crust
Crystal
Crystallisation
Deep time
Deposition
Dissolution
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
Sandstone
Sedimentary
Sediments
Smelting
Streak test
Surface mining
Translucent
Transparent
Underground mining

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5.1 Rock formation

Learning goals

1. To consider the role of forces and heat energy in the formation of igneous, sedimentary and metamorphic rocks.
2. To be able to compare how quickly or slowly different rock formation processes can occur.
3. To be able to describe the major processes of the rock cycle.

WORKSHEET
Formation of rocks

Rocks and minerals

Rocks are a naturally occurring substance made up of one or more **minerals**. Minerals are 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.

Mineralogists are experts in the study of minerals, and **crystals** are one of the most fascinating aspects of this field. Crystals are highly ordered arrangements of atoms or molecules that form naturally in many minerals.

rock
solid material forming Earth's crust; 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

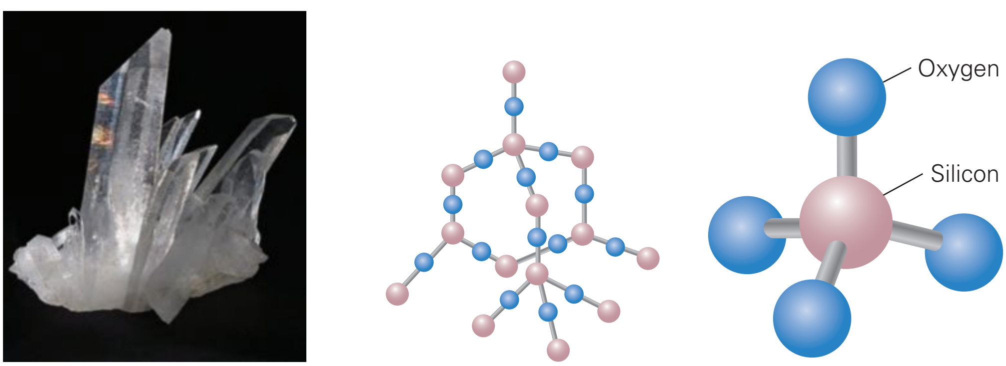

Figure 5.1 Quartz (left) is a mineral made of silicon and oxygen atoms arranged in a continuous framework, forming crystals.

Did you know? 5.1

Gemstones

Gemstones are a subset of minerals that are prized for their beauty, rarity and durability. They are cut and polished to enhance their visual appeal and can be used in jewellery, decorative objects and other luxury goods. Some of the most well-known gemstones include diamonds, emeralds, rubies and sapphires, but there are many other varieties that are highly valued by collectors and enthusiasts.

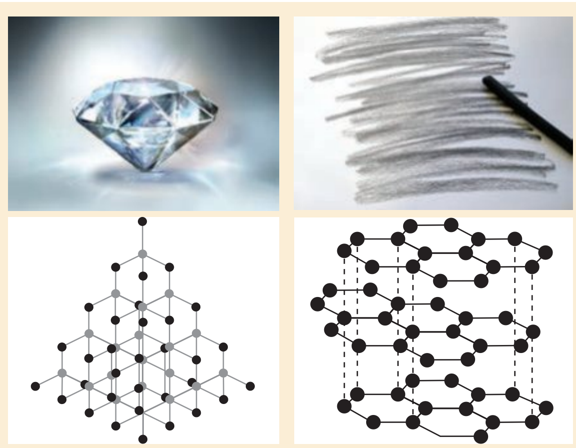

Figure 5.2 Diamond (left) and graphite (right) are both made of carbon atoms. However, the arrangement of the atoms makes a big difference to their properties.

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Rocks and Earth

inner core
the solid centre of Earth; probably made of iron

outer core
the liquid layer surrounding the inner core; probably made of liquid iron

mantle
the layer of Earth underneath the crust that is made up of solid and semi-molten rock and surrounds the outer core

crust
the solid, outer layer of Earth that supports all life on Earth

lithosphere
the solid outer layer of Earth consisting of the crust and top layer of the upper mantle. It is split into giant slabs called tectonic plates

The **inner core** of 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**. Continental crust (supporting land) is on average 35 km thick, while oceanic crust (supporting ocean) is around 10 km thick. Rocks are formed and reformed in the **lithosphere**, which includes the crust and the uppermost mantle.

The composition of Earth's mass is dominated by a few key elements, with iron being the most abundant, followed by oxygen, silicon and magnesium. These elements make up the bulk of the planet's solid materials, including the rocks and minerals that comprise Earth's crust and mantle. Each type of rock is unique in its composition and properties.

Element	Proportion of Earth's mass (%)
Iron	35
Oxygen	30
Silicon	15
Magnesium	13

Table 5.1 These four elements make up most of Earth's mass.

Quick check 5.1

1. Define and distinguish between rocks and minerals.
2. Where are rocks formed on Earth?
3. What elements make up most of Earth's mass?

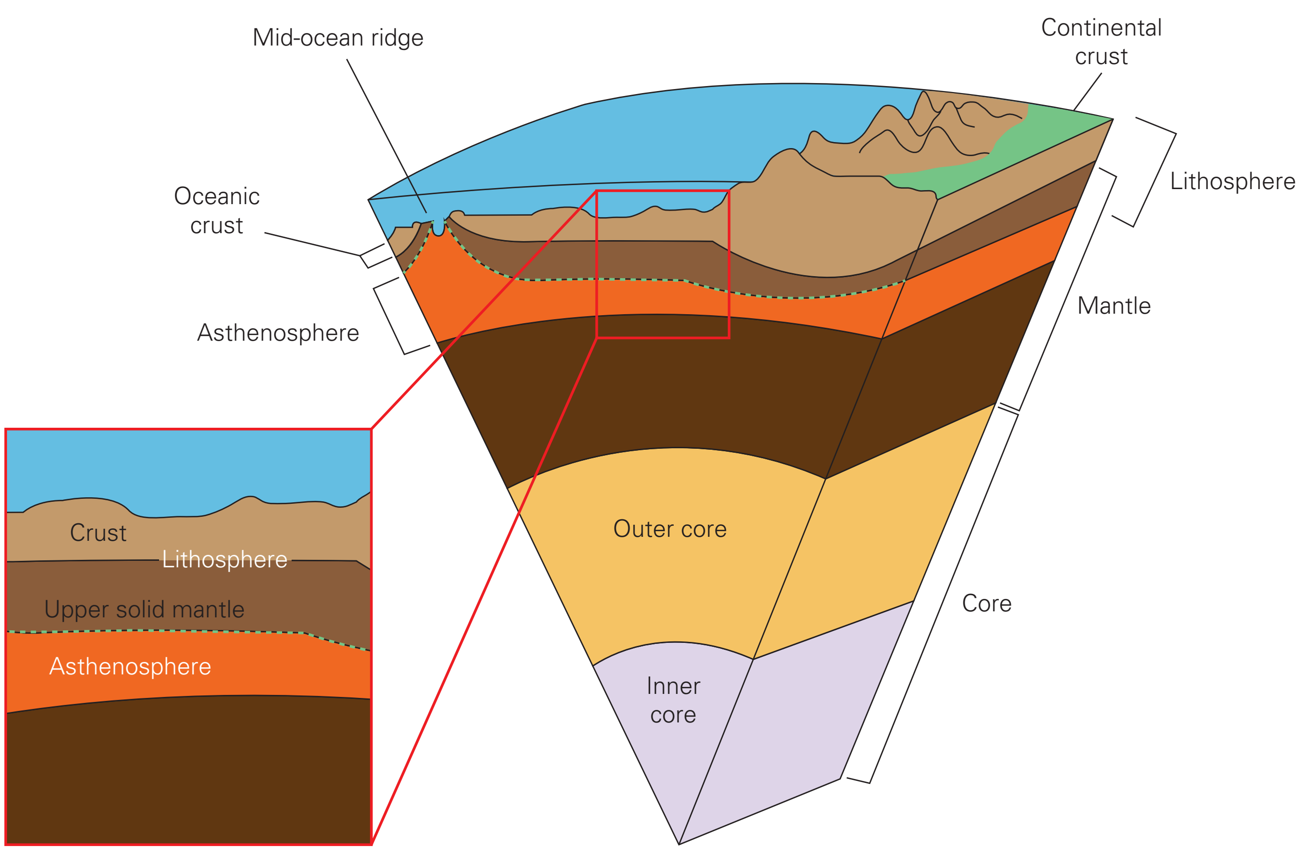

Figure 5.3 Earth is composed of several layers.

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The rock cycle

The Moon has stayed unchanged for millions of years, but the **geology** of Earth is very different. James Hutton, the father of modern geology, tried to explain why the surface of Earth is so complex. He came up with two conclusions.

- Earth is very old – Hutton called this **deep time**.
- 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 crystallisation

As you can see in Figure 5.4, the melting of rock to form magma (molten rock), and then the cooling of that magma, results in the formation of igneous rock. The process of melting takes place beneath Earth's crust at temperatures that can be as low as 500°C and as high as 1600°C. The process of cooling can happen below or above Earth's surface. An interesting characteristic of igneous rocks is that the minerals in them may form crystals. This is because, when **magma** cools, **crystallisation** occurs. Below Earth's surface, magma takes a long time to cool, and the crystals formed in it are large. Magma that reaches 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.

DOC
WORKSHEET
The rock cycle

geology
the study of the rocks and similar substances that make up Earth and other planetary objects

deep time
the idea first suggested by James Hutton that Earth is very old

rock cycle
the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

magma
hot liquid rock found just below the surface of Earth

crystallisation
the formation of rock crystals in cooling magma

lava
molten rock from inside Earth (magma) that has reached the surface

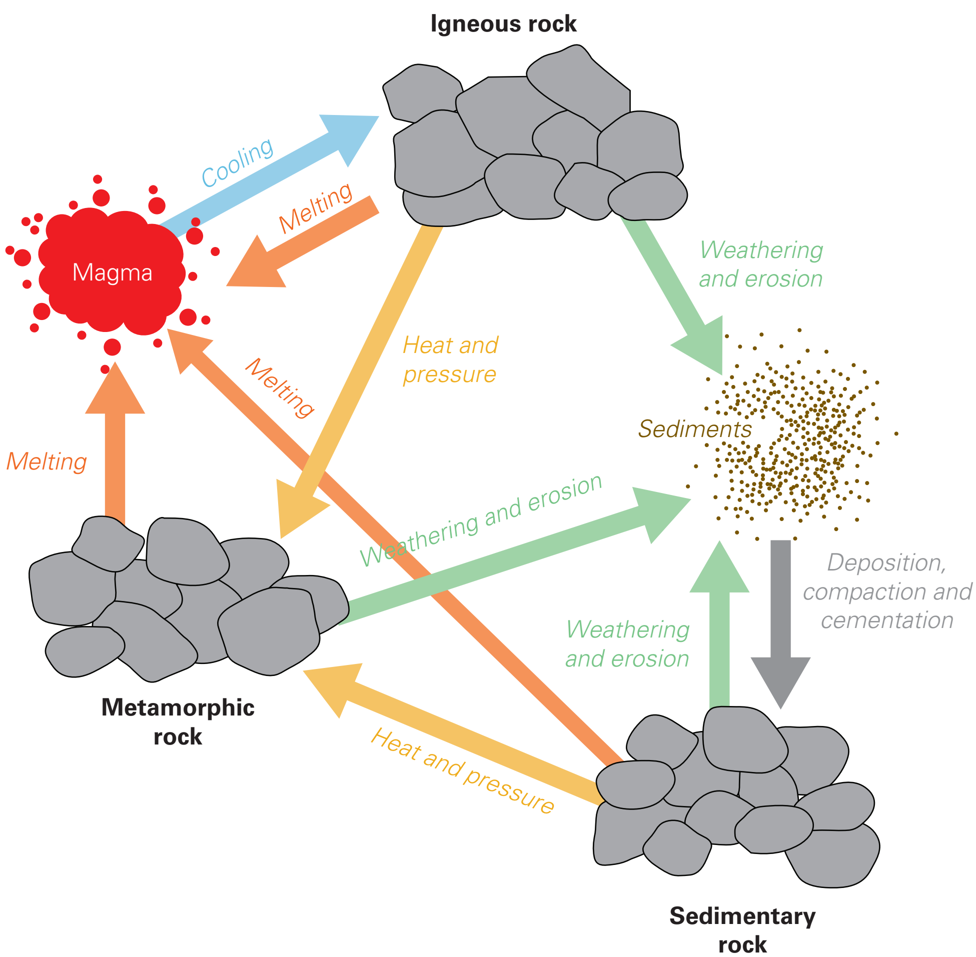

Figure 5.4 In the rock cycle, the three types of rock can change, through the action of weathering and erosion, deposition, compaction and cementation, melting and cooling, and heat and pressure.

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Figure 5.5 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.

Figure 5.6 The Granite Arch, Girraween National Park

Did you know? 5.2

Igneous rocks

'Igneous' and 'ignite' come from the same Latin word, *ignis*, which means 'fire'. This is an easy way to remember that igneous rocks are formed from hot magma.

Figure 5.7 'Igneous' comes from a Latin word meaning 'fire'.

Explore! 5.1

What is a meteorite?

meteorite
a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground

From time to time, rocks arrive on Earth from space, in the form of **meteorites** that land on the surface. Use the internet to answer the following questions.

1. What is the composition of meteorites?
2. How does a meteorite end up on Earth?
3. Propose whether meteorites pose a threat to life on Earth. Justify your argument using examples of meteorites that have landed on Earth and their impact.

Figure 5.8 An iron meteorite that landed on Earth from space

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Try this 5.1

Making crystals

You will need the following materials:

- soluble crystals such as copper sulfate, sugar or salt
- beaker
- warm water
- 2 Petri dishes

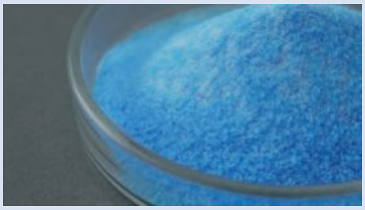

Figure 5.9 Copper sulfate crystals

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.

Quick check 5.2

1 What are the three types of rocks formed in the rock cycle?
2 What role does melting and cooling play in the rock cycle?

Weathering

Weathering is an important process that contributes to the formation of **sediments**. When rocks and minerals are exposed to the elements, they can be broken down into smaller particles through physical, chemical and biological weathering. The size and composition of sediments can vary widely depending on the type of rock and the weathering processes that created them.

Physical weathering is the process of breaking down rocks into smaller pieces without changing their chemical composition. Temperature changes, pressure and mechanical forces from weathering agents, such as wind, water, ice and gravity, can cause physical weathering. Freeze–thaw action is a specific example of physical weathering caused by the repeated freezing and thawing of water in cracks and crevices of rocks. When water enters a crack in a rock and freezes, it expands and widens the crack. The repeated expansion and contraction due to freeze–thaw action can cause the rock to break apart into smaller pieces.

sediments
sand, stones and other materials 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

Figure 5.10 A rock split in two by freeze–thaw action

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chemical weathering
the disintegration of rocks caused by acidic rainwater

dissolution
when water dissolves minerals in rocks

karst
an area of land formed of rock such as limestone that is worn away by water to make caves and other formations

Chemical weathering is the process by which rocks are broken down by chemical reactions. Rainwater is naturally slightly acidic because it contains carbon dioxide from the air, which forms carbonic acid when it dissolves in water. This slightly acidic water can react with certain types of rock, such as limestone, to dissolve them over time. As rainwater seeps through the ground, it can dissolve and carry away minerals from the rock, leading to the formation of underground caves, rivers and other unique geological features. The **dissolution** of the rock can lead to the formation of stalactites and stalagmites, which are mineral formations that grow from the ceiling and floor of the cave, respectively. When they eventually meet, they can form columns.

When limestone contains underground rivers, it can give a very characteristic landform called a **karst** landscape (see Figure 5.12), which has caves, sink-holes, limestone outcrops and dry valleys with no water because the river that formed them has gone underground. The Nullarbor Plain between South Australia and Western Australia is the world's largest karst landscape.

Figure 5.11 Limestone caves such as the Jenolan Caves are often developed as tourist attractions because of the beautiful limestone features they contain. These are often formed by the dissolution of limestone by slightly acidic water over many years.

Figure 5.12 The entrance to a cave in a typical karst landscape. Rainwater enters the cave and can travel underground for many kilometres.

Did you know? 5.3

Exploring cave systems

A person who studies caves scientifically is called a 'speleologist', but a person who explores caves as a pastime is called a 'caver' or a 'spelunker'.

Figure 5.13 Cavers explore underground cave systems, looking for amazing rock formations like this.

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Science as a human endeavour 5.1

Early Ipswich limestone quarries

Ipswich was originally known as The Limestone Hills or The Limestone Station, before it was shortened to Limestone in 1842, and then renamed Ipswich in 1843. 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 5.14 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 5.15), 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.

Quick check 5.3

Distinguish between the three types of weathering: physical, chemical and biological.

Figure 5.15 These steps have been 'weathered' by people walking on them. The particles of stone have been washed away or eroded by the rain.

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.

biological weathering the disintegration of rocks that is caused by living things

erosion the transport of rocks from one place to another as a result of weathering

VIDEO Australian landmarks

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.

Figure 5.16 The Wave Rock formation in Girraween National Park has been formed through the action of water.

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Figure 5.17 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 5.18 Dove Lake on Cradle Mountain in Tasmania. The smooth appearance of the rocks is due to the action of glaciers 20 thousand years ago.

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 the Australian mainland nor Tasmania was covered in an ice sheet, glaciers formed on Cradle Mountain in Tasmania and the surrounding areas. The landscape was transformed by the ice moving over the rocks, leaving the characteristic smooth surface.

Figure 5.19 Wave Rock in Western Australia is made of granite that is over two billion years old.

The profile of Wave Rock in Western Australia (see Figure 5.19) 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.

Try this 5.2

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?

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Deposition, compaction and cementation

Particles or sediments that are eroded come to rest when the wind or water moves more slowly or the ice melts. When the particles reach their destination, they are dropped, in a process called deposition.

Often **deposition** occurs on ocean beds or lake beds. The particles are often deposited in visible layers, which become **compacted** or compressed by the weight of the layers above and **cemented** together. These processes finally form sedimentary rocks.

deposition
process that occurs when eroded particles stop moving and build up to form sedimentary rocks

compaction
the process of particles becoming closely positioned together, using very little space

cementation
the sticking together of sediment

Figure 5.20 Sedimentary rocks are very common, covering over 70% of Earth's surface. Some contain fossils that are billions of years old. Note the different layers of sediment, all cemented together.

Quick check 5.4

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 containing fossils from different time periods, with the oldest at the bottom.

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

Try this 5.3

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 three quarters full and put the lid on.
3 Make sure the lid is tight and shake the jar for one minute. How do you predict the particles will settle?
4 Observe how the particles settle. Time how long it takes for each layer to form.

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.

Try this 5.4

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 5.21. 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?

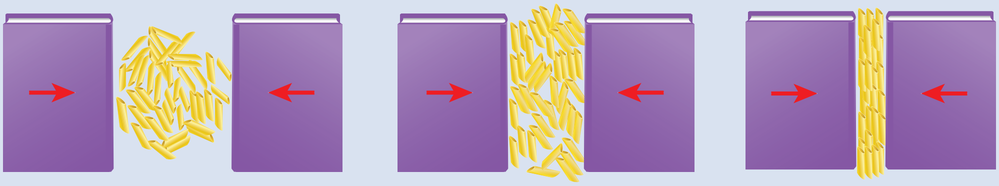

Figure 5.21 As you compress the pasta, the pieces align.

Quick check 5.5

In order to understand the unique characteristics of different types of rocks, it is essential to examine how they are formed. Distinguish between the three kinds of rock in terms of how they are formed.

Figure 5.22 Slate is a metamorphic rock formed when mudstone is subjected to high pressure and temperature.

Figure 5.23 Pieces of schist, formed when slate is subjected to high temperature and pressure

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Uplift

Uplift refers to the movement of rocks from deeper parts of Earth's crust to the surface. This occurs through tectonic activity, volcanic eruptions or erosion of overlying rock layers. As rocks are uplifted, they are exposed to environmental processes, including weathering, erosion and deposition. These processes can break down and reshape the rocks, leading to the formation of new sediments and minerals. Uplift is also involved in the creation of mountain ranges, as tectonic forces cause rocks to be pushed upwards and folded into complex structures.

Explore! 5.2

The Great Dividing Range

The Great Dividing Range is a vast mountain range that runs parallel to the east coast of Australia, stretching from the tip of Cape York Peninsula in the north to the Grampians in Victoria in the south. The formation of this mountain range is largely attributed to uplift, which occurred over millions of years.

The uplift was caused by tectonic forces that led to the gradual uplifting of the Australian continent over millions of years. Recent research has revealed that the mantle under Australia's east coast has been uplifted twice – once during the Early Cretaceous Period, when Australia was part of the ancient 'supercontinent' Gondwanaland, and then a second time about 50 million years later. As the Australian continent was uplifted, the overlying sedimentary rocks were also uplifted and folded, leading to the formation of the mountain range.

Over time, erosion has also played a significant role in shaping the Great Dividing Range. The forces of wind, rain and ice slowly wore down the mountains, carving out deep valleys and gorges and smoothing out the peaks.

Figure 5.24 The Great Dividing Range

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Energy sources for the rock cycle

It takes a lot of energy to move rocks around, break them up, heat them until they melt, or change them physically or chemically.

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 Earth was formed, it contained radioactive atoms left over from a supernova. This radioactive energy has been released ever since and is what keeps the centre of Earth at a high temperature.
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 5.2 The energy required for the formation of the different rock types comes from different sources.

Speed of rock formation

Different rock formation processes occur at different rates, and the speed at which they occur depends on various factors, such as the type of rock being formed, the environmental conditions and the geological processes involved.

Type of rock	Speed of formation
Igneous	Depends on the cooling rate of lava or magma, which depends on the depth and pressure of the magma chamber, the rate of magma flow and the presence of water or other minerals
Metamorphic	Depends on the temperature and pressure involved
Sedimentary	Depends on the rate of sediment deposition and the degree of compaction and cementation

Table 5.3 The speed at which rocks form can vary widely.

Did you know? 5.4

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 Earth itself.

Figure 5.25 This piece of rock is a sample of Acasta Gneiss, the oldest body of rock yet discovered on Earth.

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Try this 5.5

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.

Section 5.1 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 Earth's surface.

Comprehension

4 Copy the image of the rock cycle in Figure 5.26 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 Earth's core suddenly lost its thermal energy. Identify which type(s) of rock formation would be affected and explain why.

Knowledge utilisation

9 Examine Figure 5.27 and **decide** whether it is a mineral or a rock. Justify your answer.
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.

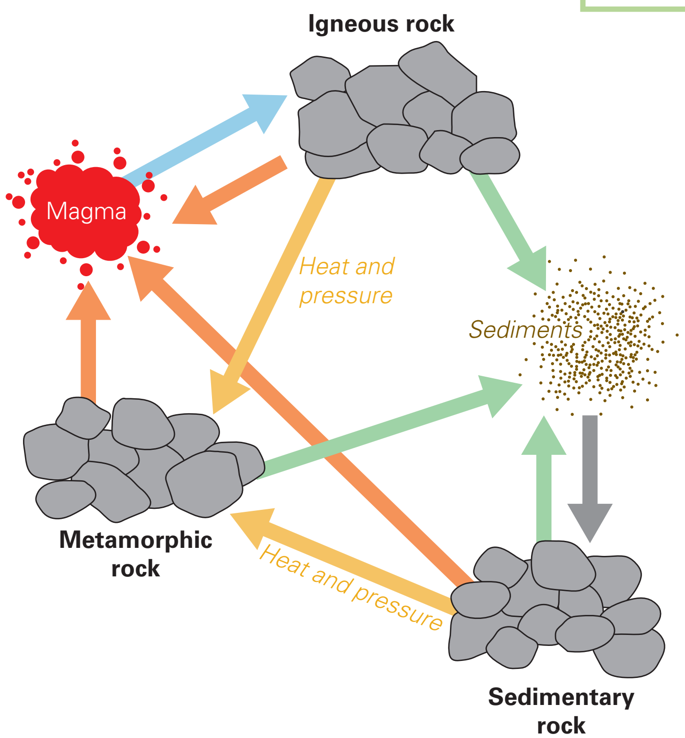

Figure 5.26 The rock cycle


Figure 5.27

5.2 Types of rocks

DOC
WORKSHEET
Types of rocks

Learning goals

1. To explore the formation of igneous, sedimentary and metamorphic rocks.
2. To examine how fossil evidence can predict how and when a rock was formed.

Igneous rocks

Beneath Earth's thin outer crust is molten and semi-molten rock, called magma. When the surface crust becomes fractured, thin or weakened, molten magma can reach the surface and a volcano is formed. You may recall from the previous section that igneous rocks are formed when lava cools quickly following a volcanic eruption, sometimes within minutes. Igneous rocks can also be formed when magma cools and solidifies slowly underground in a magma chamber after it has been pushed close to the surface.

Figure 5.28 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!

extrusive
describes igneous rocks formed on Earth's surface; also called volcanic rocks

intrusive
describes igneous rocks formed underground; also called plutonic rocks

Figure 5.29 The hexagonal pillars of basalt found at the Giant's Causeway in Northern Ireland are an example of lava flowing onto the surface, solidifying and forming igneous rock.

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.

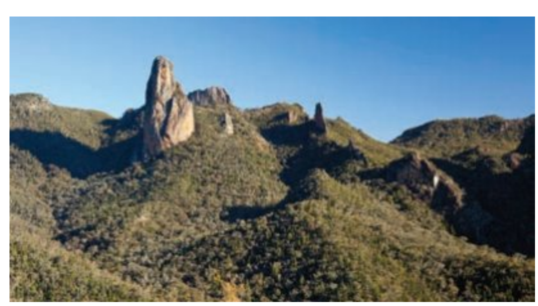

Figure 5.30 An example of intrusive igneous rock. This unusual landform in New South Wales contains the remains of an ancient volcano. Belougery Spire, on the left, was the magma chamber. The Breadknife, running along the right, was a crack in the volcano that filled with magma.

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Figure 5.31 Granite has a distinctive mosaic of crystals of different colours.

Did you know? 5.5

Brisbane tuff

Brisbane tuff is a distinctive type of volcanic rock that is found in and around the city of Brisbane, in Australia. It is a type of ignimbrite, which is formed by the explosive eruption of volcanic material and the subsequent deposition of ash, pumice and other debris. Brisbane tuff is characterised by its pinkish-grey colour and its porosity, which means it is full of tiny holes that make it easy to carve and shape. The rock was extensively used in the construction of many of Brisbane's early buildings and structures, including the Story Bridge. Today, Brisbane tuff is still visible in many of the city's older buildings and landmarks, serving as a reminder of the area's volcanic past and its geological history.

Figure 5.32 St Mary's Church, Kangaroo Point, is built from Brisbane tuff.

Quick check 5.6

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.

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Investigation 5.1

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 solution
- water
- test tubes
- beakers
- ice
- hand lens

Method

Using the materials above, design an experiment to investigate how cooling rate affects the size of crystals formed from saturated potassium nitrate or magnesium sulfate.

Hint: To create crystals, you need to use a saturated solution of potassium nitrate or magnesium sulfate.

Results

Record your results. Consider different ways your results could be presented.

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.

Sedimentary rocks

There are three different types of sedimentary rocks: clastic, organic (biological) and chemical. Each type is formed from pieces of other existing rock or organic material and can take thousands to millions of years to form.

clasts
small pieces of pre-existing rock that form a sedimentary rock

Clastic sedimentary rocks are made up of small pieces of other rocks, which are called '**clasts**'. Over time, clasts can be transported by wind, water, ice or other forces and then deposited in a new location. Eventually, the layers of clasts become compacted and cemented together to form a solid rock.

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Sedimentary rocks can be classified based on their texture, composition and origin.

Clastic sedimentary rocks

Sedimentary rocks mainly made of gravel

Conglomerate is a coarse-grained sedimentary rock that is made up of large, rounded clasts that are greater than two millimetres in size. The clasts in a conglomerate are usually well-rounded as they have been transported a long distance from their source, indicating a high-energy environment, such as a river or beach.

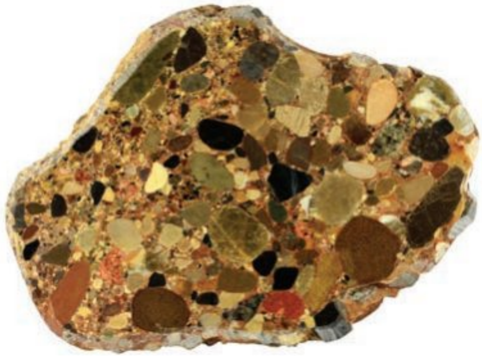

Figure 5.33 Sedimentary rock made from rounded pebbles is called conglomerate.

Breccia is also a coarse-grained sedimentary rock, but it is made up of large, angular clasts that have been cemented together. The clasts in a breccia are usually less rounded than those in a conglomerate and have been transported a shorter distance. Breccia often forms in areas where there has been a lot of tectonic activity or landslides, as the rocks are broken into angular fragments during these events.

Figure 5.34 Sedimentary rock made from angular pebbles is called breccia.

Sedimentary rocks mainly made of sand

Sandstone is a medium-grained sedimentary rock that is made up of sand-sized silicate grains. The sand grains are typically well rounded, indicating a long period of transport and weathering. Sandstone varies in colour and composition depending on the minerals that make up the sand grains. Most sandstone is composed of quartz or feldspar.

conglomerate sedimentary rock composed of rounded rock fragments larger than two millimetres

breccia sedimentary rock composed of angular broken pieces of rock larger than two millimetres

sandstone sedimentary rock composed mainly of sand-sized silicate grains

Figure 5.35 Jimbour is a homestead on one of the earliest stations established on the Darling Downs in Queensland. Its buildings are made of sandstone.

Uluru is a sedimentary rock made of sandstone, but the layers are almost vertical. The rock that forms Uluru would originally have been horizontal, but over time the movement of Earth's crust tilted it. The top of the rock has been weathered and eroded, until today just the end is showing. This is evidence that Earth is very old.

Figure 5.36 Uluru is an ancient sedimentary rock tilted nearly 90° by the movement of Earth's crust.

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Figure 5.37 Wulingyuan in China is noted for more than 3000 quartzite sandstone pillars and peaks.

Sedimentary rocks mainly made of silt or clay

Mudstone is a fine-grained sedimentary rock that is made up of silt- and clay-sized particles. The particles in mudstone are so small that they are not visible to the naked eye. Mudstone is typically deposited in low-energy environments, such as swamps or lakes, where the water is calm enough for fine particles to settle out. Mudstone can be easily split into thin layers, or laminations, due to the flat shape of the clay particles. Half of the sedimentary rocks on Earth are made of mudstone. Mudstone turns into the metamorphic rock slate at high temperature and pressure. Slate is used as a roofing material in some parts of the world.

Figure 5.38 Fossilised leaves in mudstone

Biological sedimentary rocks

Organic or biological sedimentary rocks are formed from the remains of living things, such as plants, animals or shells. Over time, these remains can accumulate and become buried and, with high pressure and temperature, they become compacted and cement together to form a solid rock. For example, chalk is made up almost entirely of the microscopic skeletal remains of plankton, called coccolithophores. These organisms are covered in small plates made of calcium carbonate, which accumulate on the ocean floor when they die and sink. Over time, these plates are compacted and cemented together to form chalk.

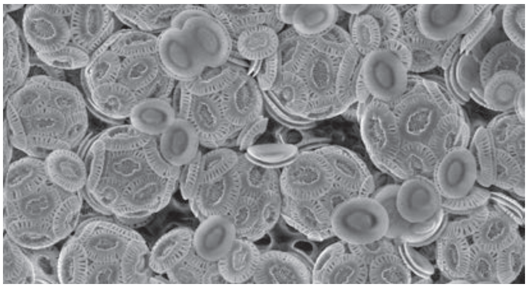

Figure 5.39 Coccolithophore cells covered with calcium carbonate scales

Sometimes, gaps in the chalk fill with dissolved silica (from sea creatures with silica-rich skeletons) and form flint nodules. Flint was one of the first substances used to make tools.

Other examples of organic sedimentary rocks include coal, which is made from compressed plant material, and limestone, which is made from the shells of ancient sea creatures.

Figure 5.40 A chert nodule, found in chalk. Chert is also a sedimentary rock.

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Explore! 5.3

How coal is made

Organic material from living creatures can also form sedimentary layers. Layers of plant material form coal, while oil is formed mostly from plankton. Although oil is a liquid, it is still sedimentary.

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?

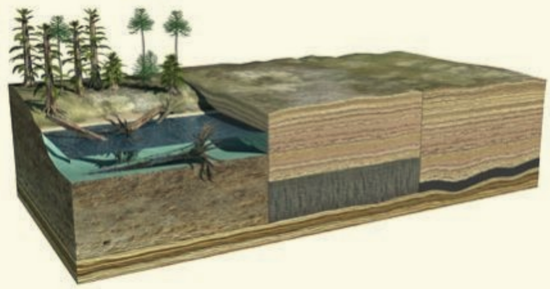

Figure 5.41 How coal is formed. Left: In the Carboniferous Period, trees died and formed a layer of wood. Middle: The wood was compressed by the layers of sediment above. Right: The compressed wood was transformed by heat and pressure into coal.

Chemical sedimentary rocks

Chemical sedimentary rocks are formed when minerals dissolved in water (such as calcium carbonate or salt) precipitate out and form solid crystals. Over time, these crystals can accumulate and become cemented together to form a solid rock. Examples of chemical sedimentary rocks include limestone, which can form from the precipitation of calcium carbonate, and rock salt, which can form from the precipitation of salt minerals.

Figure 5.42 Limestone boulders in Chillagoe, Queensland

Figure 5.43 Rock salt is a sedimentary rock made of halite, a mineral composed of sodium chloride, NaCl.

Did you know? 5.6

Identifying underground resources

Advances in deep earth imaging techniques have greatly enhanced our ability to identify and locate mineral, energy and water resources beneath surface sedimentary rock. One technique is seismic reflection imaging, which uses sound waves to create images of subsurface structures. By analysing the way that these sound waves bounce off different layers of rock and other geological features, detailed 3D models of Earth's interior can be built. This technique has been particularly useful for identifying oil and gas reservoirs, as well as underground aquifers.

Another technique is magnetotelluric (MT) imaging, which measures variations in Earth's natural electromagnetic field to identify subsurface structures. This has proven especially effective for identifying mineral deposits, as different minerals have unique electrical properties.

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Did you know? 5.7

Coral beaches

While most beaches are made of quartz sand, some beaches near coral reefs are entirely composed of tiny fragments of coral made of calcium carbonate.

Figure 5.44 Fragments of coral found on a coral beach

Metamorphic rocks

The third type of rock in the rock cycle is metamorphic rock. Earth's crust is very thin in proportion to its size, and the rocks that lie beneath the surface are subjected to high pressure and temperature. Metamorphic rocks are either igneous or sedimentary rocks that have been irreversibly changed by being subjected to these conditions. For example, if limestone (sedimentary) is subjected to high pressure and temperature, it turns into marble (metamorphic).

Rocks that have been changed into metamorphic rock tend to be denser and harder than before. Layers may become twisted when rocks are metamorphosed. Over millions of years, buried metamorphic rocks can eventually make their way to the surface again. These rocks are found all over the world and they constitute about 10% of Earth's surface.

Foliated metamorphic rocks have a layered or banded appearance, with the mineral grains arranged in parallel layers. This banding is the result of the intense pressure and heat that the rock experienced during its formation. The pressure causes the mineral grains in the rock to realign, giving the rock a distinct pattern. Examples of foliated metamorphic rocks include schist, gneiss and slate.

Figure 5.45 Folds in schist (top), gneiss (middle) and slate (bottom)

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Non-foliated metamorphic rocks, on the other hand, do not have a layered or banded appearance. Instead, they have a more uniform texture and composition. Examples of non-foliated metamorphic rocks include marble and quartzite.

VIDEO Igneous, sedimentary and metamorphic rocks

Figure 5.46 Marble (left) and quartzite (right)

Quick check 5.7

1 Describe how metamorphic rock is formed.
2 Recall some examples of a metamorphic rock and what components make up each one.

Try this 5.6

Chocolate rock cycle

You can model the rock cycle using chocolate, which can be easily weathered, heated, cooled and compressed, unlike rocks. By creating 'sedimentary', 'metamorphic' and 'igneous' chocolate, you can model the transformations that rocks undergo over time.

Be careful

Do not consume food items in the laboratory.

You will need blocks of dark and white chocolate, aluminium foil or cupcake holders, hot water and a plastic knife or scraping device.

To create the 'sedimentary' chocolate, scrape small shavings from the chocolate blocks and put them onto a piece of aluminium foil. Fold over the foil and press down, creating chocolate that represents sedimentary rock.

To make the 'metamorphic' chocolate, place a small pile of sedimentary chocolate, unused shavings and small chunks of chocolate into aluminium foil or a cupcake holder and float this on *warm* water. The heat from the water will melt the chocolate, and after removing the foil, the partially melted and cooled chocolate will resemble metamorphic rock.

To create 'igneous' chocolate, place a small pile of sedimentary and metamorphic chocolate, along with chunks of chocolate, into aluminium foil or a cupcake holder and float this on *hot* water. Watch as the chocolate melts into a smooth liquid, then carefully remove the foil and allow the molten chocolate to cool. This melted and cooled chocolate represents igneous rock.

Try this 5.7

Summing up

Using the poster you began in Section 5.1, annotate it with information about the three different rock types you have learned about and their characteristics and examples.

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Explore! 5.4

Stone pigments

First Nations Australians 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

Figure 5.47 Stencil art paintings on sandstone walls at Carnarvon Gorge, Queensland, contain paintings from thousands of years ago.

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 First Nations Australians.

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.

Explore! 5.5

Fossil formation

Use the internet 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 5.4.

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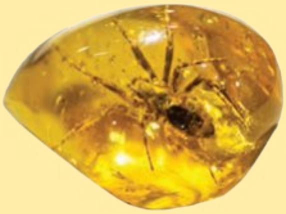
Fossil type	Details	Image
Mould	When a plant or animal decays in sediment, it may leave a hollow impression of itself.	 **Figure 5.48** The mould of an ammonite
Cast	When an animal or plant dies, its body creates a space in the sediment. This gap fills with minerals, such as silica, over time, and the shape of the animal is preserved as rock.	 **Figure 5.49** A fossilised trilobite, an extinct creature that once dominated life on Earth
Imprint	These fossils leave behind a two-dimensional (flat) print.	 **Figure 5.50** Leaves are pressed flat by the pressure in the sedimentary layers and all that is left is a dark area, like a shadow.
True form/ whole body	This is the most common type of fossil. It consists of parts of the remains of living things, mainly the hard parts, e.g. teeth, shells, bones.	 **Figure 5.51** True form fossils are also found intact in a medium such as amber (tree resin that has become fossilised).
Indirect or trace	These fossils do not consist of part of the organism. They are indirect records of biological activities, such as footprints, teeth marks or burrow marks.	 **Figure 5.52** 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 5.4 Five common types of fossils

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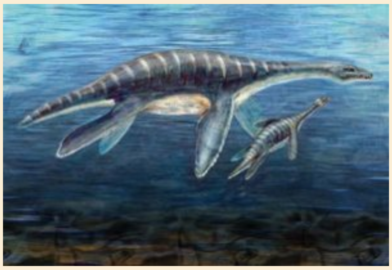
Did you know? 5.8

Opal fossils

Opalised fossils are a type of fossil that has been replaced by opal. These fossils are formed when minerals in the surrounding rock dissolve and are replaced by silica-rich solutions that penetrate the spaces in the original organic material. Over time, the silica hardens into opal, preserving the details of the original organism. They are particularly abundant in Australia.



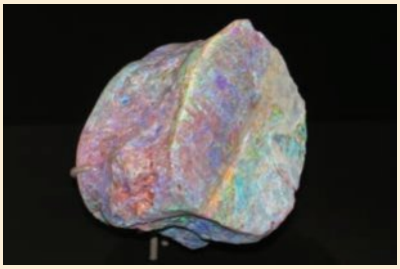


Figure 5.53 An artist's impression of plesiosaurs (left); an opalised fossil plesiosaur vertebra found in Australia (middle) and a cast fossil of a plesiosaur found in the UK (right)

Finding information from fossils

Fossil evidence can be used to predict how and when a rock was formed. It can be used to determine the age of a rock layer relative to other rock layers. This is because different organisms evolved at different times in Earth's history, and the fossil record provides a timeline of the evolution of life. 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.

Fossils can also provide information about the environmental conditions that existed when the rock was formed. For example, the types of fossils found in a rock layer can indicate the type of habitat that existed, such as a marine or terrestrial environment. The size and shape of fossils can also provide information about the water depth, temperature and other environmental factors.

Figure 5.54 The Tepees in Petrified Forest National Park, Arizona. This area is known for its fossils, especially fallen trees that lived about 225 million years ago. The fossil logs contain colourful sediment formations.

Fossils can be used to estimate the age of rocks from different places in the world that were formed at the same time. This is because similar types of fossils found in different locations indicate rocks of a similar age. By comparing the fossils found in different rock layers, scientists can reconstruct the geological history of a region.

Quick check 5.8

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.

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Science as a human endeavour 5.2

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! 5.5*, specific conditions are required for fossilisation to take place. Not all dead things become fossils.

Interpretation of the fossil record has always presented difficulties for palaeontologists (scientists who study fossils). For example, for many years it was believed that the extinction of dinosaurs was gradual, but in 1980 evidence was found of a meteor impact that is now thought to have caused mass extinction. Also, disappearance from the fossil record does not always mean that a species is extinct; there may be many other reasons for its absence from the record.

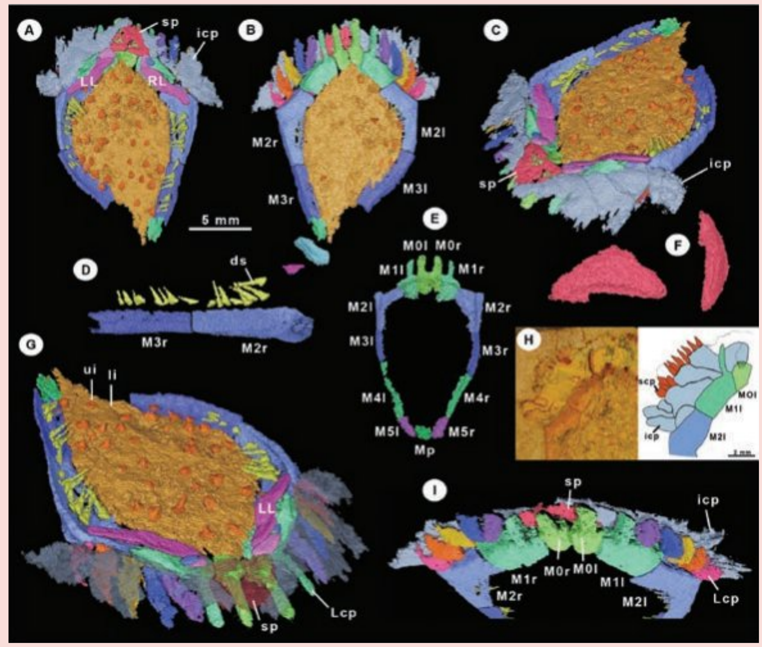

Figure 5.55 Computer models can aid research in various fields, including the study of fossils.

Palaeontologists Steven Holland and Mark Patzkowsky designed computer models to aid the study of mass extinction, and are using the models to decipher the fossil record more accurately. Their work is still in progress; however, it provides an initial guideline for analysis and assessment of extinction events.

Section 5.2 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 Earth is old.

7 Figure 5.56 shows the Organ Pipes rock formation at Organ Pipes National Park in Victoria. Use what you have learned about igneous rocks to **explain** how this formation came to be.

Figure 5.56 A set of basalt columns at Organ Pipes National Park in Victoria

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8 Look at the igneous rocks in Figure 5.57. **Identify** which one is intrusive and which is extrusive. **Explain** your reasoning by first recalling the difference between intrusive and extrusive.

Figure 5.57 Which one is intrusive, and which is extrusive?

Analysis

9 **Classify** the types of fossils shown in Figure 5.58.

Figure 5.58 Types of fossils

Knowledge utilisation

10 **Discuss** why the water in the Brisbane River is brown (see Figure 5.59). Use the following terms in your explanation: particles, sediment, weathering, erosion, deposit, rock.

Figure 5.59 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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5.3 Classifying and using rocks

Learning goals

1. To be able to compare the observable properties of different types of rocks and identify them using a dichotomous key.
2. To be able to describe the tests available to classify rocks.
3. To explore the traditional geological knowledges of First Nations Australians that are used in the selection of different rock types for different purposes.

DOC
WORKSHEET
Identifying rocks

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 using a dichotomous key.

Figure 5.60 Painite, the world's rarest gem

Figure 5.61 Vivianite is often found growing in, on or around dead bodies.

Dangerous rocks

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.

Figure 5.62 Asbestos is a dangerous mineral and should not be handled.

Characteristics of the different rock types

ore
a rock that can be mined and smelted to produce a metal

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 5.63 Examples of igneous rock are pumice (left) and diorite (right).

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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 5.64 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 5.65 Examples of metamorphic rock are gneiss (left) and granulite (right).

Explore! 5.6

Classifying rocks

You now know that rocks are made of minerals, that 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 5.8

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.

Tests for classifying 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.

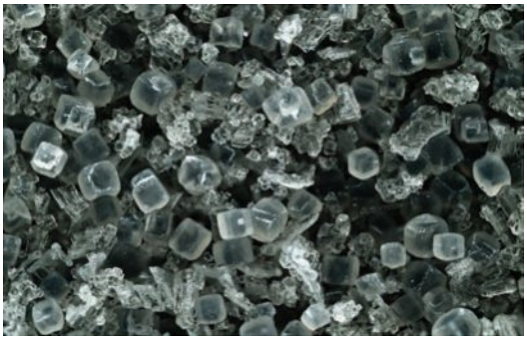

Figure 5.66 Table salt contains tiny crystals that are cubic in shape.

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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. 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.

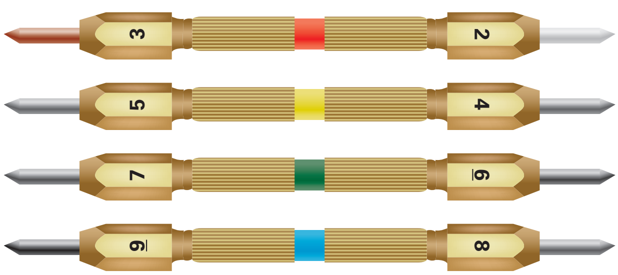

Figure 5.67 A set of Mohs hardness picks, which can be used to help identify a rock by its hardness

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** rocks, such as diamond (metamorphic) and quartz (igneous), allow light to pass through and images are visible through them.

Figure 5.68 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 rocks (such as slate, which is a metamorphic rock containing mica).

Figure 5.69 Slate (top) can be split into thin sheets for building. Slate is composed mostly of quartz and mica (bottom left). Galena (bottom right) is another mineral which, like mica, has an identifiable cleavage plane.

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

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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 5.70 Magnetite is a mineral found in igneous, metamorphic and sedimentary rocks. It is also found in meteorites.

WIDGET
A key to identify rocks

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.

streak test
a test used to help identify a mineral by scratching a rock on a hard ceramic tile

Figure 5.71 Examples of a streak test

Figure 5.72 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 5.9

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

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 will also help.

Table 5.5 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 • Usually soft • Flat layers may be visible	• Layers may be folded • Can often be cleaved to a straight plane • Higher density than sedimentary rock

Table 5.5 Some characteristics of rocks

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Practical skills 5.1

Identifying 12 common rocks

Aim

To practise identifying and finding patterns, by classifying 12 of the most common rocks found in Earth's crust

Materials

- 0.1 M hydrochloric acid
- dropper
- beaker of water
- hand lens
- disposable gloves
- 12 Petri dishes for the hydrochloric acid test
- 2 of each of the following rocks: basalt, chalk, gneiss, granite, limestone, mica, pumice, quartz, quartzite, sandstone, schist, slate

Figure 5.73 12 common rocks found in Earth's crust, in random order

continued …

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… continued

Method

1 Use this dichotomous key to identify the rock and the rock type. You can work in 12 groups, each group being responsible for one rock type (each group will hold two rocks: one for the general test and one for the hydrochloric acid test).

Rocks are composed of one or more minerals. For this practical, if a rock is made up of only one type of mineral, identify the rock as a 'mineral'.

1	Is the rock composed of crystals?	Yes	Go to 2
		No	Go to 5
2	Are the crystals flat and silvery?	Yes	Mica (igneous, metamorphic)
		No	Go to 3
3	Are the crystals large and transparent?	Yes	Quartz (igneous)
		No	Go to 4
4	Are the 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 fingernail?	Yes	Chalk (sedimentary)
		No	Limestone (sedimentary)
7	Place the rock in a beaker of water. Does the rock float on the water?	Yes	Pumice (igneous)
		No	Go to 8
8	Is the rock translucent (allows some light to pass through)?	Yes	Quartzite (metamorphic)
		No	Go to 9
9	Does the rock have visible layers that may be curved or bent?	Yes	Gneiss (metamorphic)
		No	Go to 10
10	Does the surface of the rock appear to be made up of plates?	Yes	Schist (metamorphic)
		No	Go to 11
11	Does the rock break to form layers with a flat surface?	Yes	Slate (metamorphic)
		No	Basalt (igneous)

Table 5.6 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.

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 on water.
3 Design some rules and a different dichotomous key or chart to classify rocks as minerals, or igneous, sedimentary or metamorphic rocks. Identify any difficulties you encounter in doing this.

Science as a human endeavour 5.3

It used to be hotter

Studying the first billion years of Earth's evolution has always been uncertain. It is difficult to compare ancient rocks with modern rocks, as the original rocks have often been destroyed or changed over time. Researchers at Louisiana State University have shown that komatiites (three-billion-year-old volcanic rocks) were formed from the hottest lava that ever erupted on Earth. Temperatures were close to 1600°C, which is about 400°C hotter than the volcanic eruptions in modern-day Hawaii!

Figure 5.74 Komatiite

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VIDEO
Using rocks

Using rocks

All types of rock are formed in different ways, giving them unique properties that make them useful for a range of purposes. Table 5.7 gives some common uses of the different types of rock.

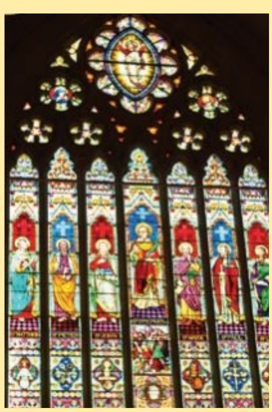
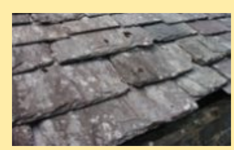
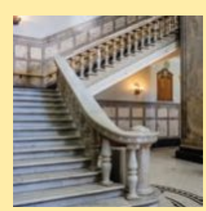
Type of rock	Examples	Use of rock
Intrusive igneous	Granite Gabbro	Building materials Sculptures  **Figure 5.75** A granite kitchen worktop
Extrusive igneous	Basalt Pumice	Road construction, building materials Abrasive in cleaning and polishing compounds  **Figure 5.76** A basalt building in Germany
Clastic sedimentary	Sandstone Shale	Construction, building materials Glass  **Figure 5.77** Stained glass at St Stephens Church, Brisbane
Chemical sedimentary	Limestone Rock salt	Construction, production of cement, glass and fertilisers De-icing roads, food preservation and flavouring  **Figure 5.78** Limestone is used in the production of cement.
Organic (biological) sedimentary	Coal	Fuel  **Figure 5.79** A fern fossil in coal
Foliated metamorphic	Slate Gneiss	Building materials Decorative stones  **Figure 5.80** Slate roof tiles
Non-foliated metamorphic	Marble Quartzite	Building materials Decorative stones Electronics  **Figure 5.81** Brisbane City Hall's marble staircase

Table 5.7 Some common uses of rocks

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Try this 5.9

Form influences function

Using Table 5.7, suggest why the properties of the rock examples are appropriate to their uses.

Explore! 5.7

Traditional geological knowledge

The traditional geological knowledge of First Nations Australians is based on a deep understanding of the land. This knowledge has been passed down from generation to generation and is based on both observations and spiritual connections to the land.

When different rock types are used for different purposes, First Nations Australians rely on their geological knowledge of the properties of rocks, as well as their understanding of the spiritual and cultural significance of different rock types.

For example, some groups of First Nations Australians use particular types of rocks for tool-making and other practical purposes. These rocks are selected based on their physical properties that make them well suited for specific tasks. Rocks are also considered to have spiritual or ceremonial significance in First Nations Australian cultures.

Figure 5.82 Uluru is a place of great spiritual significance for the Anangu people. Many Anangu people go to Uluru to connect with their ancestors and to perform traditional ceremonies and rituals.

Research the spiritual and cultural connection that certain groups of First Nations Australians have with the following rock formations:

- Kalkajaka (Black Mountain)
- Mount Coolum
- Carnarvon Gorge

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Section 5.3 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 5.1*.

a The rock in Figure 5.83 does not bubble when acid is placed on it.

Figure 5.83

b The rock in Figure 5.84 does not bubble when acid is placed on it.

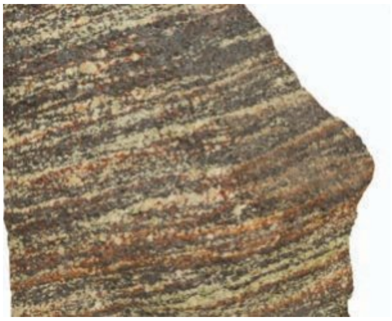

Figure 5.84

c The rock in Figure 5.85 bubbles when acid is placed on it. It cannot be scratched easily with a fingernail.

Figure 5.85

d The rock in Figure 5.86 does not bubble when acid is placed on it. The crystals are not easily removed.

Figure 5.86

Knowledge utilisation

6 Using the rocks in Question **5** and the dichotomous key in *Practical 5.1*, **determine** the rock type for 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 you agree with this statement.

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5.4 The mining process

Learning goals

1. To explore the six stages of the mining cycle.
2. To explore how the mining of ores and minerals impacts on local environments and examine environmental rehabilitation initiatives.
3. To investigate how First Nations Australians have used quarrying to access rocks for use as or production of everyday objects.

DOC
WORKSHEET
The mining process

VIDEO
The mining process

Some minerals are useful to humans and can be mined. Mining is the process by which minerals and other useful materials are extracted from Earth. Salt, slate, gold, marble and coal can be used as they are found. Others need to be processed to make useful products, such as metals or building materials like cement.

The extraction of metals, ores and other materials from Earth has a very long history. Archaeologists have named two periods of human history, the Bronze Age and the Iron Age, according to the metals that people were producing at that time.

The mining process has several stages: exploration, planning and design, construction, mining, processing, and closure and rehabilitation.

1 Exploration

Before any mining project begins, mining companies enlist the expertise of geologists to scout areas and search for mineral deposits. It is important that they find out the quality of the mineral and the size of the deposit. This is to determine whether it would be cost effective for the mineral to be mined, as a mining project is extremely expensive once it has started.

Mining companies should also communicate with the traditional owners of the land to ensure that they are aware of any important cultural or archaeological sites so that they can be protected. In 2020, Rio Tinto blasted a 46 000-year-old First Nations 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 First Nations Australian heritage sites at risk of demolition.

Figure 5.87 Geologists sampling rocks during iron-ore exploration in the outback (Pilbara, Australia)

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Science as a human endeavour 5.4

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

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 5.88 Miners can use a PMI gun to determine the composition of a rock.

Figure 5.89 Core samples taken from a diamond mine

2 Planning and design

If the results of the exploration strongly suggest that mining in a certain area would yield good results, then the project moves into the planning stage. Collaboration occurs among project managers, mining engineers, ecologists, environmental scientists, finance consultants and other experts to design safe, sound, economically viable and socially responsible plans.

Figure 5.90 Social responsibility in planning includes considering how a new mine will affect society and the natural environment.

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Explore! 5.8

Environmental impacts of mining

Mining of ores and minerals can have significant impacts on local environments. Some of the issues caused by mining are listed below.

- soil and water contamination
- deforestation and habitat destruction
- land subsidence and sinkholes
- air pollution
- greenhouse gas emissions
- water overuse

These impacts can be long lasting and can have significant consequences for local ecosystems, wildlife and human communities. Mining companies are required to follow regulations and guidelines to reduce these impacts.

The environmental impacts and benefits of mining can be both short-term and long-term. Conduct research on recent applications for new projects in your region. What role did government, both state and federal, play in allowing or blocking the application?

3 Construction

After research is carried out, planning is completed and permits are approved, the project moves to the construction stage. This may involve building roads, mining facilities and housing.

Figure 5.91 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 larger depths than 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 5.92 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

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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 the Pacific Ocean; however, there are strong environmental concerns associated with deep-sea mining, and to date, it is too difficult and expensive.


Figure 5.93 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.

Making thinking visible 5.1

Here now/there then: Coal mining

Coal mining in Australia is controversial for several reasons, including issues surrounding the environmental impact, Indigenous land rights and climate change. Attitudes to coal mining have changed over time.

- Create a two-column table.
- In column A, list **present** ideas and values about the topic.
- In column B, list **past** ideas and values about the topic.
- Compare columns A and B.
- Why do you think ideas and values have changed?
- How could we find out more about the ideas and values people had in the past?

The *Here now/there then* thinking routine was developed by Project Zero, a research centre at the Harvard Graduate School of Education.

Explore! 5.9

Mining extraction processes

There are different types of mining. Underground mining and surface mining are two of these; another two methods are placer mining and in-situ leach mining. Research these methods and answer the following questions.

1 What is involved in placer mining and in-situ leach mining?
2 List some advantages and disadvantages of the types of mining.
3 Which of the mining types are most environmentally friendly? Justify your answer.
4 Describe some of the ethical issues that need to be considered with regard to mining.

Explore! 5.10

Fully automated mines

Australia has the largest number of autonomous mining trucks in the world. Use the internet to search for 'Christmas Creek automated mine'. Do some research with regard to advances in mining technology and automation and answer the following questions.

1 Identify the advantages of fully automated mining technology.
2 Assess the concerns that have been raised for fully automated mining. Do you think these concerns are justified?

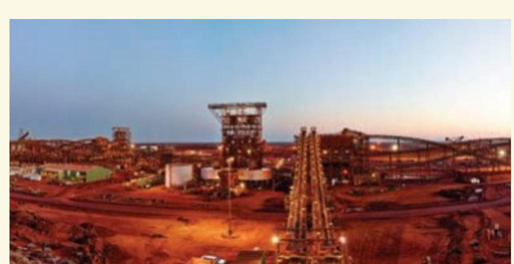
Figure 5.94 Christmas Creek Mine

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Quick check 5.10

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 design		
3 Construction		
4 Mining		
5		
6		

Explore! 5.11

Stone tools

In different parts of Australia, First Nations Australians have developed varying techniques of quarrying and crafting stone tools for various purposes. Stone tools are used in day-to-day life for activities such as hunting, harvesting and preparing. Quarrying involves identifying and extracting suitable rocks from natural outcrops or from boulder fields. Different groups of First Nations Australians have used a variety of rocks, such as basalt, sandstone, quartzite, chert and flint, depending on what is available on Country. These rocks are then shaped and transformed into a variety of objects, such as grindstones, hammerstones, anvils, cutting tools and weapons. The techniques involved in creating stone tools require knowledge from the various disciplines of science.

Conduct research to investigate the following questions.

1 Explain how having knowledge of the geological, biological, chemical and physical sciences helps to create stone tools that are fit for the intended purpose.

2 Determine why the following rock types are used as the named tools in various First Nations Australians' cultures.
   a the use of flint as a cutting tool
   b the use of quartzite as an anvil
   c the use of limestone as a hammerstone
   d the use of sandstone as a grindstone
   e the use of silcrete as a knife blade
   f the use of basalt as an axe head

3 Examples of techniques and methods for toolmaking are knapping, lithic reduction, percussion flaking, pressure flaking and grinding. Describe what each of these processes involves and how they help create stone tools from the raw material.

Figure 5.95 Grain grinding using rocks

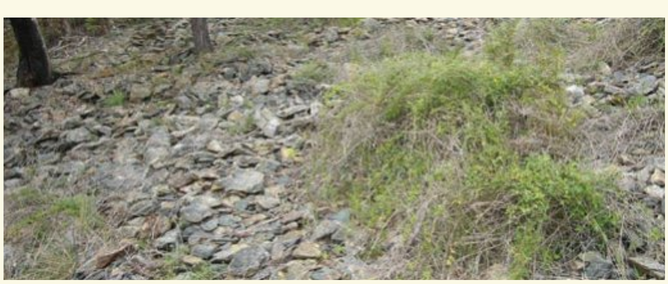

Figure 5.96 Wil-im-ee Moor-ring (Mount William stone axe quarry) located in western Victoria was an important source of raw material for the manufacture of greenstone ground-edge axes, which were traded over a wide area of south-eastern Australia.

Figure 5.97 First Nations Australian grinding stones

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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, many metal ores consist 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.

$$\text{metal oxide} + \text{carbon} \xrightarrow{\text{yields}} \text{metal} + \text{carbon dioxide}$$

Purifying

Electricity can be used to purify an impure sample of metal in a process called **electrolysis**. The sample is connected to a positive terminal and a pure piece of the metal is connected to the negative terminal. The terminals are placed in a solution containing the metal and, when the circuit is connected, the metal in the impure sample slowly moves through the solution from positive to negative. Any impurities are deposited near the positive terminal. When this is done with copper ore, the impurities may contain valuable metals, such as gold.

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

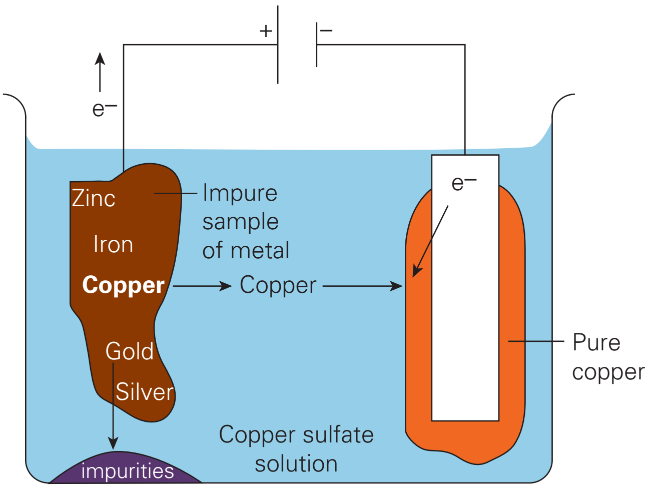

Figure 5.98 Use of electrolysis in purifying copper

Remining

Remining involves extracting valuable minerals from waste materials that have already been mined. Remining critical metals, such as lithium, cobalt, tin, tungsten and indium, can reduce the need for new mining sites. In addition, remining limits the impact on pristine areas, while also providing economic benefits by unlocking additional value from previously mined sites. While remining has not yet been widely adopted in Australia, it is a promising approach that aligns with the growing sustainability priorities of mining companies.

Practical skills 5.2

Electrolysis of copper

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
- a metal fork or spoon
- 0.5 M copper sulfate solution
- beaker
- 3 V DC power supply

continued …

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… continued

Method

Part 1

1 Place two copper electrodes in a beaker containing a solution of copper sulfate.
2 Connect the electrodes to a battery or low-power direct-current supply (make sure it is switched off when you do this) using alligator leads.
3 Switch it on and leave it for a while (it may take 20–40 minutes). The cathode will slowly grow, and the anode will become smaller.
4 Switch the power supply off.

Part 2

1 Replace the copper plate connected to the negative terminal with a fork.
2 Switch the power supply on. Copper will move from the other plate to the fork. When it reaches the fork, it will be deposited on the surface and a thin layer of copper will appear. This is called electroplating.

Be careful

Ensure personal protective equipment is worn. Electrical shocks may occur. Ensure the recommended voltage output is not exceeded. Turn off the power supply when changing the circuit.

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.

Phytomining can be used as a tool for rehabilitating areas that have been impacted by mining activities. In many cases, mining can leave behind soils that are contaminated with heavy metals and other pollutants, which can have long-term negative impacts on the environment and surrounding communities. Phytomining can be used to help remediate these contaminated soils by using hyperaccumulator plants to absorb and accumulate the contaminants. Once the plants have accumulated the pollutants, they can be harvested and removed from the site, effectively removing the contaminants from the soil. This process not only reduces the amount of pollutants in the soil, but it can also provide a potential source of revenue through the recovery of valuable metals.

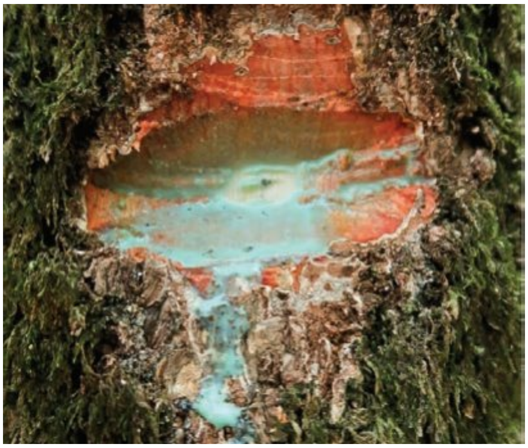

Figure 5.99 The sap from *Pycnandra acuminata*, found in New Caledonia, contains 25% nickel.

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Did you know? 5.9

Rehabilitation and biodiversity

Rehabilitation of the land also takes into consideration the native plants and animals that were in the site before it was mined. Disturbed areas are reshaped to reflect their original state as closely as possible, and care is taken to preserve plant species. In 2022, the Chuwar coal mine near Ipswich became the first open-cut coal mine in Queensland to be fully rehabilitated and relinquished. The Queensland Government accepted surrender of a company's mining leases for the site, after concluding that all rehabilitation requirements had been met in full. The site, which was mined in the 1980s, has been backfilled, reshaped and rehabilitated to meet community expectations. The area is now safe, stable, non-polluting and able to support grazing.

Figure 5.100 The rehabilitated Chuwar coal mine

The mining industry in Australia

The mining industry is one of the most important industries in Australia. Table 5.8 shows a summary of some of the metal resources mined in this country.

It is not just metals that are mined or quarried. Stones are used to make roads. Coal (sedimentary) is mined as a source of energy; Australia is ranked fourth in the world in terms of coal supply. Limestone (sedimentary) is used to make cement; also, when sand is combined with small amounts of limestone and sodium carbonate, heated until it melts and allowed to cool, it becomes glass.

Gemstones such as diamonds and opals are mined in Australia, and gemstone mining is a major source of income for some Australian towns. Coober Pedy, for example, is the largest opal-mining area in the world.

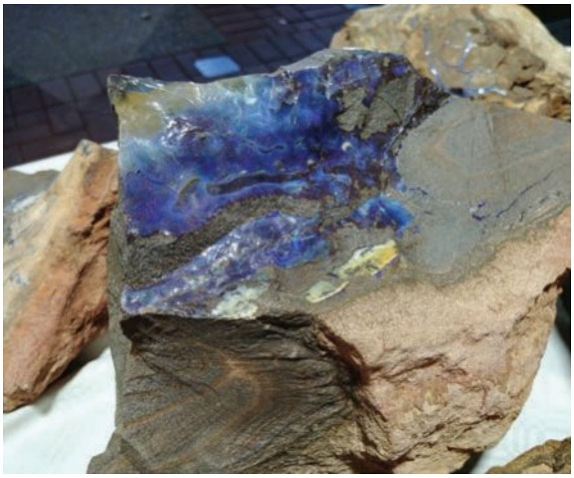

Figure 5.101 An Australian uncut opal sourced from Queensland. Australia produces around 95% of the world's opals.

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 5.8 Some important metals mined in Australia

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Explore! 5.12

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.

Explore! 5.13

Sustainable mining

Many mining companies are making sustainability a core element in their business strategies. Research how the following practices have increased efficiency and limited environmental impact at mine sites.

- use of renewable energy sources
- waste reduction and recycling
- use of digital technologies such as automation, artificial intelligence and advanced analytics
- regeneration of mine sites
- adoption of circular economy practices

Quick check 5.11

1. Add the last two mining processes to your table from *Quick check 5.10.*

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 5.4 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.

Success criteria		Linked questions	Check
5.1	I can describe the role of forces and heat energy in the formation of igneous, sedimentary and metamorphic rocks.	3, 4	
5.1	I can compare how quickly or slowly different rock formation processes can occur.	9	
5.1	I can describe the major processes of the rock cycle.	12	
5.2	I can describe and explore the formation of igneous, sedimentary and metamorphic rocks.	3, 4, 5, 13	
5.2	I can describe how fossil evidence can predict how and when a rock was formed.	11	
5.3	I can compare the observable properties of different types of rocks and identify them using a dichotomous key.	8, 13, 15	
5.3	I can describe the tests available to classify rocks.	6	
5.3	I can describe the traditional geological knowledges of First Nations Australians that are used in the selection of different rock types for different purposes.	19	
5.4	I can describe the six stages of the mining cycle.	7	
5.4	I can describe how the mining of ores and minerals impacts on local environments and examine environmental rehabilitation initiatives.	10	
5.4	I can describe how First Nations Australians have used quarrying to access rocks for use as or production of everyday objects.	18	

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 5.102 shows limestone in the Naracoorte Caves of South Australia.
   a **Identify** the property of the limestone that allows the caves to form.
   b **Name** the geological name for this type of weathering.

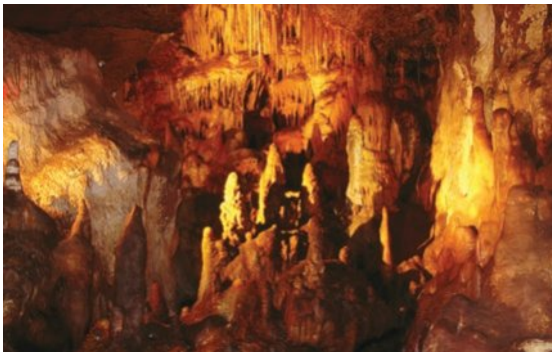

Figure 5.102 Naracoorte Caves, South Australia

6 **Recall** the test for a rock that contains carbonates.
7 **Recall** the six stages of the mining cycle.

Comprehension

8 **Describe** how you can physically distinguish between a rock and a mineral.
9 **Describe** the difference between igneous rocks that have cooled slowly and those that have cooled quickly.
10 **Describe** one impact that mining has on local environments.
11 **Describe** how fossil evidence can predict how and when a rock was formed.
12 **Illustrate** a diagram of the rock cycle.

Analysis

13 a **Infer** the geological process that occurred to produce the formation shown in Figure 5.103.
b One feature of metamorphic rock is that it can appear layered. The rock shown in Figure 5.104 is layered. However, it is sedimentary rock. **Evaluate** why this might be the case.

Figure 5.103

Figure 5.104

14 **Contrast** between breccia and conglomerate.

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Knowledge utilisation

15 Examine the image in Figure 5.105 and **determine** whether it is a rock or a mineral.

16 A rock is made of a single crystal. **Deduce** whether or not this rock is a mineral and explain your reasoning.

17 a The sedimentary rocks in Figure 5.106 are lying at an angle. **Determine** the geological event that might have caused this to happen.

b Figure 5.107 shows a fossil lying on a beach. **Deduce** where it would have come from.

Figure 5.105

Figure 5.106

Figure 5.107

18 The photo in Figure 5.108 shows grooves in sandstone due to many years of First Nations Australians using it for a particular purpose. **Deduce** why these grooves have been formed.

Figure 5.108

19 **Propose** the type of rock that would be the best for use as an axe by First Nations Australians.

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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 5.9, and an example of the percentage of mineral components at different depths of an iron-ore deposit drill sample is shown in Figure 5.109.

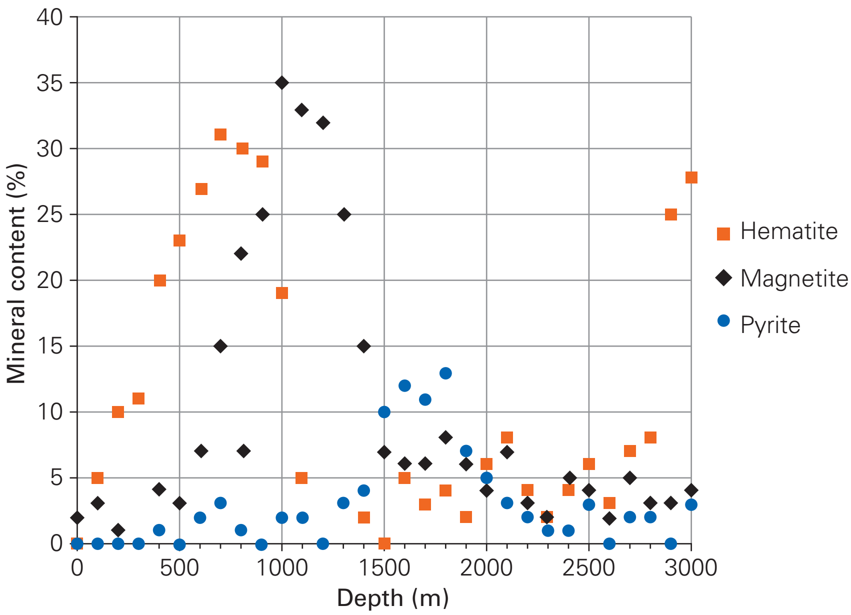

Figure 5.109 Mineral content of an iron-ore exploration extract, depending on the depth of drilling

Mineral	Formula	Iron content	Colour
Hematite	Fe_2O_3	70%	red
Magnetite	Fe_3O_4	72%	black
Pyrite	FeS_2	47%	yellow

Table 5.9 Examples of minerals found in Australian iron ores

Apply

1 **Identify** which mineral described in Table 5.9 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 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 at 1200 m depth.

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STEM activity: Underground bunkers and asteroids

Background information

A bunker is a structure built underground for people to shelter or live in, protecting them from dangers on the surface of Earth. For example, many homes in parts of the world that are prone to tornados have a bunker to protect the homeowners. During 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.

Figure 5.110 A bunker provides protection from dangers above.

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.

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.

Suggested materials

- large plastic container
- soil and crushed rock
- cardboard
- icy pole sticks
- scissors
- sticky tape
- glue
- slotted masses/weights

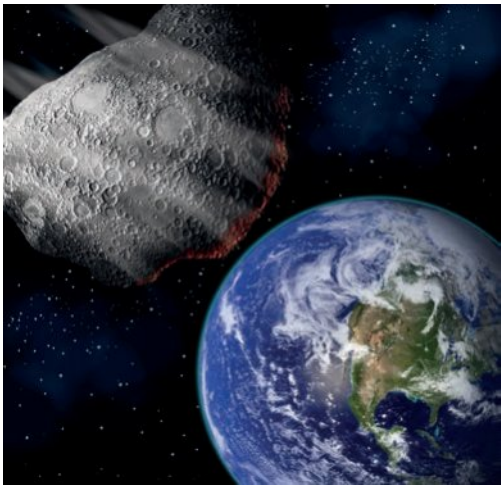

Figure 5.111 Only 20 days to find cover!

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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 modify

6 Describe some of the difficulties you encountered while calculating and estimating the amount of space people will need to live in.

7 Did you need to make compromises 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.

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Chapter 6
Energy

Chapter introduction

Your senses can detect several types of energy – your eyes detect light, your ears detect sound, and your skin can feel heat. You use your muscles to move and to give objects kinetic energy, or to lift objects, giving them gravitational potential energy. The food you eat contains chemical energy, which is used by your cells. The cells in your brain are constantly exchanging electrical energy, and your nervous system uses electrical energy to send messages between your brain and the rest of your body. In this chapter, you will explore the different types of energy and how energy can be transferred or transformed.

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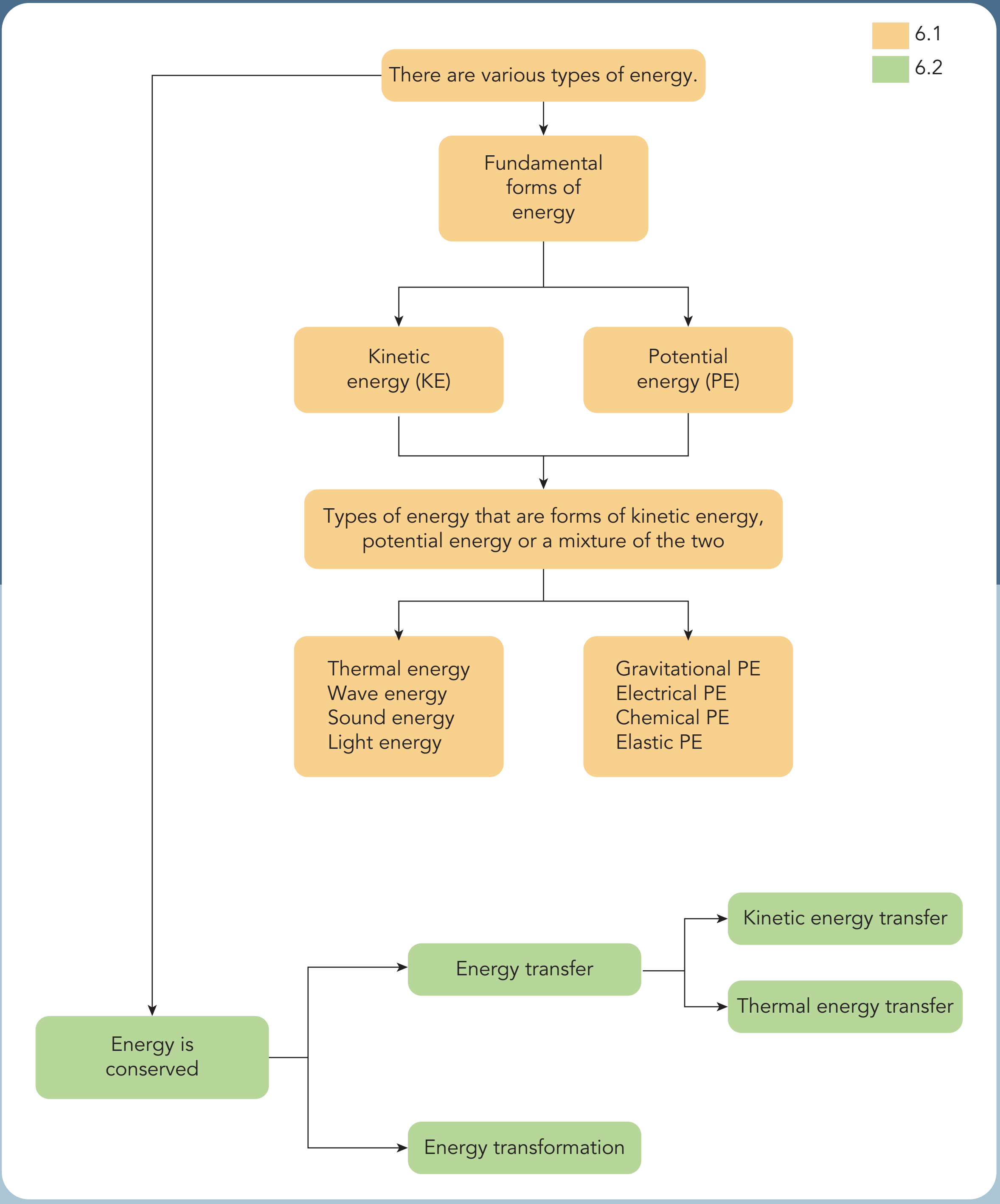
Concept map



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Curriculum

Classify different types of energy as kinetic or potential and investigate energy transfer and transformations in simple systems (AC9S8U05)	
investigating relationships between kinetic and potential energy in a simple system, such as a roller coaster or Newton's cradle	6.1
classifying types of energy as either kinetic energy, such as movement, heat and electricity, or potential energy, such as chemical, elastic and gravitational	6.1
using electrical circuits and components to demonstrate electrical energy transfer and its transformation into heat, light and sound	6.1
critiquing and using representations such as flow diagrams to illustrate changes between different forms of energy in a system	6.2
identifying where heat energy is produced as a by-product of energy transfer, such as filament light globes, exercise, and battery charging and use	6.2
observing a Rube Goldberg machine and identifying the energy transfers and transformations involved	6.2
investigating traditional fire-starting methods used by First Nations Australians and their understanding of the transformation of energy	6.2

Glossary terms

Chemical potential energy
Elastic potential energy
Electrical energy
Electromagnetic spectrum
Energy
Energy transfer
Generator
Gravitational potential energy
Heat
Input energy
Joule
Kinetic energy
Law of conservation of energy
Light energy
Nuclear energy
Output energy
Potential energy
Radiation
Radioactive
Rotational kinetic energy
Sound energy
Temperature
Thermal energy
Travelling wave
Turbine
Waste energy
Wave energy

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6.1 What is energy?

WORKSHEET
Types of energy

VIDEO
Types of stored energy

Learning goals

1. To be able to define energy.
2. To be able to provide examples of different forms of kinetic and potential energy.
3. To be able to distinguish between heat, thermal energy and temperature.

Energy is the capacity to do work and it cannot be created or destroyed. That is, the amount of energy in our universe is always the same. However, energy can change form; it can be transferred from one object to another, or it can be stored for later use. For all the different types of energy, the unit of measurement is the **joule** (J). One joule is the work done by a force of one newton (N) over one metre, that is, 1 J = 1 Nm.

While we experience energy in different ways, including light, heat, sound and movement, all types of energy can be categorised as either kinetic or potential energy.

Kinetic energy

The energy an object has when it is moving is called **kinetic energy** (KE). The amount of KE depends on the mass of the object and its speed. Objects that are spinning or rotating also have kinetic energy, but this energy is called **rotational kinetic energy**.

Figure 6.1 A jumping kangaroo has kinetic energy. What potential energy might it have?

Potential energy

Some objects can store energy until it is ready to be used, but the energy still exists. This stored energy is called **potential energy** because it has the potential to do work. For example, a stretched rubber band has stored elastic potential energy. The energy is not being used at that point, but it has the potential to make something happen. Some forms of stored energy are summarised in Table 6.1.

energy
the capacity to do work; the total amount of energy is conserved in any process

joule
the unit of energy or work done by a force of one newton over one metre

kinetic energy
the energy of moving matter

rotational kinetic energy
the energy an object has because it is rotating

potential energy
the energy stored in something because of its position, shape or composition; e.g. due to height above the ground, being stretched or compressed, or in chemical form

Form of potential energy	Description
Gravitational potential energy (GPE)	Energy stored when an object is lifted up; energy released when the object falls
Electrical energy	Energy stored in electrostatic situations (e.g. thunderclouds, capacitors); energy released when current flows (includes sparks like lightning)
Chemical potential energy	Energy stored in chemicals such as food, fuel and batteries. For example, the chemical energy in batteries is released when connected to an electric circuit, in which the chemical energy is converted to electrical energy.
Elastic potential energy	Energy stored when an object is stretched or compressed; energy released when an object returns to original size and shape
Nuclear energy	Energy stored in unstable (radioactive) nuclei of atoms; energy released when radioactive atomic nuclei decay or undergo fission or fusion

Table 6.1 Potential energy is a form of energy that can be stored.

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Try this 6.1

Kinetic and potential energy

Observe the image in Figure 6.2. How might the kinetic and potential energy in this system interact as Newton's cradle is in full swing?

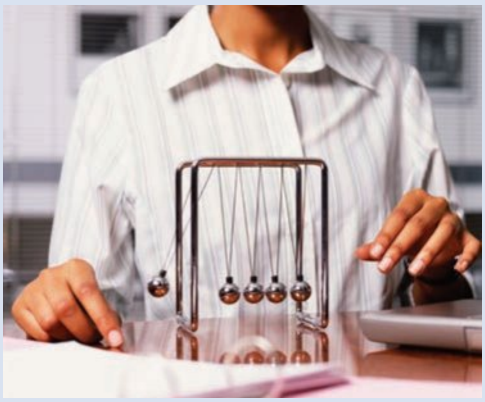

Figure 6.2 Newton's cradle in action

Forms of energy

Thermal energy

Heat is related to the kinetic energy of particles of matter. As heat increases, particles of matter gain this energy and have more kinetic energy to move more rapidly. In this chapter, we will use the more technical term for 'heat', and that is **thermal energy**. To change an object's **temperature**, thermal energy needs to be either added (to raise it, i.e. heating) or removed (to lower it, i.e. cooling). The total amount of thermal energy in an object is influenced by three factors:

- temperature – Objects with higher temperature have more thermal energy than identical cold objects.
- mass – Heavier objects have more thermal energy than lighter ones of the same material and temperature.
- material – Some materials are better at storing thermal energy than others.

heat
thermal energy that is transmitted due to differences in temperature

thermal energy
the energy contained within a material that is responsible for its temperature

temperature
a measure of the degree of heat present in a substance; gives an indication of the average kinetic energy of the particles

DOC
WORKSHEET
Boiling point of water

Did you know? 6.1

Forms of energy we can detect with our senses

The types of energy that we can detect with our senses are listed in Table 6.2.

Form of energy	Description
Thermal energy	We can sense both hot and cold temperatures with our skin.
Sound energy	Our ears can hear sound energy.
Light energy	Our eyes can see light energy.

Table 6.2 Types of energy, other than kinetic energy, that we can sense

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 6.3 A warm bath contains more thermal energy than the flame of a candle.

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Investigation 6.1

Investigating thermal energy

Be careful
Ensure safety equipment is worn at all times. Do not stand over the beaker once it has been heated.

Aim
To investigate the 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 for one minute using a Bunsen burner.
3 Stir the water and measure the final temperature after it has been heated. Record in your results table.
4 Repeat steps **1–3** using 300 mL, 400 mL and 500 mL of water. Make sure the glass beaker is cooled between experiments, so that the initial temperature is the same. It might save time to start with four identical beakers with water at room temperature.

Results
Complete the following table with your results.

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

Data processing
1 Calculate the thermal energy in each volume of water using the equation:
Volume in mL × specific heat capacity × change in temperature
The specific heat capacity of water is 4.2 J/mL/°C.

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...continued

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.

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**.

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

Water waves are not the only type of waves that can carry energy. Waves can travel through Earth after an earthquake. These are also an example of a travelling wave. They occur when the ground suddenly moves and can transmit a huge amount of energy.

Figure 6.4 These water waves at Surfers Paradise have wave energy.

Figure 6.5 The energy of an earthquake damaged this road in Christchurch, New Zealand, in 2011.

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Sound energy

Sound energy is a form of wave energy. When sound is emitted from an object, the particles in the surrounding air are repeatedly compressed and then stretched. This disturbance travels through the air at about 330 m/s. Sound energy consists of a travelling wave of vibrating air particles.

Figure 6.6 Sound energy travels as vibrational waves in the air.

Light energy

Light energy is a special kind of wave that is part of the **electromagnetic spectrum**. Unlike sound, light waves do not require particles, so light energy can also travel in a vacuum, such as space. Light waves include all the colours of the visible spectrum: red, orange, yellow, green, blue, indigo and violet. The electromagnetic spectrum also includes waves that humans cannot see. Gamma rays emitted from radioactive materials, X-rays used in hospitals, ultraviolet light that causes sunburn, infrared radiation (also called heat), microwaves used by mobile phones and radio waves used for long-distance communication are all components of the electromagnetic spectrum.

sound energy
a form of travelling wave; sound consists of vibrations in the air

light energy
a form of energy that travels as electromagnetic waves and can travel in a vacuum

electromagnetic spectrum
a way of organising electromagnetic waves according to their energy and wavelength

Figure 6.7 5G communication is possible due to radio waves, a form of light energy.

Making thinking visible 6.1

Think, feel, care: The Matilda effect

Ruby Payne-Scott was an Australian radio engineer and astronomer who worked throughout the 1940s as a respected and prominent scientist. Up until 1966, the Australian Public Service required women to resign from their profession when they married. Payne-Scott married in 1944 and in 1950 she was made to resign from her role as a scientist. In the process, her work in the field was often discredited and overlooked by her male colleagues. The 'Matilda effect' is a term coined to describe the systematic and historical tendency to undervalue or disregard the contributions of women in science.

What do you know about Ruby Payne-Scott and the Matilda effect and what further questions do you have?

Do you think the Matilda effect could still be an issue today?

Why is it important to acknowledge and celebrate the contributions of all scientists, regardless of gender or context? What can you do to raise awareness about the Matilda effect and support the recognition of women in science?

Figure 6.8 Ruby Payne-Scott was a female Australian researcher in radioastronomy.

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

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Quick check 6.1

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 Earth, and 'potential' means the energy is stored. The gravitational potential energy (GPE) gained by an object when it is lifted depends on three things:

gravitational potential energy a type of potential energy; the energy an object has because of its height; GPE = *mgh*, where m is the mass of the object in kg, h its height in metres and g is acceleration due to Earth's gravity, 9.8 m/s^2

- the strength of gravity
- the mass of the object
- the height the object is lifted.

Figure 6.9 The water at the top of the Millaa Millaa waterfall, in the Atherton Tablelands, has gravitational potential energy that is converted to kinetic energy when falling 18 m to the lake below.

Did you know? 6.2

Sir Isaac Newton's apple

There is a story that has been told for hundreds of years regarding the situation that led to Sir Isaac Newton's discovery that gravity is a universal law applying to planets and the Moon as well as objects on Earth. There isn't enough evidence to determine whether it is true or not, but, in any case, it is a fun story!

Figure 6.10 Sir Isaac Newton wondering whether the Moon falls towards Earth

The story goes that in the mid-1600s, Sir Isaac Newton was sitting under a tree when an apple fell onto his head. In this moment he pondered, 'If this apple falls towards Earth, could the same law of physics be holding the Moon in its orbit?'. This thought sparked years of work that culminated in the publication of his book *Philosophiae Naturalis Principia Mathematica* in 1687. His work included his laws of motion, now known as Newton's laws of motion, and the universal law of gravitation.

To answer his original question, Newton confirmed that the Moon is constantly falling towards Earth and is attracted according to the same law that attracts the apple, but rather than collide with Earth, it stays in orbit. Can you imagine the amount of GPE that the Moon has?

Try this 6.2

Investigating energy with a bouncy ball

Take a bouncy ball and hold it above your head. Drop the ball and let it bounce twice.

Describe the transformations involved as GPE changes to KE over the two bounces. Explain where elastic potential energy fits in.

Electrical energy

Electrical energy is carried by charged particles, called *electrons*, that can transport charge from one atom in a wire to the next, carrying energy as they do so. The rate of movement of charge through an electrical circuit is called current (I) and is measured in amperes or amps (A). Circuits often contain resistance (R), which restricts the movement of charge. Resistance is measured in ohms (Ω).

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

Voltage (V) is related to the amount of electrical energy each unit of charge carries. For example: AAA batteries supply 1.5 joules of electrical energy per unit of charge, so they have a voltage of 1.5 volts; smartphones operate at 5 volts; car batteries are 12 volts; and in Queensland, electricity in the home is 230 volts. Voltage, current and resistance are related by 'Ohm's Law', $V = IR$.

Explore! 6.1

Transmission lines

Transmission lines carry electrical energy long distances to all parts of Queensland and the rest of Australia.

1 Use the internet to research the types of materials used in transmission lines.
2 If materials of less resistance are used, would there be less heat energy produced?

Figure 6.11 Transmission lines deliver electrical energy to all parts of Queensland, losing a minimal amount as heat.

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Practical skills 6.1

Transfer of electrical energy

Be careful

Electrical shocks may occur. Ensure the recommended voltage output is not exceeded. Turn off power supply when changing the circuit.

Aim

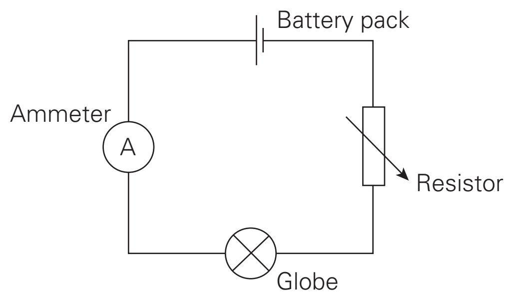
To investigate the relationship between current and resistance using a variable resistor

Materials

- 6 V power supply
- 6 V light globe
- variable resistor
- 4 connecting wires and connectors
- ammeter

Method

1. Draw the results table below.
2. Set up the circuit as shown in the diagram and set the power supply to 6 V.
3. Adjust the variable resistor so that the light globe is at its brightest. Record the current shown.
4. Adjust the variable resistor so that the light globe gets dimmer and dimmer, recording the current at various points until it is at its dimmest.



Results

Brightness of globe	Current (A)
Brightest	
Bright	
Dim	
Dimmest	

Analysis

1. Describe what happens to the current in the circuit as the resistance of the variable resistor increases.
2. Describe what happens to the brightness of the globe as the resistance is increased.
3. Predict what is happening to the voltage across the globe as it gets dimmer.
4. Describe what type of energy the electrical energy in the wire is converted to.

Conclusion

Draw a conclusion from this experiment regarding current and resistance.

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Did you know? 6.3

Lightning strikes

Electrical energy can be very dangerous when it causes a large electric current to flow through the body. The highest voltages on Earth are in lightning strikes, which can be hundreds of millions of volts. Think about thunderstorms: what other forms of energy are released when lightning strikes?

Figure 6.12 A lightning strike in Brisbane city

Quick check 6.2

1 State some types of energy that can be stored.
2 Look at the following image. Explain where you would stand to have the greatest gravitational potential energy.

Figure 6.13 Where is GPE greatest?

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...continued

3 Figure 6.14 shows a roller coaster. Roller coasters are a great example of GPE. Answer the following questions, remembering that as an object loses GPE, it gains KE (kinetic energy).

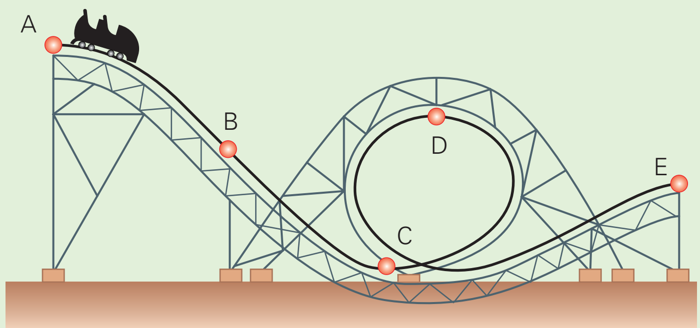

Figure 6.14 A roller coaster

a Identify the step (A, B, C, D or E) where the cart would have the greatest GPE.
b Identify the step where the cart would have the greatest KE.

Chemical potential energy (chemical energy)

Many substances contain stored **chemical potential energy**, which can be released in a chemical reaction. For example:

- Trees store chemical potential energy in their wood, which is released when the wood is burned.
- The food we eat contains chemical potential energy, which is released slowly in our bodies, giving us the energy we need to keep warm and move around.
- Cars have engines that convert the chemical energy in petrol to kinetic energy, heat and sound.
- Batteries store chemical energy that can be used to power household devices when required.

chemical potential energy the energy stored in the chemical bonds between atoms

elastic potential energy the energy stored when an elastic material is compressed or stretched

Figure 6.15 Fireworks in Surfers Paradise. Fireworks contain chemical potential energy, which is released when the fireworks are lit.

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 6.16 A large rubber band stores energy when it is stretched.

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Figure 6.17 A bungee cord stores elastic potential energy when it is stretched.

Try this 6.3

Exploring elastic potential energy

Take a rubber band and stretch it as tightly as possible. Explain how the stretched rubber band is an example of potential energy. Point the rubber band at the wall and let it go. Explain how the potential energy stored in the band was converted to a different form of energy.

Nuclear energy

The *nucleus* (plural *nuclei*) of certain atoms contains **nuclear energy**, a form of potential energy. Most nuclei are stable and do not release nuclear energy, but the **radioactive** nuclei of some atoms can undergo radioactive decay, emitting electromagnetic wave energy and/or particles with kinetic energy. The electromagnetic radiation emitted is high energy gamma rays, part of the electromagnetic spectrum. One source of radioactive energy is fission, in which an atomic nucleus splits into smaller fragments releasing energy as it does so. Nuclear power stations use the *fission* reactions of a radioactive material such as uranium to produce thermal energy, which in turn is used to generate electricity.

Unfortunately, such **radiation** can be hazardous to health, as high energy gamma rays and particles with high kinetic energy are capable of damaging human cells. Great care must be taken to prevent people being exposed to it in nuclear power stations.

nuclear energy
a non-renewable source of energy that uses the energy released by the nucleus of radioactive atoms

radioactive
having or producing the energy that comes from the breaking up of atomic nuclei

radiation
the emission of energy from a source, such as from unstable nuclei

Making thinking visible 6.2

The explanation game: Types of energy

Observe the scene in Figure 6.18.

Figure 6.18 A pool party always involves energy!

What are the types of energy, and where do you **notice** them, in Figure 6.18? **Explain** why you think those types of energy are present.

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

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Explore! 6.2

The relationship between mass and energy

In 1893, physicist Nikola Tesla and philosopher Swami Vivekananda met at the Congress of the World's Religions in Chicago. They discussed the interrelatedness of energy and matter, with Vivekananda being interested in the relationship between matter and spiritual energy and Tesla interested in physical mass and energy. Their collaboration was significant in bridging the gap between the perspectives of scientists and those of spiritual leaders around the world but also in highlighting the potential relationship between mass and energy.

1 Use the internet to explore how Albert Einstein's theory of special relativity provided more information on the relationship between mass and energy in 1905.

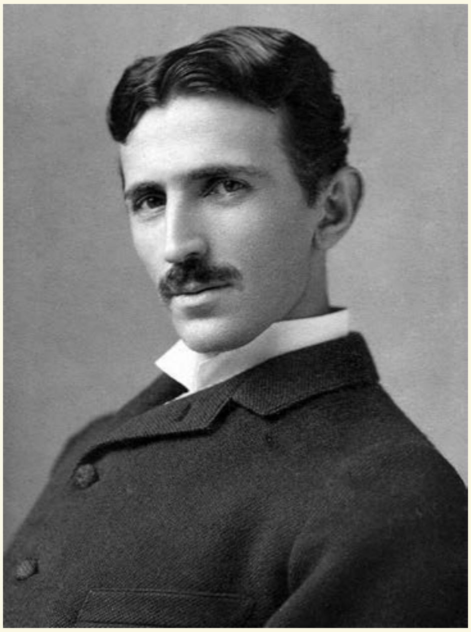

Figure 6.19 Swami Vivekananda (left) and Nikola Tesla (right) met for the first time in Chicago in 1893.

Quick check 6.3

1 State three examples of chemical potential energy.
2 Explain what is happening to a material if elastic potential energy is being stored.
3 State the name of the process in which energy is released from the nucleus when it breaks apart or releases a particle.

Try this 6.4

A world without energy

Think about a world in which there is no electrical energy. Suppose there was no light or sound energy either. Could life exist in such a world? Write down a few sentences to say if you think it could and what it would be like. Now imagine that there is no potential or kinetic energy of any type. What would that world be like? Discuss and collate your ideas as a class and see if you agree.

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Section 6.1 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 forms of energy a piece of wood gives out when it burns (Figure 6.20).
5 **Identify** the form of energy, other than thermal, gained when a person climbs a ladder (Figure 6.21).
6 **Identify** the forms of energy emitted by lightning (Figure 6.22).
7 **Identify** a form of energy that is *not* a form of wave energy.
8 **Identify** the forms of energy possessed by a helicopter as it hovers in the air (Figure 6.23).

Figure 6.20 Wood stores energy that can be released in a form of useful energy when burned.

Figure 6.21 Man climbing a ladder

Figure 6.22 Lightning

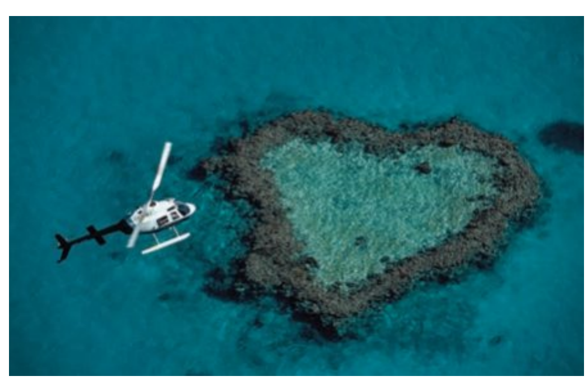

Figure 6.23 A hovering helicopter

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9 **Identify** the main form of energy that peanuts contain.

10 Look at the diagram in Figure 6.24 and use it to answer the following questions.

a **Identify** which letter represents the position where the ball has the most GPE.

b If the ball moved from C to A, **state** if there would be an overall gain or loss of GPE.

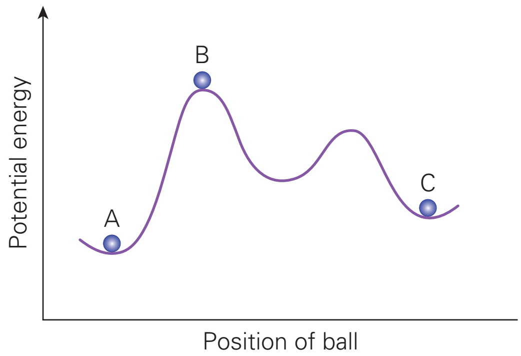

Figure 6.24 Gravitational potential energy

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'.

14 **Explain** which balloon in Figure 6.25 has the most elastic potential energy.

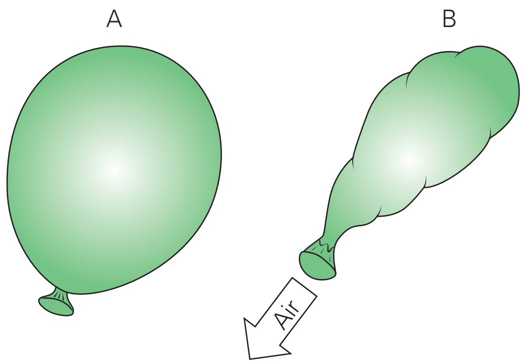

Figure 6.25 Elastic potential energy of balloons

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 6.26 and **identify** all the different forms of energy that you can see evidence of.

Figure 6.26 A laundry 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 it) and the forms of energy that it outputs (include the 'useful' output as well as the outputs that represent wasted energy).

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6.2 Energy is conserved

Learning goals

1. To be able to define the law of conservation of energy.
2. To be able to describe how energy is transferred and transformed using flow diagrams.
3. To be able to calculate energy efficiency using energy inputs and outputs.

WORKSHEET
Energy transfers and transformations

Energy can be transferred from one object to another or even transformed into another type of energy. However, when energy is transferred or transformed, it always obeys the **law of conservation of energy**: energy can neither be created nor destroyed. In any process, the amount of energy present at the beginning must equal the amount of energy present at the end.

law of conservation of energy
the law that states that energy cannot be created or destroyed

Figure 6.27 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? 6.4

Where does the Sun get its energy from?

Einstein stunned the world when he proposed that mass can be converted into energy (and vice versa), according to a simple and famous formula:

$$E = mc^2$$

In this formula, E = energy, m = mass and c = the speed of light (3×10^8 m/s). Basically, the formula means that a small amount of mass can be converted into a lot of energy, or the reverse.

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 five billion kilograms of matter into energy every second. This energy is emitted at the Sun's surface as light and heat.

Will the Sun ever run out of fuel? Luckily for us, the answer is: not for a very long time. The Sun is so big that, even at its current rate, much less than 1% of its mass has been radiated away since it was formed. As the Sun loses mass, its luminosity increases and it is estimated that in a billion years, a 10% brighter Sun will have rendered Earth inhospitable to life. It will take a few more billions of years before it runs out of fuel.

Figure 6.28 The Sun will not run out of fuel any time soon.

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Quick check 6.4

1 State the law of conservation of energy.
2 Explain the meaning of the law of conservation of energy.

Energy transfer

Kinetic transfer

Energy is the ability of an object to do work, and this energy can be transferred from one object to another. This is known as an **energy transfer**. For example, a golf club has kinetic energy when it swings through the air. When the club hits a golf ball, some of this kinetic energy is transferred to the ball, making it move.

energy transfer
the movement of energy from one place or object to another

Figure 6.29 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 in contact with an object of lower temperature, thermal energy will flow from the hot object to the cold object. This flow will continue until the objects are the same temperature.

generator
a device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

turbine
a device that converts the kinetic energy of a fluid into useful work, e.g. a windmill

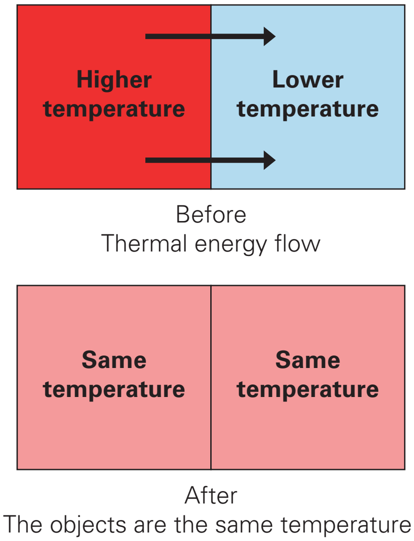

Figure 6.30 Heat (thermal energy in transit) flows from an object of higher temperature to one of lower temperature, until the objects are at the same temperature.

Energy transformations

There are many ways in which energy can be converted from one form to another. Combustion involves burning and converts chemical energy into thermal and light energy. Machines use fuel or electrical energy and convert it into kinetic energy. **Generators**, powered by steam **turbines**, can convert kinetic energy into electrical energy. In leaves, the biological processes in photosynthesis convert light energy from the Sun into chemical energy in the form of carbohydrates, such as sugars. Thermal energy or sound energy is often produced as a by-product of energy transfers and transformations.

Energy transformations can be represented in a flow diagram (see Figure 6.31). On the left-hand side of the flow diagram are the energy inputs. On the right-hand

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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.

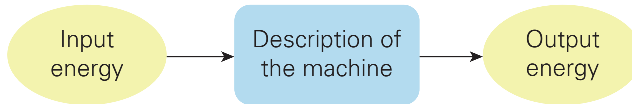

Figure 6.31 A simple energy flow diagram

For example, Figure 6.32 shows the energy flow diagram for a candle that has been lit.

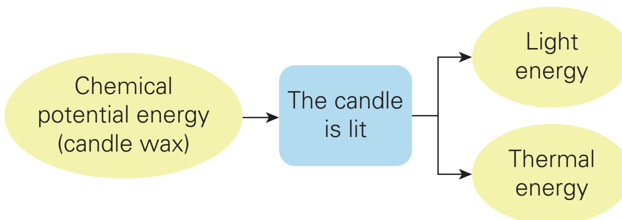

Figure 6.32 Energy flow diagram for a burning candle

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 6.33).

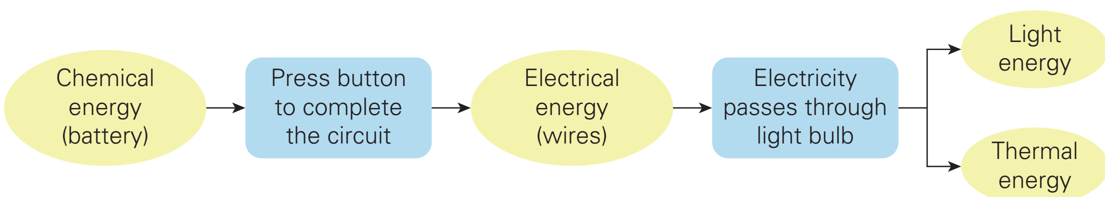

Figure 6.33 Energy flow diagram for a battery-powered torch

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 6.34 An electric kettle converts electrical energy into thermal energy.

Figure 6.35 shows a flow diagram representing the changes in energy in the example of the kettle.

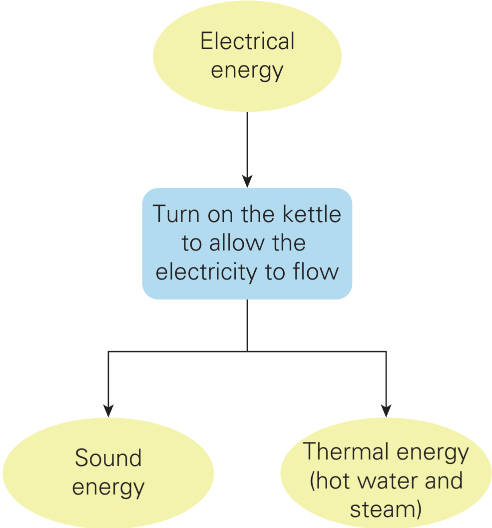

Figure 6.35 Energy flow diagram for an electric kettle

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Quick check 6.5

1 Explain what occurs during an energy transformation.
2 Provide two examples of an appliance that transforms energy.

Explore! 6.3

Fire starting

Different groups of First Nations Australians use 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 long, thin stick (called the drill stick) is pushed into the notch and twirled vigorously by rubbing it between the hands. The friction between the two pieces of wood causes the end of the drill stick to glow red and embers are formed. The hearth is tapped to move the embers to the bark or dried grass, and then they are blown on until a flame forms.

The fire saw method works by rubbing two pieces of wood together in a sawing motion. One piece of wood has a notch at the end of it (or a split branch can be used), while the other is a piece of hardwood with a sharp edge (for example, a boomerang). The hardwood saws the notched piece until embers form, which ignite flammable material placed beneath it.

Figure 6.36 Can you identify the drill method and the saw method in this illustration?

Two other methods used less commonly are the *fire plough* and *percussion methods*. The first method is mainly used by people in the north-west of Australia. It involves rapidly rubbing a stick back and forth within a trough or groove cut into the base timber to create embers. Percussion methods of fire starting are used by groups in south-central Australia and involve striking stones together to create sparks that can then ignite dried grass.

1 Which method do you predict is the most efficient to start a fire?
2 Conduct some research and find out whether your prediction was correct or not.
3 Draw an energy flow diagram for the fire drill method.

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Investigating a car accelerating from rest

A petrol-powered car accelerating on a flat road uses its engine to convert the chemical potential energy of the fuel into kinetic energy as the car increases its speed.

Figure 6.37 An accelerating car is gaining kinetic energy.

Figure 6.38 shows a flow diagram for a petrol-driven car accelerating from rest.

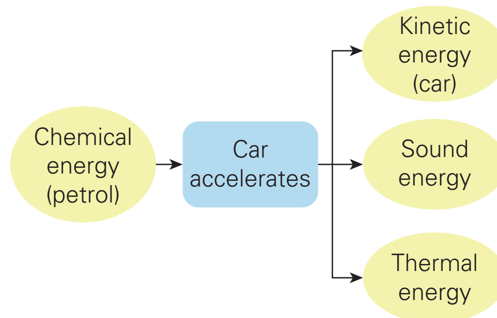

Figure 6.38 Energy flow diagram for a petrol-driven car accelerating from rest

If the car was powered by an electric battery, then the energy flow diagram would be slightly different (Figure 6.39).

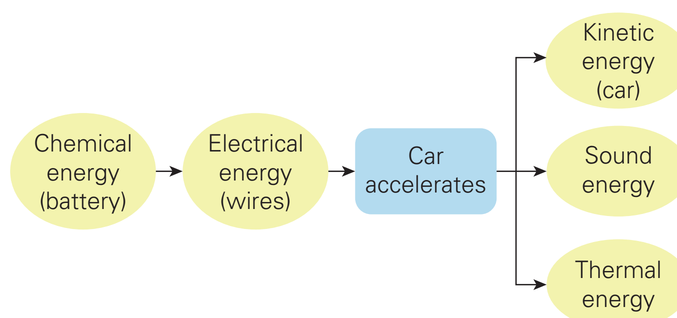

Figure 6.39 Energy flow diagram for a battery-powered car accelerating from rest

Practical skills 6.2

Rube Goldberg machine

Introduction

Machines are useful – we use them to make tasks easier. However, some machines are not as efficient or useful as others. These machines were named after Rube Goldberg, an American inventor and cartoonist. A Rube Goldberg machine is a type of machine that relies on a significant number of energy transfers and is designed to carry out a simple task in a very complicated and convoluted way.

Energy transfers and transformations occur throughout Rube Goldberg machines due to the chain reactions involved. An energy transformation is a change in energy from one form to another, and energy transfer is the movement of energy from one place to another.

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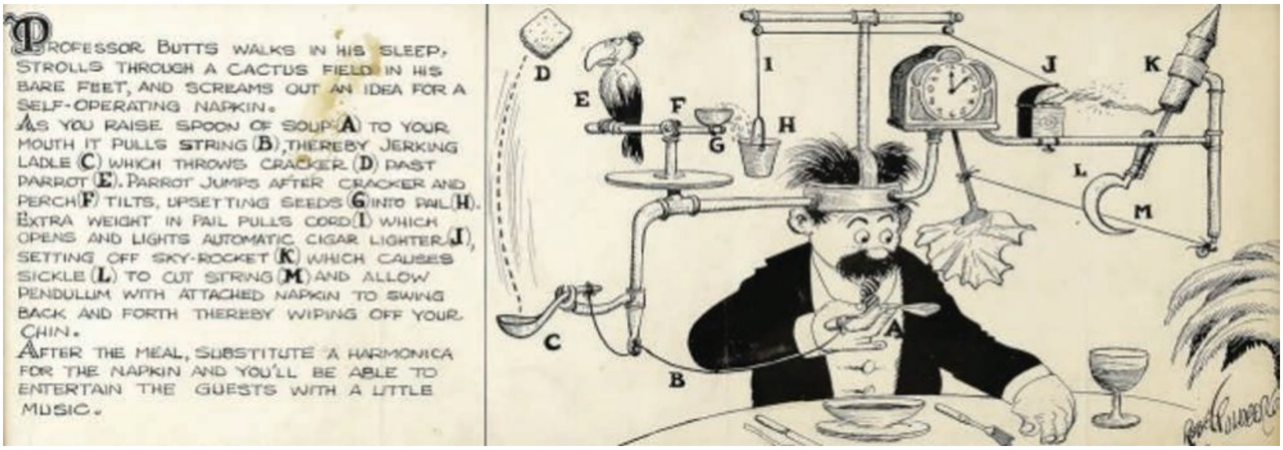

Figure 6.40 Original artwork for Rube Goldberg's 'self-operating napkin' machine

Aim

To design and construct a Rube Goldberg machine to complete a common task

Materials

As chosen by students but may include:

- dominoes
- playing cards
- marbles
- elastic bands
- string
- springs
- toy cars
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- bouncy balls
- cans
- plastic bottles
- flat cardboard
- ramps
- books (preferably sturdy ones, such as old textbooks)
- sticky tape
- appliances (fans, lamps etc.)

Method

1. Identify a simple common task that you would like to be done by a machine.
2. Draw a plan of your Rube Goldberg machine.
3. Start building your machine, ensuring that you test each step as you progress.
4. Once your machine is complete, make a video recording of it in action.

Results

Remember to take a video of your machine in action.

Analysis

1. Explain the energy transfers and transformations that took place in your Rube Goldberg machine.
2. How could you reduce the amount of waste energy produced by your Rube Goldberg machine to make it more efficient?

Evaluation

1. Compare your final machine to your plan. Which parts (if any) are different? Why did you change them?
2. Propose any improvements or extensions you would make if you were to build another machine.

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Try this 6.5

Energy transfer and transformation infographic

Create a digital infographic using your preferred software, comparing and contrasting the energy transfer and transformation of at least five different forms of energy. Present your infographic to your classmates and try to teach them something new!

Investigating a bow and arrow

When a bow is stretched to shoot an arrow, the wood and bowstring bend with an elastic force, and this stores energy. The further the bow string is pulled, the more energy is stored. When the arrow is released, the elastic potential energy is converted to kinetic energy as the arrow increases its speed.

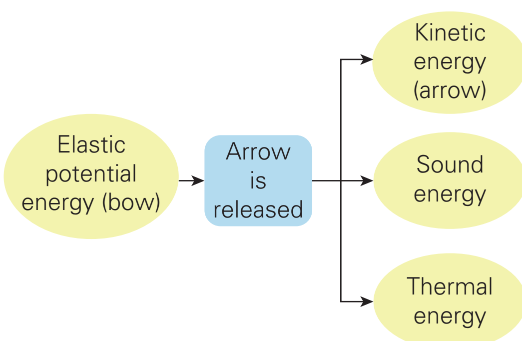

Figure 6.41 Energy flow diagram for an arrow being shot from a bow

Investigating a hot-air balloon

Sometimes a machine can convert a source of energy into two or more forms at the same time. The operation of a hot-air balloon involves multiple energy changes. When the hot-air balloon first takes off, chemical potential energy is stored in the form of natural gas (in the gas cylinder in the basket of the balloon). When the gas is burned, it releases thermal energy, which heats the air in the balloon, as well as some waste sound energy. The air in the balloon expands as it warms up, and this makes the air inside the balloon lighter than the air around the balloon. The balloon then rises, due to buoyancy forces, gaining kinetic energy and gravitational potential energy as it gains altitude.

VIDEO Energy transformations in a hot-air balloon

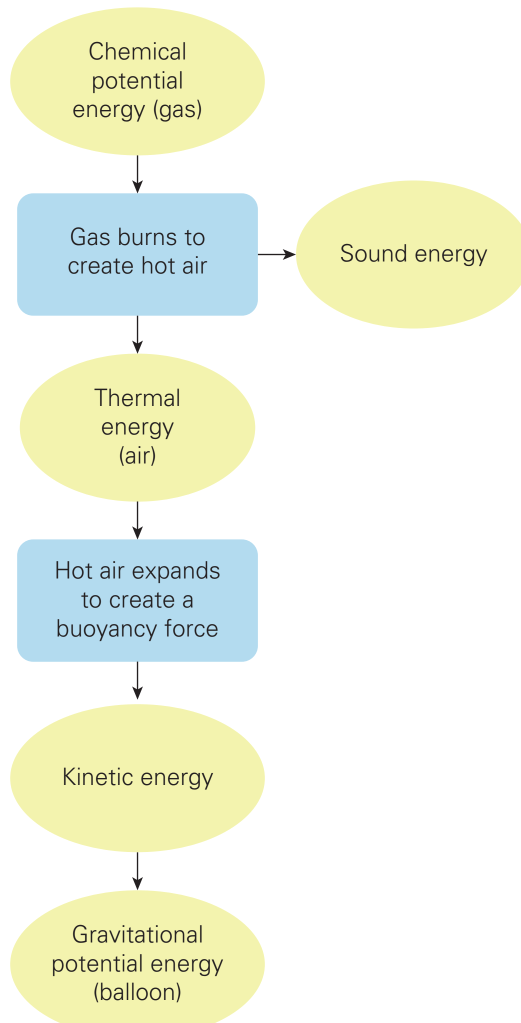

Figure 6.42 Energy flow diagram for a hot-air balloon

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Figure 6.43 A hot-air balloon converts chemical energy to thermal energy, then kinetic energy as it moves and then gravitational potential energy as it gets higher.

Investigating an aircraft taking off

When an aircraft takes off, it starts moving slowly from one end of the runway and then accelerates under full power until it leaves the ground at the other end. When it first starts its take-off, the jet has chemical potential energy stored in the form of aviation fuel in its tanks. The fuel is ignited in the jet engines to create a force that accelerates the aircraft along the runway, gaining kinetic energy as it does so. When the aircraft reaches sufficient speed, it lifts off and gains gravitational potential energy as it rises into the air.

Figure 6.44 An aircraft converts chemical potential energy to kinetic energy and gravitational potential energy.

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An aircraft in flight is burning fuel and making noise while in movement. This thermal and sound waste energy can even be quantified in an energy flow diagram. In Figure 6.45, 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

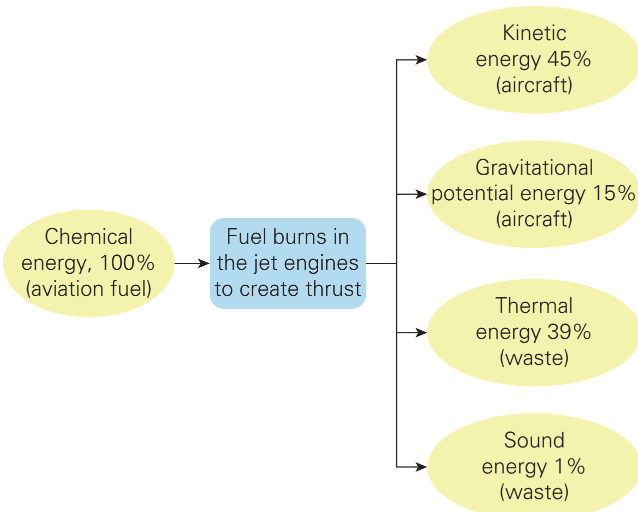

Figure 6.45 Energy flow diagram for a jet aircraft taking off

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 6.6

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

Figure 6.46 A filament light bulb emits light energy but also thermal energy as waste.

Waste energy

Useful energy is the output energy that the process is designed to produce. **Waste energy** is any other form of energy, usually thermal energy or sound, that is not wanted. An electric filament light bulb uses electrical energy to create light as useful energy; any thermal energy produced is waste energy. A petrol-driven lawnmower converts chemical energy in the petrol into kinetic energy and rotational kinetic energy, with thermal energy and sound as waste forms of energy.

waste energy
the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy and sound

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Figure 6.47 The chemical energy in petrol is converted into kinetic energy to move the lawnmower.

Figure 6.48 A hurdler has kinetic energy but may release waste energy as heat or sound.

When a candle burns, chemical potential energy is converted by combustion into light, with thermal energy released as waste energy. A hurdler converts chemical energy in food to kinetic energy but releases thermal energy as waste energy.

A two-step example is a battery-powered torch. The input energy source is chemical potential energy in the battery. This is converted first to electrical energy and then to light energy in the 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.

Figure 6.49 A TV remote converts chemical energy to light energy (infrared).

Explore! 6.4

Battery recharge cycles

Have you ever noticed that an older model of mobile phone or laptop runs out of battery faster than when it was new? Perhaps the chemical energy stored is just not as much as it used to be? Is energy lost as a by-product, such as heat?

Use the internet to find a credible source of information to answer the question: how does battery energy output change over many recharging cycles?

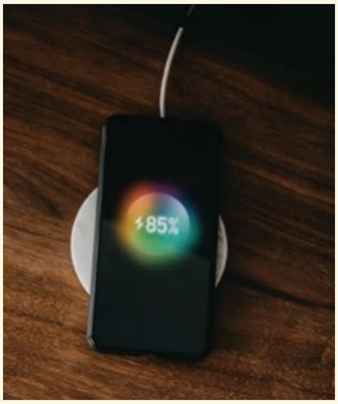

Figure 6.50 Does a smartphone battery really recharge to 100%?

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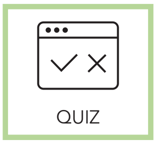
Try this 6.6

Energy transformations on roller coaster rides

Observe the roller coaster ride in Figure 6.51. Construct an energy flow diagram to represent the energy transformations in this ride.

Figure 6.51 What energy transformations occur on a roller coaster ride?

Section 6.2 questions



Retrieval

1 Look closely at Figure 6.52.

Figure 6.52 A 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.

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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 train starts from rest and builds up to full speed.

  f A person rides on an escalator from the bottom to the top.

  g A dog is sprinting.

Figure 6.53 Cooking food on a charcoal fire barbeque

Figure 6.54 An electric train

Figure 6.55 People riding escalators

Figure 6.56 An Australian shepherd in full flight

Analysis

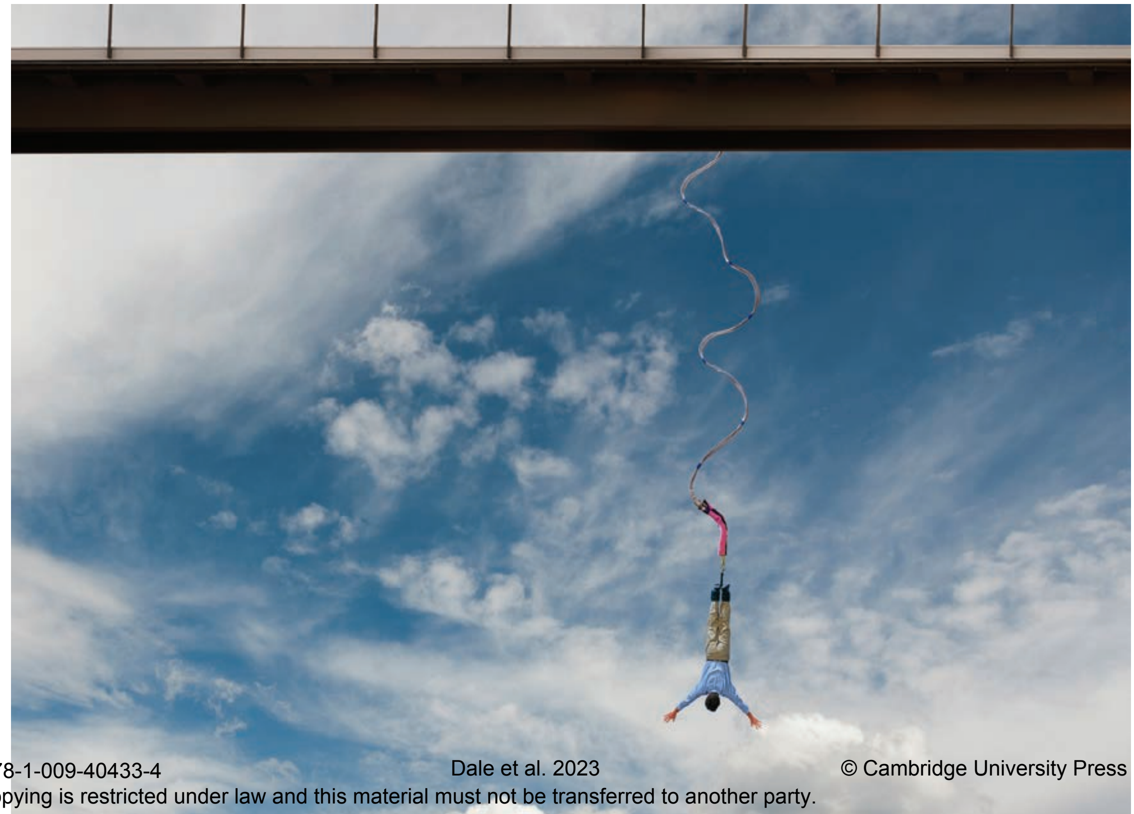
6 Think about all the different types of energy we encounter every day; driving a car is one example. Pick another example and **consider** how you can make the process more energy efficient.

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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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
6.1	I can define energy.	1, 9	
6.1	I can describe the different types of kinetic and potential energy.	2, 3, 4	
6.1	I can distinguish between temperature, thermal energy and heat.	8	
6.2	I can define the law of conservation of energy.	12	
6.2	I can describe how energy is transferred and transformed using a flow diagram.	11, 14	

Review questions

SCORCHER

Retrieval

1 **Define** energy and its units.

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 in the table below.

Term	Description
Sound energy	The energy that moving objects have
Kinetic energy	A form of wave energy that can travel through space
Wave energy	A form of wave energy consisting of vibrations in the air
Thermal energy	Energy carried by a wave travelling on or through a substance
Light energy	The energy that moves between two objects of differing temperatures

5 **State** the energy transformations that occur when someone climbs a set of stairs.

6 **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.

7 **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.

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8 **Describe** the difference between heat and temperature.
9 Look around your environment and **identify** as many examples of energy as you can see.
10 As you go about your day, **identify** all the different types of energy transformations that occur.

Comprehension

11 **Draw** a flow diagram showing the energy transformation that occurs in a gas stove.
12 **Explain** why a light globe with an input energy of 1200 J cannot produce 1500 J of light energy.
13 **Explain** the difference between an energy-efficient light globe and a less efficient light globe**.**
14 Use the diagram of a waterwheel in Figure 6.57 to **draw** an energy flow diagram for this process.

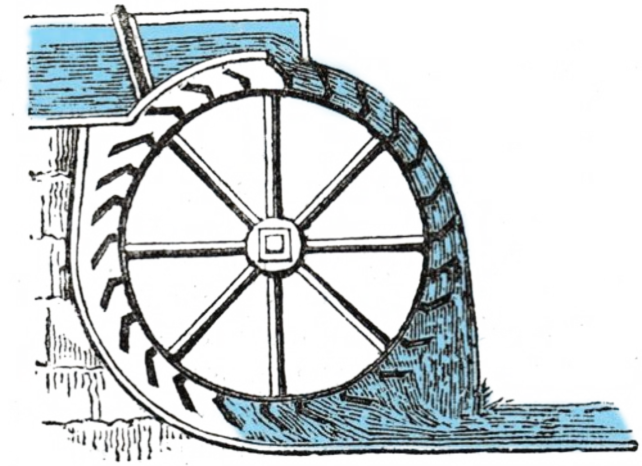

Figure 6.57 An overshot waterwheel

Analysis

15 **Consider** the Sun's role in life on Earth. Explain why there would be no life on Earth without the Sun.

Knowledge utilisation

16 **Discuss** the pros and cons of using nuclear energy.

Data questions

A group of students is testing the advertising claims of 10 different brands of rechargeable AA batteries, which are a source of chemical energy. Each AA battery is claimed to provide at least 1.50 V when new. The initial voltage for three new batteries of each brand was recorded by preparing a circuit with a multimeter, and the data are presented in Table 6.3.

Battery brand (V)	Initial voltage (V)		
	First battery (V)	Second battery (V)	Third battery (V)
1	1.63	1.60	1.61
2	1.57	1.55	1.57
3	1.24	1.29	1.45
4	1.48	1.50	1.47
5	1.52	1.50	1.51
6	1.53	1.53	1.53
7	1.50	1.55	1.50
8	1.60	1.61	1.64
9	1.65	1.65	1.65
10	1.61	1.62	1.60

Table 6.3 Recorded voltage for three new AA batteries of different brands

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Apply

1 **Identify** the battery with the highest initial voltage.

2 A 'flat' AA battery can be considered, in this case, to have a voltage of less than 1.3 V. **Determine** whether any of the newly purchased AA batteries are already flat.

3 For the first battery tested of each brand, remove any flat batteries as outliers and **calculate** the mean initial AA battery voltage.

Analyse

4 With respect to the initial voltage claim of at least 1.5 V, **identify** any patterns that appear in the observed initial voltages.

5 **Classify** the battery brands as those that meet their claim of an initial voltage of 1.5 V and those that don't consistently meet their claim.

6 Now categorise the battery brands that do meet their claim into those with an initial voltage much higher than the claim (1.60 V+) and those consistently just above the claim (1.50–1.59 V).

Interpret

7 Battery brand 9 also claims to have the 'longest lasting AA battery'. **Justify** whether the data in Table 6.3 supports this claim.

8 After complaints to battery brand 3 about the quality of their batteries, a spokesperson revealed that there was a 10% chance of a battery in their packs being sold with a voltage of less than 1.5 V. **Justify** this claim with respect to the reliability of the data presented in Table 6.3.

9 **Predict** whether these AA batteries would return to their 'as new' initial voltage after being recharged from flat.

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STEM activity: Wind power

Background information

Wind power has been used for generations as a method of generating useable 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 6.58 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.

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
- masses (you can use Lego® characters as well)
- electronic scale (optional)

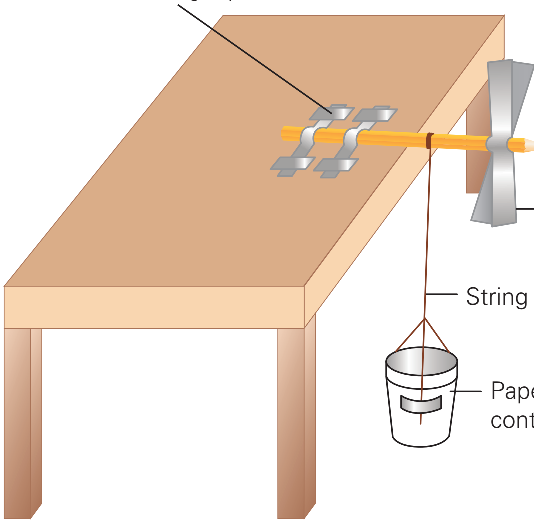

Figure 6.59 You can build ideas around this basic design.

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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 and 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 Prepare 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 the fan (wind) was turned off when the cup was halfway between the floor and the tabletop. Now test this scenario and write down your observations.

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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Chapter 7
Particles of matter

Chapter introduction

The world around you is made up of matter, and in this chapter you will learn about the particles that make up matter. Atoms, elements, compounds, molecules and mixtures can all be represented in different ways to give information about the compositions of the particles. In this chapter, you will learn about where those representations came from and how you can use them yourself to describe the matter in the world.

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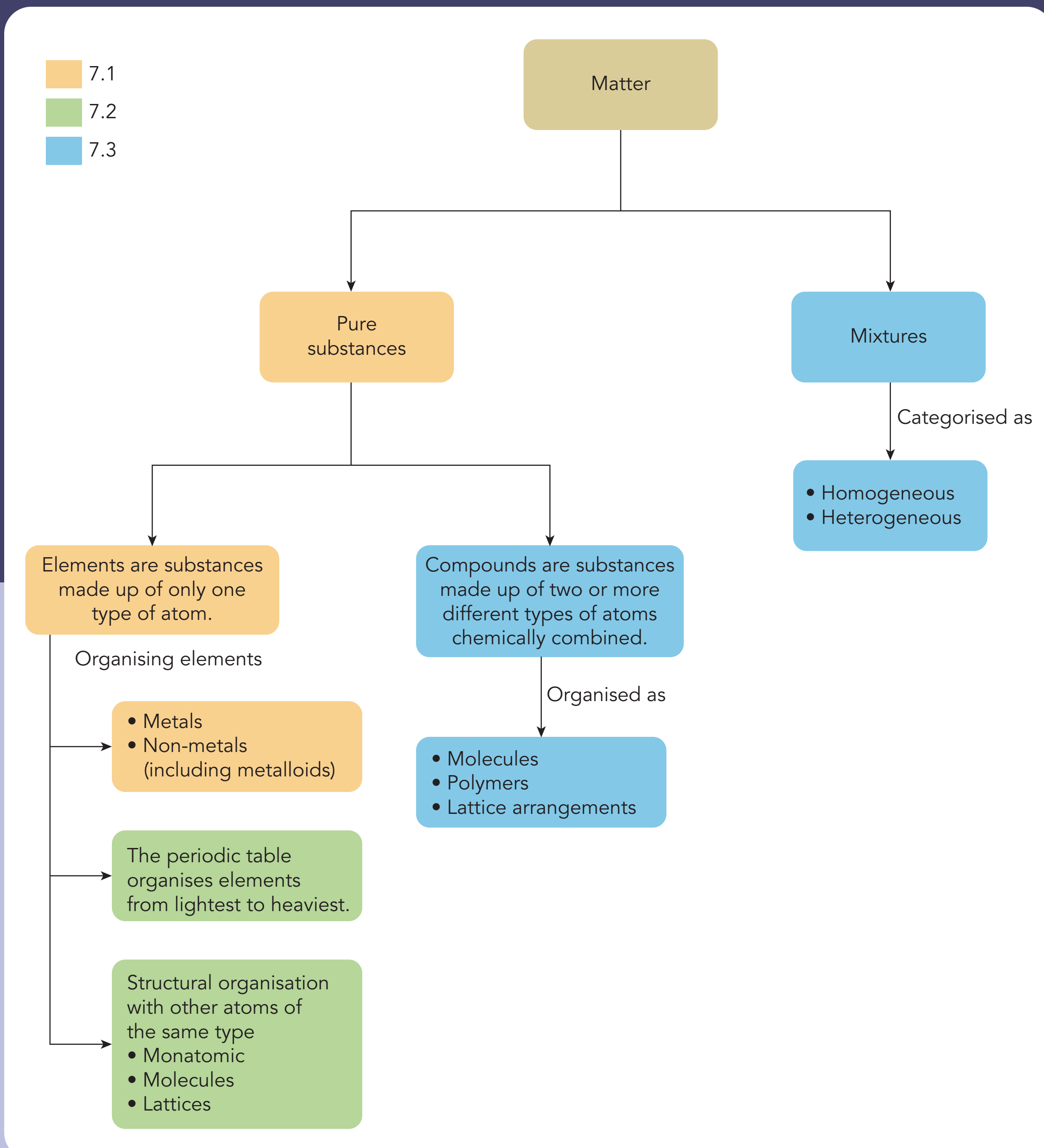
Concept map



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Curriculum

Classify matter as elements, compounds or mixtures and compare different representations of these, including two-dimensional and three-dimensional models, symbols for elements and formulas for molecules and compounds (AC9S8U06)	
using virtual and physical models to distinguish between elements and compounds in terms of types of atoms	7.1
examining how Dmitri Mendeleev arranged the elements in the first version of the periodic table and comparing his arrangement with the current version	7.2
explaining why elements are represented by symbols, compounds and molecules by formulas and mixtures by percentages	7.2, 7.3
using representations to show the classification of matter as elements, compounds and different types of mixtures, such as solutions, suspensions and colloids	7.2, 7.3
examining the information conveyed by different types of representations of elements and compounds and identifying where and why these different representations are used	7.2, 7.3
creating a timeline or models to show how the concept of an element has changed over time from Democritus to Dalton	7.1

Glossary terms

Atom
Chemical bond
Chemical formula
Chemical substance
Colloid
Compound
Conductivity
Diatomic elements
Ductility
Element
Emulsion
Heterogeneous mixture
Homogeneous mixture
Lattice
Lustre
Malleability
Metal
Metalloid
Mixture
Molecule
Monatomic
Non-metal
Periodic table
Polyatomic element
Polymer
Pure substance
Suspension

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7.1 Atoms and elements

Learning goals

1. To be able to define an element, an atom, a molecule, a compound, a pure substance and a mixture.
2. To be able to distinguish metals and non-metals, as well as metalloid elements.
3. To be able to recall the history of the development of the term 'element'.

DOC
WORKSHEET
Properties of elements and compounds

In year 7, you learned about matter and that it makes up everything in the world around you. Matter comes in three main states: solid, liquid and gas. In this chapter we are going to zoom in on what matter is actually made up of at the smallest level. If you were to cut a piece of paper in half and then in half again, you would end up with a smaller piece of paper. But what if you kept cutting it in half until all that was left was the smallest indivisible particle of paper remaining? – a particle that couldn't be cut in half again. This particle would be called an **atom** and is the smallest indivisible particle of matter. Atoms are incredibly small – and across the width of one single strand of hair there are likely close to 10 billion atoms!

Try this 7.1

Cutting paper

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 one. Repeat this as many times as you can, counting your cuts as you go.

How many cuts were you able to make? Name one item that is the same size as the paper with one cut, three cuts and five cuts. How do you think you could keep cutting the paper smaller and smaller? Imagine this: it takes 31 cuts to get a piece of paper the size of an atom!

Pure substances and mixtures

In this chapter, the word 'particles' will be used to describe a range of atoms, elements and compounds, which have a size on the atomic scale. Atoms may exist alone, but they can also join to other atoms. In this case, the strong force of attraction used to join atoms is called a **chemical bond**. There are several different types of chemical bonds: covalent bonds (a bond usually between two non-metal atoms), metallic bonds (bonds between metal atoms) and ionic bonds (a bond usually between a metal and a non-metal atom). A **chemical substance** is one type of particle of matter and a **pure substance** is made up of only one type of chemical substance. In this chapter you will learn about two types of pure substances: elements and compounds.

An **element** is a chemical substance made up of only one type of atom. These can be single atoms or atoms that are bonded together, 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 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 a covalent bond.

atom
the smallest particle that makes up all matter

chemical bond
strong force of attraction between two atoms

chemical substance
matter that contains only one type of particle

pure substance
material that is made up of just one type of chemical substance

element
chemical substance made up of only one type of atom

molecule
two or more atoms chemically bonded by strong covalent bonds

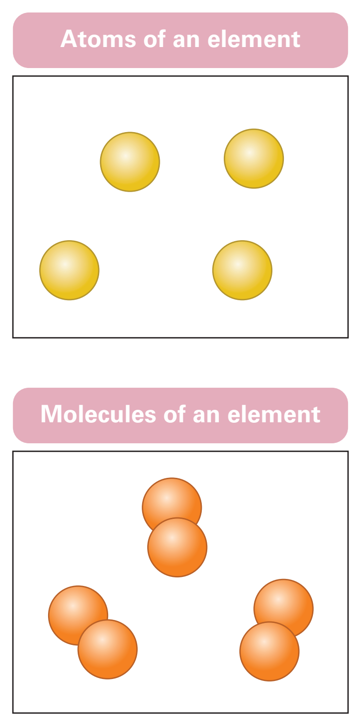

Figure 7.1 In an element, all the atoms are the same.

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Did you know? 7.1

The evolution of the element

The element has taken on a few different definitions prior to the one that scientists use today. The earliest report is from the fifth century BCE when the Greek philosopher Empedocles proposed that there were four 'roots' or 'elements' in the world: earth, water, air and fire.

Use the internet to find information on the different definitions of the term 'element' from the following philosophers and scientists and create a timeline of their models.

- Aristotle
- Democritus
- Paracelsus
- Robert Boyle
- Maria Goeppert Mayer
- Antoine Lavoisier
- John Dalton

Figure 7.2 Empedocles proposed four elements: earth, water, air and fire.

compound
chemical 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 chemically bonded together

A **compound** is a chemical 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.

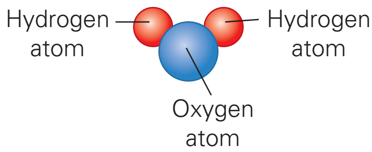

Figure 7.3 A water molecule is a compound, because it has two different types of atoms: one oxygen atom bound together with two hydrogen atoms. Water is also a pure substance, as it is made up of only one type of molecule, the one shown here.

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.

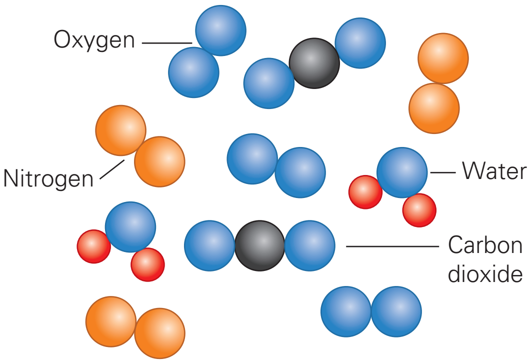

Figure 7.4 Air is a mixture of nitrogen, oxygen, argon, carbon dioxide, water vapour and very small amounts of other gases.

Making thinking visible 7.1

Parts, purposes, complexities: The water molecule

1 Identify the different parts you can see in the water molecule model in Figure 7.5.
2 What are the purposes of each of these parts?
3 What is complicated about this model? What questions do you have about water molecules?

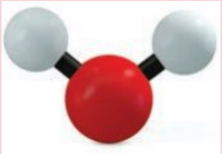

Figure 7.5 A model of a water (H_2O) molecule

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

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Putting it all together

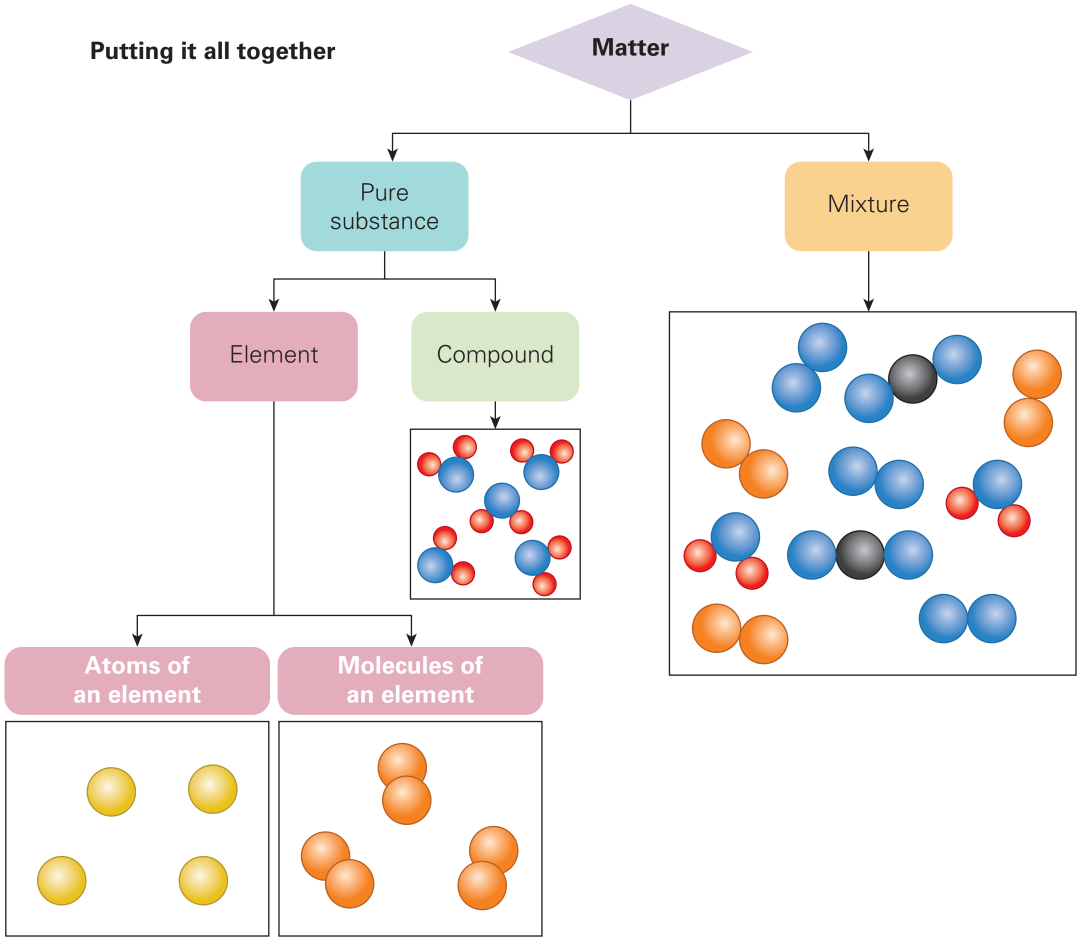


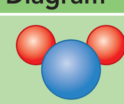
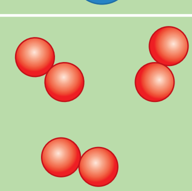
Figure 7.6 Putting it all together: matter is made up of pure substances (elements and compounds) and mixtures.

Quick check 7.1

1 Match the following terms with their correct definitions.

Molecule	The smallest particle that makes up all matter
Compound	Chemical substance made up of only one type of atom
Chemical bond	Chemical substance made from two or more different types of atoms
Element	Two or more atoms chemically bonded together by covalent bonds
Atom	Strong force of attraction that holds atoms together

2 In the following table, match each term and example with the correct diagram (A–E).

Term	Example	Diagram
Mixture of elements	Oxygen and helium	 A
Pure compound	Water	 B

continued …

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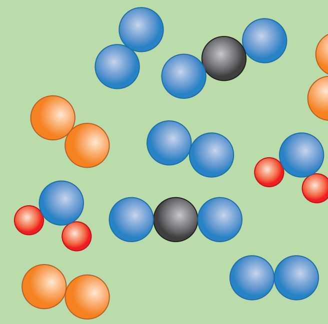
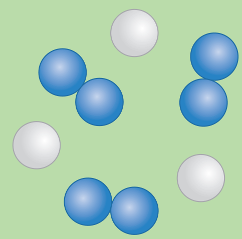
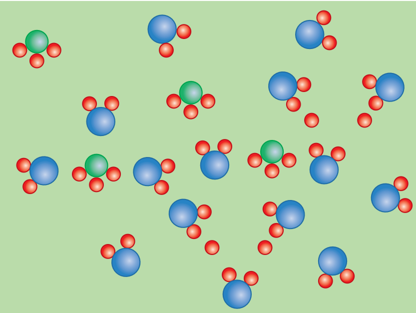
... continued

Term	Example	Diagram
Element	Hydrogen	 C
Mixture of compounds	Salt and water	 D
Mixture of elements and compounds	Air	 E

VIDEO Scanning tunnelling microscope

Did you know? 7.2

Electron microscopes

Electron microscopes allow scientists to visualise matter smaller than the microscale, which is the limit of most light microscopes that you might use in your school classroom. The three main types of electron microscope are the scanning tunnelling microscope (STM), scanning electron microscope (SEM) and the transmission electron microscope (TEM). Scientists are continuing to improve the resolution of their microscope images, and currently these types of electron microscopes can measure particles on the nanometre (nm) scale. A scanning electron microscope (SEM) has been used in recent years to image the SARS-CoV-2 virus, the virus responsible for the COVID-19 disease. These virus particles have a diameter of approximately 50–150 nm.

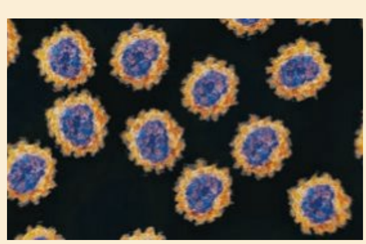


Figure 7.7 Scanning electron microscopic (SEM) image of SARS-CoV-2, which causes the COVID-19 disease

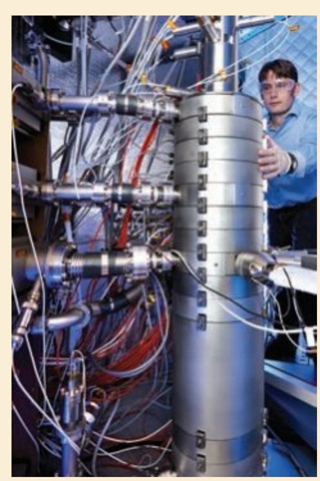


Figure 7.8 This transmission electron microscope in the USA can observe atoms.

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Elements

Elements are made up of one single type of atom. The first elements were identified thousands of years ago with the discovery of the metals, gold, tin, copper and iron. After these elements, scientists and philosophers discovered and hypothesised other elements that could be found in the earth, rocks, air and water. In more modern times, elements have been made by shooting atoms at each other at very high velocities to attempt to 'merge' them. This is how the newest element, oganesson (Og), was discovered in 2002.

Grouping elements

Metals and non-metals

Given that there are 118 elements, they can be categorised by their physical and chemical properties to more easily classify the type of element. A useful classification is whether the element is a **metal** or a **non-metal**. To do this, scientists look at the general properties that the elements have in common (see Table 7.1).

Metalloids

Some of the elements in the non-metal group have properties that could be considered in the metal group. One example is silicon (see Figure 7.9). Silicon can conduct heat and electricity a little, but it cannot be bent (malleable) or made into wire (ductile). It is lustrous (shiny) when polished but is brittle and can shatter like glass. When an element has properties of both metals and non-metals, it is called a **metalloid**. However, it should be noted that all metalloids are considered non-metals, as they are not metals! There are six elements that are typically considered metalloids: boron (B), silicon (Si), germanium (Ge), arsenic (As), antimony (Sb) and tellurium (Te).

metal
a chemical substance that is shiny (lustrous), can conduct electricity and heat, is malleable and ductile, and is usually silvery/grey

non-metal
a chemical substance that is dull, cannot usually conduct electricity and is brittle

metalloid
a non-metallic substance that has some of the properties of both metals and non-metals

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

Property	Metals	Non-metals
State at room temperature	Solid (exception: mercury)	Solid, gas or liquid
Colour	Silver/grey (exceptions: gold, copper)	A range of colours, as well as colourless
Lustre	Shiny when polished	Usually dull
Conductivity	Conducts electricity and heat	Cannot usually conduct electricity or heat
Malleability	Can be bent or flattened	Cannot be bent or flattened; Often brittle
Ductility	Can be made into a wire	Cannot be made into a wire
Melting point	Usually high temperature (exception: mercury)	Usually low temperature

Table 7.1 The general properties of the metal and non-metal elements

Figure 7.9 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? 7.3

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 Earth's crust but is rarely found naturally in its pure form. Instead, it can be extracted from silica sand, a combination of silicon and oxygen.

Practical skills 7.1: Teacher demonstration or student practical

Metals versus non-metals

Aim

To investigate the properties of metals and non-metals

Be careful

Electrical shocks may occur.

Elements may become hot. Ensure the recommended 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 7.10 – does it allow electricity to pass through, making the globe glow? Record your observations in your table.
6. Investigate another property of your choice.

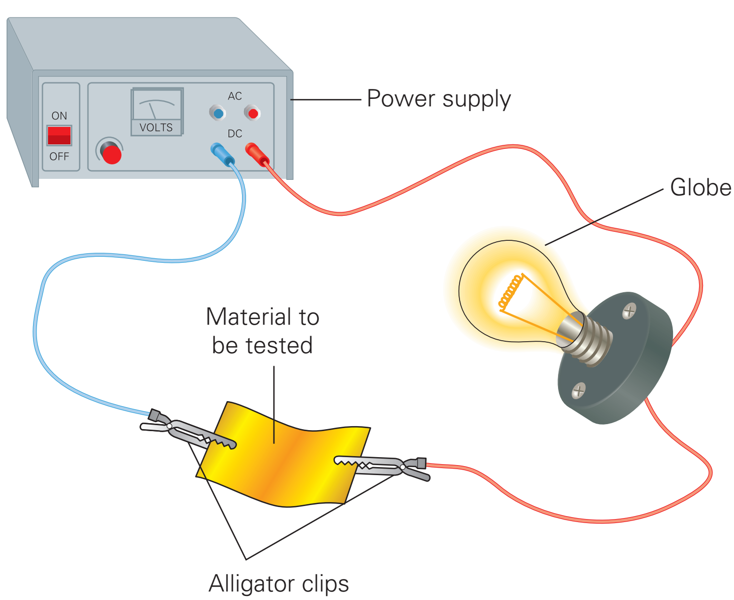

Figure 7.10 Experimental set-up for testing the electrical conductivity of different substances

continued …

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… *continued*

Results

Sample	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?

Quick check 7.2

1. Define the following key terms: element, metal, non-metal, metalloid, malleability, lustre, conductivity, ductility. Provide examples where possible.
2. Demonstrate your knowledge of metals and non-metals by rewriting the following properties in the correct columns.

Metals	Non-metals
Solid, liquid or gas	Usually dull
Usually in the solid state	Lustrous surface
Usually unable to conduct electricity or heat	Can conduct electricity and heat
Ductile	Unable to be made into a wire
Low melting temperature	Malleable
High melting temperature	Unable to bend

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Section 7.1 questions

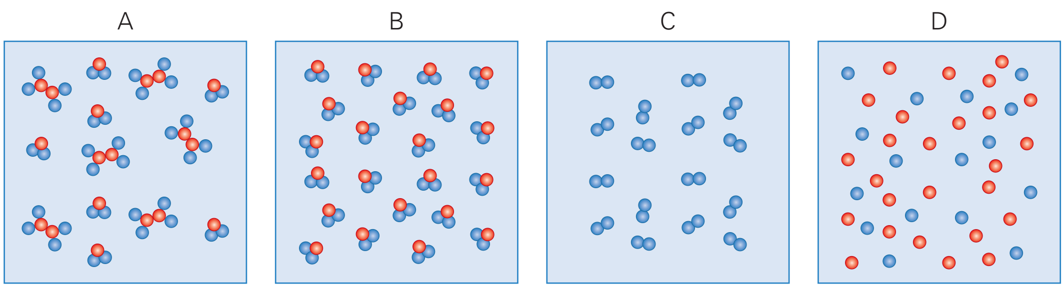
QUIZ

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.

Comprehension

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

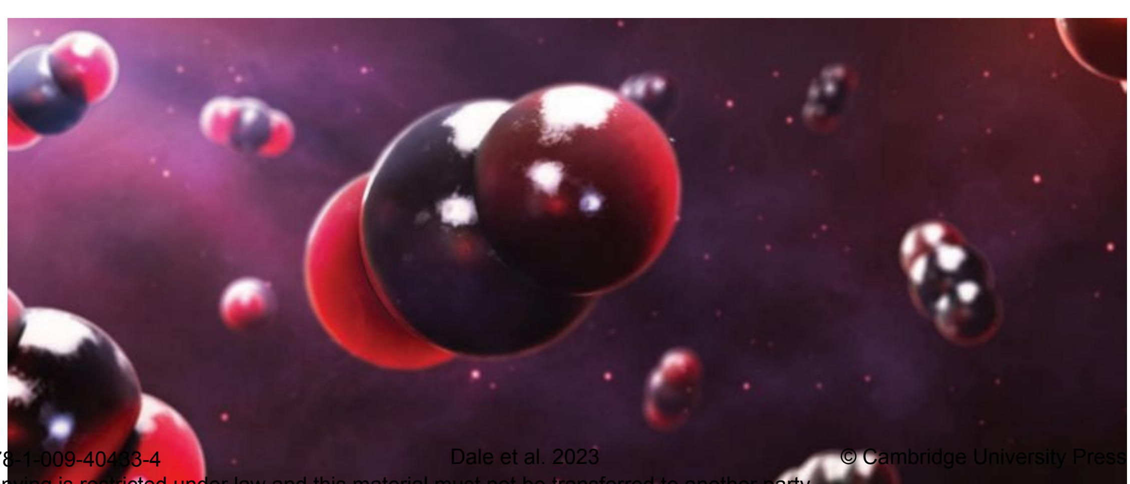
6 **Summarise** three of the tests you can do to find out whether a substance is a metal or a non-metal.

Analysis

7 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

8 Consider what elements are and what compounds are. **Discuss** why there are many more compounds than there are elements.
9 **Justify** why the metalloids are considered a separate group from the metals and non-metals. Use an example to illustrate your point.
10 **Summarise** the work of John Dalton towards the definition of the 'element'.



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7.2 Organising elements

Learning goals

1. To be able to describe how Mendeleev organised elements in his first periodic table.
2. To be able to describe different elemental structures, including monatomic, diatomic, molecules and lattices.

WORKSHEET Properties of elements

Symbols for elements

For all scientists, from all language backgrounds, to understand the language of chemistry, elements are represented by universally understood symbols. These symbols should avoid confusion when communicating about elements and therefore should be unique.

Elements are always denoted by a 'symbol' made of either a capital letter or two letters where the first letter is capitalised and the second letter is never capitalised. Usually, the letter used for the symbol is the first letter of the element's name or the first two letters to ensure an element has a unique symbol. For example, hydrogen has the symbol H, and, to not confuse with hydrogen, helium has the symbol He. 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. As chlorine was given the symbol Cl, no other element has ever been given the symbol Ch as it would just cause confusion!

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. Table 7.2 shows the symbols for the first 20 elements of the periodic table (you will learn about the periodic table in the next section). Can you identify any symbols that aren't based on the English name?

Element	Symbol	Metal/non-metal	Melting point (°C)	Year of discovery
Hydrogen	H	Non-metal	−259	1766
Helium	He	Non-metal	−272	1895
Lithium	Li	Metal	180	1817
Beryllium	Be	Metal	1278	1798
Boron	B	Metalloid	2300	1808
Carbon	C	Non-metal	3500	Ancient
Nitrogen	N	Non-metal	−210	1772
Oxygen	O	Non-metal	−219	1774
Fluorine	F	Non-metal	−220	1886
Neon	Ne	Non-metal	−249	1898
Sodium	Na	Metal	98	1807
Magnesium	Mg	Metal	650	1755
Aluminium	Al	Metal	660	1825
Silicon	Si	Metalloid	1410	1824
Phosphorus	P	Non-metal	44	1669
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 7.2 The first 20 elements, their symbols and some of their properties

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Quick check 7.3

1 Explain why not all the elements are named after the first letter of their name.
2 Recall the reason for using symbols for elements instead of the elements' full names.
3 Refer to Table 7.2 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 Match each element name below to its correct symbol.
  Names: hydrogen, carbon, oxygen, nitrogen, helium, sulfur, magnesium, aluminium
  Symbols: Mg, O, Al, S, N, H, C, He

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WORKSHEET
Elements in our world

periodic table
an organised list of all the known elements and their symbols

Periodic table

An organised list of all the known elements and their symbols is called the **periodic table** (see Figure 7.11). It shows the elements in order from lightest to heaviest (with some exceptions) and even clearly shows which elements are metals, which are non-metals and which are metalloids.

The modern periodic table displays not only elemental data, but it has its characteristic shape as it displays many trends to scientists, including metallic character and chemical reactivity. This form of the periodic table wasn't created overnight – there were many iterations with ideas from many great scientists and philosophers.

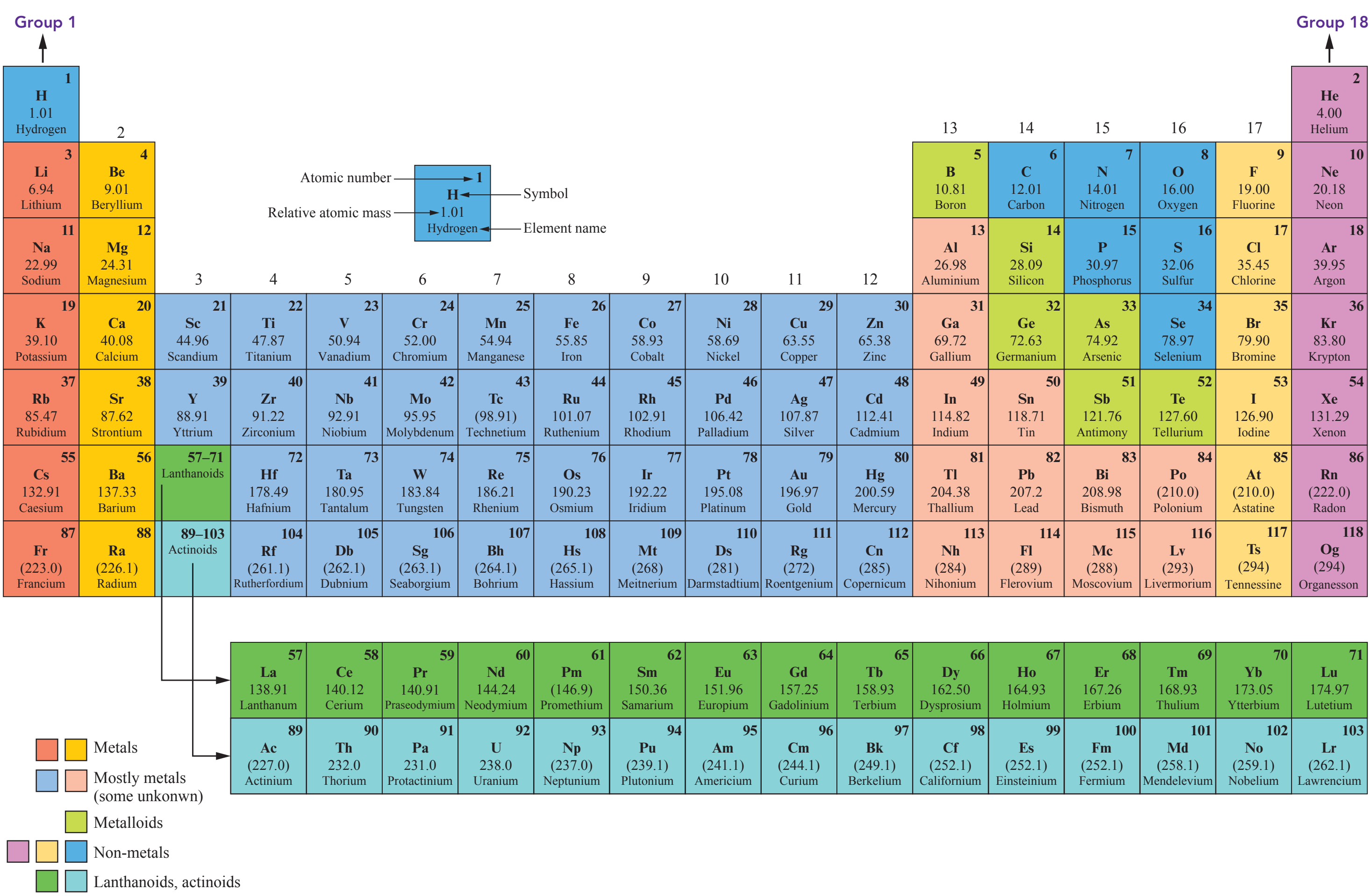

Figure 7.11 This periodic table includes all 118 known elements.

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Try this 7.2

Identifying elements

Look at the periodic table in Figure 7.11. Use the legend to identify all six metalloids. What colour are they in the periodic table?

Next, identify some of the metals you know. Where are they in relation to the metalloids? What about the non-metals – where are they positioned in the table?

Explore! 7.1

Mendeleev's periodic table

Dmitri Mendeleev was a Russian scientist who is often called the 'father of the periodic table' after he proposed the novel 'periodic system' in 1869.

Use the internet to research the following questions:

1 Why did Mendeleev arrange the known elements in the vertical groups shown in Figure 7.12, with some blank spaces?

2 How is the organisation of elements in Mendeleev's periodic table similar to the modern periodic table used today?

I	II	III	IV	V	VI	VII	VIII		
H 1.01									
Li 6.94	**Be** 9.01	**B** 10.8	**C** 12.0	**N** 14.0	**O** 16.0	**F** 19.0			
Na 23.0	**Mg** 24.3	**Al** 27.0	**Si** 28.1	**P** 31.0	**S** 32.1	**Cl** 35.5			
K 39.1	**Ca** 40.1		**Ti** 47.9	**V** 50.9	**Cr** 52.0	**Mn** 54.9	**Fe** 55.9	**Co** 58.9	**Ni** 58.7
Cu 63.5	**Zn** 65.4			**As** 74.9	**Se** 79.0	**Br** 79.9			
Rb 85.5	**Sr** 87.6	**Y** 88.9	**Zr** 91.2	**Nb** 92.9	**Mo** 95.9		**Ru** 101	**Rh** 103	**Pd** 106
Ag 108	**Cd** 112	**In** 115	**Sn** 119	**Sb** 122	**Te** 128	**I** 127			
Ce 133	**Ba** 137	**La** 139		**Ta** 181	**W** 184		**Os** 194	**Ir** 192	**Pt** 195
Au 197	**Hg** 201	**Ti** 204	**Pb** 207	**Bi** 209					
			Th 232		**U** 238				

Figure 7.12 Mendeleev's first periodic table proposed in 1869

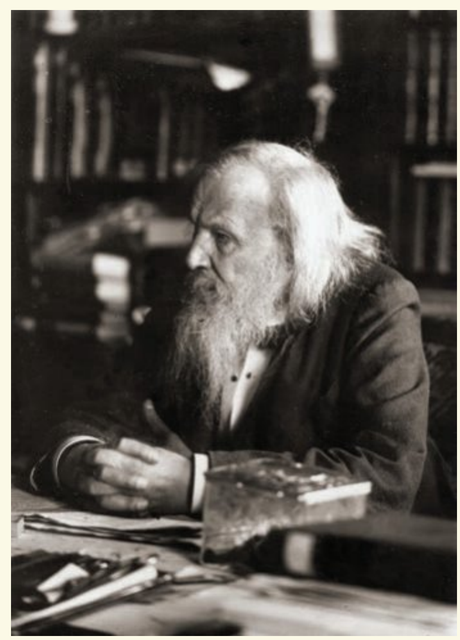

Figure 7.13 Dmitri Mendeleev, the father of the modern periodic table

Quick check 7.4

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	Cd	Si	Sb
Cl	Cs	S	Sm
Ca	Ce	Sc	
Cr	Cm	Se	
Co	Cf	Sr	
Cu		Sn	

DOC WORKSHEET Naming elements

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Practical skills 7.2

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 mol L^{-1} hydrochloric acid in five test tubes, labelled with the test solutions below
- known test solutions in test tubes:
  - barium (barium chloride)
  - calcium (calcium chloride)
  - copper (copper(II) chloride)
  - strontium (strontium chloride)
  - sodium (sodium chloride)
  - 4 unknown samples

Figure 7.14 A substance burning in the flame of a Bunsen burner, producing an orange flame

Method

1. Check if your flame wires are clean by holding the metal loop in the hottest part of the blue Bunsen burner flame. If it is not clean, a coloured flame will appear, so clean it by dipping it into the hydrochloric acid provided and then holding the loop in the Bunsen burner flame again.
2. Dip the clean flame test loop into one of the known test solutions, then hold the metal loop in the hottest part of the Bunsen burner flame. Record the colour of the flame in your results table.
3. Clean the flame test wire, then test another known test solution. Keep going until you have recorded the colour for all the known solutions.
4. Flame test the four unknown solutions and record their flame colours in a second results table.
5. Work out which metals are in each of the unknown samples and record in your table.

Results

Flame colours of known substances

	Barium	Calcium	Copper	Strontium	Sodium
Flame colour					

Flame colour of each unknown substance, and the metal indicated by the colour

	Sample 1	Sample 2	Sample 3	Sample 4
Flame colour				
Metal				

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?

continued …

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… continued

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

While elements are made up of only one single type of atom, those atoms can arrange themselves in different ways. Atoms of an element can be single atoms (**monatomic**) or chemically bonded as molecules. They can even form larger three-dimensional **lattices**.

Monatomic elements

Monatomic means 'single atom'. A monatomic element is made up of single atoms that are not chemically combined. The only elements that take this form are known as the noble gases and include helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Can you see where these elements all sit in the periodic table? (Refer back to Figure 7.11.)

Molecules

In general, non-metal atoms chemically bond to form molecules. Some elements chemically bond to form diatomic elements. These molecules have two atoms of the same type bonded together. Common examples of **diatomic elements** include hydrogen gas (H_2), oxygen gas (O_2), nitrogen gas (N_2) and chlorine gas (Cl_2).

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 7.15. As you look at the diagram, it is important to notice not only the range of molecules but also how to write the chemical formula for elements that are molecules. For example, look at the oxygen molecule. It has two oxygen atoms, so we write O_2, where O is the elemental symbol for oxygen, and the subscript 2 shows how many atoms are joined by bonds in the molecule.

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 multiple directions

diatomic element
an element that exists as a molecule consisting of two atoms of the same type

polyatomic element
an element that exists as a molecule containing more than two atoms of the same type

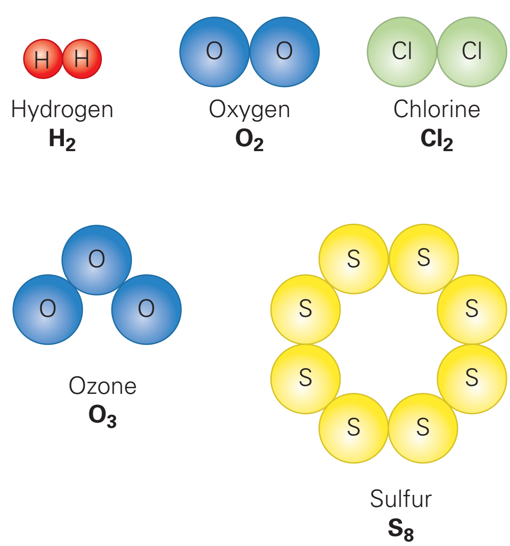

Figure 7.15 Some elemental molecules: hydrogen, oxygen, chlorine, ozone and sulfur

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.

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A lattice is a three-dimensional shape that allows the atoms to pack together very tightly and form strong bonds. The bonds are strong because the atoms bond to each other in multiple directions, and so it is hard to separate them completely.

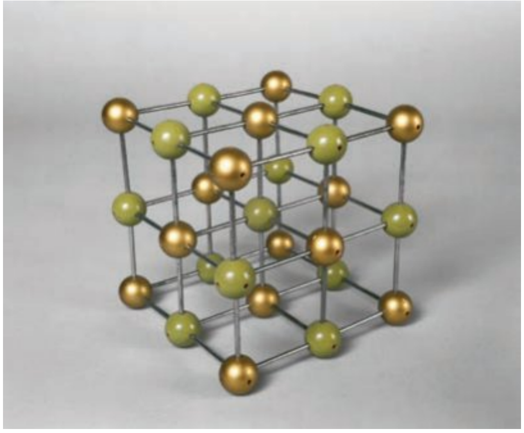

Figure 7.16 A lattice structure: every atom is attached tightly to other atoms in multiple directions.

Quick check 7.5

1 Describe the three ways in which elements can be organised.
2 Draw a simple diagram to show the arrangement of atoms in each of the three ways described in Question **1**.

VIDEO Forms of carbon

Explore! 7.2

Forms of carbon

Carbon is an element that occurs in many different forms. Each form consists solely of carbon atoms, but the way the atoms are organised differs. This affects the properties of the different forms.

1 Investigate one of the hardest substances in the world: diamond. Find out its uses and its properties.
2 Investigate the substance that is in the middle of your pencil: graphite. Find out its uses and its properties.
3 Investigate the coolest-sounding molecules: buckyballs. Find out their uses and their properties.
4 Compare the structure of the lattices of diamond, graphite and buckyballs. Do this by describing what each looks like and include a sketch.

Science as a human endeavour 7.1

First Nations Australians' material culture

First Nations Australians have passed down traditional knowledge of the properties and uses of materials found on Country for millions of years. Their knowledge of the interconnectedness of all living things allows a deep and sophisticated knowledge of the use of the properties of plant and animal life for food, clothing and medicine, as well as tools, such as boomerangs, spears, bows and arrows and didgeridoos.

Thus, a vast material culture exists in many First Nations Australian cultural groups over many generations.

Figure 7.17 First Nations Australians use the cultural knowledge of the properties of materials found on Country.

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Section 7.2 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 Li
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 a molecular element.

Analysis

7 **Classify** the following elements as monatomic, molecular or lattice: helium, diamond, hydrogen, aluminium, oxygen, argon, chlorine, copper, neon

8 **Distinguish** between a molecular element and a lattice. Include examples in your answer.

Knowledge utilisation

9 We use symbols to describe elements. **Propose** the reasons why we do this.

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7.3 Compounds and mixtures

WORKSHEET
Compounds and mixtures

Learning goals

1. To be able to name a chemical compound using naming conventions.
2. To be able to distinguish homogenous and heterogenous mixtures.
3. To be able to explain why mixtures are represented by percentages or ratios and not chemical formulas.

Compounds

When two or more different types of atoms chemically bond together, a chemical compound is formed. For example, water is a compound. It is made up of two hydrogen atoms 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.

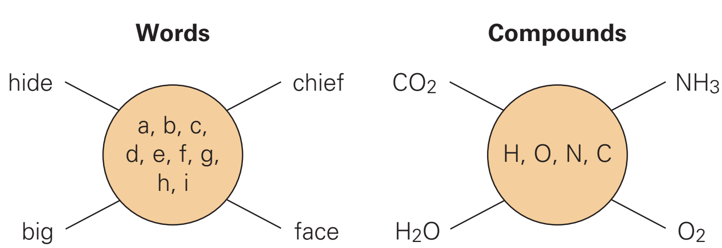

Figure 7.18 Elements are like the letters of the alphabet – letters can form thousands of words, and elements can form millions of compounds.

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 are affected by the elements that are in the compound, the types of bonds between atoms and how they are arranged. For example, the properties of carbon vary depending on the arrangement of the carbon atoms. You learned about some of the different forms of carbon in *Explore! 7.2:* graphite, diamond and buckyballs. Hydrogen has the following properties: it is colourless, odourless, non-toxic and highly combustible. However, the properties of the compounds formed from carbon and hydrogen are very different from the two elements on their own. Figure 7.19 shows examples of the uses and properties of compounds made of only carbon and hydrogen.

Figure 7.19 Substances that contain only carbon and hydrogen. From left to right: butane (in lighter fluid); polymers (plastic waste); octane (a component of petrol)

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Organisation of compounds

The atoms in compounds can be arranged in three different ways: as a discrete molecule, a **polymer** or a lattice. These are summarised in Table 7.3.

polymer
a long molecule made of a chain of atoms in a pattern that repeats

Arrangement	Description	Examples
Small molecule	Groups of atoms held together by covalent bonds. A particular compound always has the same elements in the same ratio and these molecules are generally called 'discrete' due to being distinctly separate from one another, unlike in polymers and lattices.	Carbon dioxide (CO_2) Water (H_2O)
Polymer	A long molecule made of a chain of atoms in a pattern that repeats	Plastics Natural fibres (e.g. cotton) Proteins
Lattice	A 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 7.3 The atoms in a compound can be arranged into a small molecule, a polymer or a lattice.

Science as a human endeavour 7.2

VIDEO
Polymers and bioplastics

Bioplastics

For over 100 years, humans have been developing plastic products for use in a plethora of circumstances, including food packaging, electronics and other consumer products. However, when these materials are disposed of in landfill, they take thousands to millions of years to degrade to natural products! This issue sparked the Queensland Government to ban the supply of single-use plastic food packaging, straws and cutlery in 2021, and in 2023 the ban was expanded to include plastic shopping bags, polystyrene loose packaging and some plastics from personal care products, such as cotton buds.

Figure 7.20 Cotton buds with plastics stems are banned from supply as of 2023, to promote the production of biodegradable alternatives.

Single-use plastics can be replaced with much more environmentally friendly biodegradable or biobased products, which degrade when placed in soil or landfill. Biodegradable products can be broken down in the soil to produce biomass, carbon dioxide and water, while biobased materials are sourced from biomass, which naturally decays when placed in the earth.

By placing bans on non-degradable plastic products, the Queensland Government is making an informed decision to promote biodegradable and environmentally friendly alternatives.

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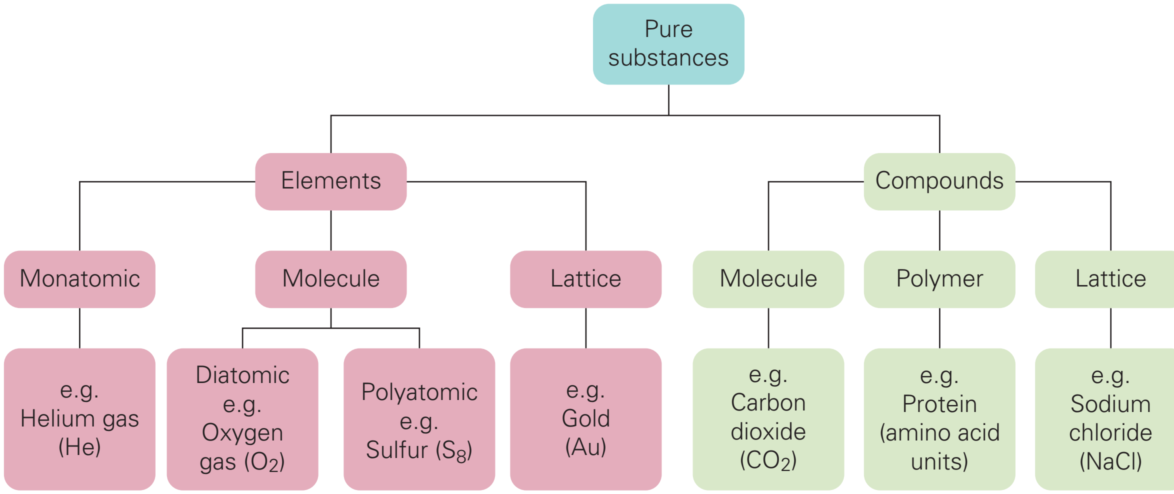

Figure 7.21 Summing up: the organisation of atoms in elements and in compounds

Did you know? 7.4

Polymer banknotes

In 1988, Australian scientists at CSIRO developed the first polymer banknotes and they were introduced to the general population. These polymer-based Australian banknotes start out as plastic pellets, which are melted and blown into a bubble three storeys high! The walls of the bubble are pressed together and cooled to form laminated polymer films. Since the introduction of polymer banknotes in Australia, they are now used in over 30 countries in the world, including our neighbours, New Zealand and Indonesia.

Figure 7.22 Australian, Indonesian and New Zealand polymer banknotes

Quick check 7.6

1 Compare and contrast the terms 'compound' and 'molecule'.
2 Explain why the properties of elements and the compounds made up of those elements are different.
3 Name two examples of compounds that have a molecular structure, two that have a polymer structure and two that have a lattice structure.

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

Symbols for compounds

A **chemical formula** is a shorthand way of representing the elements that are in a compound. The formula tells you which elements are present in the compound and how many atoms of each element are present in one molecule or one basic unit of that particular compound.

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For example:

- Carbon dioxide, found in the air, has the chemical formula CO_2. This means that one covalent molecule of the compound carbon dioxide has two elements in it: carbon (C) and oxygen (O). There are one carbon atom and two oxygen atoms.
- Sodium sulfate, found in common detergents, is an ionic compound and has the chemical formula Na_2SO_4. This means that one basic unit of the compound has three elements in it: sodium (Na), sulfur (S) and oxygen (O). Each basic unit of sodium sulfate contains two atoms of sodium, one atom of sulfur and four atoms of oxygen.

Figure 7.23 Sodium sulfate is a compound used in common household detergents.

What if the formula has brackets in it? Consider the compound aluminium carbonate. Its formula is $Al_2(CO_3)_3$. The brackets tell us that there is more than one CO_3 unit. In this case, there are three units of CO_3. So, from the formula, we can see that there are three elements in each basic unit of this compound: aluminium (Al), carbon (C) and oxygen (O). Each unit of aluminium carbonate is made of two atoms of aluminium, three atoms of carbon and nine atoms of oxygen.

Try this 7.3

Ethanoic acid

Consider the compound ethanoic acid, CH_3COOH, more commonly known as vinegar. First, identify the elements in one basic unit of the compound and then how many atoms there are of each of the elements.

Naming compounds

When naming a compound, there are some general rules to follow depending on whether the compound contains a metal and a non-metal or only non-metals. Note that there are some exceptions to these rules, but the exceptions will be learned in future school years.

Metal and non-metal compounds

1. If there is a metal in the compound, it gets named first. For example, $CaCl_2$ is calcium chloride. Calcium is the metal, so it is named first.
2. If the non-metal present is a single element, it will usually be named with a suffix, -ide. Again, consider $CaCl_2$. As the non-metal present is only chlorine it will be named second as chlor*ide*.
3. When the non-metal component of a metal and non-metal compound contains more than one element, it usually takes a special name ending in -ate. Some common examples include: nitrate (NO_3), carbonate (CO_3), sulfate (SO_4) and phosphate (PO_4). For example, $CaCO_3$ would be named calcium carbonate.

Non-metal only compounds

1. When a compound contains only non-metals, such as oxygen (O) and chlorine (Cl), the start of the second element word changes based on how many atoms there are in the compound. For example, CO_2 contains one carbon atom and two oxygen atoms, and so the second word starts with a prefix di- and the compound is called carbon dioxide. Another example would be the compound CO, which would be named carbon monoxide, as the second element starts with the prefix mono-. Table 7.4 summarises the prefixes used, depending on how many atoms of the second element there are in the compound.

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2 In some cases, there is more than one atom of the first non-metal element present, and in these cases the prefix is also used for the first element. For example, H_2O would be named dihydrogen monoxide, although you will be more familiar with its common name of water!

3 If the prefix ends in an 'a' and the start of the element name starts with a vowel, the 'a' can be dropped from the name. For example, N_2O_4 would be dinitrogen tetroxide (rather than tetraoxide).

Number of atoms of second element	Prefix (start) of second element word	Example
1	Mono-	Monochloride
2	Di-	Dichloride
3	Tri-	Trichloride
4	Tetra-	Tetrachloride
5	Penta-	Pentachloride

Table 7.4 Prefix used at the start of the second element when naming compounds containing only non-metals

Practical skills 7.3

Making a compound

Aim

To make a compound from two elements and to practise using elemental symbols and naming compounds

Be careful

Do not look directly at the reaction. The reaction is very bright and can damage your eyes. Wear safety glasses.

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 7.24.
3 Put on your safety glasses. Heat the crucible with a blue flame and, every so often, monitor the reaction using the tongs to carefully lift the edge of the crucible lid.
4 When the reaction has finished, the magnesium ribbon will no longer be recognisable. Turn off the Bunsen burner and let the crucible cool down.
5 Record what you see in the crucible.

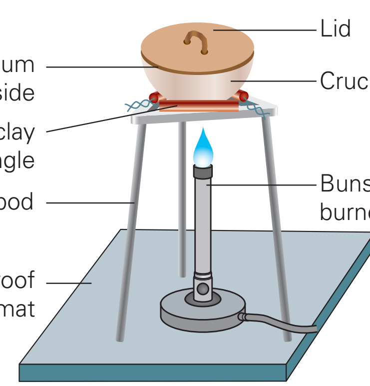

Figure 7.24 Experimental set-up

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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.

Quick check 7.7

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, 12 hydrogen atoms and six oxygen atoms
   c rust – contains two atoms of iron and three atoms of oxygen.
3 Determine the names of the following compounds:
   a one carbon atom and four chlorine atoms
   b two hydrogen atoms and one oxygen atom
   c one magnesium atom and one oxygen atom

Practical skills 7.4

Breaking down a compound

Aim

To investigate the breakdown of copper carbonate

Materials

- copper carbonate
- limewater
- straw

Be careful

Safety glasses must be worn at all times.
Wash hands thoroughly at the end of the experiment.

continued …

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… continued

- 3 large test tubes
- Bunsen burner
- matches
- heatproof mat
- wooden tongs
- paper towel
- retort stand and clamp
- delivery tube and stopper
- spatula

Method

1 Half fill a test tube with limewater. Using the straw, blow into the limewater so it bubbles. Record your observations when CO_2 from your breath is bubbled through limewater.

2 Use the diagram in Figure 7.25 as a guide to the steps that follow.

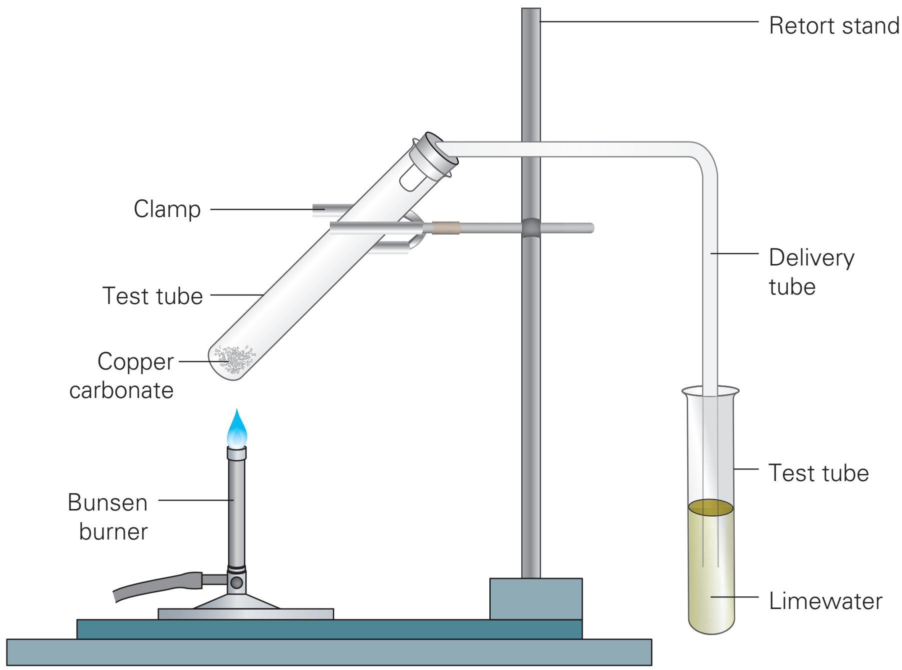

Figure 7.25 Experimental set-up

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?

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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.

Mixtures

A compound or a molecule is not a mixture as the atoms are joined with chemical bonds. A mixture is the name given to a material or substance made up of more than one type of pure substance that are not chemically combined. This means that the components of a mixture can be separated. Some examples of mixtures that you may be familiar with are soft drinks (a mixture of sugar, water, carbon dioxide, flavouring and colouring), a cup of tea (a mixture of tea leaves and water), tap water (a mixture of water, oxygen, carbon dioxide and dissolved ionic compounds, and spaghetti bolognaise (a mixture of tomatoes, beef, garlic and herbs).

Figure 7.26 This salad is an example of a mixture – the components are not chemically combined, and so they can be separated.

Mixtures have different properties from those of compounds, as there is no chemical bond between the parts of a mixture. Table 7.5 summarises the differences between compounds and mixtures.

Mixtures can be broadly classified into two categories: **homogeneous mixtures** and **heterogeneous mixtures**.

homogeneous mixture describes a mixture of two or more substances that are evenly distributed and do not separate out easily

heterogeneous mixture describes a mixture that can be separated into its parts, and the parts retain their original properties; the mixture is not blended evenly

	Compound	Mixture
Components	Contains two or more elements	Contains two or more elements or compounds
Bonding between atoms	Elements are chemically bonded together	Elements/compounds are not chemically bonded together
Properties	The compound has properties that are different from the properties of the elements it contains	Each substance in the mixture keeps its own properties
Separation	Most compounds can be separated into their elements using chemical decomposition reactions	Each substance can be separated out of the mixture by a physical process
Ratio of different atoms	Elements occur in strict ratios to each other	Substances in the mixture can occur in any ratio

Table 7.5 The differences between a compound and a mixture

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colloid
a mixture in which particles of one chemical substance will not dissolve but remain distributed throughout another chemical substance

emulsion
a colloid of two or more liquids

suspension
a mixture in which one chemical substance will eventually settle out of the solvent

Homogeneous mixture

Homogeneous mixtures are those where you cannot tell that two or more substances have been mixed together, as they don't separate out when left to stand. The components of the mixture are all evenly distributed, so the entire mixture has the same properties. A type of homogenous mixture where a solute is dissolved in a solvent is called a solution. Examples: air, water, chocolate pudding, soft drink.

Figure 7.27 Apple juice is an example of a homogeneous mixture.

Heterogeneous mixture

A heterogeneous 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. Heterogeneous mixtures that have components not evenly distributed include **colloids**, **emulsions** and **suspensions**. Examples: trail mix, choc-chip cookies, pizza topping.

Figure 7.28 A shepherd's pie is an example of a heterogeneous mixture.

Symbols for mixtures

Mixtures do not have a chemical formula as the elements are not chemically combined, but rather they are represented by a percentage composition or a ratio of each pure substance. The pure substances in a mixture retain their original chemical formulas.

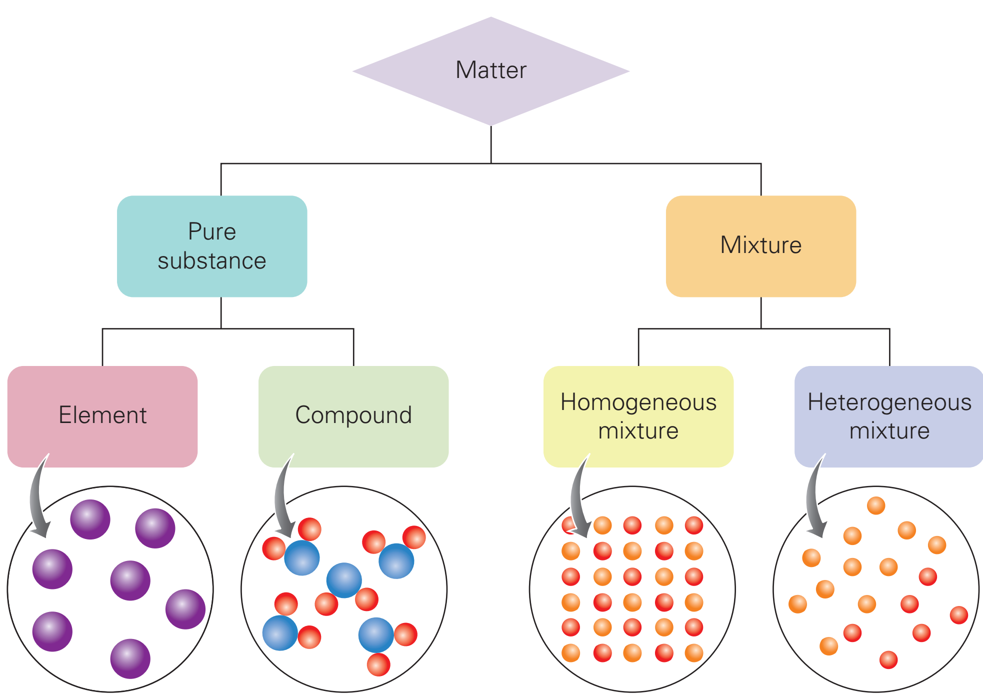

Figure 7.29 Matter consists of pure substances and mixtures. In this chapter, you have learned about both these groups.

WIDGET
Elements, compounds and mixtures

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Did you know? 7.5

Composition of mixtures

The simplest unit of the compound sodium chloride is made up of one Na atom and one Cl atom. Thus, its symbol formula is NaCl. Similarly, the molecular compound water is made up of two H atoms and one O atom in its simplest formula. Thus, its symbol formula is H_2O.

Mixtures of elements or compounds are often represented by the relative percentage or ratio of their mass in the total mass. This is commonly used to describe the composition of colloids and suspensions as well as solutions. For example, a brine solution (NaCl dissolved in H_2O) could be described as having 25% NaCl by mass or even one part NaCl to three parts H_2O (or 1:3, NaCl:H_2O). Mixtures are not represented by elemental symbols being combined, such as with compounds, as this would suggest that the elements are chemically combined, but in mixtures they are not.

Figure 7.30 Adding table salt (NaCl) to water (H_2O) creates a mixture. The two compounds might interact, but they do not chemically combine.

Investigation 7.1

Investigating heat energy from alcohols

Be careful
To be conducted in a fume hood or well-ventilated area.
Wear safety glasses.

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

- retort stand and clamp
- 150 mL conical flask
- 100 mL measuring cylinder
- thermometer
- spirit burners containing the following alcohols:
  - methanol
  - ethanol
  - propanol
  - butanol
- stopwatch
- matches

continued …

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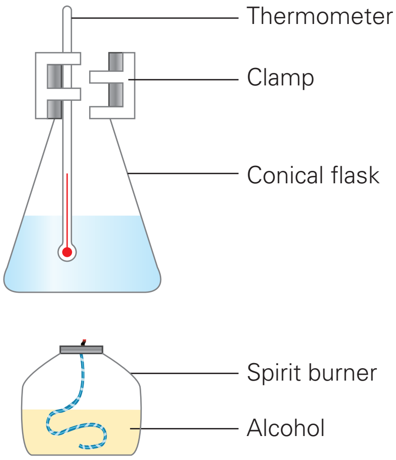
Method

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 other three 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.

Section 7.3 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.

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- d Its properties are not the same as the properties of the elements that make it up.
- e The substances can be separated by chemical means only.
- f The substances can be separated by physical methods.

2 **State** the 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 **Compare** a heterogeneous mixture with a homogeneous mixture.

Knowledge utilisation

6 A tiny sample of quartz contains 1 000 000 atoms of silicon and 2 000 000 atoms of oxygen. **Determine** what the formula would be, based on this information.

7 Substances A, B and C were tested and were found to have the following chemical compositions:
A: 70% oxygen, 30% carbon
B: 60% hydrogen, 40% carbon
C: 60% oxygen, 40% carbon
Deduce if any two of these substances are the same compound. Give reasons for your answer.

8 **Determine** the correct answers to complete the following table.

Name	Formula	Number of different elements in the compound	Number of atoms in each molecule
Water	H_2O	2	3
	CO		
Sulfuric acid	H_2SO_4		
Nitrogen monoxide	NO		
Dinitrogen monoxide			
Methanol	CH_4O		

9 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.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
7.1	I can define the following key terms: atom, molecule, element, pure substance, compound, mixture.	1, 4, 7, 9	
7.1	I can distinguish between metals, non-metals and metalloids.	10	
7.1	I can create a timeline of the development of the term 'element'.	3	
7.2	I can describe how Mendeleev organised elements in his first periodic table.	12	
7.2	I can describe monatomic, diatomic, molecular and lattice structures.	11	
7.3	I can recall some rules that are required when naming compounds.	13, 14	
7.3	I can distinguish between homogeneous and heterogenous mixtures.	8	
7.3	I can explain why mixtures are represented by percentages or ratios and not chemical formulas.	16	

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 **List** the key scientists and philosophers who contributed to the modern knowledge of the elements.

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 known elements are listed and classified in the _____________.
- **c** In compounds, the atoms are _____________ combined using bonds.
- **d** The properties of a compound are usually _____________ to the properties of the elements it contains.
- **e** Mixtures contain two or more _____________ or _____________ that are not chemically combined.
- **f** Mixtures can be uniform (called _____________).
- **g** Mixtures can also be non-uniform (called _____________).
- **h** The properties of a mixture are _____________ to the properties of its components.

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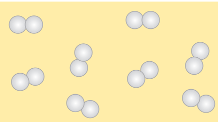
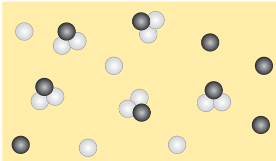
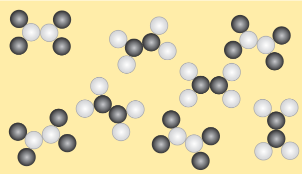
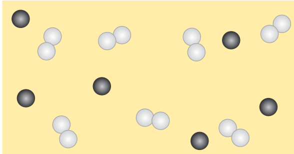
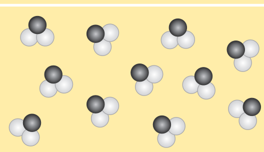
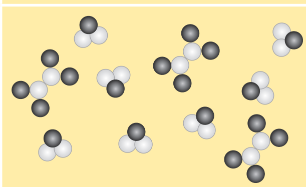
Comprehension

5 **Explain**, using examples, how the properties of an element relate to its use.
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.

Analysis

8 **Distinguish** between a homogenous mixture, a heterogenous mixture and a chemical compound.
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.
11 Sodium chloride (NaCl) has a lattice arrangement of atoms, whereas oxygen gas (O_2) is a diatomic molecule. **Describe** the difference between these structures.

Knowledge utilisation

12 Describe how Mendeleev's first periodic table provided a scaffold for the development of the modern periodic table used today.
13 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.
14 **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			

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15 We can use the letters of the alphabet to make up words, sentences, paragraphs and more. Using this analogy, what would best represent compounds, mixtures and elements – letters, words or paragraphs? **Justify** your answers.

16 **Propose** why elements and compounds can be represented by chemical formulas, but mixtures are represented by percentages or ratios.

Data questions

Refer to the melting points and boiling points for various elements shown in Table 7.6 and Figure 7.31.

Element	Classification	Melting point (°C)	Boiling point (°C)
Carbon	Non-metal	3550	4827
Nitrogen	Non-metal	−210	−196
Oxygen	Non-metal	−219	−183
Helium	Noble gas	−272	−269
Neon	Noble gas	−249	−246
Fluorine	Halogen	−220	−188
Chlorine	Halogen	−102	−34
Bromine	Halogen	−7	59
Iodine	Halogen	114	184
Magnesium	Metal	650	1091
Iron	Metal	1538	2861
Nickel	Metal	1455	2913
Copper	Metal	1085	2560
Silver	Metal	962	2162
Platinum	Metal	1768	3825
Gold	Metal	1064	2836
Mercury	Metal	−39	357

Table 7.6 Classification, and melting and boiling point of various elements

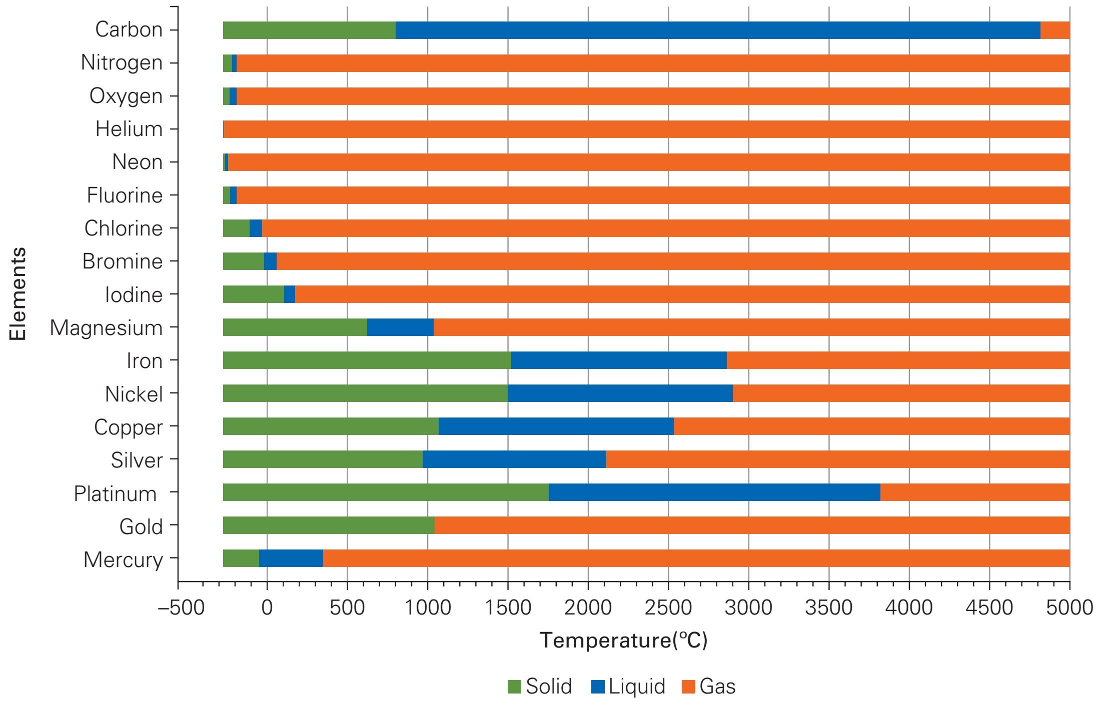

Figure 7.31 States of various elements at different temperatures

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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 7.6 are classified as halogens.

Analyse

4 **Contrast** the general melting point of the noble gases and the metals in Table 7.6.
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 7.6, **deduce** whether the noble gases can exist in the liquid state.
9 Argon is another noble gas element. **Predict** whether the boiling point of elemental argon is closer to 3000°C, 100°C or −150°C.

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STEM activity: Prosthesis design

Background information

Your skeleton protects your organs and gives your body shape and structure. Your skeleton is necessary for you to move, make blood cells, store calcium and more. You would look very different without it. For various reasons, not everyone has all the bones that complete their skeleton. Biomedical engineers can help in this area. They 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 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. First, list the characteristics and features that are important for a prosthetic leg, then design your prototype using various ordinary materials that you have selected on the basis of their physical properties, before creating a lower-leg prosthetic prototype. Your team will then demonstrate your prosthetic's strength, analyse your prototype and make suggestions for design improvements.

Figure 7.32 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		
Useability (how easy it is to use)		

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.

Figure 7.33 An artificial limb restores functionality and independence.

Create

4 Construct the lower leg prosthesis you have designed using the materials available.

Evaluate and modify

5 Create a reflection chart containing positives, negatives and interesting observations, and evaluate your constructed lower leg prosthesis prototype. Make sure you reflect on the strength, durability, useability and comfort of the prototype.

Positives	Negatives	Interesting
e.g. Ankle movement is realistic and the ankle has a 60° range.	e.g. Cardboard tubing used was not strong and broke when tested.	e.g. The foam used around the tubing was a strong support for the tubing.

6 Explain the improvements and modifications you would make to the prototype in a presentation to the class.

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Chapter 8
Physical and chemical change

Chapter introduction

When different particles collide under specific conditions, new substances can form in a chemical reaction. There are observations that can be made to indicate a chemical change has occurred and most of these are quite different to the indicators of physical change. One indicator of chemical change could be a temperature change, and you will explore how temperature indicates that either an exothermic or endothermic chemical reaction has occurred. A combustion reaction is a very common exothermic reaction in which the heat released can be harnessed as energy for a variety of applications.

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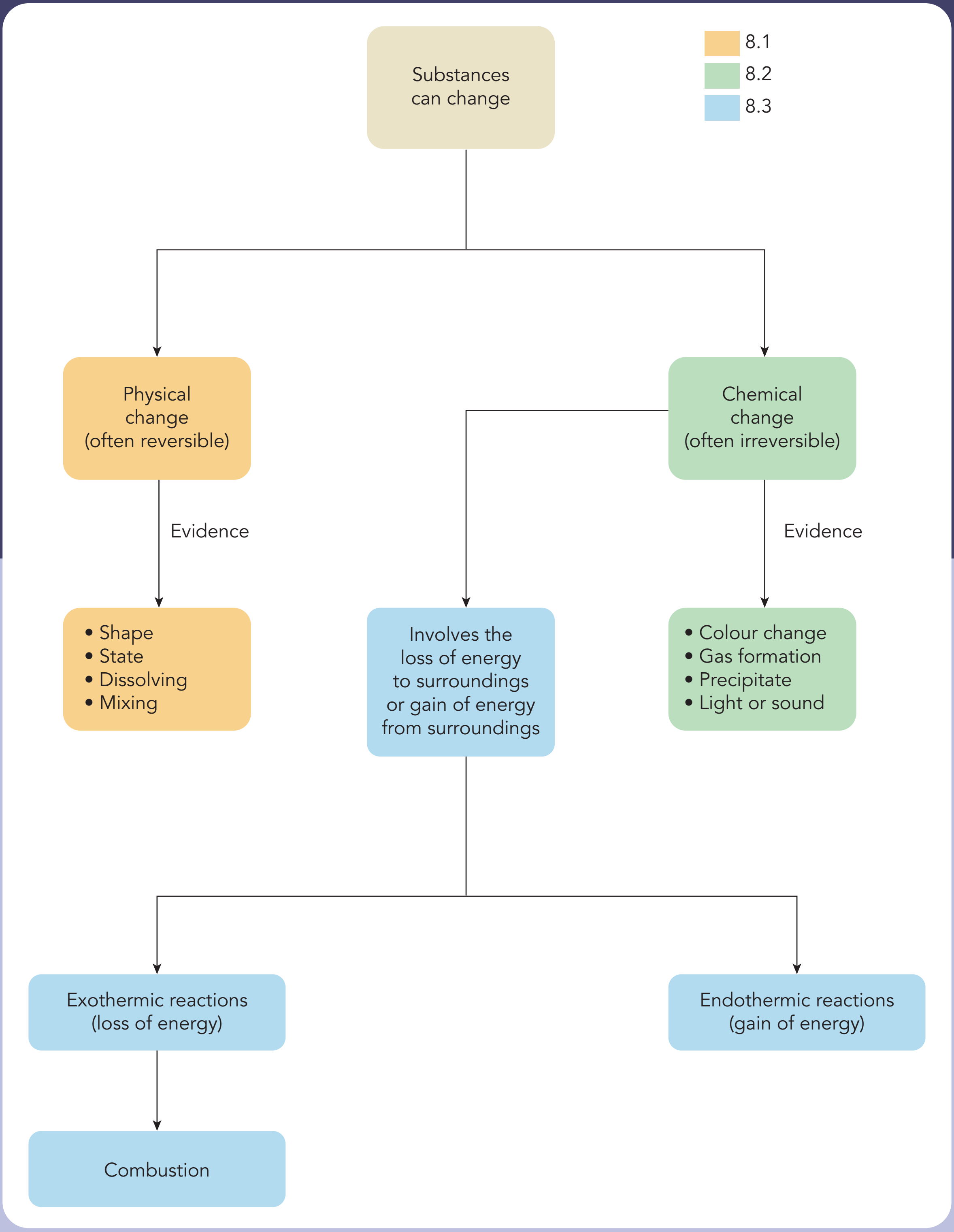
Concept map



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Curriculum

Compare physical and chemical changes and identify indicators of energy change in chemical reactions (AC9S8U07)	
performing simple chemical reactions to identify the indicators of chemical change, such as gas production, solid production, colour change and temperature change	8.2
analysing and interpreting data on the properties of substances before and after the substances interact to determine if a chemical or physical change has occurred	8.1, 8.2
investigating and identifying energy changes in different chemical reactions, such as differences in temperature	8.3
examining how the physical and chemical properties of a substance will affect its production or use	8.3
discussing where indicators of chemical change are used for identifying the presence of particular substances, such as in soil, water and medical testing kits	8.2, 8.3

Glossary terms

Bioluminescence
Chemical change
Chemiluminescence
Combustion
Corrosion
Decomposition
Diffusion
Dissolve
Endothermic
Exothermic
Galvanisation
Hydrocarbon
Irreversible
Kinetic energy
Physical change
Potential energy
Precipitate
Products
Reactants
Reversible

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8.1 Physical change

Learning goal
To be able to describe the common evidence of physical change.

WORKSHEET
Dissolving substances

Evidence of physical change

During a **physical change**, the characteristics of a substance, or its physical properties, change in some way, but no new chemical substance is formed. Examples of physical properties are texture, shape, size, colour, odour, volume, mass and density. As the chemical nature of the substance is not changed, physical changes are usually considered to be **reversible**.

Evidence of a physical change can be any one or more of the following:

- a change in shape
- expansion or contraction
- a change in state
- mixing or dissolving
- a non-permanent colour change.

Changing shape

When an object changes shape, it is generally a physical change. For example, when an elastic band is stretched, the physical properties of the elastic band change but its chemical structure does not; no new chemical substance has formed and it is reversible. Think about a soft drink can being crushed. Have its physical properties changed? Has its chemical structure changed? Has anything new been made? Is it reversible? So, is it a physical change?

physical change
when the physical properties of a substance change in some way, but no new chemical substance is formed; it is mostly reversible

reversible
capable of going in both directions

Figure 8.1 Different types of evidence that a physical change has occurred: change in shape (a), expansion or contraction (b), change in state (c) or mixing (d)

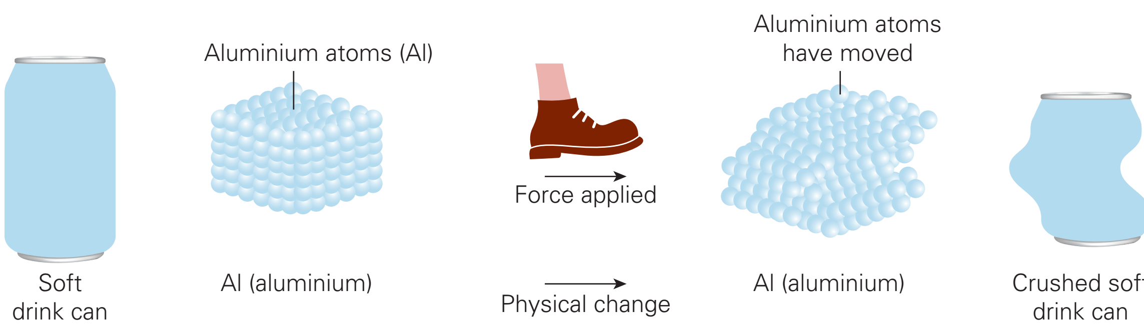

Figure 8.2 When an aluminium can is crushed, the characteristics of the can have changed, but nothing new is formed. Therefore, it is a physical change.

VIDEO
Physical change

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Figure 8.3 An example of a physical change is when glass breaks: its physical characteristics change, but it is still glass.

Figure 8.4 When the air inside a hot-air balloon is heated, the atoms in the heated air gain energy, move faster and move away from one another, 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.

Quick check 8.1

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

Particles expand or contract when exposed to changing temperatures. As the particles in a solid, liquid or gas are exposed to a higher temperature, they absorb some of the energy and convert it to kinetic energy. The particles move more rapidly and this causes the particles to move apart. This is called expansion. Expansion is an example of physical change as the properties of the chemical substance have changed (volume increases and density decreases), but no new chemical substance has formed, and it is reversible. Hot-air balloons and thermometers are two examples of where we can see evidence of the physical change, expansion.

The reverse of expansion is contraction, and this is also evidence of a physical change occurring. The substance cools down, the particles lose energy, they move less rapidly, and the distance between the particles gets smaller (volume decreases and density increases).

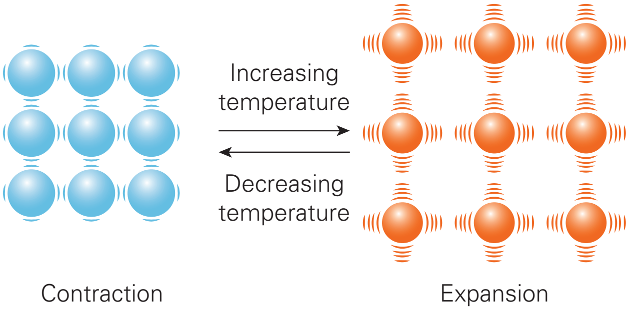

Figure 8.5 The physical changes experienced by atoms during expansion and contraction

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Practical skills 8.1

Making a model thermometer

Aim

To demonstrate expansion and contraction by making a model thermometer

Materials

- 250 mL conical flask
- glass thermometer
- clear plastic straw or clear narrow plastic tubing
- 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 when you change the ratio of hot and cold water in the ice cream container. Check your predictions with the glass thermometer.

Results

Record your observations and tabulate your results: the temperature of each environment and the height of the fluid in the 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 and physical change 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.

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Changing state

If the temperature change is large enough, particles can move beyond expansion and contraction and change into another state! You learned about these states in year 7, and they are solids, liquids and gases. If the heat energy is sufficient, particles in a solid can gain enough kinetic energy to move them apart into a liquid state, or even a gaseous state. In contrast, if heat energy is removed, gaseous particles can move closer together to form a liquid or a solid. The different changes of state are summarised in Figure 8.6 below.

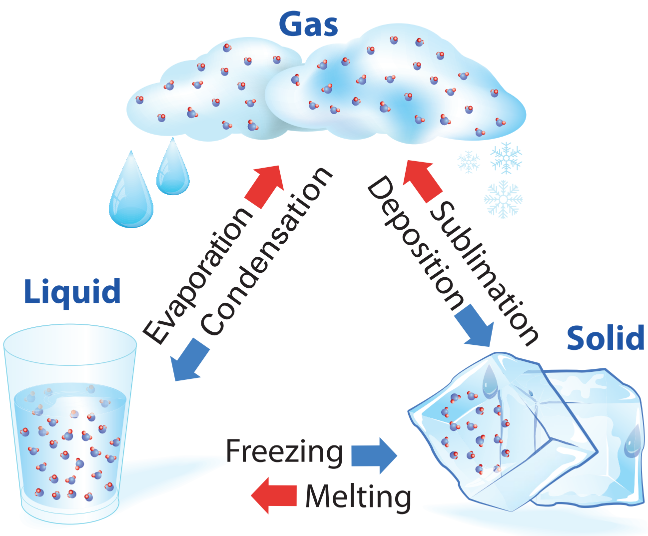

Figure 8.6 When some substances gain or lose heat, they undergo a physical change: no new substance is produced and the substance changes its physical properties but is still the same substance.

Figure 8.7 A snowman melting is an example of physical change. Can you explain why?

Figure 8.8 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.

Did you know? 8.1

Physical changes formed the Glass House Mountains

The Glass House Mountains in Queensland are a picturesque example of physical changes occurring over a very long period of time. The mountains themselves were formed thousands of years ago when molten lava erupted from a very large volcano. The molten lava solidified to form solid rock, changing state, which is now seen as the mountains. The shapes of these rocks have also undergone weathering and erosion, another physical change, due to wind and rain over millennia.

Figure 8.9 Solidification of volcanic lava and physical erosion over thousands of years have formed the Glass House Mountains in Queensland.

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Quick check 8.2

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. For example, a solute (e.g. sugar) **dissolves** in a solvent (e.g. water) to form a solution. The solute does not evenly distribute itself in the solvent immediately. The particles, in this case sugar, spread out in the water from an area of high concentration of sugar to an area of low concentration, until there is an even distribution of sugar throughout the water. This process is called **diffusion**. When the sugar is evenly spread out in the water, there are still the chemical substances of sugar and water, but they are now mixed with each other. The characteristics of the sugar have changed from a crystalline, solid structure to one where all the sugar molecules can move around freely in the water. No new chemical substance has been formed, and the process is reversible if you evaporate the water.

This is why mixing and dissolving are considered evidence of physical change.

dissolve
the process where individual molecules of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

diffusion
the movement of particles from an area of high concentration to low concentration

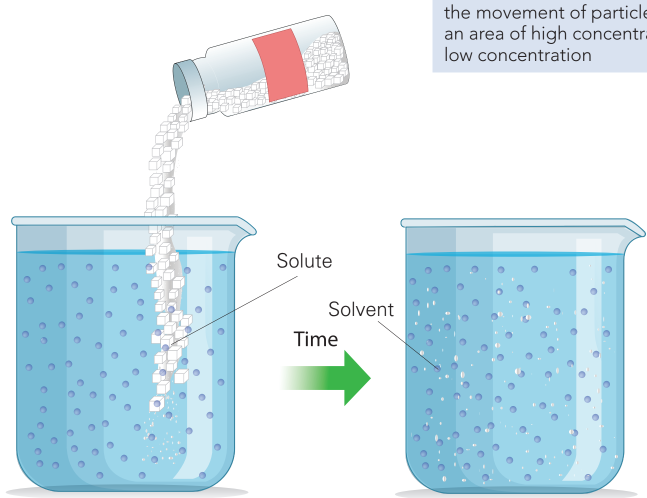

Figure 8.10 Molecules of water (blue) move randomly in a beaker. Add sugar (white) and the new, dissolved molecules will eventually become distributed uniformly throughout the water. This is diffusion.

Making thinking visible 8.1

See, think, wonder: Diffusion

1 Observe a tea bag being added to some hot water.
2 What do you think is happening to the particles to cause the change in appearance? How long does the change take to complete?
3 What questions do you have about the physical change taking place?

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

Figure 8.11 A tea bag in hot water can demonstrate diffusion.

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Quick check 8.3

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 past its use-by date
- o popping popcorn
- p squeezing an orange

Try this 8.1

Modelling physical changes

Using software of your choice, create a model to help your classmates visualise one of the following physical changes:

- changing shape
- changing state
- dissolving and diffusion

Present your visual model to the class to aid their understanding of the physical change.

Section 8.1 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 past its use-by date
- c digesting food
- d ice melting
- e cooking pikelets
- f wood rotting
- g reacting with vinegar
- h inflating a bike tyre
- i grass growing
- j silver tarnishing
- k mopping up water
- l Milo® dissolving in milk

3 **Define** the following terms: reversible, expansion, contraction, melting, freezing, evaporation, condensation, dissolving, diffusion.

4 **State** if each of the following statements is true or false. Then, rewrite the false statements so that they are true.

- a During a physical change, the chemical make-up of the substance also changes.
- b Melting is a physical change.
- c As particles warm up, expansion can occur, so this is a physical change.

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- **d** Physical changes are never reversible.
- **e** When heat is lost from a substance, the particles can move closer together, and a gas can change to a liquid.
- **f** Cutting up a cake changes the shape and size of the cake, so this is a physical change.
- **g** Burning wood in a fire forms charcoal and ash, so this is a physical change.
- **h** When a solute dissolves in a solvent, nothing new is formed, so this is a physical change.

5 **Identify** five physical changes that happen in your home.

6 **State** the name of the process whereby a strong-smelling deodorant is sprayed in one corner of the room but eventually everyone in the room can smell it.

Comprehension

7 **Summarise** the following physical changes, using your knowledge of how particles behave.
- **a** why the tyres on your family car seem more deflated on a cold day
- **b** how the liquid in a glass thermometer works
- **c** why, on extremely hot days, there are concerns about train tracks not working well

Analysis

8 **Consider** how you could reverse the following physical changes.
- **a** salt dissolving in water
- **b** inflating a balloon
- **c** ice melting
- **d** glass breaking

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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8.2 Chemical change

WORKSHEET
Chemical reactions in bread

Learning goal
To be able to describe the common evidence of chemical change.

Evidence of chemical change

During a **chemical change**, a new chemical substance is formed. This new chemical substance could be a solid, a liquid or a gas. The following list describes some examples of when a chemical change has occurred:

- a permanent colour change
- a gas being given off; effervescence (as an odour or bubbles)
- a solid (called a **precipitate**) forming in a solution
- a change in temperature (increase or decrease)
- energy in the form of light or sound being produced (e.g. an explosion).

Chemical changes are generally considered as **irreversible**. 'Irreversible' means that the products cannot easily be converted back to the substances that formed them. Reversing a chemical change requires another chemical reaction to take place.

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 solutions are mixed and undergo a chemical change

irreversible
incapable of going in the opposite direction

Figure 8.12 This brown-coloured rust on the shipwreck of the HMQS Gayundah at Woody Point is an example of a chemical change. Could the rusting be reversed easily?

Did you know? 8.2

Queensland's sugarcane
Sugarcane harvesting is an important industry in Queensland. The physical and chemical properties of the plantation are considered when the time comes to harvest. The physical properties of the plants, such as size, shape and density, will contribute to how effectively the plants can be harvested and processed, while the chemical properties, such as the pH levels of the soil and water, as well as of the plant itself, will impact the quantity of sugar in each plant.

Thus, farmers working on sugarcane plantations must monitor both the physical and chemical properties of their plantation to ensure the highest quality harvest.

Figure 8.13 Sugarcane ready for harvest

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Quick check 8.4

1. On a chemical level, what has happened when 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 fizzing in your mouth
   c. bread baking in the oven

A campfire burning away is an example of chemical change; light, heat and gas are produced and the burning wood permanently changes colour. First Nations Australians have been using fire to cook meat and bush bread for thousands of years. Cooking is also a chemical reaction that provides evidence of chemical change. Think about how your favourite meal changes pre- and post-cooking. Is there evidence of chemical change?

Figure 8.14 Bush bread prepared over hot coals in Broome, WA. Also known as seedcake or damper, it has been cooked by First Nations Australians for thousands of years.

Colour change

A permanent colour change is evidence that a chemical reaction has occurred, as the new chemical substance formed has a different colour to the reactants that made it. Cooking is an example in which colour changes frequently occur. Consider what happens to a marshmallow when it is held over a fire or when a piece of bread is put in the toaster. Can the cooking of the crispy brown marshmallow or toasted bread be easily reversed?

The ripening of fruit and vegetables is another example of a colour change indicating that a chemical change has occurred. For example, when a banana reaches the green stage of its development, it starts to produce ethene gas. The ethene then interacts with enzymes in the banana to start the ripening process, which involves chemical reactions. The evidence of this chemical change is the banana changing from green to yellow to brown.

VIDEO Evidence of chemical reactions

Figure 8.15 Bananas ripening and changing colour are evidence that a chemical change has occurred.

Rusting, a type of **corrosion**, is a slow and usually unwanted chemical change that causes iron and steel to go flaky and brown. This is not desirable in construction when building bridges and train tracks, which are made of iron and steel. Rusting occurs when iron reacts with the oxygen in the air to form iron (III) oxide, also known as 'rust'. This is a new chemical substance forming, and the change in colour is evidence of a chemical change.

corrosion the gradual and natural process of metals reacting with oxygen to form a new chemical substance; an example is rusting

The word equation for the process of rusting is:

$$\text{iron} + \text{oxygen} \rightarrow \text{iron(III) oxide}$$

Given the widespread use of iron and steel, we need ways to prevent rusting. The equation shows that there are two chemical substances

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galvanisation
the process of coating iron or steel in zinc to prevent corrosion

that react together to form one new chemical substance. If iron and steel are not exposed to oxygen, then iron(III) oxide cannot be made and rusting does not occur. There are some methods of stopping the contact of oxygen with iron:

- A surface protector can be painted onto the iron or steel surface. This is like the paint we put on cars to prevent the metal panels being exposed.
- **Galvanisation** is a process in which the iron or steel is coated in a layer of zinc. If a corrugated iron roof has been galvanised, the zinc coating will corrode before the iron, and so the iron is protected from rusting.

Figure 8.16 Iron metal corrodes to form brown iron oxide after years of exposure to oxygen and water.

Figure 8.17 A galvanised corrugated-iron roof: the zinc coating will corrode before the iron underneath, preventing rusting of the iron.

Investigation 8.1

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 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.

continued…

...continued

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.
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

In some chemical reactions, the new chemical substance formed is in a gaseous state. These gases can be useful, particularly in cooking when we want a cake to rise. This occurs because gases are formed and inflate the cake mix or dough.

Another example is when bread is made using microorganisms called yeast. The yeast uses the starch and sugars in the flour to produce alcohol and carbon dioxide. The alcohol escapes during cooking, but the carbon dioxide expands inside the dough, creating bubbles of gas and making the bread rise.

Rotting fruits often produce gas, and again, this is evidence that a chemical change is occurring. For example, vegetable scraps in the compost bin are broken down by microorganisms in a process called **decomposition**, and this produces carbon dioxide gas.

decomposition
a reaction in which one substance breaks up into smaller ones

Figure 8.18 Croissants are a delicious result of chemical change.

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VIDEO
Airbags

Try this 8.2

Thermal decomposition

Many metal carbonates can be involved in thermal decomposition reactions. For example, copper(II) carbonate breaks down easily when it is heated:

Word equation: copper(II) carbonate → copper(II) oxide + carbon dioxide

Chemical equation: $CuCO_3 \rightarrow CuO + CO_2$

Your teacher may demonstrate this. Wearing safety glasses, add two spatulas of copper(II) 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?

Precipitate is formed

The formation of a solid, or precipitate, from a solution is an indicator of chemical change. 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.

Quick check 8.5

1. Name three examples where a colour change indicates that a chemical change has occurred.
2. Recall the word equation that represents the process of rusting.
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

A chemical reaction produces a new chemical substance, however, in every chemical reaction there will always be a change in temperature, even if it is by less than 1°C. Every chemical reaction either releases energy as heat or absorbs energy from the surroundings as heat. For example, when you have started a campfire and the fire burns, you will feel heat radiating from the fire. The chemical reaction that is occurring is:

carbon + oxygen → carbon dioxide + heat

In this case, heat is released as part of the chemical change, and the surrounding temperature increases.

Figure 8.19 When natural gas burns, a lot of heat energy is released, and we use this heat to cook our food.

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But the opposite can also happen; heat energy can be absorbed, and the temperature decreases. Chemical ice packs are a common example of this. If you injure yourself, you may be offered an ice pack. You pop a bubble inside the pack and the pack starts to 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

Light and sound can be evidence that a chemical change has taken place. Fire is a great example. Fire releases light energy and is always an indicator of a chemical change. Consider fireworks that release light and sound; could it be a chemical change? What other examples can you think of where light or sound are emitted as evidence of a chemical change?

WIDGET
Physical versus chemical change

WORKSHEET
Physical versus chemical change

Did you know? 8.3

Queensland's glow worms

A chemical reaction occurs in the abdomens of glow worms, allowing them to produce light! This process is called **bioluminescence** and is shared by many other organisms, mostly sea-dwelling or marine organisms. (Note that bioluminescence is a type of **chemiluminescence**).

When oxygen combines with the chemical luciferin, and a bioluminescent enzyme is also present, light is produced. When oxygen is available, the glow worm's light organ glows, and when it is not available, the light goes out. The glow worm can control the beginning and end of the chemical reaction, and thus start and stop the production of light. However, the glow worm has limited control over how much oxygen can enter its light organ. Unlike a light bulb, which gets hot when it produces light, a glow worm's light is cold light, and so very little energy is lost as heat. This is very lucky for the glow worm because it would not survive getting as hot as a light bulb!

Figure 8.20 The abdomen of a glow worm produces light through a chemical reaction known as bioluminescence.

bioluminescence
a chemical reaction that produces light in living things

chemiluminescence
a chemical reaction that produces light

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Explore! 8.1

Rapid antigen tests (RATs)

The rapid antigen test (RAT) is commonly used for the detection of some types of virus particles, such as flu viruses and coronaviruses, and it is likely that you have used one of these at home.

This test uses antibodies to chemically react with the antigen (proteins on the virus particle), and if this chemical reaction occurs, a new antigen-antibody product is formed. This new product then reacts with enzymes that cause a colour change. This colour change is observed as a line on the RAT, confirming that the virus particle is present.

Figure 8.21 Rapid antigen tests work because chemical reactions occur.

If a virus particle isn't present, the chemical reactions won't occur, and no colour change will be observed.

Use the internet to explore what other viruses RATs are currently being used to detect.

Quick check 8.6

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 produced provides evidence of chemical change.

Practical skills 8.2

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 mol L^{-1} hydrochloric acid
- thermometer
- 100 mL glass beaker
- lemon juice
- baking soda
- Pasteur pipette

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Method

Copy the results table.

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 full Pasteur pipette volumes 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.

Results

Activity	Change in colour	Change in temperature (°C)	Gas produced	Light produced	Precipitate produced	Other 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.

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Did you know? 8.4

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 8.1 Some of the many physical and chemical changes that occur in the digestive system

Figure 8.22 The digestive system uses physical changes and chemical changes to break down your food for absorption.

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Did you know? 8.5

The detection of doping in sport

The fairness of professional sport is of utmost importance for the integrity of many sporting codes and competitions worldwide. In Australia, the Australian Government founded the Australian Sports Anti-Doping Authority (ASADA) in 2006, to protect Australia's sporting integrity and eliminate doping. Doping is the act of giving a person or animal drugs in order to make them perform better or worse in a competition.

ASADA uses a variety of chemical tests on athletes to detect the use of recreational or performance-enhancing drugs. These tests work by using chemical reactions to identify specific chemicals, such as enzymes and proteins, or to prepare a sample for further testing.

This type of testing is becoming more and more commonplace at professional Australian sporting events and is prominent in ensuring that Australian athletes and sporting competitions are fair.

Figure 6.23 ASADA officers are present at many professional Australian sport matches and competitions.

Practical skills 8.3: 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

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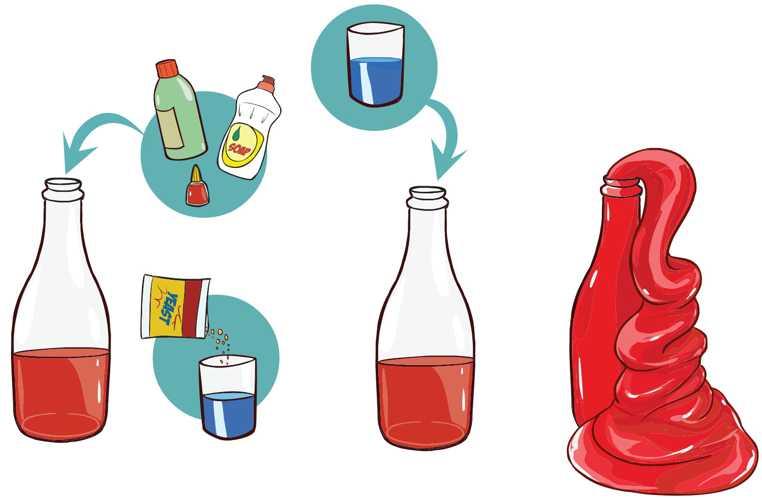
Method

1 Pour the hydrogen 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 four 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.
5 Write the chemical equation for the decomposition of hydrogen peroxide (H_2O_2).
6 Investigate yeast and find out why it is included as an ingredient in this reaction.

Section 8.2 questions

QUIZ

Retrieval

1 **Name** three examples of chemical change occurring in your home.
2 For each of the following situations, **summarise** the signs of chemical change you would observe.
   a Bread is baking in an oven.
   b Glow sticks emit light when you break them.
   c Sandwiches go mouldy.
   d Baking soda and vinegar are mixed.

Comprehension

3 **Explain** the process of rusting and why it is an example of chemical change.
4 A stoppered test tube of yellow liquid is left on the window sill 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.

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Analysis

5 **Distinguish** between bioluminescence and chemiluminescence.

6 **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

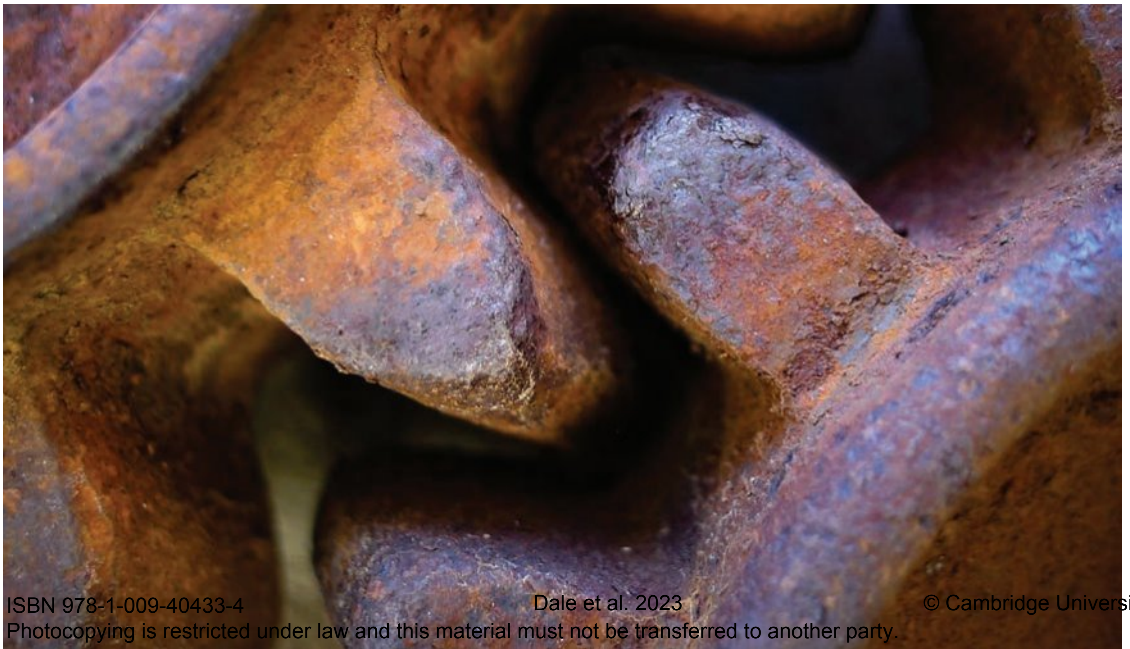
7 **Identify** the types of changes occurring in the following situations. (There may be more than one type.)
   - a Pastry is defrosted and then used to make a pie.
   - b To make honeycomb, sugar is mixed with water and honey, heated, and then bicarbonate of soda is added.
   - c A candle burns and wax drips down the side.

Knowledge utilisation

8 **Determine** the reasons why galvanised iron does not rust.

9 **Propose** why rusting occurs faster on door hinges of boat sheds compared to door hinges a kilometre inland from the beach.

10 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



8.3 Energy in chemical reactions

WORKSHEET
Graphing endothermic and exothermic reactions

Learning goals

1. To be able to identify reactants and products in a chemical reaction.
2. To be able to compare the indicators of exothermic and endothermic reactions.
3. To write a word equation for the combustion reaction of a hydrocarbon.

In this section you will further explore temperature change in chemical reactions, which is an indicator of chemical change. Heat energy can either be absorbed from the surroundings and added to the reactants or released to surroundings when the new chemical products form.

Reactants and products

In a chemical reaction, the chemical substances that react are called **reactants**, and the substances that are produced are called **products**. A chemical reaction can be represented in different ways, such as a word equation or a symbol equation (also called a chemical equation).

reactants
the chemical substances that are present at the beginning of a chemical reaction

products
the chemical substances that are present at the end of a chemical reaction

An example of a chemical reaction is when light hits photographic film coated with tiny crystals of the compound, silver chloride. When the film is exposed to light, a chemical reaction occurs, and this darkens the film to produce an image. This reaction can be represented by a word equation and by a chemical equation.

Figure 8.24 Photographic film works because of chemical reactions.

Word equation:

silver chloride → silver + chlorine

Chemical equation:

$$2AgCl \rightarrow 2Ag + Cl_2$$

The reactants, or in this case reactant, are 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. 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 created or destroyed, they just move around during chemical reactions. 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. These 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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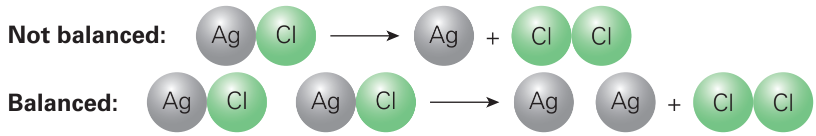

Figure 8.25 Keeping it simple: balancing equations is like working out whether you need one or two cups of flour to make bread. The top equation is not balanced, because the number of chlorine atoms is not the same on both sides of the reaction.

Quick check 8.7

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 8.26 The rusting on a railway track is evidence of a chemical reaction.

Exothermic and endothermic reactions

Particles in a chemical reaction are constantly moving as they have **kinetic energy**. There is also **potential energy**, also known as chemical energy, stored within the chemical bonds between atoms in molecules. When the atoms rearrange in a chemical reaction, the potential energy stored in the bonds also changes, as old bonds are broken and new bonds are formed. As the new chemical bonds will always be different to the old chemical bonds, the potential energy of the reactants and products will always be different. But as energy cannot be created or destroyed, it must go somewhere! If the energy is lost, it is lost as heat energy to the surroundings, and if it is gained, heat energy is removed from the surroundings. This is observed as a change in temperature, an indicator of chemical change.

VIDEO Exothermic and endothermic chemical reactions

kinetic energy
the energy of moving matter

potential energy (chemical)
the energy stored in the chemical bonds of a substance

exothermic
a release of heat in a chemical reaction characterised by an increase in surrounding temperature

Reactions that release energy, like the burning of wood on a campfire, are described as **exothermic** reactions.

In science, it is useful to understand where words come from, so let us split up the word *exothermic*. The *exo* part of exothermic means external. The *thermic* part of exothermic means heat. If you put these two parts together, then exothermic just means external heat (heat leaving the reaction).

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You can tell if a reaction is exothermic because you will observe a rise in temperature. Heat has left the chemical reaction and gone into the immediate surroundings; it is the temperature of the surroundings that you will measure in an experiment.

Figure 8.27 The word 'exothermic' means external heat.

Figure 8.28 Burning wood is an example of an exothermic reaction because heat is released.

In exothermic reactions, the products have less potential energy than the reactants, which is why this extra energy is released into the surroundings. It is helpful to see what is happening in an exothermic reaction by looking at an energy profile diagram, such as shown in Figure 8.30.

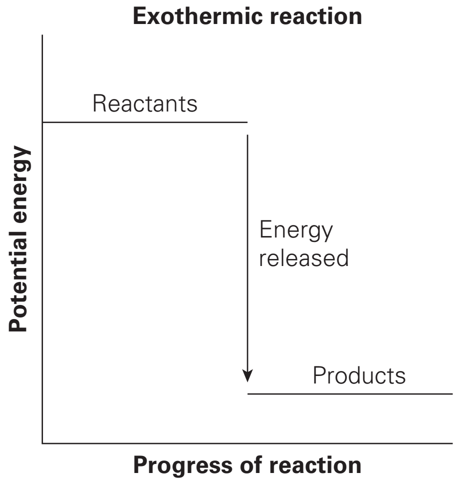

Figure 8.30 An energy profile diagram for an exothermic reaction

In this reaction, the reactants have more potential energy in their bonds than the products, so surplus energy is released into the surroundings.

Figure 8.29 These fireworks in Brisbane were launched into the sky using an explosion, which is a very fast exothermic reaction.

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Reactions that take in energy from the surroundings, for example, photosynthesis, where plants use light energy to make their own food, are described as **endothermic** reactions.

In this word, *endo* means internal and *thermic* means heat. You can tell if a reaction is endothermic because you will observe a decrease in temperature: heat has left the immediate surroundings and has gone into the reaction.

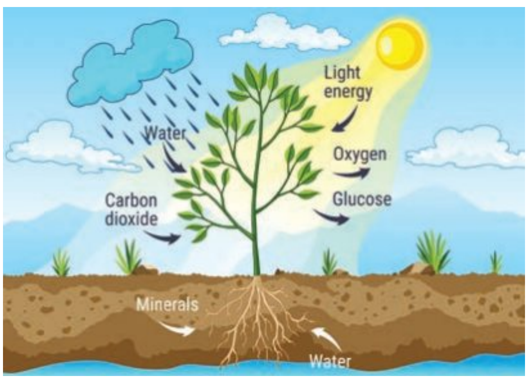

Figure 8.31 Photosynthesis, in which plants use the Sun's light energy to make their own food, is an example of an endothermic reaction.

Figure 8.32 The word 'endothermic' means internal heat.

In endothermic reactions, the products have more potential energy than the reactants, because extra energy is absorbed from the surroundings. It is helpful to see what is happening in an endothermic reaction by looking at an energy profile diagram, such as shown in Figure 8.33.

In this reaction, the products have more potential energy than the reactants, so energy is absorbed into the reaction from the surroundings.

endothermic
an absorption of heat in a chemical reaction characterised by a decrease in surrounding temperature

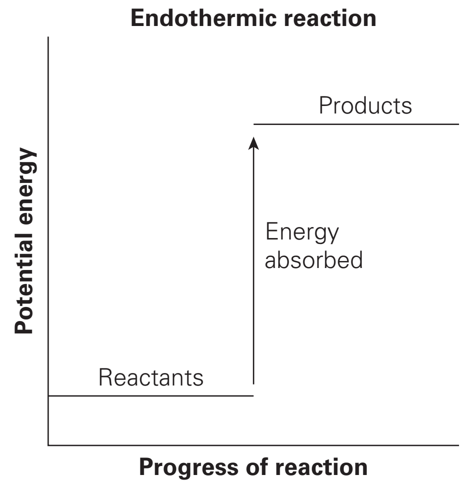

Figure 8.33 An energy profile diagram for an endothermic reaction

Quick check 8.8

1. During a chemical reaction, the temperature of the solution decreases. Infer whether this reaction is endothermic or exothermic.
2. 'Cellular respiration is an example of an endothermic reaction because it releases energy into the surroundings.' Is this statement true or false?
3. During a chemical reaction between hydrochloric acid and sodium hydroxide, the temperature went up by 5°C. Infer whether the reaction is endothermic or exothermic.
4. 'Burning wood is an example of an exothermic reaction because the products have more potential energy than the reactants.' Propose whether this statement is true or false.

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Practical skills 8.4: Teacher demonstration

Endothermic and exothermic reactions (1)

Be careful
Ensure that appropriate gloves are worn during this experiment.

Aim

To determine whether a reaction is endothermic or exothermic

Materials

Experiment 1

- 1.4 g of potassium iodide
- 30% hydrogen peroxide solution
- food colouring
- dishwashing detergent
- 100 mL plastic measuring cylinder
- plastic tray
- spatula

Experiment 2

- 10 g of ammonium chloride
- 32 g of barium hydroxide
- 250 mL beaker
- wooden block
- glass stirring rod
- thermometer

Method

Copy the results table.

Experiment 1

1. Place the 100 mL measuring cylinder in the middle of the plastic tray.
2. Add a squirt of dishwashing detergent and a few drops of food colouring to the measuring cylinder.
3. Pour about 65 mL of 30% hydrogen peroxide into the measuring cylinder.
4. Add the potassium iodide to the flask, stand back and watch.

Experiment 2

1. Put a drop of water on the wooden block and place the 250 mL beaker on top of the water.
2. Mix the ammonium chloride and barium hydroxide together in the beaker, stirring with the stirring rod, and observe the change in temperature.
3. Now try to remove the beaker from the block.
4. Pass the wooden block around the class and feel the change in temperature.

Results

Experiment	Observations	Exothermic or endothermic
1		
2		

Analysis

1. How did you know that a chemical reaction had taken place in both experiments?
2. Draw an energy profile diagram for each experiment.
3. Explain why the two solids in *Experiment 2* changed into a liquid without any heat being applied to the beaker.
4. Determine why the reaction mixture shot out of the measuring cylinder in *Experiment 1*.

Conclusion

Draw a conclusion from this experiment regarding whether each reaction is endothermic or exothermic.

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Practical skills 8.5

Endothermic and exothermic reactions (2)

Be careful

Ensure that appropriate gloves are worn during this experiment.

Aim

To determine whether a reaction is endothermic or exothermic

Materials

- 0.5 mol L^{-1} hydrochloric acid
- 1.0 mol L^{-1} hydrochloric acid
- 0.5 mol L^{-1} sodium hydroxide solution
- 1 mol L^{-1} copper sulfate solution
- 1 mol L^{-1} sodium hydrogen carbonate solution
- 2 × 3 cm piece of magnesium ribbon
- 1 spatula of zinc powder
- 1 spatula of citric acid
- 10 mL measuring cylinder
- thermometer
- foam cup with lid

Method

1. Copy the results table, which gives the reactants to be used in five experiments.
2. Pour 10 mL of the first substance in *Experiment 1* into the cup and measure the starting temperature. Record the temperature in your results table.
3. Add the required amount of the other substance listed in *Experiment 1* to the cup, poke the thermometer through the lid and attach the lid to the cup.
4. When the temperature on the thermometer remains stable, record the final temperature in the results table.
5. Work out the temperature change and decide whether the reaction is endothermic or exothermic.
6. Repeat for the other experiments listed in the table.

Results

Experiment		Start temperature (°C)	Final temperature (°C)	Temperature change (°C)	Endothermic or exothermic
1	10 mL 0.5 mol L^{-1} hydrochloric acid + 3 cm piece of magnesium ribbon				
2	10 mL 1.0 mol L^{-1} hydrochloric acid + 3 cm piece of magnesium ribbon				
3	10 mL 0.5 mol L^{-1} hydrochloric acid + 10 mL sodium hydroxide solution				
4	10 mL copper sulfate solution + 1 spatula zinc powder				
5	10 mL sodium hydrogen carbonate solution + 1 spatula citric acid				

Analysis

1. Explain how you determined if each reaction was endothermic or exothermic.
2. Compare the temperature change for *Experiments 1* and *2*. Did changing the concentration of HCl affect the temperature change in the reaction?
3. Describe what happened to the energy in the reaction between sodium hydrogen carbonate and citric acid in *Experiment 5*.

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Combustion

combustion
a reaction that involves the burning or exploding of a chemical substance in the presence of oxygen

Chemical reactions that involve the burning or exploding of a chemical substance in oxygen are called **combustion** reactions. This type of reaction is exothermic, and the heat released can often be harnessed and transformed to different types of energy, including electrical energy.

For example, methane, also called natural gas, can be used for cooking or heating water in a household. Methane 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 modern cars. 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 8.34 Octane is a component of petrol.

Try this 8.3

Creating a visual model of a combustion reaction

For this task you will need to:

- draw and colour in two circles labelled 'C' for carbon, eight circles labelled 'H' for hydrogen and eight circles labelled 'O' for oxygen
- cut out these circles such that they represent individual atoms
- organise the atoms such that they illustrate the following combustion reaction $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- check whether all atoms are present on either side of the chemical reaction. Why or why not?

hydrocarbon
chemical substance containing only hydrogen and carbon atoms

When **hydrocarbons**, chemical substances containing only hydrogen and carbon atoms, are burned in oxygen, carbon dioxide and water are produced, as well as light and heat. This is one example of how the heat released in an exothermic reaction can be harnessed to provide energy for tasks in our daily lives.

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Did you know? 8.6

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 have allowed candles to be a perfect candidate for lighting purposes for thousands of years.

Figure 8.35 The wick provides a surface on which the wax can undergo a combustion reaction.

Practical skills 8.6: Teacher demonstration

Sugar snake

Be careful

Wear appropriate personal protective eqiupment, including safety glasses. Only conduct this experiment in a well-ventilated area.

Aim

To investigate a combustion reaction

Materials

- fume hood or well-ventilated area (outdoors recommended)
- teaspoons
- aluminium pie tin
- sand
- mixing bowl
- lighter fluid (or isopropyl alcohol)
- matches
- powdered sugar
- baking soda

Method

1. In a bowl, combine four teaspoons of powdered sugar with one teaspoon of baking soda.
2. 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. Which 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?

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Quick check 8.9

1 Explain how you would identify that a chemical reaction was a combustion reaction.

Science as a human endeavour 8.1

Synthesis of medicines

Scientists employ a wide range of chemical reactions to create new complex molecules. An example of this is the development of medicines to specifically target certain diseases.

Scientists are always working to create new vaccines, and antiviral and antibiotic agents for a range of new and old diseases. The synthesis (making) of such molecules may require more than 10 or 20 steps of chemical reactions to achieve the complex medicine. Each one of these steps either uses energy (endothermic) or loses energy to the surroundings (exothermic).

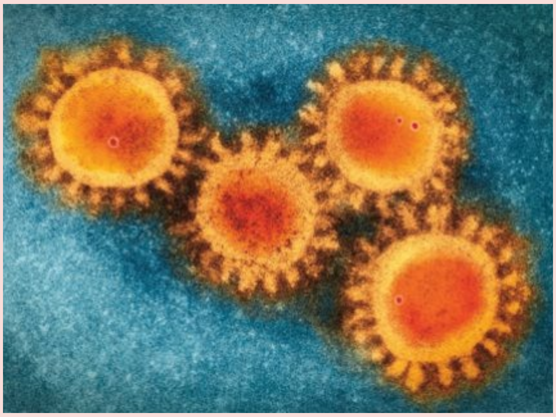

Figure 8.36 The coronaviruses are a family of viruses that includes SARS (shown in the image), MERS and more recently, SARS-CoV-2.

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 virus responsible for COVID-19.

Section 8.3 questions

QUIZ

Retrieval

1 **Identify** the gases that are products of combustion reactions involving hydrocarbons.
2 **Recall** one example of an endothermic reaction and one example of an exothermic reaction.

Comprehension

3 **Explain** why when fire blankets are put over a fire, they cause the fire to be put out.
4 During photosynthesis, plants use the Sun's energy to make their own food. **Explain** why this is an example of an endothermic reaction.

Analysis

5 **Contrast** exothermic and endothermic reactions.
6 **Classify** the following as exothermic or endothermic reactions.
   a a reaction in which the temperature decreases
   b releasing energy from food in cellular respiration
   c baking a cake
   d combustion

Knowledge utilisation

7 **Construct** a word equation for the combustion of butane (barbeque gas) to form carbon dioxide and water.
8 **Decide** if the following statement is true or false: 'Combustion is a chemical reaction'. Give reasons for your choice.

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Chapter review

Chapter checklist

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

Success criteria		Linked questions	Check
8.1	I can describe ways to identify if a physical change has occurred.	2, 4, 15	
8.2	I can describe ways to identify if a chemical change has occurred.	4, 11, 15	
8.3	I can identify the reactants and products in a chemical reaction.	8, 10	
8.3	I can compare the indicators of exothermic and endothermic reactions.	5, 9	
8.3	I can write the word equation of a combustion reaction.	3, 6, 8	

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 **State** whether each of the following processes is a physical or chemical change.
   - a moth balls evaporating in a cupboard
   - b building a sandcastle
   - c hydrogen burning in chlorine gas
   - d fogging up a mirror by breathing on it
   - e breaking a bone
   - f a broken bone mending
   - g slicing potatoes for making chips
   - h hand sanitiser evaporating
   - i mixing sugar with coffee
   - j making a paper aeroplane
   - k pan frying dumplings
   - l copper turning green when exposed to the air
   - m paper ripping

4 **State** whether the temperature of the surroundings would increase or decrease in an endothermic reaction.

Comprehension

5 When Tori reacts a lump of calcium carbonate with sulfuric acid, she notes that water, carbon dioxide and calcium sulfate form.
   - a **State** the word equation representing the information given.
   - b **Identify** the reactants and the products and give reasons for your answer.

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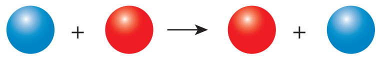
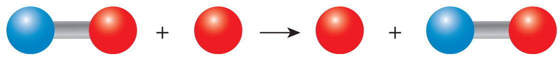
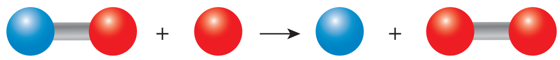
6 **Identify** which of the following are examples of chemical reactions.

A 

B 

C 

7 When a chemical substance containing carbon and hydrogen burns, it reacts with a gas in the air and forms another gas.
   a **Name** the gas produced from this reaction.
   b **Identify** the type of chemical reaction.

8 **Explain** what evidence could determine whether a combustion reaction is an exothermic or endothermic reaction.

9 a **Explain** why baking cookies is not an example of physical change.
   b **Explain** why bending metal in half is not an example of chemical change.

10 **Summarise** the observations you could make if a chemical change had occurred.

Analysis

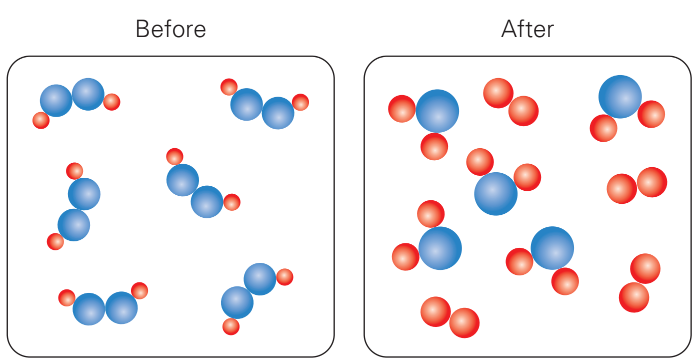
11 **Explain** why a colour change occurring is not always a sign that a chemical change has occurred.

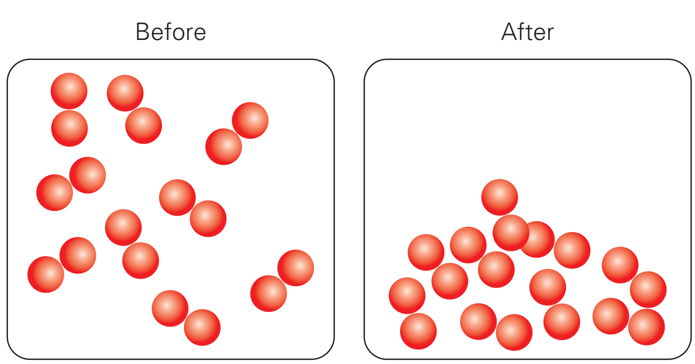
12 **Critique** the following statement: 'Atoms that are not in the reactants can end up in the products of a chemical reaction'.

Knowledge utilisation

13 a When you combine bicarbonate of soda and buttermilk, a gas is produced. **Propose** why the gas is considered evidence that a chemical reaction occurred.
   b **Propose** whether it is possible to continue adding more and more of only one reactant and expect to get more and more product. Give reasons why or why not.

14 **Determine** whether each of the particle diagrams below indicates a chemical or physical change. Justify your answer.

a


b


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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 → B reaction 1
B → C reaction 2

The mass of each species is plotted in Figure 8.37, with respect to time passed in the reaction.

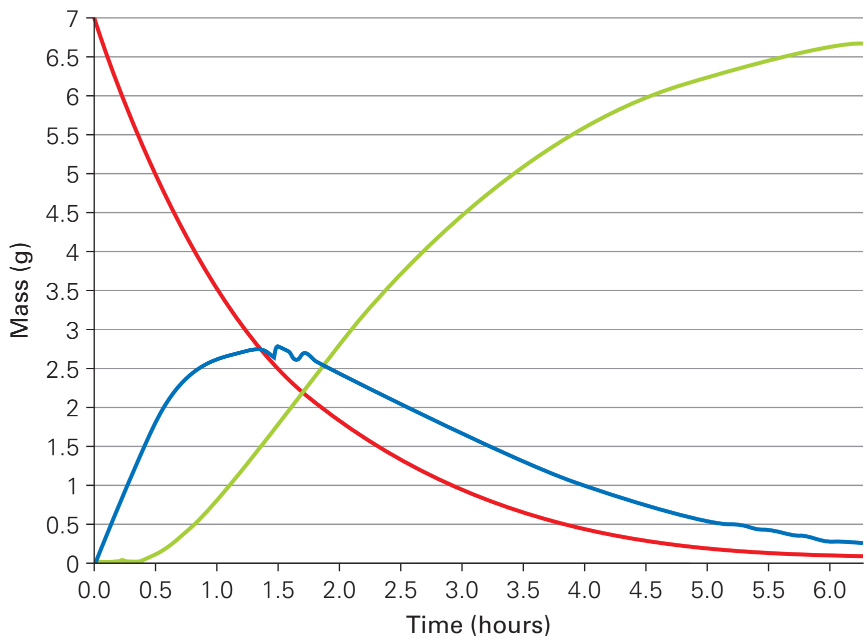

Figure 8.37 Change in mass of the reactant (in red), intermediate (in blue) and product (in green) over time in a chemical reaction.

Apply

1 **Identify** the colour of the line that represents the reactant A.
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 curves 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 the reaction mixture would have appeared blue.

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STEM activity: Building a rocket

Background information

Rockets are very heavy machines capable of lifting off the surface of Earth and obtaining a height sufficient to reach the orbit of Earth. This lift-off requires a combustion reaction to provide the thrust needed to overcome the force of gravity and shoot up into orbit. Combustion is a rapid, heat-producing (exothermic) reaction between a fuel and oxygen. During a chemical reaction, chemical bonds are broken and new bonds are formed, creating new chemical products. The exhaust from the bottom of the rocket produces a great thrust or force, and the opposing force pushes the rocket upward.

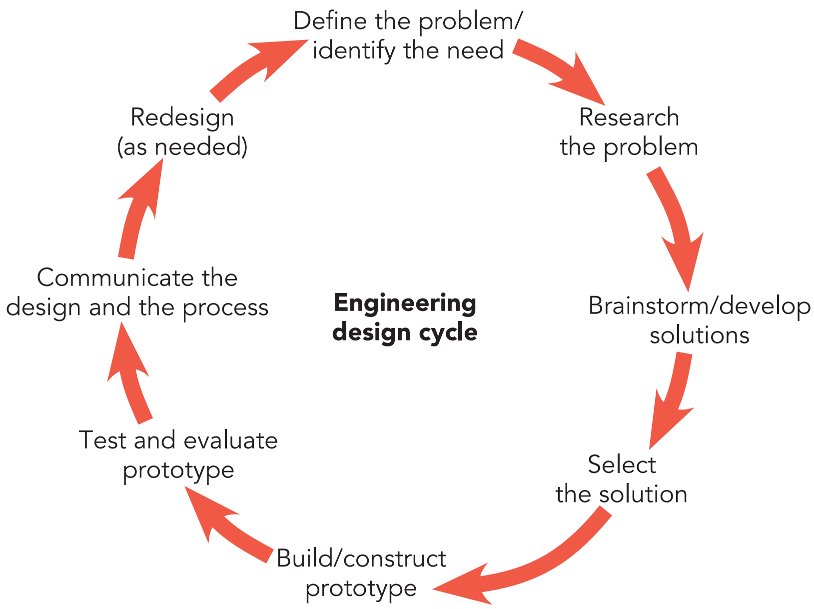

Figure 8.38 Designing and testing of a model comes before construction of the real thing.

Figure 8.39 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 ensure the rockets will work, without wasting time and money on testing full-size rockets. They can test the thrust and stability and make modifications in order to design the best rocket possible with the materials available.

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 such as some prescription medicine bottles)
- 1 antacid tablet
- water
- scissors, sticky tape, markers, 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 reusable 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 identifying the correct amount of antacid and water in the film canister in order to ensure the rocket launches at approximately 10 seconds. The build team needs to ensure the rocket can launch safely and sustainably.

Evaluate and modify

8 Discuss the different conditions you investigated and what you found out about the effect of temperature, surface area and mass of 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 changes/improvements you made at each step along the way.

10 Consider both your rocket and the other rockets you observed being launched. Identify and describe the characteristics that make one rocket perform better than another.

11 Discuss what challenges you faced while designing and testing your rocket and how you overcame these challenges.

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Glossary

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

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

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

Anus the opening at the end of the digestive tract, through which solid waste leaves the body

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

Artery a thick, muscular elastic vessel that carries blood away from the heart

Asthenosphere the softer layer of rock under the lithosphere

Atom the smallest particle that makes up all matter

Atrioventricular node a natural pacemaker that controls the heartbeat and is located between the atria and the ventricles

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

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

Biconcave concave on both sides

Bile a substance produced in the liver and stored in the gall bladder, which helps break down fats

Biological weathering the disintegration of rocks that is caused by living things

Bioluminescence a chemical reaction that produces light in living things

Bolus a lump of partially digested food

Breccia sedimentary rock composed of angular broken pieces of rock larger than two millimetres

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

Causation one event is caused by another event occurring

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

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

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

Cementation the sticking together of sediment

Chemical bond strong force of attraction between two atoms

Chemical change where one or more substances undergo a chemical reaction and a new substance, or substances, is formed; mostly irreversible

Chemical digestion a series of chemical reactions in which enzymes break food into simpler chemical substances that can be used by the body

Chemical formula a symbol for a compound that shows which elements, and how many atoms of each element, are present in one molecule or one basic unit of that compound

Chemical potential energy the energy stored in the chemical bonds between atoms

Chemical substance matter that contains only one type of particle

Chemical weathering the disintegration of rocks caused by acidic rainwater

Chemiluminescence a chemical reaction that produces light

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

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

Clasts small pieces of pre-existing rock that form a sedimentary rock

Cleavage the tendency of a mineral or a rock to break in a particular way because of its structure

Colloid a mixture in which particles of one chemical substance will not dissolve but remain distributed throughout another chemical substance

Combustion a reaction that involves the burning or exploding of a chemical substance in the presence of oxygen

Compaction the process of particles becoming closely positioned together, using very little space

Compound chemical substance made up of two or more different types of atoms

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Conductivity the ability of a substance to conduct or carry electricity or heat

Conglomerate sedimentary rock composed of rounded rock fragments larger than two millimetres

Constructive (divergent) a type of plate boundary that occurs when plates move away from one another

Continental drift the theory of how the continents on Earth have moved over millions of years

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

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

Convection currents the transfer of heat due to temperature differences between the upper and lower layers of Earth's mantle, causing movement of rocks within the mantle

Core the inner part of Earth's structure

Corrosion the gradual and natural process of metals reacting with oxygen to form a new chemical substance; an example is rusting

Craton the stable interior portion of a continent

Crust the solid, outer layer of Earth that supports all life on Earth

Crystal a mineral in which the atoms are arranged in an ordered way to form a geometric shape

Crystallisation the formation of rock crystals in cooling magma

Cultural appropriation use of cultural knowledge or tradition without acknowledgement or consent

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

Decomposition a reaction in which one substance breaks up into smaller ones

Deep time the idea first suggested by James Hutton that Earth is very old

Dependent variable the variable in an experiment that you measure to see if changes to the independent variable cause it to change

Deposition process that occurs when eroded particles stop moving and build up to form sedimentary rocks

Destructive (convergent) a type of plate boundary that occurs when plates move towards one another

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

Diatomic element an element that exists as a molecule consisting of two atoms of the same type

Differentiation the process by which stem cells become specialised

Diffusion the movement of particles from an area of high concentration to low concentration

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

Dissolution when water dissolves minerals in rocks

Dissolve the process where individual molecules of a solute are separated from one another and surrounded by solvent molecules, causing them to no longer be visible in a solution

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

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

Ductility the ability of a substance to be drawn into a wire

Duodenum the first section of the small intestine where many enzymes are secreted

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

Electrolysis a method of extracting a metal from its ore or purifying it using electricity

Electromagnetic spectrum a way of organising electromagnetic waves according to their energy and wavelength

Element chemical substance made up of only one type of atom

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

Emulsion a colloid of two or more liquids

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

Endothermic an absorption of heat in a chemical reaction characterised by a decrease in surrounding temperature

Energy the capacity to do work; the total amount of energy is conserved in any process

Energy transfer the movement of energy from one place or object to another

Enzyme a protein that can speed up chemical reactions in living organisms

Epicentre the location on Earth's surface directly above the focus of an earthquake

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Erosion the transport of rocks from one place to another as a result of weathering

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

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

Exothermic a release of heat in a chemical reaction characterised by an increase in surrounding temperature

Exponential a growth or decline that becomes more rapid proportional to the growing number or size

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

Extrusive describes igneous rocks formed on Earth's surface; also called volcanic rocks

Filaments red, fleshy part of the gills with thousands of fine branches that take oxygen from water into the blood

Focus the exact point under the surface of Earth where the earthquake occurs

Fossil the remains, shape or trace of a bone, shell, microbe, plant or animal that has been preserved in rock for a very long time

Function the job that an object does

Gall bladder a small organ near the liver that stores bile and secretes it into the duodenum

Galvanisation the process of coating iron or steel in zinc to prevent corrosion

Generator a device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

Geoid a model of Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

Geology the study of the rocks and similar substances that make up Earth and other planetary objects

Geosphere the parts of Earth that are solid (like the mantle and crust)

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

GPS Global Positioning System, a radio navigation system that allows land, sea and airborne users to determine their exact location, velocity and time

Gravitational potential energy a type of potential energy; the energy an object has because of its height; GPE = mgh, where m is the mass of the object in kg, h its height in metres and g is acceleration due to Earth's gravity, 9.8 m/s^2

Guard cells cells on either side of a plant stoma that control gas exchange by opening and closing the stoma

Haemoglobin a protein in red blood cells that binds to oxygen

Heat thermal energy that is transmitted due to differences in temperature

Herbivore a consumer (heterotroph) that feeds on plant matter

Heterogeneous mixture describes a mixture that can be separated into its parts, and the parts retain their original properties; the mixture is not blended evenly

Heterotroph any organism that obtains its nutrients by consuming other organisms

Homogeneous mixture describes a mixture of two or more substances that are evenly distributed and do not separate out easily

Hotspot a pocket of magma that sits just underneath the crust

Hydrocarbon chemical substance containing only hydrogen and carbon atoms

Igneous describes rocks made from lava on the surface or magma below the surface

Ileum the third section of the small intestine, where further food breakdown and nutrient absorption occur

Independent variable the variable in an experiment that you change or allow to change so it causes change in the dependent variable that you can measure

Inner core the solid centre of Earth; probably made of iron

Input energy the energy that a machine or device uses as its source of energy

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

Intolerance an inability to eat a food without resulting in adverse effects

Intrusive describes igneous rocks formed underground; also called plutonic rocks

Irreversible incapable of going in the opposite direction

Jejunum the second section of the small intestine, where food breakdown and nutrient absorption occur

Joule the unit of energy or work done by a force of one newton over one metre

Karst an area of land formed of rock such as limestone that is worn away by water to make caves and other formations

Kinetic energy the energy of moving matter

Lag time the time between the arrival of the P and S waves

Large intestine the organ that is connected to the small intestine at one end and the anus at the other

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Lattice a three-dimensional shape of atoms that pack together very tightly and form bonds that are extremely strong because the atoms bond to each other in multiple directions

Lava molten rock from inside Earth (magma) that has reached the surface

Law of conservation of energy the law that states that energy cannot be created or destroyed

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

Light energy a form of energy that travels as electromagnetic waves and can travel in a vacuum

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

Lithosphere the solid outer layer of Earth consisting of the crust and top layer of the upper mantle; it is split into giant slabs called tectonic plates

Liver a large organ that has many functions, including the production of bile

Lustre the ability of a substance to become shiny when polished

Macroscopic visible to the naked eye

Magma hot liquid rock found just below the surface of Earth

Malleability the ability of a substance to be bent or flattened into a range of shapes

Mantle the layer of Earth underneath the crust that is made up of solid and semi-molten rock and surrounds the outer core

Mechanical digestion a series of mechanical processes that break food down, such as chewing with teeth, mixing in the stomach and emulsification with bile

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

Metal a chemical substance that is shiny (lustrous), can conduct electricity and heat, is malleable and ductile, and is usually silvery/grey

Metalloid a non-metallic substance that has some of the properties of both metals and non-metals

Metamorphic describes rocks that are changed by being exposed to high temperature, pressure or both

Meteorite a rock from space (meteor) that has entered the atmosphere as a 'shooting star' and reached the ground

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

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

Mineral a chemical substance that is formed naturally in the ground

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

Mixture a substance made up of two or more different pure substances (compounds or elements) that are not chemically bonded together

Mohs scale a scale from 1 to 10 that indicates the hardness of a rock

Molecule two or more atoms chemically bonded by strong covalent bonds

Monatomic made up of single atoms, all of one type

Multicellular made of many cells

Neuron a nerve cell

Non-metal a chemical substance that is dull, cannot usually conduct electricity and is brittle

Nuclear energy a non-renewable source of energy that uses the energy released by the nucleus of radioactive atoms

Nucleus part of a cell that contains the genetic material

Omnivore a consumer (heterotroph) that eats a variety of plant and animal matter

Opaque blocking light completely

Ore a rock that can be mined and smelted to produce a metal

Organ a group of tissues working together to perform a function

Organ rejection when an organ transplant recipient's immune system recognises the organ as foreign and attacks it

Organ transplantation the process of removing a donor organ and then surgically implanting it into a recipient, to improve their organ function or replace a diseased organ

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

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

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

Outer core the liquid layer surrounding the inner core; probably made of liquid iron

Outlier an anomalous data point likely the result of error or mistake in data collection

Output energy the energy that a machine or device provides or wastes

Pancreas an organ that secretes pancreatic juices containing enzymes into the duodenum to assist with the digestion of food

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Pangaea the supercontinent that has since broken into pieces and drifted apart

Periodic table an organised list of all the known elements and their symbols

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

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

Physical change when the physical properties of a substance change in some way, but no new chemical substance is formed; it is mostly reversible

Physical weathering the breaking down of rocks into smaller particles by contact with other rocks, wind, water or ice

Plasma the yellow liquid component that makes up 55% of blood; it carries water, dissolved gases, hormones and other proteins

Plate boundaries the edges where two tectonic plates meet

Plate tectonics the theory that Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

Platelets tiny cell fragments that assist with blood clotting

Polyatomic element an element that exists as a molecule containing more than two atoms of the same type

Polymer a long molecule made of a chain of atoms in a pattern that repeats

Potential energy the energy stored in something because of its position, shape or composition; e.g. due to height above the ground, being stretched or compressed, or in chemical form

Potential energy (chemical) the energy stored in the chemical bonds of a substance

Precipitate the solid that forms when two solutions are mixed and undergo a chemical change

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

Primary source a first-hand record or account

Products the chemical substances that are present at the end of a chemical reaction

Prokaryote a unicellular organism that lacks membrane-bound organelles and a nucleus

Protist a eukaryotic organism that is part of the kingdom Protista

Pure substance material that is made up of just one type of chemical substance

Pyroclastic consisting of or relating to small pieces of rock from a volcano

Qualitative data data values that are descriptive or categorical in nature

Quantitative data data values that are numerical in nature

Radiation the emission of energy from a source, such as unstable nuclei

Radioactive having or producing the energy that comes from the breaking up of atomic nuclei

Radioactivity energy released from the nucleus of an atom when the atom decays; the age of rocks can be determined by measuring their radioactivity

Reactants the chemical substances that are present at the beginning of a chemical reaction

Rectum the second-last section of the large intestine; stores faeces

Reflection seismology the use of shockwaves to investigate the structure of rocks underground

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

Reversible capable of going in the both directions

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

Richter scale a system used to measure the strength of an earthquake

Ridge push a force that causes a plate to move away from the crest of an ocean ridge and into a subduction zone

Rift valley an elongated depression in Earth's surface formed by the separation of tectonic plates

Rock solid material forming Earth's crust; formed as part of the rock cycle

Rock cycle the constant process of change that rocks go through, between igneous, metamorphic and sedimentary forms

Rotational kinetic energy the energy an object has because it is rotating

Saliva liquid secreted by the digestive system to lubricate a bolus of food; also contains enzymes to assist chemical digestion

Sandstone sedimentary rock composed mainly of sand-sized silicate grains

Seafloor spreading a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

Secondary source a second-hand account; a source that summarises, analyses or interprets primary sources

Sedimentary describes rocks made from deposited materials that are the products of weathering and erosion

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Sediments sand, stones and other materials that slowly form a layer of rock

Seismic wave a wave that moves through Earth during an earthquake

Seismogram the pattern produced when seismic activity is recorded by a seismometer

Seismometer an instrument that measures the intensity and duration of seismic waves during an earthquake

Sinoatrial node a natural pacemaker that controls the heartbeat and is located in the wall of the right atrium

Slab pull the pulling force exerted by a cold, dense oceanic plate plunging into the mantle due to its own weight

Smelting the process of getting a metal from rock by heating it to a very high temperature

Sound energy a form of travelling wave; sound consists of vibrations in the air

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

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

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

Stomata tiny pores (holes) in leaves that allow entry/exit of gases such as oxygen and carbon dioxide

Streak test a test used to help identify a mineral by scratching a rock on a hard ceramic tile

Structure a physical part of an object

Subduction when the denser oceanic plate sinks underneath a less dense continental plate

Subduction zone the area where a collision between two of Earth's tectonic plates causes one plate to sink into the mantle underneath the other plate

Surface mining method of mining that extracts a mineral from the surface, such as by digging an open pit

Suspension a mixture in which one chemical substance will eventually settle out of the solvent

Tectonic plates giant slabs of rigid rock that float on the partially molten rock below Earth's surface and make up the lithosphere

Temperature a measure of the degree of heat present in a substance; gives an indication of the average kinetic energy of the particles

Thermal energy the energy contained within a material that is responsible for its temperature

Tissue a group of cells performing the same function

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

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

Transform (conservative) a type of plate boundary that occurs when plates move parallel to one another

Translucent allowing some light through, but no clear image can be seen through the substance

Transparent allowing light to pass through, and a clear image can be seen through the substance

Travelling wave a wave that can carry energy from one place to another

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

Tsunami a great wave produced by an earthquake or volcanic eruption in the ocean

Turbine a device that converts the kinetic energy of a fluid into useful work, e.g. a windmill

Underground mining traditional method of mining by digging tunnels underground to extract ore

Unicellular made of just one cell

Vacuole a structure in a cell that stores water and nutrients

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

Valve a structure that prevents the backward flow of blood

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

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

Vena cava the large vessel that returns deoxygenated blood from the body to the heart, emptying into the right atrium

Ventricle one of the two lower chambers of the heart, the left and right ventricles

Villi finger-like structures in the digestive system that have a high surface area and rich blood supply for absorption of nutrients

Waste energy the output energy that a machine creates that is not useful; waste energy is often in the form of thermal energy and sound

Wave energy the energy carried by a travelling wave (e.g. an ocean swell) or trapped in a standing wave (e.g. a guitar string)

Xenotransplantation transplanting organs from one species into another

Zygote a fertilised egg cell

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