

CAMBRIDGE

INTERACTIVE  
TEXTBOOK  
INCLUDED



Stage

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Cambridge   
**science**  
for the NSW Syllabus



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# How to use this resource

## Class activities in the print book

### Glossary

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

### Learning goals

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

### Explore!

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

### Did you know?

These are short facts that contain interesting information.

### Quick check

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

### Advances in science

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

## Section questions

End of section question sets are under the following headings: Remembering, Understanding, Applying, Analysing and Evaluating. Action 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.

### Practicals

Classroom or laboratory activities and investigations help consolidate student understanding. These activities are also available as Word document downloads in the Interactive Textbook.

# End-of-chapter features

## Chapter review

### Chapter checklist

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

Success criteria	Check
1.1 I can describe each stage of the experimental design process. e.g. State the missing stage: Research question; _____; Hypothesis and variables; Procedure; Results; Analysis; Discussion; Conclusion.	
1.1 I can identify independent, dependent and controlled variables. e.g. Explain the importance of controlled variables.	
1.1 I can outline experimental validity and assess whether the experiment is suitable for the research question. e.g. Recall the definition of validity.	
1.1 I recognise the need to write a risk assessment before completing any experiment. e.g. Create a general risk assessment for any experimental work in your lab.	
1.1 I can describe the information found on a safety data sheet (SDS). e.g. Summarise the information you would find on a safety data sheet.	
1.1 I can describe the ethical requirements of working with humans and animals. e.g. Describe some of the principles that scientists must follow if they are working with animals.	
1.1 I can define primary and secondary data. e.g. Contrast primary and secondary data.	
1.1 I can distinguish between quantitative and qualitative data. e.g. State the type of data that is collected when undertaking an interview.	
1.1 I recognise the difference between discrete and continuous data. e.g. Contrast discrete and continuous data.	
1.1 I can construct a results table. e.g. State which column the independent variable is found in when drawing a results table.	
1.2 I can describe the use and importance of specialised equipment such as burettes, pipettes and data loggers. e.g. Describe why a data logger may be useful in some scientific experiments.	

### Data questions

High school students were analysing the content of ethanoic acid in a commercial vinegar sample and had made up a dilute solution of 0.1 M ethanoic acid based on the concentration of ethanoic acid given on the bottle of vinegar. The students set up a titration with 20.00 mL of their ethanoic acid in a conical flask (via pipette) and filled a burette with 0.1 M NaOH.

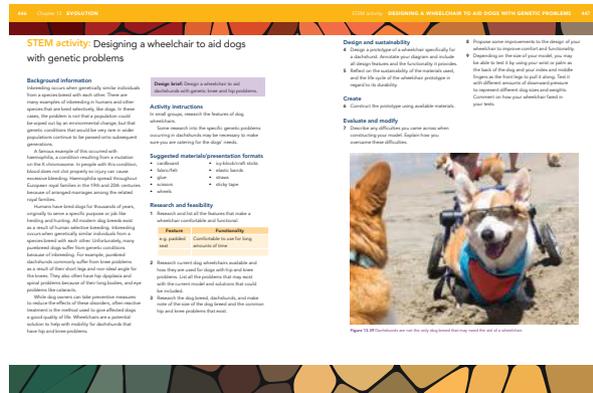
If the ethanoic acid content quoted on the vinegar bottle was correct, the students hypothesised that 'if 20 mL of 0.1 M ethanoic acid is present, then 20 mL of 0.1 M NaOH will be required to reach an end point'. The titration data from two students attempting six replicated trials are tabulated below.

Titration	Volume (mL) 0.1 M NaOH to end point	
	Student 1	Student 2
1	19.95	20.50
2	20.00	20.50
3	20.50	20.50
4	22.70	29.30
5	19.95	20.40
6	20.00	20.40
Mean		

- Identify and circle any outliers in each student's trials.
- Calculate the mean volume of NaOH required to reach the titration end point, after removing outliers for each student.
- The 'true' value for the titration given the actual concentration of ethanoic acid should have been 20.00 mL of 0.1 M NaOH. Assess the validity of this experiment in identifying the concentration of ethanoic acid.
- Identify if any patterns occur in the results obtained by the students.
- Contrast the data tabulated. Was each student accurate?
- Analyse the data tabulated. Were the results reliable?
- Justify whether the data presented by students 1 and 2 provide evidence to support the hypothesis.
- Compare the data fluctuations for each student. Do the data points fluctuate randomly above and below the true value or are they biased in one direction?
- Based on the data presented, infer whether the experiment was accurate, reliable and valid.

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

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



**STEM activity: Designing a wheelchair to aid dogs with genetic problems**

**Design brief:** Design a wheelchair to aid dogs with genetic problems.

**Activity instructions:** In small groups, research the features of dog wheelchairs.

**Suggested materials/presentation formats:**

- Index card
- Stapler
- String
- Wool
- Thin cardboard
- Styrene foam
- Wool
- Wool
- Wool

**Research and feasibility:** Research and list of the features that make a wheelchair comfortable and functional.

**Questions:**

- Research current dog wheelchairs available and how they are used by dogs with genetic problems. List the problems that each one with the current model and solutions that could be created.
- Research the dog breed, characteristics, and make note of the use of the dog breed and the common hip and knee problems that exist.

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

## Links to the Interactive Textbook



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



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



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



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



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

## Overview of the Interactive Textbook (ITB)

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

**Definitions** pop up for key terms in the text.

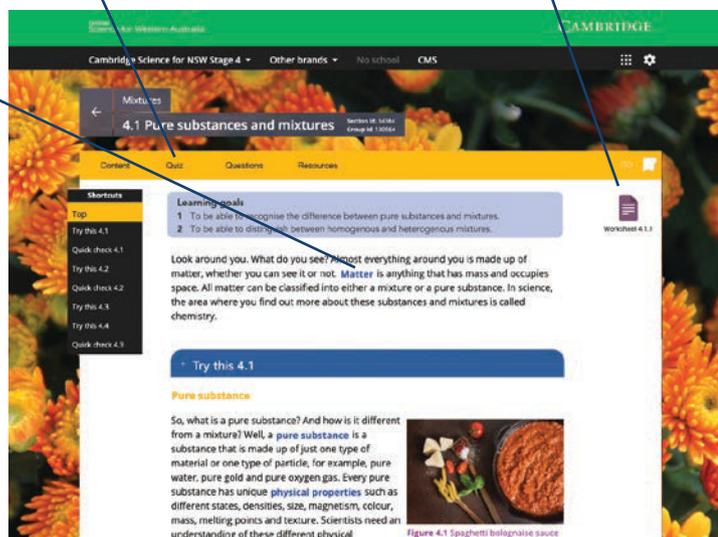
**Quizzes** contain automarked questions that enable students to quickly check their understanding.

**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 2.1: Self-design

#### Modelling heat transfer

##### Aim

To design your own experiment that models the three types of heat transfer.

##### Materials

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

##### Procedure

Design an experiment that demonstrates the three types of heat transfer. In a group, discuss ways in which you could do this. Choose the best method and plan the experiments. You must include information on variables, a risk assessment and a step-by-step method for carrying out the experiment.

##### Results

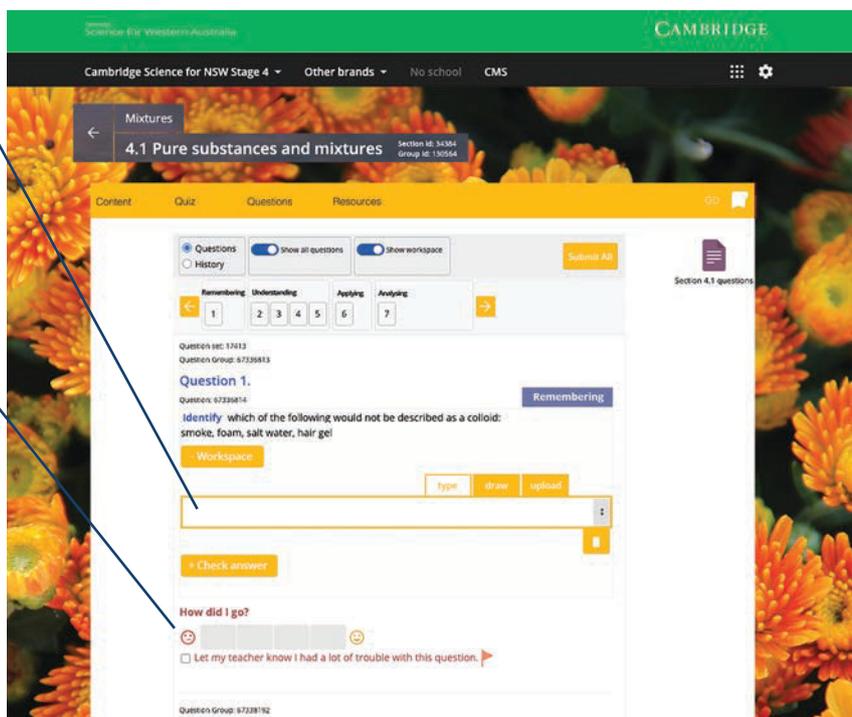
Record your observations for each of the experiments in an appropriate manner.

##### Discussion

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

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

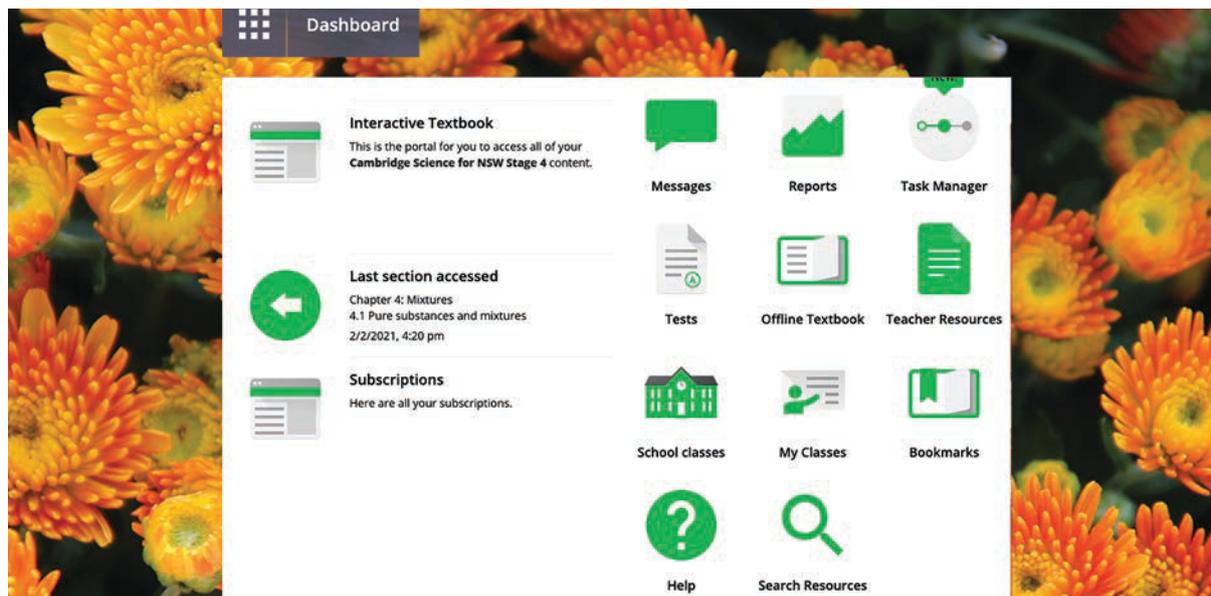
**Self-assessment tools** enable students to check answers, mark their own work, and rate their confidence level in their work. This helps develop responsibility for learning, and communicates progress and performance to the teacher. Student accounts can be linked to the learning management system used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



## Overview of the Online Teaching Suite (OTS)

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

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



# Chapter 1

## Working scientifically

### Inquiry questions

How do scientists formulate a testable hypothesis?

What is involved in planning and conducting an investigation?

How do scientists communicate their findings?

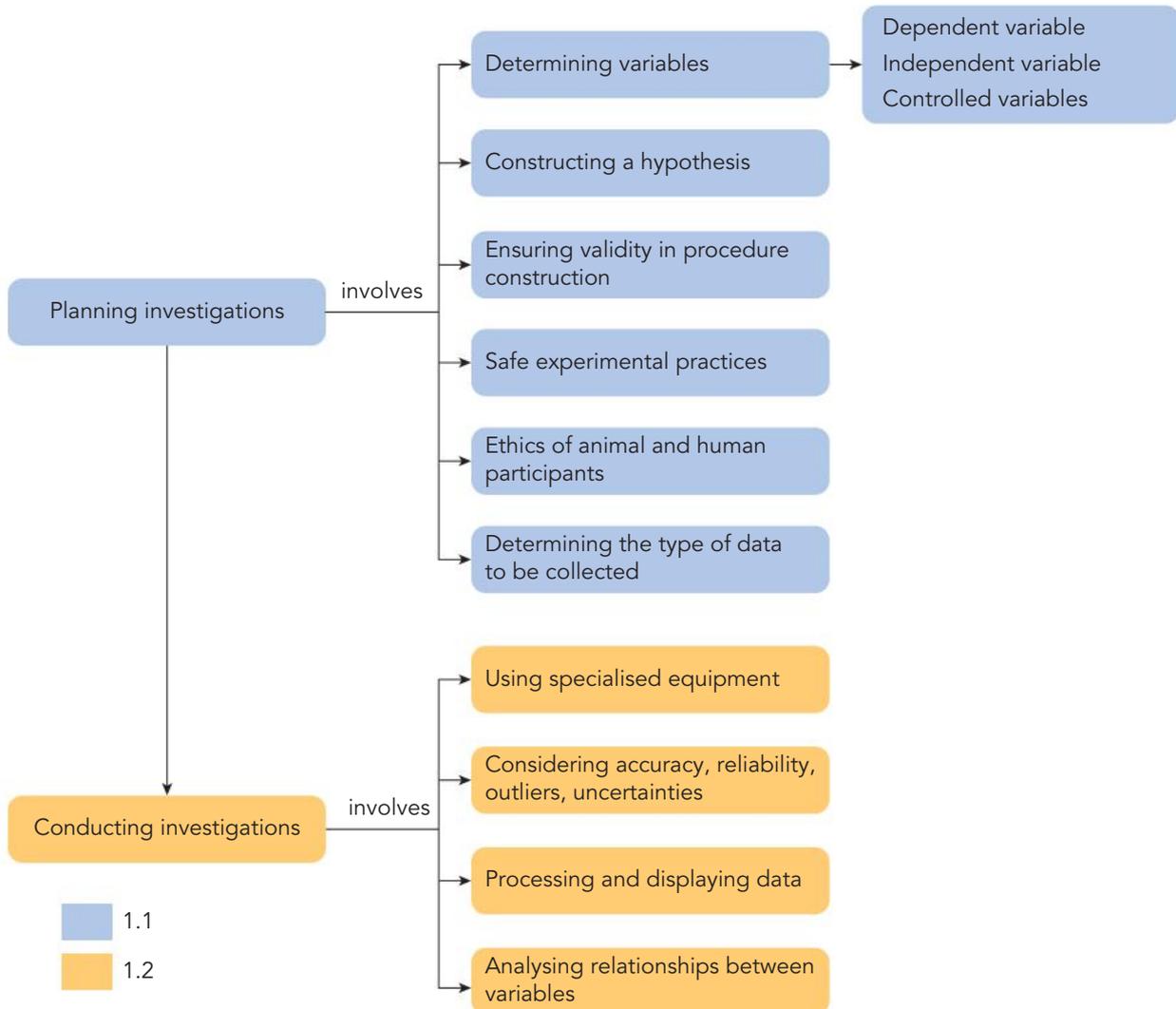


### Chapter introduction

In this chapter you will study the scientific method and how it can be used to test a claim or hypothesis. While learning to design an investigation, you will look at the skills of questioning and predicting and use that to develop a testable hypothesis. Following that, you will learn the skills required to plan and conduct a safe investigation. Finally, you will learn how to record and analyse data as well as how to communicate your proposed ideas and investigation findings.



# Chapter map



# 1.1 Planning investigations

## Learning goals

- 1 To use the scientific method when planning and conducting an investigation
- 2 To identify and control the experimental variables
- 3 To develop and test a hypothesis
- 4 To compare primary and secondary data and give examples of how each type is obtained
- 5 To plan a reliable, accurate and valid procedure for an investigation
- 6 To consider safety and ethical implications when designing an investigation
- 7 To contrast quantitative and qualitative data
- 8 To distinguish data as being continuous or discrete
- 9 To draw up a table in which to record data



This section covers the various aspects of planning an investigation. Deciding experimental variables, choosing methods of collecting evidence, ensuring the integrity of the experiment and ethics all need to be thought about before beginning the investigation.

### STEP 1: OBSERVE AND ASK QUESTIONS

A research question may be identified once an area of scientific interest has been analysed.



### STEP 2: BACKGROUND RESEARCH

The introduction of a scientific report contains a concise version of a literature review or background information. A scientist who is interested in conducting an experiment on a certain topic of interest will first search relevant scientific literature. This requires the ability to find and analyse past research articles and results.



### STEP 3: CONSTRUCT HYPOTHESIS AND STATE VARIABLES

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



### STEP 4: ESTABLISHING THE PROCEDURE AND CONDUCTING THE INVESTIGATION

An investigation may include controlled laboratory experiments, naturalistic observations, case studies, surveys and interviews. Conducting the experiment requires a specific methodology. In a report, the method usually contains at least three sections:

- Materials (lists the scientific apparatus required to conduct the experiment)
- Method (a step-by-step procedure of how the experiment was conducted). This may be a modified version of a previous experiment.
- Risk assessment (considers how to manage any risks in the experiment).

The experiment is then conducted according to the methodology.



### STEP 5: PROCESSING OF SUFFICIENT AND RELEVANT DATA

Data collection is of utmost importance in any scientific experiment. This step involves organising, summarising and representing the data that was collected in the experiment (raw data) in a meaningful way. Generally, descriptive statistics are used to organise and summarise the data. Graphs and tables can be used to represent the data; calculation of means, medians or modes can be used to summarise the data. Error bars can be included to represent uncertainty in any measurements.



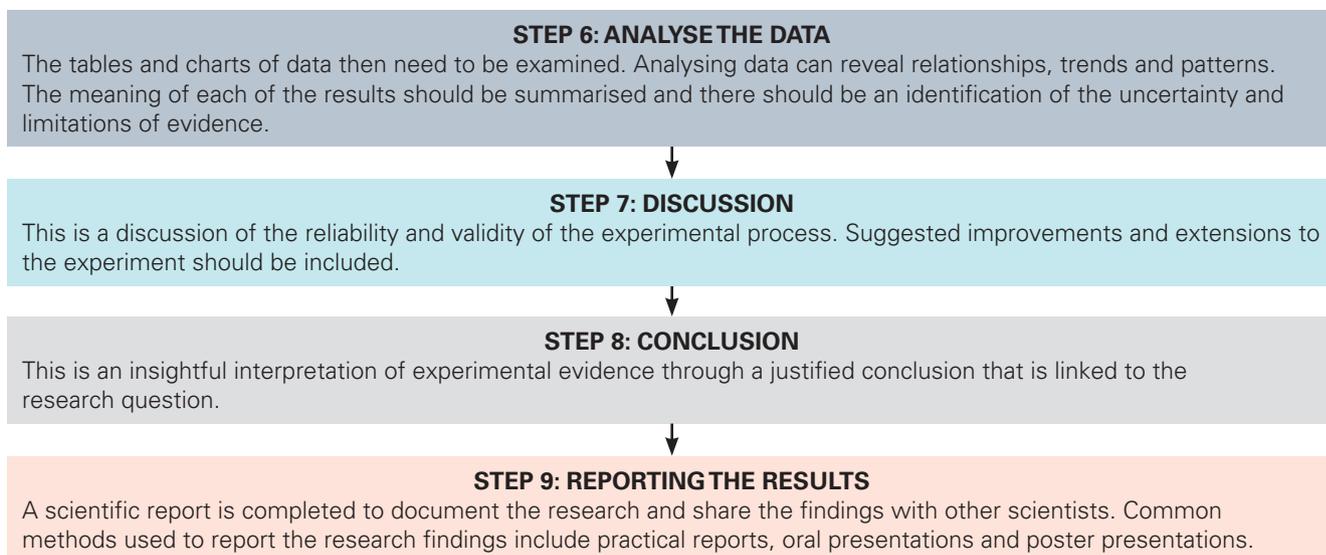


Figure 1.1 Scientific method framework

## Experimental variables

Let's say you have a broad research question that has been developed from observations of the world around you; for example: Does temperature affect the rate of a chemical reaction?

You have done the necessary background research and have started to come up with some hypotheses. Before you can perform an experiment, you must first construct an appropriate hypothesis. To do this, you must identify the research variables.

The **independent variable** is what is being manipulated by the experimenter in the experiment. You need to state exactly how it will be manipulated or changed. The independent variable should be measurable – for example, the temperature of a chemical reaction mixture. In this case measurement can be achieved using a thermometer.

The **dependent variable** is what is being measured in the form of the results of the experiment. You need to identify the dependent variable and state how it will be measured. For example, in the experiment mentioned, it is the time taken for the chemical reaction to be completed.

Sometimes other factors can affect the dependent variable and thus affect the experiment in an unwanted way. The presence of these variables makes it difficult

to conclude that the change in the dependent variable was solely caused by the change in the independent variable. Scientists seek to minimise these variables by keeping them constant, and they are therefore referred to as **controlled variables**.

**independent variable**  
the variable that is systematically manipulated or changed in order to investigate its effect on the dependent variable

**dependent variable**  
the variable that is measured to see if the independent variable has had an effect

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

Once you have identified the experimental variables, a hypothesis can be constructed using the 'if ... then ...' approach (Table 1.1).

Construct a hypothesis (a–f)			
a	b	c	d
If	independent variable changes	then	trend indicator (effect on the dependent variable)
	state independent variable change		show an increase/decrease; be greater than/less than; be larger/smaller
<b>Hypothesis:</b> If the temperature of a chemical reaction is increased, then the time for the reaction to be completed will decrease.			

Table 1.1 How to construct a hypothesis using the 'if ... then ...' statement.

### Quick check 1.1

- 1 Explain controlled variables.
- 2 Consider an investigation that could be used to test the hypothesis 'Does eating chocolate improve health?'. List your:
  - a independent variable
  - b dependent variable
  - c controlled variables.

### Try this 1.1

#### Evaluating an experiment

A student was interested in conducting an experiment to address the research question: 'Does light intensity affect the growth of alfalfa sprouts?'

They were thinking of setting up this experiment under three different conditions: darkness, ambient light and a greenhouse setting.

- 1 Choose the best independent variable for this research question:
  - a the total length of alfalfa sprout growth
  - b light levels
  - c length (cm)
  - d level of light intensity.
- 2 Choose the best dependent variable for this research question:
  - a length of alfalfa sprout growth
  - b light levels
  - c length (cm)
  - d level of light intensity.
- 3 Come up with a possible research hypothesis for this investigation using the 'if ... then ...' framework. Remember, it should be a prediction of what the results will be (including the independent variable and dependent variable), and as specific as possible.
- 4 List three variables that must be controlled in this experiment.
- 5 Explain why the above three variables should be controlled.



**Figure 1.2** Scientists conducting an experiment on alfalfa sprouts

### Validity of the experimental method

If a scientific experiment is to fairly test a hypothesis and answer a research question, then it must test what it claims to test and yield consistent and accurate results.

Experimental **validity** assesses whether the experiment is suitable for the research question and whether it

#### validity

the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what it says it measures

measures what it claims to be measuring. All factors other than the one being investigated must be kept constant. For example, an

experiment that is testing the effect of temperature on enzyme action should not have one set of enzymes at 20°C and pH 4, and another at 40°C and pH 9.

It is essential that only one variable (the independent variable) is changed at a time so that you can determine its effect on the dependent variable. This is a fair test. If other variables are not adequately controlled, then you cannot draw a valid conclusion because you cannot distinguish which variable has actually had the impact.

To increase the validity of an investigation you should only have one independent variable and have a range

of levels of that independent variable. For example, if you are testing the effect of pH on rate of reaction, it is better to test at pH of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 than to only test at pH 4 and pH 6. All variables other than the dependent and the independent variables should be controlled to prevent them from having an effect on the dependent variable.

### Quick check 1.2

- 1 Describe what a fair test is.
- 2 Identify three ways that you can ensure that your investigation is valid.

## Safe experimental practices

Whenever you are carrying out an experiment, it is your job to eliminate risks to health and safety, so far as is reasonably practicable, and if they cannot be eliminated, they need to be minimised. This can be done through the use of a risk assessment that allows you to identify, assess and control risks.

When assessing any risk, you need to consider two factors: a) the likelihood of the hazard actually occurring, and b) the level of harm that might result from the hazard. Experiments sometimes require the use of hazardous chemicals that could cause harm. A **safety data sheet** (SDS) must be provided during all experiments. The SDS is a document that provides teachers and students with relevant information about the health risks and safety of products (such as chemicals) that are classified as being dangerous goods or hazardous substances.

Ultimately, the safety data sheet provides precise information about how to use a substance during and after the experiment, including the associated health risks and how to dispose of waste products.

### Quick check 1.3

- 1 Recall what SDS stands for.
- 2 Explain why SDSs are essential within the science classroom.

## Ethical implications of the use of animals

Animal ethics involves consideration of respectful, fair and just treatment of animals. The use of animals in science should consider three main principles:

**Replacement:** substituting conscious living animals with insentient materials such as plants and microorganisms or with invertebrates with simple nervous systems.

**Reduction:** using the minimum number of animals required to satisfy the statistical requirements of the research

**Refinement:** decreasing the number of inhumane procedures applied to those animals that still have to be used in any procedures.

## Ethical implications of human participants

Humans also play a role as participants in some experiments, and this raises a number of ethical issues that need to be addressed. **Ethics** refers to the principles and standards upheld by scientists that guide them to display acceptable and appropriate conduct during experiments.

In fields such as psychology, using people as participants is a critical source of data in experiments. Before the commencement of any research involving humans, a research plan is submitted to an ethics committee for discussion and approval. This ensures that the participants' physical and psychological welfare is considered by a team of medical and non-medical professionals. Any participant must be voluntarily involved in the research, have given **informed consent** and not be harmed by their involvement. All data must be kept **confidential**, and all participants should have the **right to withdraw** at any point for any reason.

#### safety data sheet

a document that provides information regarding hazardous chemicals and substances

#### ethics

the standards used to appraise and guide what is considered as acceptable conduct

#### informed consent

where possible, participants are informed about the risks and procedures involved in an experiment and they sign to say they agree to participate

#### confidentiality

participants' data and results must be kept private

#### withdrawal rights

the right for a participant to leave a study at any time for any reason

## Explore! 1.1

**When ethics goes wrong**

Unfortunately, some very distressing research has been conducted on participants in the past. One of the most infamous experiments is the Stanford Prison experiment, conducted by Professor Philip Zimbardo and his colleagues in 1971 at Stanford University. Research what took place in this experiment and outline the ethical rights that were followed and the ones that were breached.

**Figure 1.3** Philip Zimbardo at the 2015 opening night of *Stanford Prison Experiment*, a movie based on true events that happened during the 1971 experiment



## Quick check 1.4

- 1 Define the term 'informed consent' in your own words.
- 2 Define the term 'withdrawal rights' in your own words.

**Data collection**

The purpose of any investigation is to collect data that can be analysed to answer a question. Data is an important part of how science progresses and how new discoveries are made. Before you start conducting an investigation, you need to be clear about what type of data you need to collect.

**Primary data** is data that researchers collect themselves for a specific purpose. This kind of data can be obtained from observations, experiments, surveys or interviews.

**Secondary data** is data that is collected by other people. A scientist can research and analyse this type of data. Secondary data can be obtained from scientific journals, the Australian Bureau of Statistics, or investigations that other people have conducted.

**primary data**  
data that is collected or observed directly by a scientist

**secondary data**  
data that has been previously collected for another purpose

Secondary data can be useful during the planning phase of an investigation. You can learn from the experiments or studies that other people have conducted to better understand how to answer your research question.

**Literature reviews**

A literature review is a comprehensive summary of any previous research completed on a subject that is written as an introduction to a topic you are investigating, forming the basis of your own research. Sometimes, the same skills that are used to write a literature review can be extended to write a research paper. This is a longer publication, which contains a summary of results of original research or an evaluation of research conducted by others. For example, a scientist may want to research the effectiveness of different bushfire management strategies. A combination of comprehensive fire records and previous studies done on the same topic would allow the scientist to evaluate the different strategies and the development of their own conclusions. Literature reviews can be considered as secondary sources of information.

## Experiments

You will have tested a number of your own theories over the years:

'If I don't have an extra serving of chips, then I'll have room for ice cream.' This is cause and effect, but causation can be difficult to prove, thus scientists can set up specific experiments that are in controlled environments that allow relationships between variables to be examined.

Often, data collection will take place using a datalogger. **Data logging** allows scientists to measure data more accurately, or over a prolonged period.

Experiments can take place in a laboratory, but sometimes, scientists may have to do **fieldwork**. This involves evidence collection that takes place in the real world, away from the controlled environment of a laboratory. Fieldwork allows scientists to examine the way their theories interact with the real-world environment. Data from your own experiments can be considered as primary sources of information.

## Modelling and simulations

Sometimes, scientists want to investigate phenomena that cannot be directly experienced.

A model is a simplified representation of an object, system or process. A model can be physical or digital and is designed to be similar to, but simpler than, what it is supposed to be representing, while simultaneously attempting to approximate most of the relevant features of the real object.

A good example of this is a globe. A globe is a model of Earth, and it is easy to see how the model has evolved through time. The first record of Earth being spherical was made in the fifth century BCE by the Ancient Greeks. For over 1500 years, this model was repeatedly updated,

but every version was merely an artistic impression of what Earth looks like. However, this all changed when NASA started to use technology such as their Earth Polychromatic Imaging Camera (EPIC) to create highly detailed images of Earth.

### data logging

the process of using electronic equipment to collect data through sensors where information needs to be collected faster than a human can do independently, or where accuracy is essential

### fieldwork

practical work conducted by a scientist in a natural environment, rather than in a laboratory

A simulation is used to bring a model to life, allowing scientists to determine how a particular object or phenomenon will behave. In a simulation, a model is used to study existing or proposed features of a system. Simulations enable the study of system characteristics by allowing the manipulation of variables that could not be controlled in a real system. They are useful to study properties of a model of a real-life system that would otherwise be too complex, too large, too small, too fast, too slow, or simply too dangerous to change. While a model aims to be true to the system it has been developed to represent, a simulation can allow a model to experience far more states than would normally be possible in the original system.



**Figure 1.4** On the left, the *Erdapfel*, translated 'Earth's apple', was created by Martin Behaim who lived in the late fifteenth century. It looks different to the globe we use today, because the Americas are not included, and some elements are the wrong size, shape and position. How do you think it compares to the image of Earth on the right taken in 1972 by the Apollo 17 spacecraft on the way to the Moon?

**Quick check 1.5**

- Other than experiments, outline another method used to collect evidence.
- Classify these scenarios as primary or secondary data:
  - Gathering student data from the Australian Bureau of Statistics
  - Recording the running speed of classmates
  - Observing the time taken for traffic lights to turn green
  - Using data that you gathered as a class and analysing it individually
  - Referencing data from a project you did in the past.

**Types of data**

Once you have selected your research question and the variables, you will need to think about what kind of data you need to collect. This will also help you select the appropriate measuring equipment for the experiment.

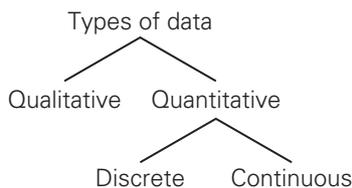


Figure 1.5 Different types of data

**Quantitative vs. qualitative data**

You can collect two types of data from an investigation:

**Quantitative data** is collected when you have to take specific measurements that involve numbers or when you are required to count or measure objects, for example, 10 cm, 39 seconds, 100 grams, 5 red flowers.

Not all investigations involve taking measurements. The data you collect from some investigations is **qualitative**

**quantitative data**  
data values that are numerical

**qualitative data**  
data that is descriptive and non-numerical

**continuous data**  
quantitative (numerical) data that is measured and has a value within a range

**discrete data**  
quantitative (numerical) data that is counted in whole numbers

**data.** This means that the data is non-numerical. Qualitative data could be descriptive or some other type of written observation, for example, the shape of leaves, how something tastes or open-ended interview transcripts.

**Quick check 1.6**

- Explain how qualitative data is different to quantitative data.
- Look at the image below. What kinds of data could be derived from it? Categorise them as qualitative or quantitative.

**Continuous vs. discrete data**

**Continuous data** is the type of quantitative data that is measured. It can take any value within a given range. For example, if you weighed 100 dogs, their weights could be any value within the range of dog weights, meaning the value is continuous. Continuous data can be measured in units such as seconds, metres, grams, degrees Celsius, kilometres per hour and volts.

**Discrete data** is the type of quantitative data that is counted. For example, when you count the number of dogs. Discrete data must always be whole numbers; you cannot count halves or fractions of things.

Examples of discrete data include the number of people in your class, the number of cars of each different colour on the road, the number of goals scored by your best friend.

**Quick check 1.7**

- Identify the following data as continuous or discrete.
  - Temperature readings
  - The number of trees in the local park
  - The height of students at your school
- Stefan plans to investigate how much his pet guinea pigs grow over the next 2 months. State if Stefan will be collecting continuous or discrete data. Give a reason for your answer.

## Recording data

Collecting data from an investigation, experiment or survey is an important part of the scientific process. Once the data is collected, it needs to be recorded or written down so that it is manageable and easy to use.

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

The data must be recorded neatly and accurately to avoid any confusion.

## Table of results

When recording your collected data in a table, the independent variable data is recorded in the first (left-hand) column, while the dependent variable data is recorded in the columns to the right. You may decide to record data from additional trials to make sure the data is consistent. That way, a **mean** can be calculated. Figure 1.6 shows what the results table should look like.

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

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

Plant height recorded over 25 days

Time (days)	Plant height (cm)			
	Plant 1	Plant 2	Plant 3	Mean
1	10.0	9.8	10.1	10.0
5	10.5	10.2	10.5	10.4
10	14.2	14.0	13.9	14.0
15	18.5	17.8	18.0	18.1
20	21.9	21.4	20.5	21.3
25	23.5	22.8	24.1	23.5

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

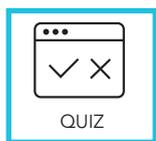
Figure 1.6 How to set up a table of results

## Quick check 1.8

- Olivia loves drinking hot chocolate. She wants to find out at which temperature the chocolate powder dissolves the quickest. For Olivia's investigation, identify the independent, dependent and controlled variables.
- Olivia records her results in the table below. Determine how many mistakes can be found in the table. Copy the table below into your workbook and correct the mistakes.

Dependent variable: Time (days)	Independent variable: Temperature (cm)			
	Trial 3	Trial 2	Trial 1	Total
20	5.5	5.5	6.0	17.0
30	4.5	4.5	5	14.0
40	2.5	3.5	3.0	9.0
50	1.5	2.0	1.5	5.0
60	0.5	1.0	1.0	2.5

## Section 1.1 questions

**Remembering**

- Name** two ethical principles that must be upheld by a scientist conducting research using humans.
- Identify** the missing elements on different types of data to complete the table.

Type of data	Description
Quantitative	
	Data values that are descriptive and non-numerical
	Quantitative (numerical) data that is whole numbers
Continuous	

- Outline** what information is located on an SDS.

**Understanding**

- Identify** the independent, dependent and controlled variables in the following investigations.
  - Phoenix wants to investigate whether music helps plants grow quicker.
  - Ishan is going to investigate if mass affects the time it takes for an object to fall.
- Leo conducts a simple investigation into how long different brands of kettles take to boil water. He chooses three different kettles: an electric metal kettle, an electric plastic kettle and a metal kettle for putting on the stovetop. Leo boils half a litre of water in each and waits for each kettle to be cool before he starts the next trial. **Identify** the controlled variables in Leo's investigation.
- While conducting the investigation outlined in Question 5, Leo records the following results.
 

Electric metal kettle	3 minutes 30 seconds, 3 minutes 42 seconds, 3 minutes 44 seconds
Electric plastic kettle	4 minutes 2 seconds, 3 minutes 52 seconds, 3 minutes 57 seconds
Stovetop metal kettle	5 minutes 5 seconds, 4 minutes 47 seconds, 4 minutes 54 seconds

**Create** an appropriate results table, including the names for the variables and their units.

- Contrast** primary data and secondary data, giving an example for each.
- Give examples of the data you have collected in your science class over the last year. Then **classify** each as primary or secondary data.
- Saria and Jake are investigating three aspects of the students in their class:
  - hair colour – number of students with each hair colour
  - eye colour – number of students with each eye colour
  - height – the height of each student.

They are arguing over whether the quantitative data they need to collect for their series of investigations is continuous or discrete. Saria says all the data is discrete while Jake disagrees and says all the data is continuous.

**Discuss** who is right and who is wrong. Give reasons for your answer.

**Applying**

- Classify** the following as either discrete or continuous data.
  - The number of days on which it hailed in a year
  - The diameter of hailstones
  - The speed of a car
  - How many cracks appear on a wall after an earthquake
  - The length of cracks in different materials
- You are constructing a scientific poster. Select and **describe** one situation when it would be appropriate to include a line graph (instead of a table of data) in the results section.

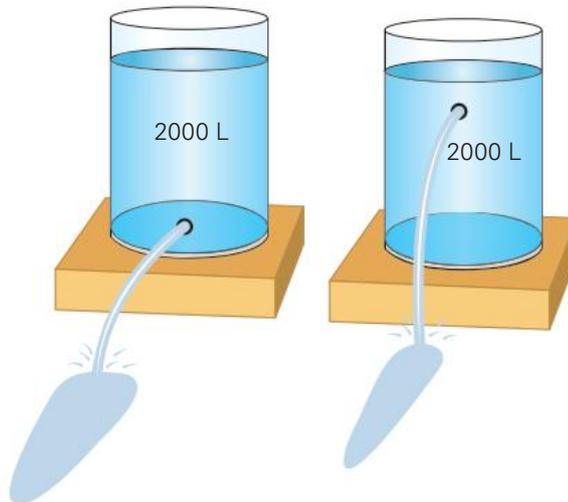
- 12 Biology students were learning that, on a hot day, plants lose water out of pores (called stomata) in the underside of their leaves. The students were asked to design an experiment that would test how factors of their choice influence the rate of water loss. After conducting some background research, one student identified that humidity and temperature should affect the rate at which water is lost out the stomata. She set up the experiment below:



- a **Identify** the two independent variables manipulated in this experiment.
- b **Identify** a relevant dependent variable in this experiment.
- c **Propose** which set-up acts as a control with which to test all three factors.

### Analysing

- 13 A farmer noticed that his leaky tanks seemed to lose water quicker if the hole was closer to the bottom of the tank. He designed the research question: Do tanks leak water faster when the hole is positioned higher on the tank? The experimental set-up is shown below:



- a **Identify** the independent variable of this experiment.
- b **List** three variables that must be controlled.
- c The farmer repeated his experiment on five different occasions and found the same result: that the water flows more strongly from the lowest hole in a water drum. **Assess** the reliability and validity.

### Evaluating

- 14 Jake took 12 identical pots and 12 identical plants. In four pots he placed soil and 10 grams of fertiliser A and one plant. In another set of four pots he placed in each a plant, 15 grams of fertiliser B and the identical amount of soil as in the previous four pots. In another four pots he placed the same amount of soil with a plant but provided no fertiliser. All 12 pots were placed in the same location and received the same amount of water and sunlight every day. Plants with fertiliser B grew much larger than all the others. Jake concluded that fertiliser B was better than fertiliser A. **Determine** if his conclusion was valid.

# 1.2 Conducting investigations and processing data

## Learning goals

- 1 To use specialised equipment to obtain more accurate results
- 2 To consider errors and uncertainties when assessing the accuracy and reliability of the results obtained
- 3 To describe the different types of errors and their possible effects on results
- 4 To calculate uncertainty and use it to assess the accuracy of data
- 5 To represent data in an appropriate graph dependent on the data and relationship between the variables
- 6 To use descriptive statistics to determine if there is a trend in the data obtained
- 7 To define the mean and median and use them to determine the correlation between the variables
- 8 To evaluate the effectiveness of a procedure and suggest improvements



## Using specialised equipment

Specialised equipment can often give more accurate results, thereby enhancing the validity of the experimental data.

The benefits of using a data logger in scientific experiments include:

- highly accurate measurements
- an automated process that can be programmed and left to take readings regularly over a long period of time (for example, overnight) or many readings over a very short period of time
- removing the risk of human error or miscalculations in interpreting a measurement scale and recording data.

## Data loggers and probes

A data logger is an electronic measuring tool that accurately records data over time. It features a built-in instrument, such as a probe or sensor, that can measure a physical stimulus such as temperature, light, pressure, humidity or pH. The device is connected to a computer and converts the stimulus into a readout on the screen. This means the experimenter does not have to manually take a reading at set intervals, as the data logger takes very frequent (almost continuous) readings over time.

The data collected from the experiment can be processed by specialised software or placed into a spreadsheet to allow for further analysis at a later point. This allows scientists to easily generate tables of values and graphs.

## Practical 1.1: Teacher demonstration

### Titration using a pH probe

#### Aim

To complete a titration using a pH probe linked up to a data-logging program to produce a graph showing pH changes as a base is added to an acid.

#### Materials

Four different combinations of acid and base solutions are supplied for the class to test. Such combinations include: strong acid–strong base; strong base–weak acid; strong acid–weak base; weak base–weak acid.

- pipette
- burette
- burette funnel

#### Be careful

Ensure appropriate personal protective equipment is worn.

*continued...*

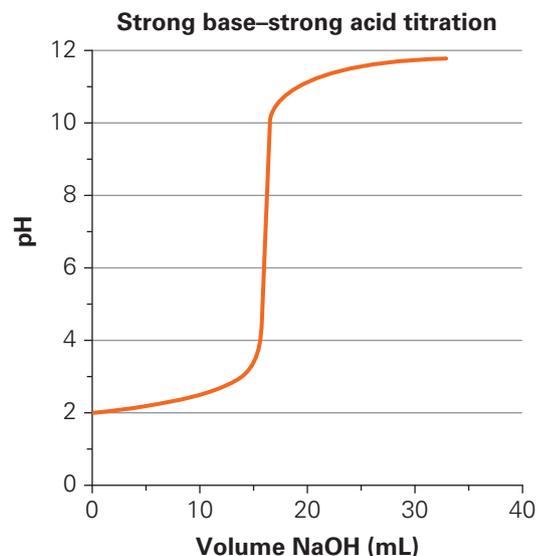
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- conical flask
- retort stand
- burette clamp
- pipette bulb
- bosshead
- clamp
- wash bottle
- pH probe and data logger
- computer or laptop
- data-logging software

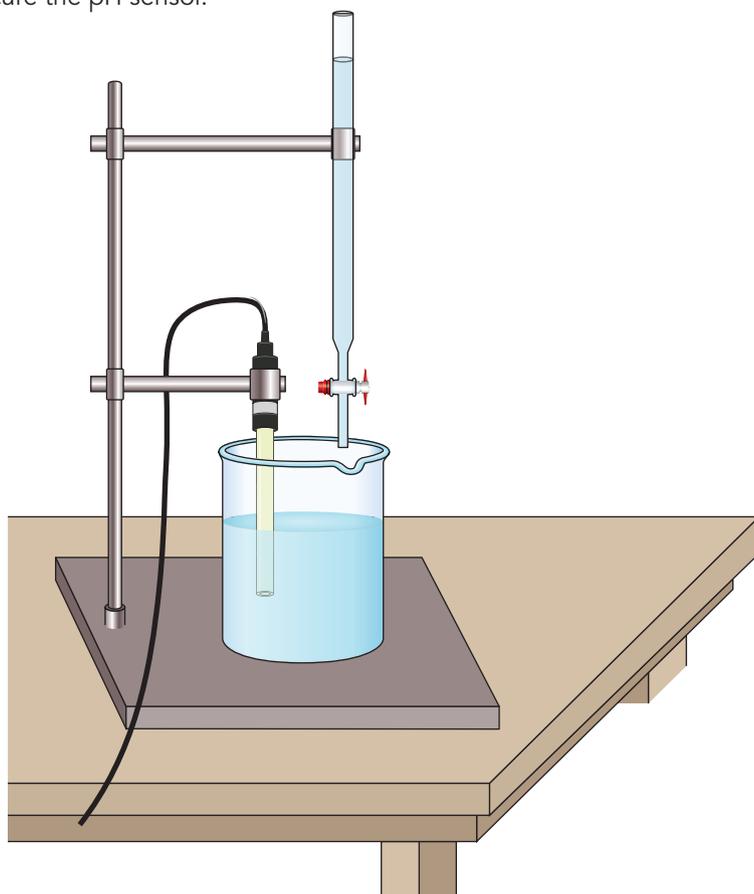
### Procedure

You will be provided with four different combinations of acid and base solutions to titrate. Decide who will be in charge of the continual stirring of the solution in the beaker and who will be in charge of releasing the base into the beaker using the burette.

- 1 Set up the burette and apparatus as shown in the diagram by using a clamp and a retort stand to secure the pH sensor.
- 2 Rinse the burette thoroughly with a few millilitres of the basic solution.
- 3 Fill the burette using approximately 50 mL of basic solution and record the precise volume.
- 4 Add 50 mL of distilled water to a 250 mL beaker.
- 5 Pipette 10 mL of the acid into the beaker of distilled water.
- 6 Connect the data logger and pH sensor to the computer or laptop and open up the relevant 'Acid-Base' titration program.
- 7 Monitor the pH for approximately 20 seconds and wait for the reading to stabilise.
- 8 Enter 0 mL as the first data point of base added in the computer program.
- 9 Slowly start to add some of the basic solution until the pH has risen approximately 0.2 units.
- 10 Wait for a stable pH reading and record the burette reading (volume of base left in the burette) to the nearest 0.01 mL.



**Figure 1.7** A graph showing how the pH (concentration) changes as a volume of sodium hydroxide (a strong base) is titrated into a strong acid



**Figure 1.8** Experimental set-up

continued...

...continued

- 11 Repeat steps 9 and 10 until the pH starts to get close to 3.5.
- 12 Start adding smaller equal volumes of approximately 0.1 mL of basic solution to the beaker, making sure to record the burette reading into the software after each increment.
- 13 When the pH reaches close to 10, add larger amounts of basic solution that raise the pH approximately 0.2 units.
- 14 Continue adding the basic solution until the pH remains constant and stable.
- 15 Click stop on the software and save copies of the table and graph.
- 16 Dispose of the beaker contents as directed by your teacher and the safety data sheet.
- 17 Repeat steps 1–16 with the three other acid–base combinations.

### Results

Print out your table and graph.

### Discussion

- 1 Compare the four different graphs you have produced.
- 2 Discuss the different shapes of curves that were produced in relation to the strength of the acid and base combinations used.
- 3 Discuss whether this experiment would have been possible without the use of a data logger.
- 4 Propose any extensions or improvements that could be made to this experiment if you were to do it again.

### Conclusion

- 1 State a conclusion that can be made regarding the pH when a base is titrated into an acid.
- 2 Justify your conclusion by using the data you gathered.

## Accuracy, reliability and outliers

Experimental **accuracy** refers to how closely the experimental results match the ‘true’ values. For example, if you record the mass of a product of a chemical reaction as 1.55 g, but the chemical equation suggests that based on the amount of reactants, you should only have 1.20 g, then you have a measurement error of 0.35 g. Choosing the best equipment and using a method that avoids errors

will improve the accuracy of the experiment as a whole. For example, you could use an electronic timer system to record measurements at given time intervals rather than rely on a human to use a hand-operated stopwatch.

#### accuracy

how closely measures match the ‘true’ or accepted values

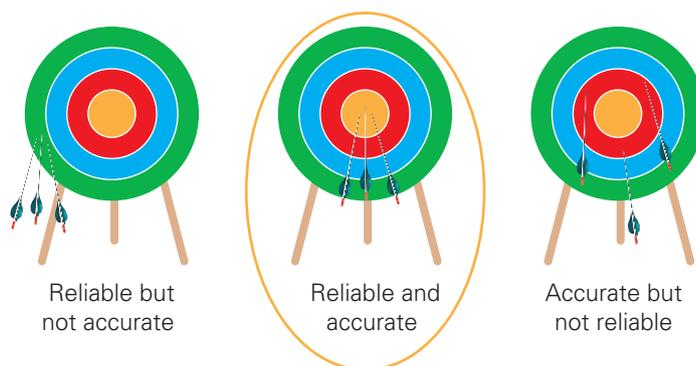
#### reliability

how closely repeated measures agree with each other

#### outlier

extreme data value that does not seem to fit the rest of the data

Experimental **reliability** refers to how closely repeated measurements agree with each other. For example, let’s say you record the mass of a product of a chemical reaction, and you repeat the experiment four times, getting results of 1.54 g, 1.55 g, 1.55 g and 1.54 g. The data shows low variation from the mean (it is clustered



**Figure 1.9** A faulty piece of measuring equipment might consistently give wrong values, like the target on the left. This measurement would be reliable but the results are inaccurate and do not measure what they claim to measure; therefore, they have low validity.

tightly) and can be said to be consistent and thus reliable. Note that, even though this data is reliable, it is not necessarily accurate. Reliability does not give us an indication of how ‘true’ the data is; that is, how accurately it matches the actual values. An investigation can be reliable without being valid, but cannot be valid unless it is reliable.

**Outliers** are extreme data values that do not appear to fit with the other recorded values. These values are

often situated a long way from the mean, and may represent an experimental error, such as human error in reading the scale or a fault in measuring equipment. It is important that outliers are investigated and accounted for in the discussion of your results. Repeating the experiment allows for the identification and thus exclusion of an outlier when calculating the mean; alternatively, the calculation of a mean reduces the effect of an outlier, but you need to mention that this has occurred. The most common causes of outliers in a data set within the scientific laboratory are:

- data entry errors (human miscalculation)
- measurement inaccuracies (instrument error)
- data transfer or experiment planning/execution deficiencies.

### Quick check 1.9

- 1 Define the term 'outlier' in your own words.
- 2 If a data set had a number of outliers, state if the data would have high or low reliability.
- 3 Identify the missing word in the following sentence. An experiment is conducted and the results align very closely with the expected values, meaning the experiment could have high \_\_\_\_\_.

## Errors and uncertainties

### Systematic and random errors

Measurements are never perfect. The accuracy of any measurement will always be limited by the apparatus being used, the skills of the person collecting the data, the method being used and the environment where the experiment is being carried out. Whenever we do an experiment, we are attempting to determine the 'most true' data, but we will normally have a variation in the results.

So, what are the possible reasons for the different values seen in our data? Mistakes are avoidable problems made by the person collecting the data, such as selecting the wrong piece of equipment or writing down results incorrectly. Although these are possible, a careful scientist should not make mistakes and would not include them in any report.

Errors are the difference between the results of experimental measurements and the true or reference values involved. They are not the same as mistakes.

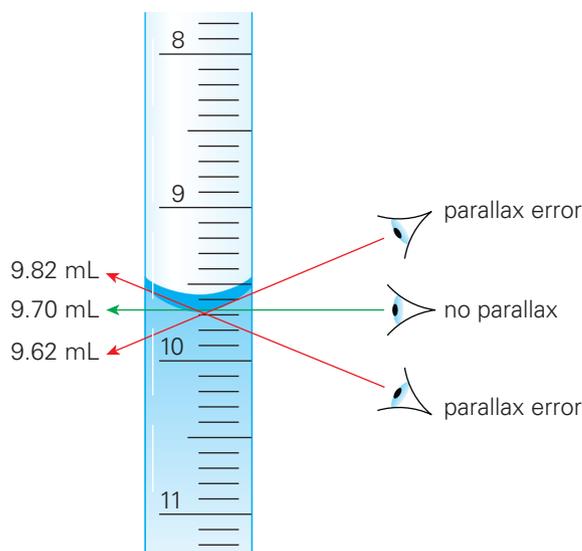
**Systematic errors** arise from measured values that are either larger or smaller than the true value of your data if equipment is used in the same way. Systematic errors affect the accuracy of your measurement and can be minimised by careful experimental design, including calibrating measuring instruments correctly. Some examples are given below.

- **Instrument effects:** These are caused when a measuring instrument is faulty or has not been calibrated correctly. For example, if a scale used to measure a mass was not properly calibrated, so that all the readings were 3.00 g greater than they should be, then all the measurements of mass would be consistently overestimated by 3.00 g. This would lead to a systematic effect because the data is all wrong by the same amount each time a measurement is taken. A **zero calibration error** occurs when the initial value shown by a measuring instrument is not zero when it should be zero. For example, a scale may show 0.001 g, even when nothing is being weighed.
- **Environmental effects:** These are caused by external factors such as temperature or humidity. For example, the measurements taken using a metal ruler will differ depending on the temperature. In low temperatures the ruler will contract, whereas in warmer temperatures it will expand. This means that the measurements would always be lower or higher than the correct value.
- **Observation errors:** These are caused by undertaking the wrong observations or reading instruments incorrectly. For example, a **parallax error** may be caused when the observer's eye is positioned at an angle to the measurement markings, causing the data to be either larger or smaller than the correct value.

**systematic error**  
error affecting accuracy that occurs through a poorly calibrated device (consistently high or consistently low)

**zero calibration error**  
a measuring instrument giving a non-zero reading when the true value should be zero

**parallax error**  
a measurement taken that is not the true value due to the position of the object along various lines of sight



**Figure 1.10** The position where there is no parallax is the correct eye level for reading the measurement.

Even if careful experimental design removes systematic errors, **random errors** will still remain that will affect the reliability of a measurement. These are caused by limitations of the measurement device and the observer and are equally likely to be positive or negative because they do not follow a regular pattern. They can be caused by the experimenter's inability to obtain the same measurement in exactly the same way to get exactly the same result. You may measure the mass of a piece of magnesium ribbon three times using the same balance and produce slight variation in your results: 1.36 g, 1.38 g and 1.39 g. **Reading errors** can also occur when a measurement falls between two measurement markers. An observer would have to estimate the true value, and this would differ between observers. Half of the results

obtained would be estimates that are too large, and half would be too small. These effects are an unavoidable part of doing experiments, but the resulting error can be reduced by repeating the experiment many times and taking average values.

**random error**

error affecting reliability, caused by limitations of the measurement device or an observer who does not follow a regular pattern

**reading error**

a reading or measurement that is not the true value

**absolute uncertainty**

the size of the range of values in which the actual 'true value' of a measurement probably lies

## Uncertainties

Due to random and systematic effects in the experimental process, there will always be a margin of doubt about any of your results. But how big is this margin? We have looked at how these errors can arise, but we need to be able to quantify them. This happens through estimating the uncertainty of any measurement. The uncertainty is a range around a measured value which quantifies where a result produced by the repetition of our experiment would be expected to lie.

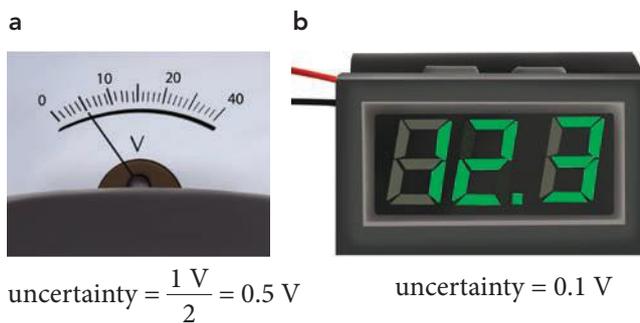
The notation for a measurement and its uncertainty should take the following format (remember to add the appropriate units):

*measured value*  $\pm$  *uncertainty (units)*

where  $\pm$  means 'give or take'. This tells us the **absolute uncertainty**.

The following rules are used to determine the absolute uncertainty in a single measurement when using an analogue or digital measuring instrument.

- The uncertainty in an analogue measuring instrument is equal to the smallest increment of the instrument, divided by 2.
- The uncertainty in a digital measuring instrument is equal to the smallest increment of the instrument.



**Figure 1.11** There are different rules for single measurements using (a) analogue or (b) digital instruments. Remember to include units!

The uncertainty of any measured value can also be expressed as a percentage or as a ratio. This is **relative uncertainty** and it is calculated by dividing the absolute uncertainty of the result by the result itself. The relative uncertainty can be more useful than the absolute uncertainty because it puts your experimental data into perspective. For example, if you made an error in measuring the length of your eraser, it would be more noticeable than if you made the same error when measuring the table. Relative uncertainties do not have units, and can be multiplied by 100 to report them as a percentage.

Consider this example.

- You measured the length of your table (80.0 cm) using a metre rule.
- The absolute uncertainty is  $\pm 0.05$  cm.
- This uncertainty can then be included when communicating your results:  
Length = 80.0 cm  $\pm$  0.05 cm.
- The relative uncertainty is calculated by  $\frac{0.05}{80.0} = 0.000\ 625$ .
- This can then be reported as a percentage by multiplying by 100:  
Percentage uncertainty =  $0.000\ 625 \times 100 = 0.0625\%$ .

Now compare this result to measuring your eraser.

- You measured the length of your eraser (5.0 cm) using a metre rule.
- The absolute uncertainty is  $\pm 0.05$  cm.
- This uncertainty is then included when communicating your results:  
Length = 5.0 cm  $\pm$  0.05 cm.
- The relative uncertainty is calculated by  $\frac{0.05}{5.0} = 0.01$ .
- This can then be reported as a percentage by multiplying by 100:  
Percentage uncertainty =  $0.01 \times 100 = 1\%$ .

## Processing data

Once you have collected your data, you will need to process and describe it using descriptive statistics as

well as present it in a way that it communicates your findings. Descriptive statistics include calculated values such as frequencies, mean, median and measures of spread. They provide basic information about your data set and can indicate relationships between variables, whereas using a graph allows for a visual representation of those relationships.

**relative uncertainty**  
the ratio of the absolute uncertainty to the reported value, often expressed as a percentage

## Displaying and representing data

There are several ways to represent quantitative (numerical) data (Table 1.2). The graph used to represent your data depends on the type of data (continuous or discrete) as well as the relationship between them.

Below is a brief summary of the types of graphs you may use in a report.

Graph type	Reason for use
Bar graph or column graph	Bar graphs are used for comparing data between different categories or groups. They are suitable for medium to large sets of data.
Histogram	Histograms are used to plot the frequency of continuous data that is divided into intervals. They are suitable for medium to large sets of data.
Scatter plot	Scatter plots are used to determine the relationship between variables. They are suitable for medium to large sets of data.

**Table 1.2** Three types of graphs which may be used to represent numerical data

### Bar graphs and column graphs

Bar graphs use rectangular bars that are proportional to the values that they represent. Bar graphs use discrete data and as such adjacent bars or columns should not touch each other as there is no relationship between them.

A vertical bar graph may be called a column graph. Bar graphs are made up of the following parts:

- a title that explains the information being graphed
- labels on axes that explain what each side of the graph is showing, including units in brackets

- a scale of numbers that increases evenly from bottom to top (or left to right if the bars are horizontal)
- category labels that explain what each bar is showing.

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

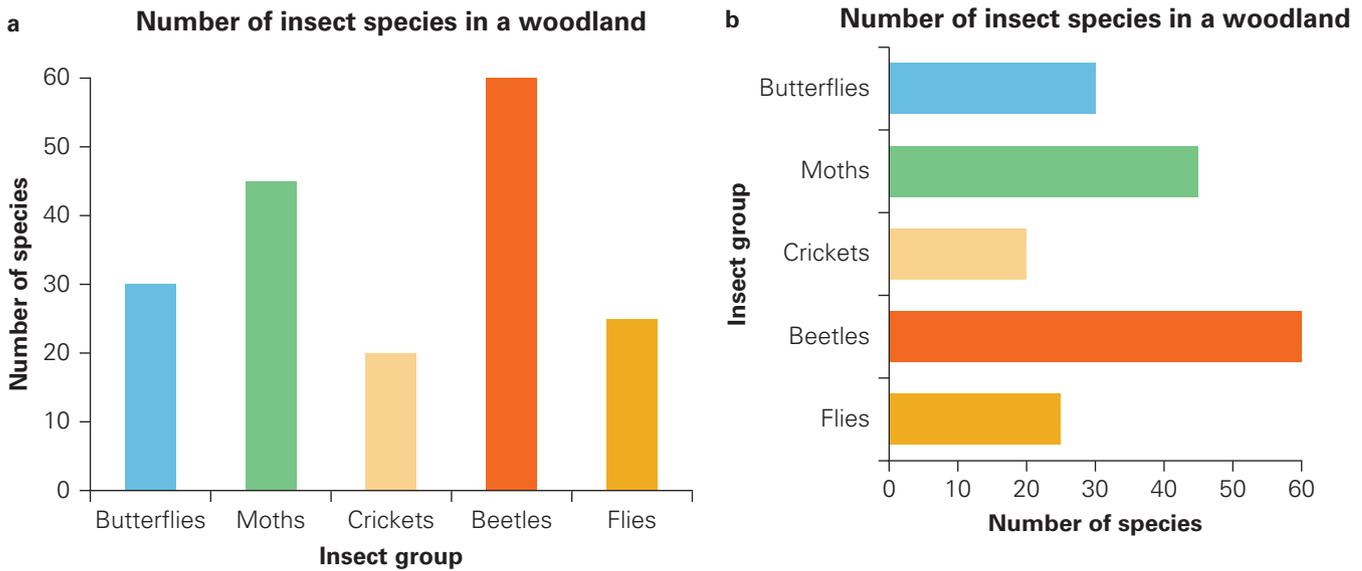


Figure 1.12 The same data presented in (a) a vertical bar graph (column graph) and (b) a horizontal bar graph

### Quick check 1.10

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

	Plant type			
	Brown algae	Red algae	Green algae	Seagrass
Number of fish species feeding	21	18	24	8

### Histograms

Histograms are similar to bar or column graphs in that they use rectangular bars that are proportional to the values that they represent. However, in a histogram the data is continuous and therefore adjacent bars or columns should touch each other, showing a continuous relationship.

### Scatter plot

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

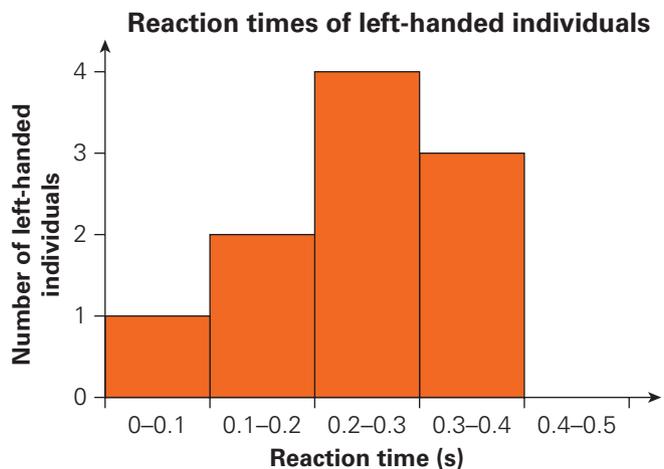


Figure 1.13 Histogram

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

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

A simple method of remembering this is remembering the acronym DRY MIX where:

D – Dependent variable

R – Responds to changes in other variables

Y – Is placed on the  $y$ -axis

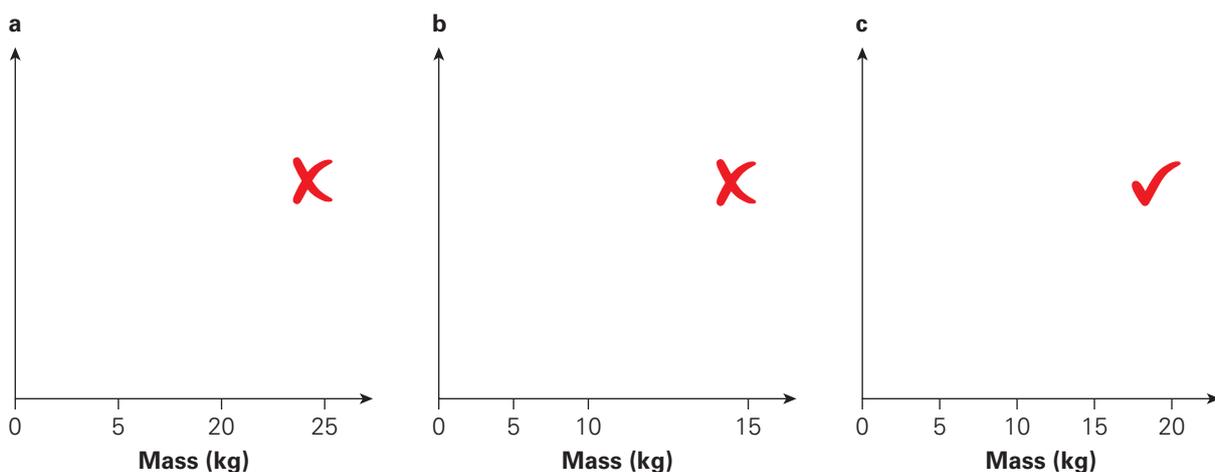
M – The **manipulated** variable is the one that is deliberately changed

I – Independent variable

X – Is placed on the  $x$ -axis

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

When preparing the  $x$ -axis and  $y$ -axis, it is important to place the numbers on the axis in a way that shows the correct relationship. The numbers on both axes need to increase evenly, starting at zero as the corner point (**origin**). Each distance of the line needs to represent the same value of the data. For example, if the first unit of the graph represents 5 kilograms (kg), every increment of the graph also has to be 5 kg (see Figure 1.14).



**Figure 1.14** Graph (a) does not increase evenly along the  $x$ -axis. Graph (b) is not spaced evenly. Graph (c) has the correct spacing and numbering for the  $x$ -axis.

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

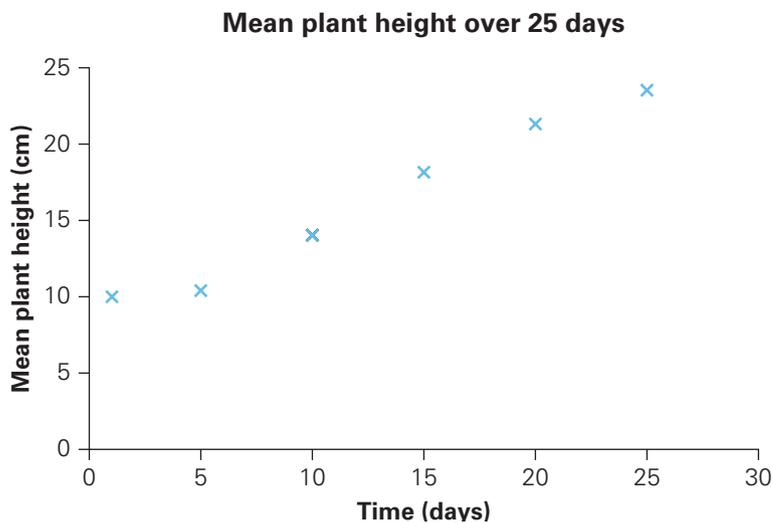
When setting up the graph paper, aim to make the graph as large as possible – at least half the page is a good guide. This will make the data clearer and easier to use when doing your analysis. Also, wherever possible, draw all parts of the graph in pencil to make it easier to correct any mistakes.

Figure 1.15 on page 22 illustrates what the data set in Table 1.2 would look like when plotted on a graph.

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

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

**Table 1.2** Mean plant height over 25 days



**Figure 1.15** Plotting the data from the table correctly on a Cartesian plane makes it much easier to analyse.

### Line of best fit

Once your data has been plotted, it may be difficult to see how the variables relate to each other on a scatter plot, especially when there are many data points. A **'line of best fit'**, also known as a trend line, can be drawn to represent all the points. It may touch some, all or even none of the data points drawn. The line is sometimes **linear** (straight), but may also be **non-linear** by adding it in as a curve. Drawing a line of best fit allows

**linear**  
a straight line plotted on a graph

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

**line of best fit**  
a line (or curve) that best represents the data set by going through, or is as close to, as many points as possible

scientists to look for a general trend in the data being analysed.

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

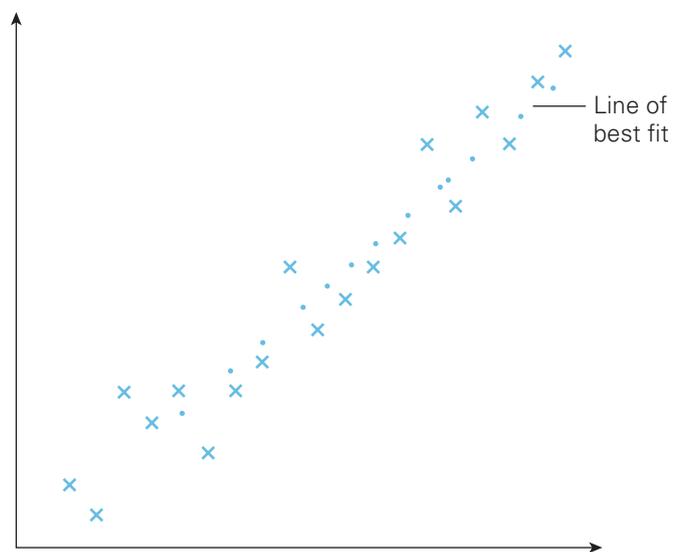
- Do not include outliers.
- Make the line as close to as many points as possible.

### Quick check 1.11

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

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

- Identify the independent variable in this experiment.
- Identify the dependent variable in this experiment.
- Use this information to draw a complete  $x$ - $y$  scatter plot graph of this data.



**Figure 1.16** A scatter plot with a line of best fit. Even though the line is not touching any of the points, it is drawn as close to all the points as possible.

### Relationships between the variables

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

## Centrality: mean and median

In descriptive statistics, we can measure the central tendency of a data set by calculating an average.

The mean and the median are two different ways of describing the centre of a data set, but they can often give two very different stories about the data, especially when there are outliers present in your data.

The mean is used to measure the centre of a data set and is the most common statistic used when talking about averages. It is the sum of all the values collected, divided by the number of values present. However, it may not be a fair representation of the data as the mean is heavily influenced by outliers – values that are either very large or very small.

### median

the middle value of the data set after all the values have been ranked (sorted in ascending order). There should be as many numbers below the median as there are above

The **median** is an alternative way of measuring the centre of your data. In a set of data, the median is the value where an equal number of data

points sit above it as below it. The median is the true middle of the data and is a good measure of the average when your data includes outliers.

## Correlation

Scientists need to understand whether a relationship exists between the numbers.

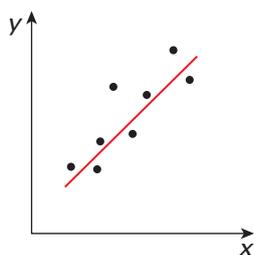
Numbers might be correlated positively or negatively, or they may have no correlation.

When interpreting a correlation between variables, it's important not to assume that one variable is having an effect on the other. A correlation may actually be caused by another factor that wasn't one of the measured variables. That is why it's important to use the word 'suggests' rather than 'proves' or 'causes' if you think there might be a relationship.

### Quick check 1.12

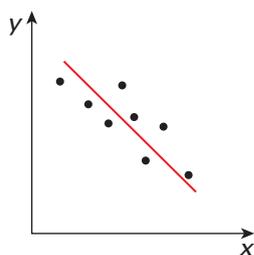
- 1 State whether you would expect a positive or negative correlation, or no correlation for each of the following examples.
  - a The volume of a set of headphones on hearing damage
  - b A high temperature forecast on the expectation of bushfires
  - c Eating fatty foods on having healthy cholesterol levels
  - d Students' absences on grades
- 2 Refer back to Quick check 1.11.
  - a Predict whether the trend line for the graph you drew will be linear or non-linear.
  - b Identify whether there is a positive or negative correlation, or no correlation.
  - c Describe what the data suggests would happen if you reduce the amount of food added.

Positive correlation



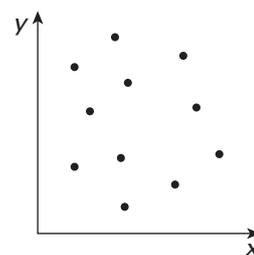
The points lie close to the line of best fit, which has a positive gradient. This suggests that as the independent variable increases, the dependent variable increases.

Negative correlation



The points lie close to the line of best fit, which has a negative gradient. This suggests that as the independent variable increases, the dependent variable decreases.

No correlation



There is no pattern in the results. There is no relationship between the independent and dependent variables.

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

## Outliers

Outliers can easily be spotted when data is graphed. There will often be a large gap between an extremely high or low value and other observations, indicating that it differs greatly.

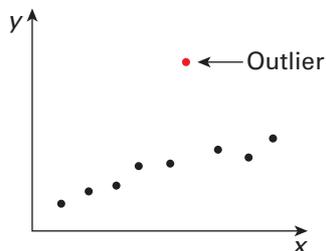


Figure 1.18 Outliers are often easily spotted in graph form.

## Range

We can also measure the dispersion of the data. This provides information about the spread of a particular variable's values. One way of doing this is to calculate the **range**, which is the difference between the smallest and largest values. Range bars can be plotted on graphs to visually represent this information. The larger the range bars, the more variation in the variable's values, suggesting that the data is less reliable. Usually, outliers are excluded from calculations.

**range**  
the difference between the highest and lowest values in the data set

### Worked example 1.1

Using the data from an investigation into the time it takes water to boil, determine which data is a likely outlier, as well as the range of the data.

Working	Explanation
<p><b>Outliers</b></p>	<p>Creating a dot plot allows us to easily see that 13 minutes to boil is likely to be an outlier.</p>
<p><b>Range</b></p> <p><math>4 - 2 = 2</math> minutes</p>	<p>Excluding the outlier, 13 minutes, we subtract the largest value, 4, from the smallest value, 2. If we include the outlier, the range would be <math>13 - 2 = 11</math> minutes.</p>

### Quick check 1.13

Calculate the mean, median and range of the following data set:

17, 14, 18, 21, 21, 19, 12, 20, 16

## Discussion

In a practical report, the discussion is a critical evaluation of how well the experimental technique and data were able to address the hypothesis.

Discussion should include an examination of the quality of the data in relation to its accuracy, reliability and validity. It should include:

- discussion of limitations imposed by the experiment and equipment used
- consideration of possible sources of systematic and random error
- identification of any outliers and potential reasons for their cause
- assessment of accuracy and reliability by looking at things like if the line of best fit intersects the origin,

closely aligns with your data or if the range bars are large or small

- suggested improvements and extensions to the experiment.

## Conclusion

The conclusion is where you should answer your original research question, stating whether your hypothesis is supported or not. You should start with a general statement that summarises your findings, but then justify this by using actual data from your results to support this statement. You can also use your own scientific knowledge to explain your results.

### Quick check 1.14

- 1 State the sort of uncertainty that each of the following scenarios represents.
  - a A measuring tool is incorrectly calibrated and regularly underestimates the mass.
  - b A measuring tool is not very precise and the temperatures vary by approximately 0.5 of a degree in either direction.
- 2 Describe how the effect of random uncertainty can be reduced.

## Practical 1.2: Student design

### Comparing the effect of indigestion remedies

#### Background

We already know from Year 9 that the stomach is an essential organ involved in the digestion of food. It achieves this by creating a highly acidic environment (pH of approximately 2 to 3) through the production of hydrochloric acid. However, an excess of acid in the stomach can cause painful indigestion.

Antacids are a common treatment option as they are alkaline, allowing excess stomach acid to be neutralised.

Now that you have a much more accurate way of measuring volume, design an experiment that will compare three different antacids (A, B and C) to determine which is most effective in relieving indigestion.

#### Materials

- hydrochloric acid (1 M)
- 3 different antacids
- titration equipment
- electronic balance
- spatula
- Phenolphthalein indicator
- watchglass

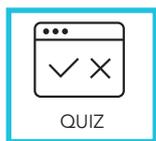
#### Procedure

Plan your experiment with a lab partner, taking into consideration:

- your aim
- the independent variable and dependent variables
- the variables that will be controlled in this experiment
- the procedure you will follow
- how you will document the results.

Carry out the experiment and derive your conclusion. Consider how you could improve the accuracy of your results in future.

## Section 1.2 questions

**Remembering**

- 1 **Name** four items that can be found on an x–y plot.
- 2 **Describe** what an outlier is.

**Understanding**

- 3 **Explain** how the mean is calculated.
- 4 **Explain** how the use of a data logger can be beneficial to an experiment.
- 5 **Classify** the following errors as either random errors or systematic errors.
  - a Instrument fault: a burette is leaking, so every reading taken is 0.1 mL lower than the actual value.
  - b Human fault: when recording the data, the researcher has a poor understanding of rounding decimals and consistently rounds them up to the nearest whole number.
  - c Instrument fault: a set of scales is not very accurate and the displayed mass is often out by around 1–3 grams in either direction.

**Applying**

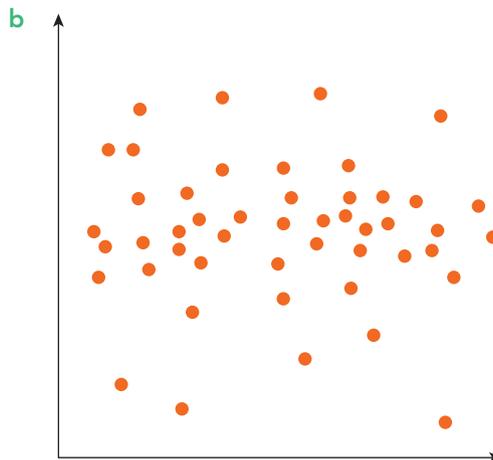
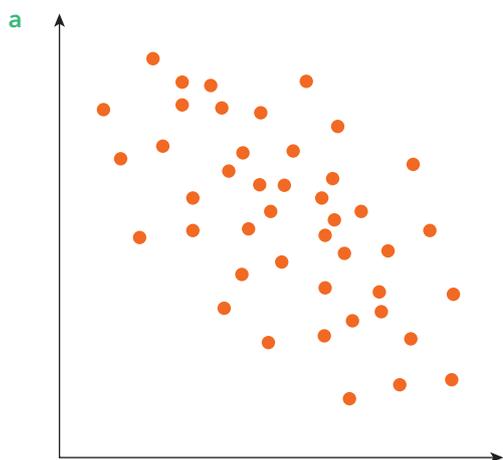
- 6 The table below shows results that a changing pH of a pond has on the number of tadpoles that are found there.

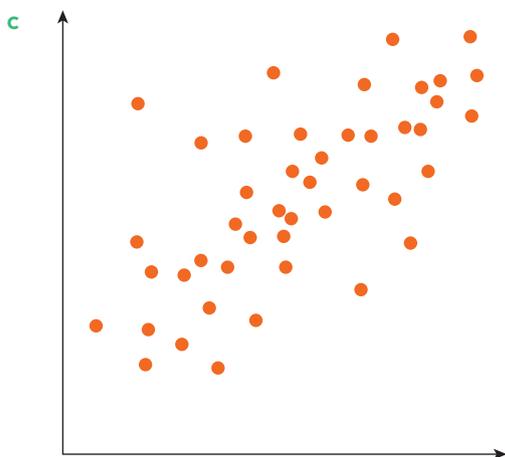
pH of water	Number of tadpoles
8.0	45
7.5	69
7.0	78
6.5	88
6.0	43
5.5	23

- a **Identify** the independent variable and dependent variable of this study.
- b **State** which pH is the optimum for tadpole growth.
- c **Construct** a scatter plot with correctly labelled axes and title, to display this data.

**Analysing**

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





- 8 A faulty burette is being used during a titration and this causes the results to all be overstated by around 0.5 mL each time.
- Identify** what type of error this represents.
  - Discuss** the effect in terms of accuracy, reliability and validity.
- 9 **Deduce** when a scientist might use a column graph rather than a dot plot.

### Evaluating

- 10 A pathologist wanted to know the effect of adding an unknown substance X to bacteria. She conducted an experiment comparing bacterial colonies where the substance had been added and where it had not been added. She then counted the number of colonies over a number of hours.

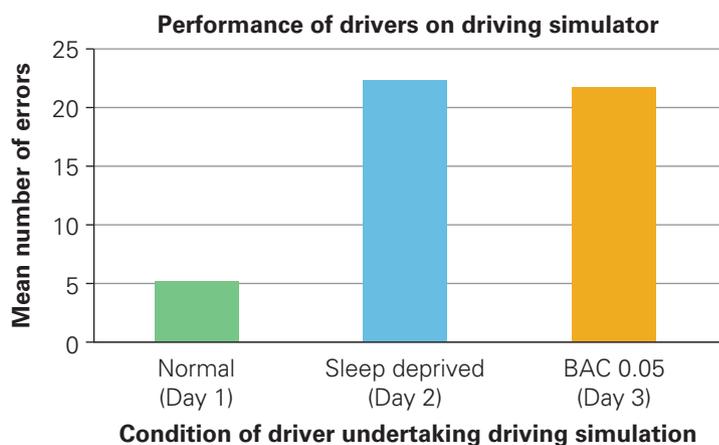
Time (hours)	Number of bacterial colonies	
	Substance X added	Nothing added
0	120	120
1	96	121
2	92	122
3	83	123
4	64	123
5	58	120
6	45	124
7	45	125
8	25	126
9	12	130

- Construct** a graph of the points of data and then draw in a line of best fit for each set of data.
- Describe** the two results in terms of correlation.
- Determine** the relationship between substance X and bacterial colony growth.

- 11 A student was interested in testing the effects of sleep deprivation on memory recall in secondary school students, so decided to conduct a study. He chose four of his friends to be the participants. Two of them went without sleep for a whole 24-hour period and were then given 20 three-letter nonsense words (for example, tuf, pud, wes) to memorise for two minutes and then recall. The other two of his friends were allowed to sleep for their usual time period and were given the same memory test: 20 three-letter nonsense words to memorise for two minutes and then recall. Results are shown below:

	Average recall score of three-letter nonsense words (out of 20)
Sleep deprived group	3
Non-sleep deprived group	7

- Construct** a testable hypothesis for this experiment.
  - Graph** the results.
  - Outline** two possible extraneous variables.
  - Discuss** whether this experiment was ethically sound.
  - Outline** a conclusion that can be drawn from the results obtained.
  - Describe** what limitations exist in this study.
- 12 A researcher was interested in investigating how driving ability was affected if people were either sleep deprived or under the influence of alcohol – specifically with a blood alcohol content (BAC) reading of 0.05. She tested 30 participants who responded to an advertisement on Facebook. They were tested in a driving simulator in one of three conditions: control, sleep deprived and BAC 0.05. Results are shown below. **Summarise** the results found, using the data from the graph.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>1.1 I can describe each stage of the experimental design process.</b> e.g. State the missing stage: Research question; _____; Hypothesis and variables; Procedure; Results; Analysis; Discussion; Conclusion.	
<b>1.1 I can identify independent, dependent and controlled variables.</b> e.g. Explain the importance of controlled variables.	
<b>1.1 I can outline experimental validity and assess whether the experiment is suitable for the research question.</b> e.g. Recall the definition of validity.	
<b>1.1 I recognise the need to write a risk assessment before completing any experiment.</b> e.g. Create a general risk assessment for any experimental work in your lab.	
<b>1.1 I can describe the information found on a safety data sheet (SDS).</b> e.g. Summarise the information you would find on a safety data sheet.	
<b>1.1 I can describe the ethical requirements of working with humans and animals.</b> e.g. Describe some of the principles that scientists must follow if they are working with animals.	
<b>1.1 I can define primary and secondary data.</b> e.g. Contrast primary and secondary data.	
<b>1.1 I can distinguish between quantitative and qualitative data.</b> e.g. State the type of data that is collected when undertaking an interview.	
<b>1.1 I recognise the difference between discrete and continuous data.</b> e.g. Contrast discrete and continuous data.	
<b>1.1 I can construct a results table.</b> e.g. State which column the independent variable is found in when drawing a results table.	
<b>1.2 I can describe the use and importance of specialised equipment such as burettes, pipettes and data loggers.</b> e.g. Describe why a data logger may be useful in some scientific experiments.	
<b>1.2 I recognise the difference between accuracy and reliability.</b> e.g. Contrast the terms accuracy and reliability.	
<b>1.2 I recognise the difference between systematic and random errors.</b> e.g. State the type of error that is caused by environmental effects such as temperature or humidity.	



Success criteria	Check
<p><b>1.2 I can state the absolute uncertainty when using both analogue and digital measuring instruments.</b> e.g. State the uncertainty of the following pieces of equipment:</p> 	
<p><b>1.2 I can calculate the relative uncertainty for a result.</b> e.g. Calculate the relative uncertainty of a measurement of 1.86 g when the absolute uncertainty is <math>\pm 0.01</math> g.</p>	
<p><b>1.2 I can represent data in different graphs.</b> e.g. Describe when you would use a scatter plot.</p>	
<p><b>1.2 I can calculate the mean, median and range of scientific data.</b> e.g. Calculate the mean of the following data: 4, 4, 1, 9, 8, 6.</p>	
<p><b>1.2 I can state the correlation between data on a graph.</b> e.g. Predict if there would be a positive or negative correlation between the number of cups of coffee drunk in a day and the number of hours slept that night.</p>	
<p><b>1.2 I can recognise outliers in scientific data.</b> e.g. Identify the outlier in the following data: 4, 4, 1, 33, 9, 8, 6.</p>	

## Reflections

- 1 What **connections** come to mind when you think about working scientifically and your everyday life?
- 2 What new concepts have **extended** your thinking about working scientifically?
- 3 What information did you find **challenging** or confusing?

## Data questions

High school students were analysing the content of ethanoic acid in a commercial vinegar sample and had made up a dilute solution of 0.1 M ethanoic acid based on the concentration of ethanoic acid given on the bottle of vinegar. The students set up a titration with 20.00 mL of their ethanoic acid in a conical flask (via pipette) and filled a burette with 0.1 M NaOH.

If the ethanoic acid content quoted on the vinegar bottle was correct, the students hypothesised that 'if 20 mL of 0.1 M ethanoic acid is present, then 20 mL of 0.1 M NaOH will be required to reach an end point'. The titration data from two students attempting six replicated trials are tabulated below.

Titration	Volume (mL) 0.1 M NaOH to end point	
	Student 1	Student 2
1	19.95	20.50
2	20.00	20.50
3	20.50	20.50
4	22.70	29.30
5	19.95	20.40
6	20.00	20.40
<b>Mean</b>		

- Identify** and circle any outliers in each student's trials.
- Calculate** the mean volume of NaOH required to reach the titration end point, after removing outliers for each student.
- The 'true' value for the titration given the actual concentration of ethanoic acid should have been 20.00 mL of 0.1 M NaOH. **Assess** the validity of this experiment in identifying the concentration of ethanoic acid.
- Identify** if any patterns occur in the results obtained by the students.
- Contrast** the data tabulated. Was each student accurate?
- Analyse** the data tabulated. Were the results reliable?
- Justify** whether the data presented by students 1 and 2 provide evidence to support the hypothesis.
- Compare** the data fluctuations for each student. Do the data points fluctuate randomly above and below the true value or are they biased in one direction?
- Based on the data presented, **infer** whether the experiment was accurate, reliable and valid.

# Chapter 2

## Transfer of energy

### Inquiry questions

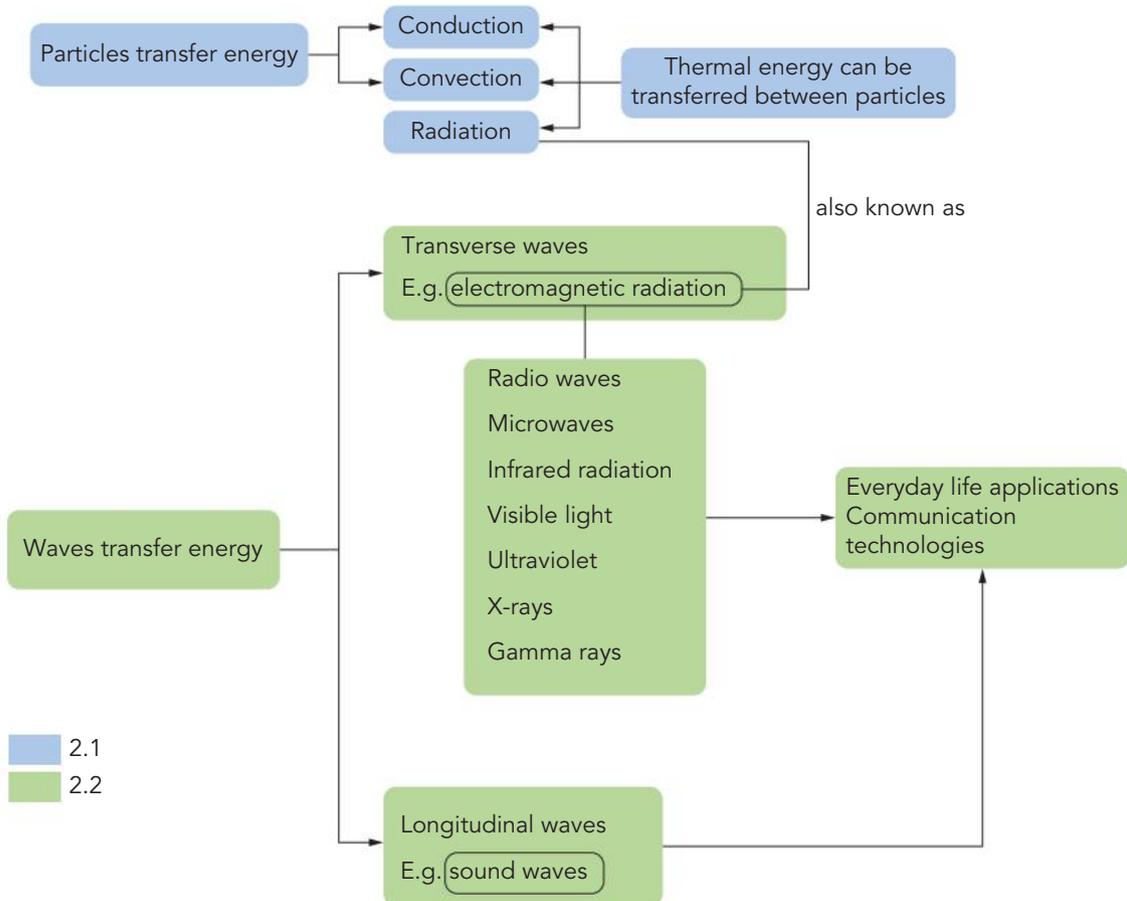
- How does a fireplace heat the whole house?
- Why do microwaves interfere with your Wi-Fi signal?
- How does sound help us to see?



### Chapter introduction

In this chapter, you will study the wave and particle models of energy transfer. You will consider the movement of energy through different mediums by investigating the transfer of thermal energy by conduction, convection and radiation. You will also explore light and sound, both situations where energy is transferred by waves.

# Chapter map



## 2.1 Particles transfer energy



### Learning goals

- 1 To compare thermal energy and temperature in terms of kinetic energy
- 2 To explain, using the particle model, the process of convection and conduction of heat energy
- 3 To describe radiation and explain why it does not require a medium (particles) to transfer heat energy
- 4 To identify everyday situations where particles transfer energy

### The particle model

According to the particle model:

- All matter is made up of particles.
- Particles are attracted to each other.
- Particles are always moving on the spot or around.
- As the temperature increases, particles move faster.

**kinetic energy**  
the energy of moving matter

**thermal energy**  
the internal energy present in an object or system due to its temperature

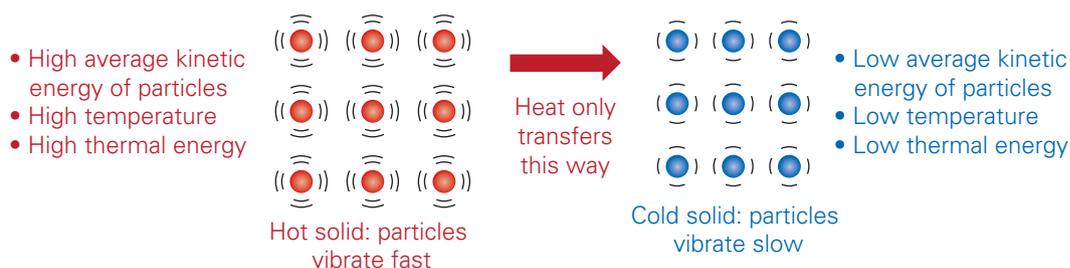
**heat**  
the transfer of thermal energy from hotter to colder objects or regions

**temperature**  
a measure of the average kinetic energy of the particles in an object

The energy of moving matter is called **kinetic energy**, and therefore all particles of matter have kinetic energy because they are in constant motion. Objects with a higher temperature have faster moving particles, and the particles have higher kinetic

energy. **Thermal energy** of an object or a system relates to the total kinetic energy of its particles. It is often called **heat**, but in science heat specifically refers to thermal energy that is transferred. Thermal energy on the other hand is something an object possesses whether there is transfer or not.

So what then is the **temperature** of an object? It is the average kinetic energy of all its particles. It tells us what the level of thermal energy is, but not how much thermal energy there is. It's like the level of water in a dam: the level tells us how high it is, but doesn't tell us completely how much water there is. Heat only transfers from hotter objects to colder ones, so temperature tells us whether heat transfer will take place, and in which direction.



**Figure 2.1** The particles in hot and cold solid objects of the same mass. The relationship between average kinetic energy of particles, thermal energy, heat and temperature is shown. This diagram also applies to liquids and gases, except in these states, the particles aren't vibrating but instead are moving around.

### Quick check 2.1

- 1 Explain the relationship between thermal energy and kinetic energy of an object.
- 2 Describe what the term heat means in science.
- 3 State what temperature measures in terms of particle theory.
- 4 Determine whether the particles in a cup of 30°C water would on average move faster or slower than the particles in a cup of 45°C water.

## Heat transfer

Heat transfer is the movement of thermal energy from an object at a higher temperature to an object at a lower temperature. The rate of heat transfer is faster when there is a larger temperature difference between the two objects. As thermal energy is transferred to an object with a lower temperature, the particles within that object vibrate or move faster, which results in (and can be measured by) an increase in the object's temperature.

In Figure 2.2, three types of heat transfer are occurring simultaneously. As you sit around the campfire, you feel an intense warmth on your skin – **radiation**. You also notice that the air above the fire is hotter than beside the fire and will burn the marshmallows – **convection**. Finally, when roasting your marshmallow over the flames you notice that heat is travelling along the metal fork, which is starting to feel warm in your hands – **conduction**. What exactly are these types of heat transfer?

## Conduction

When energy is transferred between particles of matter by contact, the process is referred to as conduction. A particle, object or region with a higher temperature naturally transfers thermal energy to a particle, object or region with a lower temperature. When substances gain energy, their particles start to vibrate faster. If a faster vibrating particle bumps into a slower vibrating one, it transfers some energy to it. This causes the slower vibrating particle to vibrate faster, increasing its temperature. The same thing happens in collisions between particles that are moving around.

Note that conduction does not happen only in the solid state. A solid surface with a high temperature transfers thermal energy to particles of a cooler gas or liquid that are in contact with it by conduction.

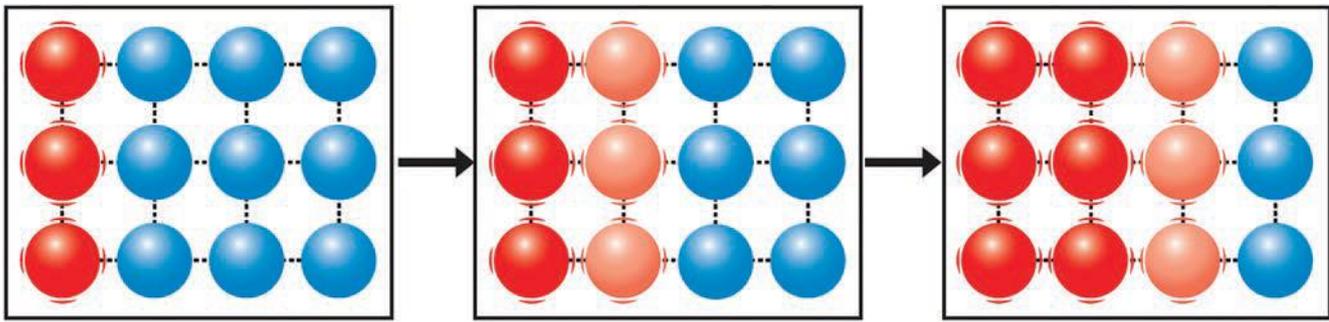
**radiation**  
transfer of energy without the presence of particles

**convection**  
transfer of thermal energy due to the movement of particles in a liquid or gas

**conduction**  
transfer of thermal energy through collisions between vibrating or moving particles



**Figure 2.2** Keeping warm around a campfire and roasting marshmallows require the transfer of heat.



**Figure 2.3** A time sequence showing heat flowing through the particles of a solid by conduction. The heat source (not shown) is on the left of the particles. At first only the particles next to the heat source become hot and vibrate. They bump into particles next to them, which warm up, and so on.



**Figure 2.4** Warming up your hands with a hot drink on a cold day is an example of conduction.

Conduction occurs when you warm up your hands when holding a hot drink. Your hands warm up because thermal energy is being transferred from the mug to your hand.

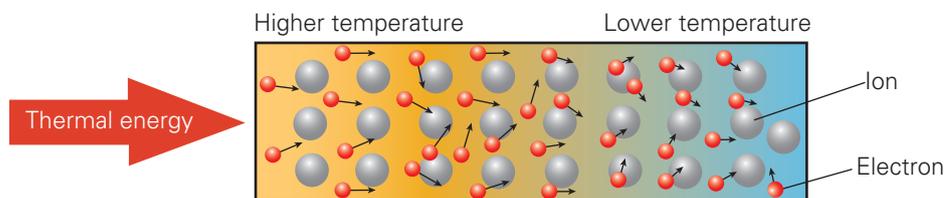
How would holding the hot drink feel different if it was a polystyrene cup? Or a metal cup? Some substances, such as metals, are good **conductors** of heat. This is because the electrons in metal can leave their atoms and move around as **free electrons**. These free electrons move fast and result in vibrations (and the associated kinetic energy) passing more quickly between particles in a metal. So thermal energy in metals spreads quickly from hot to cold (see Figure 2.5).

**conductor (heat)**  
a substance that allows heat to pass through it easily

**free electron**  
an electron that is not attached to an atom

**insulator (heat)**  
a substance or material that does not allow heat to pass through easily

Other materials, such as polystyrene, do not conduct heat well and so we call them **insulators**.



**Figure 2.5** Free electrons can travel through metals and help thermal energy spread quickly from hot to cold areas.

## Try this 2.1

### Heat-sensitive slime

You will need:

- ¼ cup of PVA glue
- 1 tablespoon of water
- a few drops of food colouring
- 3 teaspoons of thermochromatic pigment
- ¼ cup of liquid starch.

Mix together the glue, water and food colouring. Then mix in the thermochromatic pigment. Add half of the liquid starch and mix until combined. Your slime should be thick and slimy.

Mix in the rest of the starch, bit by bit, until well combined. Your slime will no longer be sticky. Observe what happens as the slime cools. When it is hot, it will be the colour of the food colouring. When it is cold, it will be the colour of the thermochromatic pigment.

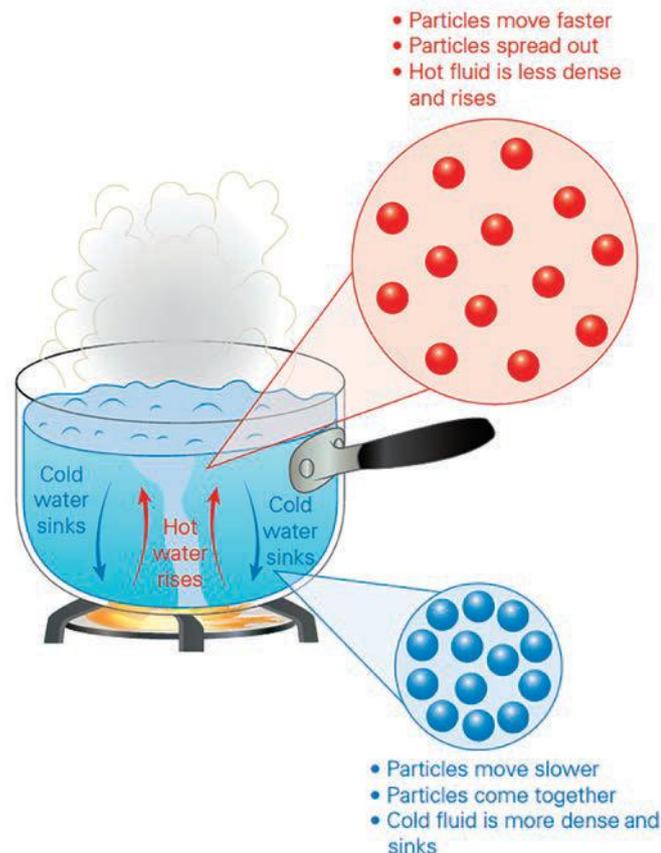
## Convection

Convection is the flow of thermal energy through a liquid or a gas that is caused by movement of the liquid or gas itself. Heating water in a pot and warming up a room with an oil heater are both examples of heating via convection.

Have you ever heard the saying, ‘Hot air rises’? When a liquid or a gas is heated, the particles vibrate faster and the space between them gets bigger, causing the liquid or

gas to expand. This means that the warmer regions become less dense and are displaced by the more dense colder regions, and so appear to rise. Figure 2.6 shows water in a pot being heated from the bottom, causing the hot water to rise. Away from the heat source, at the top of the pan, the water cools again. The water becomes more dense and sinks back down to the bottom where it will be heated again. This cycle is called a **convection current**.

**convection current**  
circulation patterns resulting from the flow of liquids or gases due to a temperature or density difference in a substance



**Figure 2.6** When water is heated, the hotter less dense water at the bottom rises and the colder more dense water sinks to take its place.

Convection is a major factor driving weather patterns. The Sun heats the Earth's surface, warming the air, which then rises, creating an upward current in the atmosphere. As this warmer air rises, cooler air from elsewhere flows in to replace it and we feel this air movement as wind. As the convection current continues and the warm air gets higher, it will cool, potentially causing any water vapour within it to condense and form a cumulus cloud. Within the Earth, convection currents move layers of magma. In the oceans, convection creates currents.

### Explore! 2.1

#### El Niño vs La Niña

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

Use your preferred search engine to find the Australian Bureau of Meteorology website to answer the following questions.

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

### Try this 2.2

#### Convection spiral

Take a piece of paper and cut out a spiral that is 6 cm in diameter. Attach a piece of string to the centre of the spiral. Turn on a desk lamp and shine it towards the ceiling. Hold the spiral by the string, suspended 10 cm over the top of the lamp. Observe what happens, and explain why.

## Radiation

Any object with thermal energy radiates heat, and you do not need to be in contact with the object to feel this thermal radiation. This is why you can feel the warmth of a fire when you stand in front of it, or feel the Sun's warmth when you are outside. Thermal radiation, also known as radiant heat or infrared radiation, is a form of electromagnetic radiation (like light and radio waves) and travels in waves (explored further in Section 2.2, page 45). This differs from convection and conduction, as it does not rely on particle movement.



Figure 2.7 Bread being toasted via radiant heat transfer

### Explore! 2.2

#### How do animals stay warm?

Conduction, convection and radiation all play an essential role in nature. All warm-blooded animals can generate their own body heat, and they radiate thermal energy. Cold-blooded animals on the other hand do not generate their own body heat all the time, so they need to lie in the sun to get warm.

Research how animals living in cold environments reduce heat loss from conduction, convection and radiation.

### Quick check 2.2

- 1 State the type of heat that occurs when you burn your hand on a hot plate.
- 2 Describe thermal conduction in a solid using the particle model.
- 3 Describe how thermal energy travels within a liquid or a gas.

## Practical 2.1: Self-design

### Modelling heat transfer

#### Aim

To design your own experiment that models the three types of heat transfer.

#### Materials

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

#### Procedure

Design an experiment that demonstrates the three types of heat transfer. In a group, discuss ways in which you could do this. Choose the best method and plan the experiments. You must include information on variables, a risk assessment and a step-by-step method for carrying out the experiment.

#### Results

Record your observations for each of the experiments in an appropriate manner.

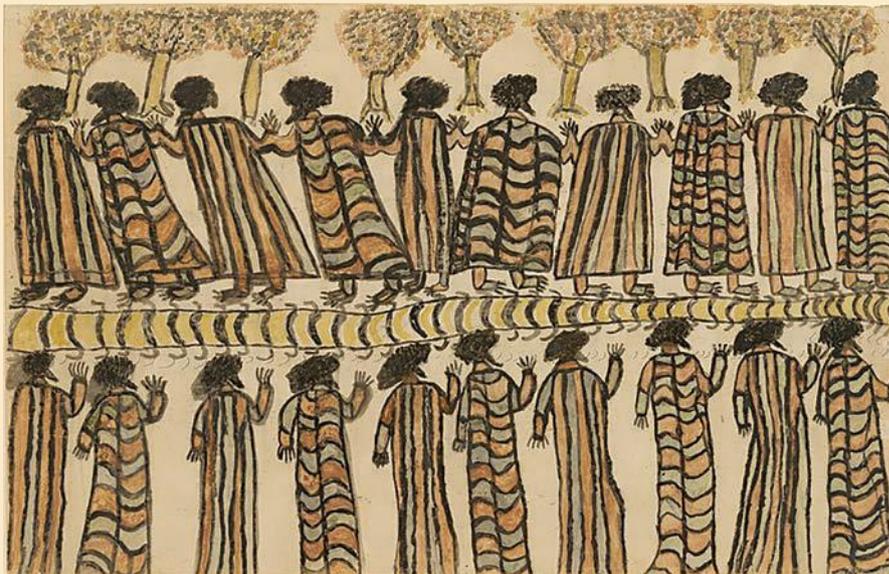
#### Discussion

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

## Did you know? 2.1

### Clothing technology

Australia has a large variety of climatic regions, and the Indigenous Australian peoples developed technologies that enabled them to live and thrive successfully in even the most extreme climates. For warmth, traditional animal skin cloaks were worn with the fur lining facing inwards, next to the body. This trapped a layer of air and provided valuable insulation. However, during rainy seasons, the cloak was worn with the fur on the outside, because the hairs had water-repellent properties. Sometimes fat was rubbed onto the outside of the fur to further increase insulation. These heat-conserving cloaks reduced thermal conduction, convection and radiation.



**Figure 2.8** Artwork by William Barak, an influential Aboriginal Australian spokesperson, depicts the use of possum skin cloaks

## Summary of heat transfer

The particle model can be used to explain conduction and convection, as they both involve the transfer of thermal energy through particles. Although radiation also involves the transfer of thermal energy, it does not

require the presence of particles. Thermal radiation is an electromagnetic wave that can travel through empty space where there are relatively few particles. This is why we can feel the warmth of the Sun despite it being about 150 million km away. Therefore, radiation is explained using the wave model.

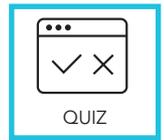
Type of heat transfer	Description	Mechanism	Example
Conduction	Transfer of thermal energy by direct physical contact between particles	Atoms are always vibrating or moving, but when heat is applied to an object, the atoms next to the heat vibrate or move more, so their kinetic energy increases. They 'bump' neighbouring atoms, passing on this kinetic energy and allowing thermal energy to move through the object or substance.	You warm up your hands when holding a hot drink. Your hands warm up because thermal energy is being transferred from the mug to your hand.
Convection	Transfer of thermal energy by molecular motion in a fluid (liquids and gases)	When a liquid or a gas is heated, the particles vibrate and move faster and the liquid or gas expands. This means that the colder regions are more dense than the warmer regions, and so the colder liquid or gas sinks to the bottom. As it is heated in turn, the material rises to the top creating a convection current.	Water in a pot being heated from the bottom, causing the hot water to rise. The cold water sinks and takes its place at the bottom, and is then also heated.
Radiation	Transfer of thermal energy without the presence of particles	Radiant heat travels in waves because it is a form of electromagnetic radiation.	When making toast, the bread does not touch the source of heat but gets toasted because of the transfer of thermal energy through space by radiation.

**Table 2.1** The three different processes of heat transfer

## Section 2.1 questions

### Remembering

- 1 **Define** the term 'thermal energy' in your own words.
- 2 **State** the conditions required for conduction to occur.



### Understanding

- 3 **Explain** how an object with a higher temperature can have less thermal energy than an object that has a lower temperature.
- 4 An electric oven has a heating element underneath its bottom surface, and two wire racks (shelves), a top and a bottom. It does not have a fan to circulate the air inside. A recipe calls for the baking dish to be placed in the hottest part of the oven. **Explain** whether you should place it on the top rack or the bottom rack.
- 5 **Explain** why the energy received from the Sun is by radiation and not convection or conduction.
- 6 Convection occurs in liquids and gases. **Explain** why convection does not (as a general rule) occur in solids.

### Applying

- 7 **Classify** the following as heat transfer by either conduction, convection or radiation.
  - a Heat escaping from the top of an open cup of a hot coffee
  - b Heat from an oven's grill melting the cheese on a pizza placed in the oven
  - c An ice cube melting in your hand.
- 8 **Differentiate** between thermal insulators and conductors in terms of their ability to transfer heat quickly.

### Analysing

- 9 A volume of 1 L of gas in a cylinder is rapidly compressed by a piston until it occupies 0.1 L. As a result the molecules of gas have less space to move, they undergo many more collisions which causes them to speed up. **Predict** what happens to the temperature of the gas.
- 10 Two cups of water have their temperature measured. One is 20°C and the other is 30°C. Using your understanding of temperature and particles, **discuss** how the movement of particles differ.

### Evaluating

- 11 Josh says insulation keeps out the cold. **Critique** this statement.
- 12 **Decide** at what point thermal energy transferring between two substances in contact will stop being transferred.



## 2.2 Waves transfer energy

### Learning goals

- 1 To compare mechanical and electromagnetic waves in terms of the wave model and their requirements for propagation
- 2 To compare transverse and longitudinal waves in terms of the direction of oscillation and energy transfer
- 3 To describe, using the wave model, the features of waves including wavelength, frequency and speed
- 4 To identify everyday situations where waves transfer energy
- 5 To identify examples of electromagnetic waves and their properties
- 6 To relate the properties of different types of radiation in the electromagnetic spectrum to their uses in everyday life, including communications technology
- 7 To describe the occurrence and some applications of absorption, reflection and refraction in everyday life
- 8 To identify sound waves as an example of longitudinal waves
- 9 To explain, using the particle model, the transmission of sound in different mediums

During a lightning storm, both light and sound energy are transferred by waves to your eyes and ears respectively. When you see the lightning, your eyes are detecting light waves, and when you hear the thunder, your ears are detecting sound waves. We see the lightning before we hear the thunder because light waves travel faster than sound waves.



**Figure 2.9** Lightning and thunder are forms of light and sound energy that travel as waves.

### The wave model

A **wave** is a carrier of energy that transfers energy from one place to another without any matter accompanying it. **Mechanical waves** transfer energy from the source of

a wave (a force that starts the disturbance in the medium). The matter through which the wave travels is called the **medium** and can be in any state. In mechanical waves, a disturbance in a medium results in the transfer of energy by the vibration or **periodic motion** of particles.

Mechanical waves, therefore, require particles to allow the energy to travel through matter. These particles don't move along the wave, they only pass on the energy of the disturbance to the particles next to them. For example, a duck will bob up and down as a ripple passes, revealing the periodic motion of the water particles, but it returns to its original position – it does not travel with the wave. Another kind of wave, called an **electromagnetic wave**, doesn't require a medium and can travel through a **vacuum**. Light and radiant heat are examples of electromagnetic waves.

Depending on the direction of oscillations relative to the direction of energy transfer, a mechanical wave can be classified as a transverse or longitudinal wave.

#### wave

carrier of energy from one place to another without any matter accompanying it

#### mechanical wave

a disturbance in a medium that transfers energy through that medium

#### medium

the matter through which a mechanical wave travels

#### periodic motion

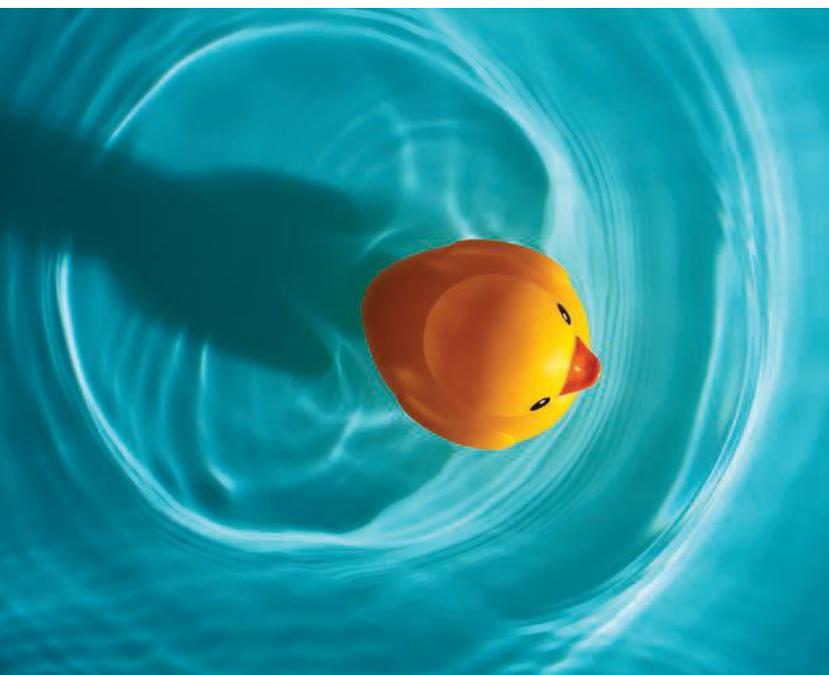
a movement of a particle or object that returns to its starting position and repeats in the same time interval, like a swing

#### electromagnetic wave

a wave with electric and magnetic properties that can travel through matter or a vacuum

#### vacuum

a space totally devoid of matter



**Figure 2.10** As a ripple passes through the medium (water), the duck is temporarily displaced as it bobs up and down, before returning to its original position.

### Quick check 2.3

- 1 Define the term 'mechanical wave' in your own words.
- 2 What is the medium of a mechanical wave?
- 3 List two types of mechanical waves.

## Transverse waves

A **transverse wave** is a wave in which the disturbance of the medium is at right angles to the direction of energy transfer. In mechanical transverse waves, the particles vibrate up and down, about their rest position, creating a series of **crests** and **troughs**. Crests and troughs represent the maximum **displacement** of a particle in the medium at the top and bottom of the wave respectively.

The number of **cycles** every second is called the **frequency**, and is measured in **hertz** (Hz). The distance measured in metres between two consecutive points on the waves is called the **wavelength**. The **amplitude** of a wave is how far the wave displaces from its middle position (centre line).

### transverse wave

a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

### crest

the maximum displacement of a particle at the top of the wave

### trough

the maximum displacement of a particle at the bottom of the wave

### displacement

the position of a particle when it has moved away from its rest position on the centre line of the wave

### cycle

one complete vibration or periodic movement of a particle through the crest and trough and back to its starting position; the length of a cycle is the wavelength

### frequency

the number of cycles of a wave per second

### hertz

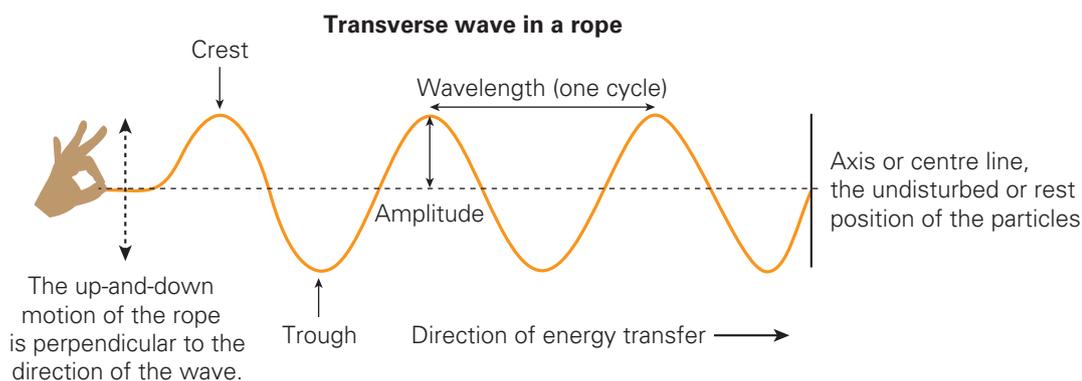
a unit for measuring the number of cycles that happen every second (frequency); abbreviation is Hz

### wavelength

the distance from one wave crest to the next

### amplitude

the distance (height) of a wave crest or the depth of a wave trough from the centre line of the wave

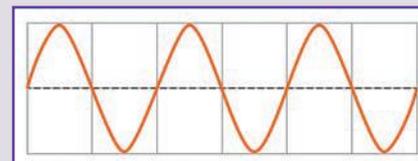


**Figure 2.11** In a transverse wave the particles move perpendicular (at right angles) to the direction of energy transfer.

### Try this 2.3

#### Looking at wavelength and amplitude

Copy the diagram on the right, using a ruler to make the sides of the grid squares exactly 1 cm long. On your copy, label the wavelength and amplitude of the waves. Use a ruler to measure these features.



**Figure 2.12** A transverse wave

### Quick check 2.4

- 1 Explain what the word 'transverse' means in relation to waves.
- 2 Recall the three measurements of waves that tell you their dimensions.

### Examples of transverse waves

The strings in musical instruments, deep ocean waves, some **seismic waves** and electromagnetic waves are all examples of transverse mechanical waves.



**Figure 2.13** When the strings of a guitar are plucked, they vibrate up and down while waves travel along the string to its ends.

### Electromagnetic waves

Electromagnetic waves consist of **oscillating** electric and magnetic fields, as opposed to particle disturbances in a medium. **Electromagnetic radiation** is the transfer of energy by electromagnetic waves. The waves transfer energy through empty space or matter, such as when light passes through glass. If these waves travel through

matter, some energy is lost to the particles of matter. When they travel through a vacuum, no energy is lost.

An electromagnetic wave begins when an electrically charged particle (such as an electron in an atom) vibrates, causing the electric field that surrounds it to oscillate. This creates an oscillating magnetic field. The two oscillating fields combine to create a **self-propagating** electromagnetic wave.

The directions that the electric and magnetic field oscillate in are perpendicular to the direction of the wave, so an electromagnetic wave is a transverse wave.

Unlike mechanical waves, electromagnetic waves all travel at the same speed through a vacuum (the speed of light) and so there is a simple proportional relationship between their frequency and wavelength. Either of these two measures determines a wave's position on the electromagnetic spectrum. As speed remains constant, the frequency of an electromagnetic wave can easily be calculated from its wavelength and vice versa.

#### seismic waves

waves that travel through the Earth and over its surface which when large enough cause earthquakes

#### oscillating

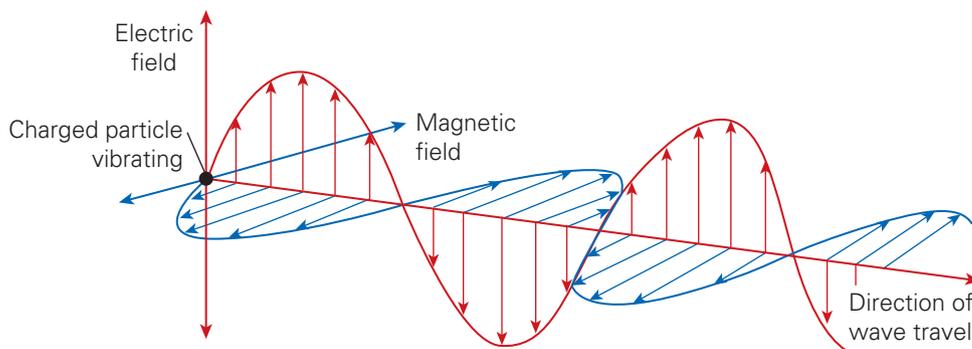
moving back and forth with periodic motion somewhat like vibration

#### electromagnetic radiation

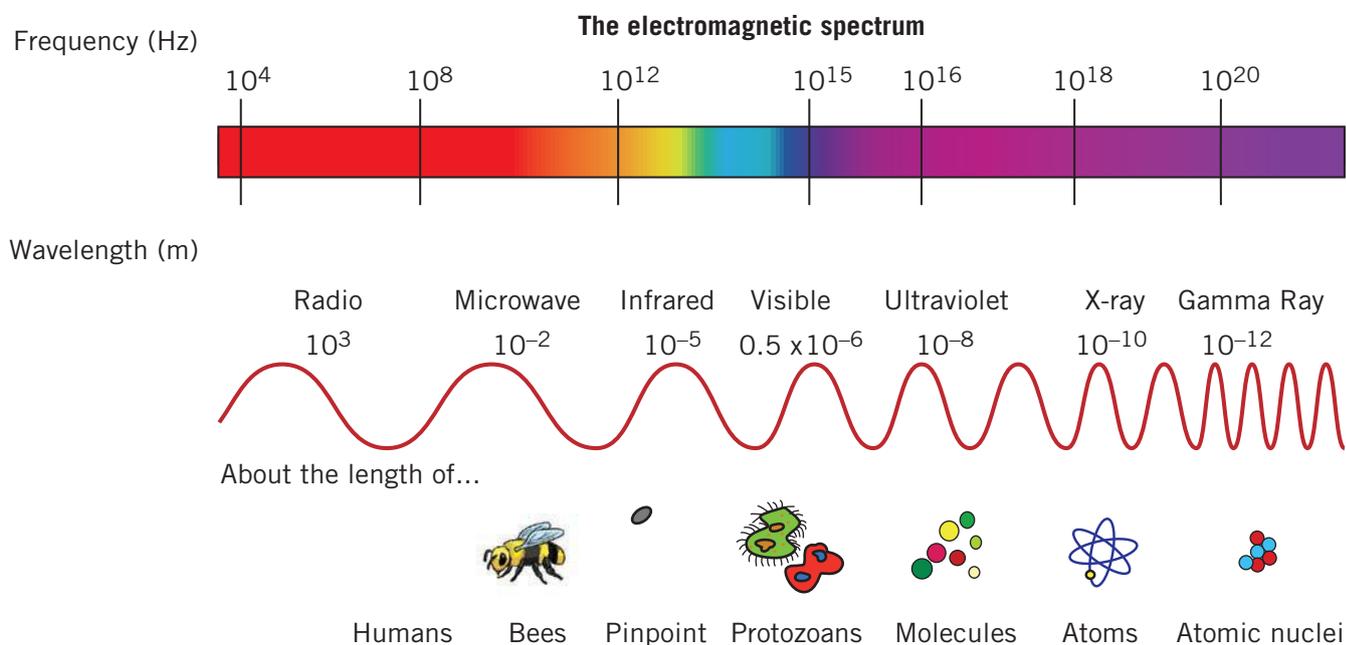
transfer of energy by electromagnetic waves

#### self-propagating

refers to a wave that (unlike mechanical waves) once started keeps going at a constant speed forever without needing the input of more energy



**Figure 2.14** A vibrating charged particle generates oscillating electric and magnetic fields. These fields are perpendicular to each other and to the direction of the wave.



**Figure 2.15** The electromagnetic spectrum extends beyond the visible spectrum (light).

The different types of electromagnetic waves and their uses are listed below.

- **Radio waves** are useful for communications and signals over long distances (including for radar). Radio waves were originally used for communication with ships at sea, then broadcasts by radio and television stations, and are now also used to send communications around the world via satellites. Radio waves have very long wavelengths (some of them are several kilometres long), but their energy and frequency are very low.
- **Microwaves** are used for cooking, Wi-Fi communications and mobile phone technology. In a microwave oven, any water molecules present in food will vibrate at the same frequency as the microwaves and convert this energy into heat, cooking the food quickly. Microwaves are also used in mobile phone networks. When a mobile phone is switched on, it produces microwave signals that are picked up by receivers in mobile phone towers. The towers then transmit signals back to the phone for incoming calls, to connect to the internet and to download files, images and video.
- **Infrared radiation** is the radiation you feel immediately when you stand near a fire or when you feel heated by the Sun. It is also used in home remote controls. Objects at a higher temperature release

more infrared radiation than similar objects at a lower temperature (this was covered as a type of heat transfer in Section 2.1). Infrared cameras can be used to detect infrared waves being emitted by an object. The signals are then processed to produce a false-colour image showing the relative temperatures of parts of the object.

- **Visible light** is the section of the electromagnetic spectrum that is visible to the human eye.
- **Ultraviolet light** is invisible radiation that can cause sunburn and skin cancer. Not all ultraviolet is bad though: skin cells use low-frequency ultraviolet light to make vitamin D.
- **X-rays** are high-energy electromagnetic waves that are used to create images of bones. Bone absorbs most of the radiation whereas X-rays will pass through soft tissue such as fat and muscle. This

#### radio waves

electromagnetic radiation that has the longest wavelength

#### microwaves

electromagnetic radiation used for cooking, communications and Wi-Fi; lies between radio waves and infrared radiation

#### infrared radiation

electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

#### visible light

the part of the electromagnetic spectrum that we can see

#### ultraviolet light

radiation that lies between visible light and X-rays; is needed by our bodies to make vitamin D; short wavelength UV can cause sunburn and cancer

#### X-rays

short wavelength electromagnetic radiation that can pass through flesh to give images of bones; hazardous and can cause cancer

**gamma ray**

high-energy ray with a very short wavelength produced when radioactive atoms decay

**ionising radiation**

higher frequency ultraviolet rays, X- and gamma rays which can turn atoms and molecules into ions; can potentially damage living cells

**opaque**

a substance that blocks the transmission of light completely

**reflect**

to throw back the energy of a wave (e.g. heat, light, sound) without absorbing it

**absorb**

to take up the energy of a wave (e.g. absorb light)

**incident ray**

a ray of light arriving at a surface

**reflected ray**

a ray of light that is reflected off a surface

**normal**

an imaginary line that is at right angles to a surface

**angle of incidence**

the angle between an incident light ray and the normal when the ray arrives at a surface

**angle of reflection**

the angle between a reflected light ray and the normal, when the ray leaves a surface

results in bones appearing white, soft tissue appearing grey and air appearing black in X-ray images. The development of imaging technologies has contributed greatly to our understanding of the functions and interactions of body systems. X-rays can cause cancer, although the radiation dose from medical scans is small.

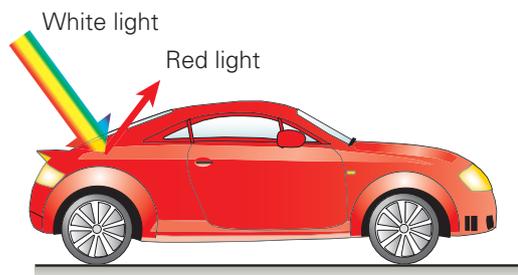
- **Gamma rays** are high-energy, high-frequency waves with a short wavelength. They are released when atomic nuclei decay, and although they can cause cancer, they can also be used in its treatment.

The higher the frequency of an electromagnetic wave, the

more energy it carries. Higher frequency ultraviolet rays, X-rays and gamma rays have enough energy to knock electrons off atoms, so they become ions. This is referred to as **ionising radiation**, and it damages living cells.

## Applications of visible light

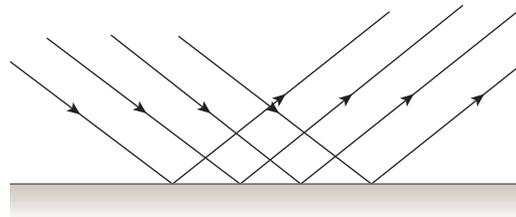
**Opaque** surfaces are able to **reflect** or **absorb** light. The colour we see an object as depends on the colour of light reflected off its surface. White objects reflect all the colours in the visible spectrum and absorb none compared to black objects, which absorb all the colours and reflect none. An object that appears red has a pigment



**Figure 2.16** A red car reflects all red wavelengths of light and absorbs all the other colours of the visible spectrum.

in its surface that absorbs all wavelengths except red, which is reflected into our eyes and seen as the colour red.

Light rays reflecting off a smooth surface bounce off at the same angle allowing a clear image to be seen.



**Figure 2.17** Light rays hitting a smooth surface are all reflected at the same angle, and an image can be formed.

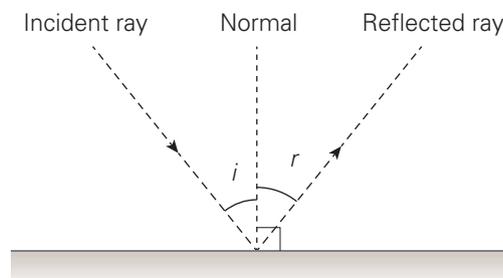
## Law of reflection of light

To understand the law of reflection of light, you first need to learn some definitions.

- The incoming ray of light that hits the reflecting surface is called the **incident ray**.
- The outgoing ray of light that is reflected off the surface is called the **reflected ray**.
- The **normal** is an imaginary line that is at right angles to the surface.
- The angle between the incident ray and the normal is the **angle of incidence** ( $i$ ).
- The angle between the reflected ray and the normal is the **angle of reflection** ( $r$ ).

The law of reflection of light states that the angle of incidence and the angle of reflection are equal to each other.

$$\text{angle of incidence } (i) = \text{angle of reflection } (r)$$



**Figure 2.18** The law of reflection of light states that the angle of incidence ( $i$ ) is always equal to the angle of reflection ( $r$ ).

### Quick check 2.5

- 1 State the law of reflection.
- 2 Explain what the law of reflection means.

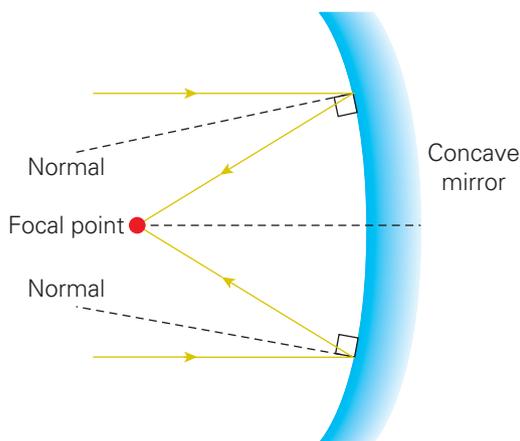
### Concave mirror

A **concave** mirror curves inwards, like a cave. Concave mirrors can be used to magnify images and are commonly used for shaving or applying make-up.

When parallel rays are reflected from a concave mirror, they converge at a *focal point*. The focal point is where an image forms. In Figure 2.19, the image is in front of the mirror, and is known as a *virtual image*.



**Figure 2.19** If you hold a concave mirror close, it will magnify your image (a virtual image), as shown here. But if you moved a long distance away from the mirror, it would turn your image upside down (a real image).



**Figure 2.20** When an object is far from a concave mirror, the reflected light rays converge to form a real image. If the object was close to the mirror, it would form a large virtual image, as in the shaving mirror shown in Figure 2.19.

### Convex mirror

**Convex** mirrors bulge outwards and give a wider field of view. They are used in car rear view mirrors to allow drivers greater visibility. You may also see large convex mirrors at intersections that have limited visibility, or in the hallways of hospitals to provide a view of what is around the corner.

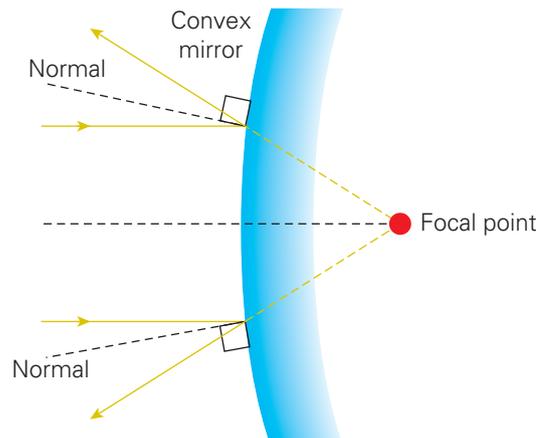
**concave**  
having an outline that is thinner in the middle, or a mirror that is curved inwards, like a cave

**convex**  
having an outline that is thicker in the middle, or a mirror that bulges outwards

When light rays are reflected from a convex mirror, the light rays diverge. An image forms behind the mirror – this is a virtual image.



**Figure 2.21** A car's side view mirror is often a convex mirror. It gives a wider field of view, but also makes objects appear smaller and further away than they actually are.



**Figure 2.22** Reflected light rays diverge from a convex mirror. The image formed is a virtual image.

## Practical 2.2

### Investigating ray diagrams with concave and convex mirrors

#### Aim

To observe and record the way in which light rays are reflected from curved mirrors.

#### Materials

- light box
- clear ruler
- pencil
- concave mirror
- convex mirror
- white A4 paper

#### Procedure

- 1 Plug in the light box and position it at the edge of a piece of A4 white paper.
- 2 Place the triple ray-forming plate into the slot and turn on the light box. Adjust the position of the bulb until you see three parallel rays of light on the paper.
- 3 Place the concave mirror about 10 cm in front of the rays, and align it so that the middle ray reflects back on itself.
- 4 Use a pencil to outline the mirror, and use a clear plastic ruler to trace the incident and reflected rays.
- 5 Label the point at which they meet the 'focal point'.
- 6 Get a new piece of paper and repeat steps 3 and 4 with a convex mirror.
- 7 Trace the reflected rays back behind the outline of the mirror with dotted lines.
- 8 Label the point at which the dotted lines meet the 'virtual focal point'.

#### Results

On your ray tracing diagrams, measure how far the focal point or virtual focal point is from the mirrors. Include this in your diagrams.

#### Discussion

- 1 Do the focal lengths for the convex and concave mirrors differ?
- 2 Why does the convex mirror produce a 'virtual focal point'?

#### Conclusion

- 1 Make a claim regarding light rays reflected from curved mirrors. Start your sentence with: 'This experiment suggests that with curved mirrors ... '.
- 2 Support your claim by using what you observed when you used convex and concave mirrors. Start your sentence with: 'It was observed that ... '.
- 3 Explain how the data supports your claim. Start your sentence with: 'This means that ... '.

#### Be careful

Take care as the light box can become hot with prolonged use.

#### translucent

allowing some light to pass through, but no clear image can be seen through them

#### transparent

allowing light to pass through and a clear image can be seen through the substance

#### refraction

the bending of light as it passes from one medium to another

#### optical density

an indicator of the refractive power of the substance, which is measured by comparing the amount incident light to the amount of transmitted light

Some materials are **translucent**. This means they allow some light to pass through, but no clear image can be seen as the light transmitted through them is scattered in many directions and thus doesn't reach the eye as a coherent image.

**Transparent** materials, such as diamond, glass and

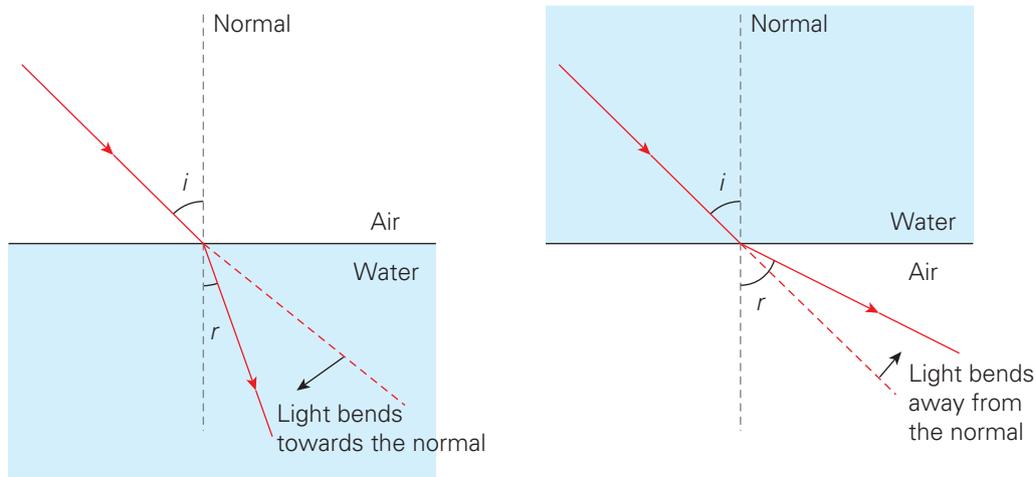
water, allow light to pass through them with little or no alteration, allowing clear images to be seen through them. When light travels from one substance into a different substance it bends. This bending of light is called **refraction** and is the result of light slowing down or speeding up when it enters a substance of different **optical density**. Each material has a **refractive index**, which is a measure of the change in the speed of light as it moves from a vacuum into that material. When light travels from a material with a lower refractive index into a material with

#### refractive index

a measure of how much the speed of light changes as it passes from a vacuum into a particular substance

a higher index (for example, from air into water), it slows down and bends *towards* the normal (see Figure 2.23, left). Conversely, when light travels from a material with a higher

refractive index into a material with a lower refractive index (for example, from water into air), it speeds up and bends away from the normal (Figure 2.23, right).



**Figure 2.23** The direction light bends is dependent on the refractive index of the materials it enters and leaves from. Water has a higher refractive index than air.

### Quick check 2.6

- 1 Define the term 'refraction' in your own words.
- 2 Explain how refraction differs from reflection.
- 3 State whether light will bend towards or away from the normal when it is travelling from a material with a refractive index of 1.02 into a material with a refractive index of 1.4.

### Practical 2.3

#### Refracting light

##### Aim

To investigate refraction of light through a glass block.

##### Materials

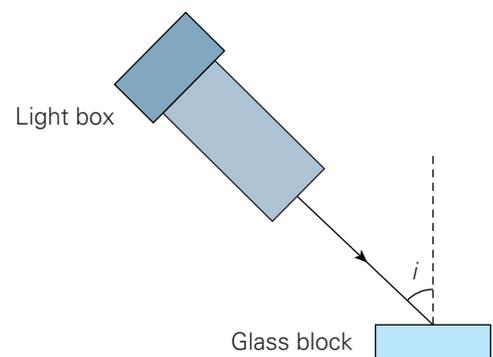
- glass rectangular block
- light box
- sheet of A4 white paper
- protractor
- clear plastic ruler
- pencil

##### Procedure

- 1 Connect the light box to a power source and insert a single-ray forming plate.
- 2 Place the light box on its side on the piece of white paper and switch it on.
- 3 Direct the single ray towards the glass block, as shown in Figure 2.24.

##### Be careful

Take care as the light box can become hot with prolonged use.



**Figure 2.24** Experimental set-up

*continued...*

...continued

- 4 Trace the outline of the glass block onto the white paper. Use the clear ruler to trace the path of the incident ray and the refracted ray.
- 5 Remove the glass block and connect the two lines to visualise the path of the light through the glass.
- 6 Use the protractor to make measurements of the angles, and record your results in the results table.

### Results

	Angle of incidence	Angle of refraction
Light entering glass		
Light leaving glass		

### Discussion

- 1 Does light bend towards or away from the normal when:
  - a entering glass?
  - b leaving glass?
- 2 What do you notice about the beam of light that is entering the glass and the beam of light that is leaving the glass?
- 3 Does all the light travel through the glass and emerge from the other side?

### Conclusion

- 1 Make a claim regarding light refraction through materials. Start your sentence with: 'This experiment suggests that light ... '.
- 2 Support your claim by using what you observed. Start your sentence with: 'It was observed that ... ' and include potential measurement uncertainties and experimental faults.
- 3 Explain how the data supports your claim. Start your sentence with: 'This means that ... '.

## Transverse wave summary

Type of wave	How is energy transferred?	Does it require a medium for propagation?	Examples
Mechanical wave	Energy is transferred as vibrations in particles between adjacent particles in a medium.	Yes	The strings in musical instruments, deep ocean waves and some seismic waves
Electromagnetic wave	Energy is carried as oscillating electric and magnetic fields.	No	Radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays

Table 2.2 The two types of transverse waves

### Quick check 2.7

- 1 State which forms of radiation can be harmful to humans.
- 2 State two uses of radio waves.
- 3 State the approximate wavelength of microwaves.
- 4 Compare radio waves and microwaves.
- 5 State what property an object should have to emit a large amount of infrared radiation.

## Longitudinal waves

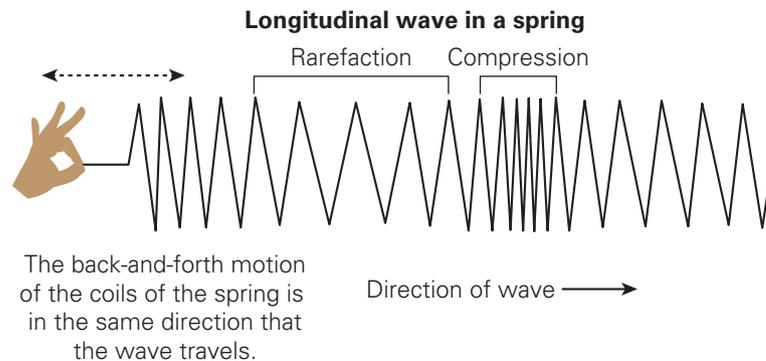
A **longitudinal wave** is a wave in which the particles of the medium oscillate (that is, vibrate) parallel to (in the same direction as) the energy transfer. The particles vibrate back and forth creating a series of **compressions** and **rarefactions**. As can be seen in Figure 2.25, longitudinal waves have areas where the particles (coils in this case) crowd close together and areas where they are spread apart. Places where the particles in a

medium are closer together are called compressions, and places where the particles in the medium are further apart from each other are called rarefactions. If a wave has more energy, then the particles in compressions are closer together and the particles in rarefactions are farther from each other.

**longitudinal wave**  
a wave with vibrations in the direction of travel instead of transversely; sound waves are an example

**compression**  
the part of a longitudinal wave where the particles are squashed together

**rarefaction**  
the part of a longitudinal wave where the particles are spread apart



**Figure 2.25** In a longitudinal wave, the particles move parallel to the direction of the wave.

## Examples of longitudinal waves

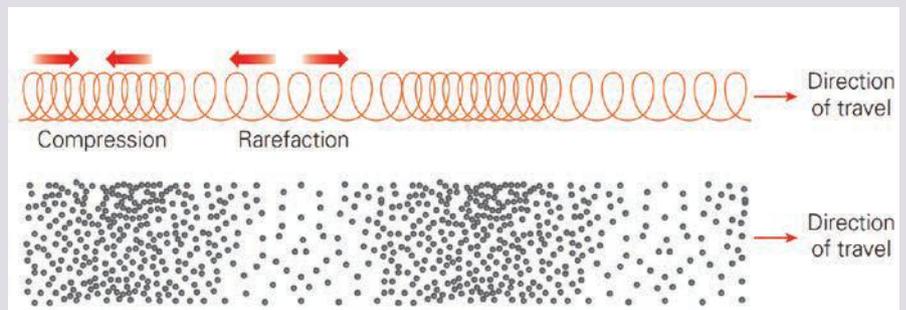
Sound is a longitudinal wave because the air particles vibrate backwards and forwards in the same direction as the travelling sound wave. The motion of sound through the air is similar to when you move the end of a slinky forwards and backwards quickly to send a series of pulses through the spring. When a sound wave passes through air, the movement of the molecules is in a pattern that consists of regions of high pressure

(compression) and regions of low pressure (rarefaction). Sound is a mechanical wave and therefore needs a medium to travel through, but the medium does not have to be air – it can also be a solid or a liquid. In fact, because sound needs particles to vibrate in order for it to travel, sound travels faster through solids, where the particles are close together and can therefore transfer energy faster. It can't travel at all through a vacuum (where there are no particles).

### Try this 2.4

#### Visualising sound

Grab a slinky and stretch it out along the floor until it is a couple of metres in length. Create vibrations in the slinky by moving the coils back and forth. Observe the areas of compression and rarefaction that move back and forth along the length of the slinky.



**Figure 2.26** Longitudinal waves in a slinky can model longitudinal sound waves.

## Explore! 2.3

**Sound waves and the didjeridu**

Aboriginal and Torres Strait Islander peoples developed various technologies and processes involving the transfer of sound. Some instruments were used for playing music, others were used for communicating or hunting. One example of an instrument for creating music is the didjeridu. Conduct some research on the didjeridu to answer the following questions.

- 1 Where is it believed that the didjeridu got its name from?
- 2 How old is the didjeridu thought to be?
- 3 Describe the construction of a didjeridu.
- 4 How does the length and flare end of a didjeridu affect its acoustic behaviour?
- 5 Outline how a didjeridu produces its unique sound, including all components that play a role.



**Figure 2.27** The didjeridu is made of bamboo or tree trunks that have been hollowed out by termites or other insects.

## Quick check 2.8

- 1 Define the term 'sound' in your own words.
- 2 Define the terms 'compression' and 'rarefaction' in your own words.
- 3 Explain why sound travels faster in solids.
- 4 Explain how sound is an example of a longitudinal wave.

## Practical 2.4

**Making sound****Aim**

To hear and observe vibrations in the air.

**Materials**

- tuning fork
- rubber stopper
- 100 mL beaker, half filled with water

**Procedure**

- 1 Strike the tuning fork on a soft surface, such as the rubber stopper.
- 2 Bring the tuning fork to your ear and see if you can hear anything. You can use a sounding board to hear the sound clearly.
- 3 Repeat step 1 and lightly touch the vibrating ends of the tuning fork to the surface of the water.
- 4 Observe what happens to the water.

**Results**

Record your observations.

**Discussion**

- 1 Explain what you heard when you held the tuning fork to your ear. How does this work?
- 2 Describe what happened when you submerged the ends of the tuning fork in water. Explain why this happened.
- 3 Could you identify areas of compression and rarefaction in the water?

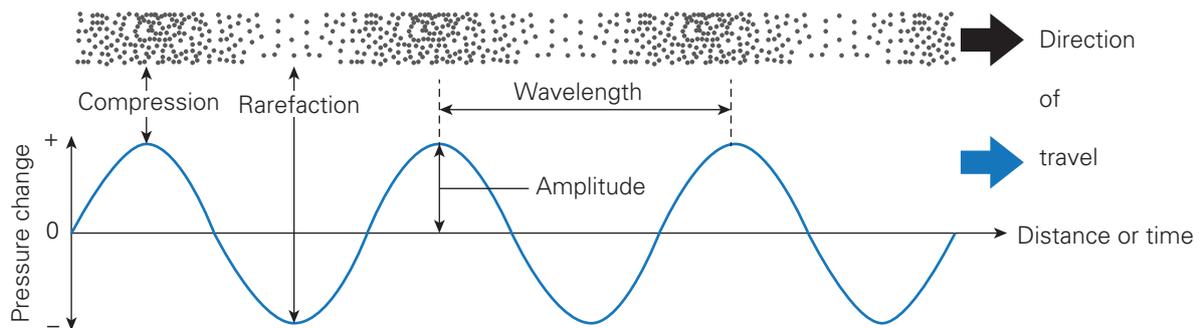
### Properties of sound waves

Similar to transverse waves, we can also describe the properties of the longitudinal waves using the terms 'wavelength', 'frequency' and 'amplitude' where:

- Wavelength (unit = metre) is the distance between two consecutive points (such as compressions or rarefactions) of a wave. The greater the distance between two points of maximum compression, the longer the wavelength.
- Frequency (unit = hertz) is the number of cycles (complete waves or vibrations) that pass a point each

second. The more cycles or wavelengths that pass in a second, the higher the frequency.

- Amplitude (unit = metre) is the maximum displacement of air particles from their undisturbed position. This is the displacement amplitude. In a sound wave, which has regions of high and low pressure, the amplitude is the difference between the maximum pressure in a compression and atmospheric pressure.



**Figure 2.28** A sound wave represented as a graph of change in air pressure over distance or time. The air pressure change with no sound is 0, and +/- represents increase / decrease in pressure. Above the graph is a diagram showing the space between the air molecules and the regions of compression and rarefaction. Amplitude and wavelength now appear like they do for a transverse wave. Note that the graph is the same shape whether air pressure or air pressure change is plotted, or whether time or distance is the horizontal axis.

The **pitch** of a sound is how high or low on a music scale (not sound volume) it seems to our ears. The pitch of a sound wave is determined by its wavelength and therefore its frequency. Shortening the wavelength increases how many wavelengths pass each second (frequency), and this increases the pitch of the sound. Low-pitched sounds have a long wavelength, whereas high-pitched sounds have a short wavelength (shown in Figure 2.29a).

The energy of a wave depends on its amplitude as well as its frequency. A higher frequency means that the energy of the wave arrives more often in a given time period. If you look at water waves, you might notice that some waves are bigger than others. Amplitude is the maximum height of a wave from its resting position.

#### pitch

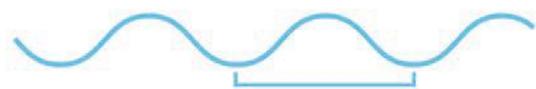
how high or low a sound seems to our ears on a music scale

If you were able to see sound waves, you would notice that loud sounds

have a higher amplitude than soft sounds – that is, have more compressed compressions and more spread out rarefactions. The loudness, thus amplitude, of the sound is a measure of the amount of sound energy. This is shown in Figure 2.29b on page 54.

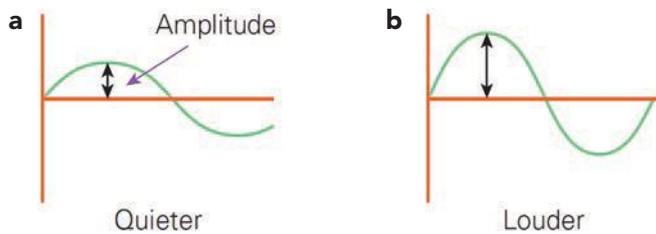


Short wavelength means lots of wavelengths per second; high frequency, high pitch



Long wavelength means fewer waves; low frequency, low pitch

**Figure 2.29a** Which of the two waves do you think would be a whistle and which would be a bass guitar?



**Figure 2.29b** The amplitude of a sound wave is an indication of the loudness of the sound.

### Quick check 2.9

- 1 Define the terms 'frequency', 'wavelength' and 'amplitude' in your own words. Include the units.
- 2 Look at these sound waves, shown as pressure against time, and answer the questions below.

A



B



C



D



- a Which wave has the highest frequency?
- b Which wave has the longest wavelength?
- c Which wave do you expect to have the highest pitch?
- d Which wave is the loudest?

## Applications of sound

Animals such as bats and dolphins use **echolocation** to navigate and locate prey. To do this, they utilise the ability of sound waves to reflect off hard surfaces. These animals emit high frequency sound (ultrasound)

waves, which hit surrounding objects and produce an echo. They then listen for the echoes that return and use them to identify objects in close proximity that they cannot see.

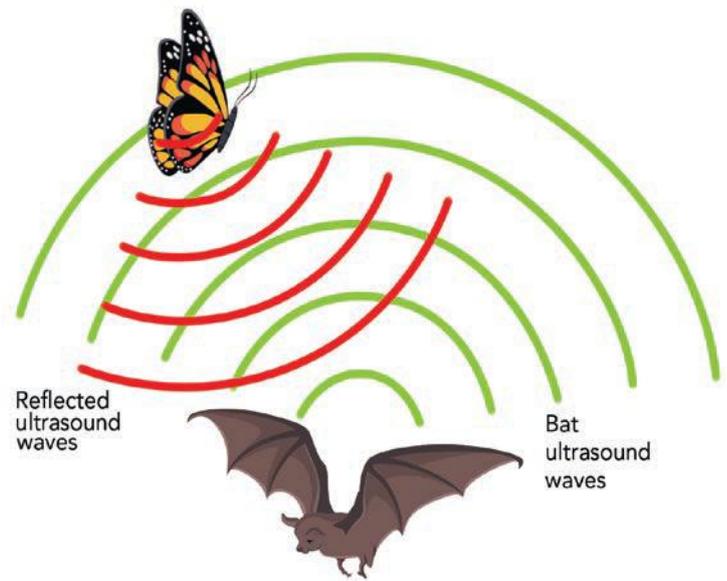
### echolocation

the location of objects using reflected sound (echo)

### SONAR

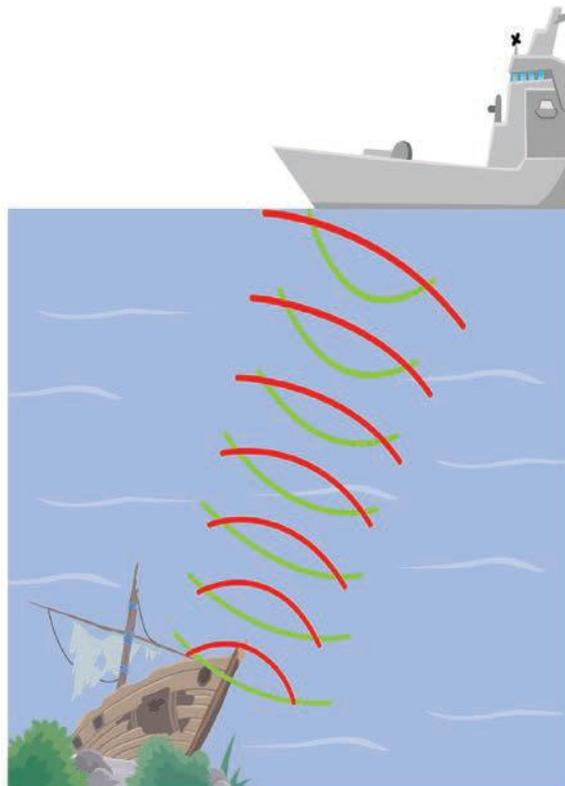
a mode of navigation used by ships to locate underwater objects using reflected sound

Interestingly, some humans have developed the ability to echolocate and by making short high-pitched clicks they are able to find their way around by listening to echoes bouncing off surrounding objects.



**Figure 2.30** A bat using the reflected sound waves produced in echolocation to locate prey.

**SONAR** (SOund NAvigation and Ranging) uses ultrasound waves, in the same way as animals use echolocation, to navigate and locate underwater objects such as land mass, submarines and schools of fish. Ships send out an ultrasound wave and a receiver detects the echo. Based on the time delay of the echo, and the speed of sound in water, the distance to underwater objects can be calculated.



**Figure 2.31** A ship using SONAR to locate underwater objects.

## Summary: Comparison between wave and particle models

Feature	Wave models	Particle models
Carries/transfers energy	Yes Mechanical waves are carriers of energy through a medium, and electromagnetic waves can transfer energy as radiation.	Yes Particles can transfer energy through conduction and convection. They also play a role in mechanical waves.
Has a measurable speed	Yes The frequency, wavelength and speed are all related.	Yes The speed of a particle may relate to its thermal energy.
Has a frequency, wavelength and amplitude	Yes Frequency, wavelength and amplitude are properties of waves.	No Frequency, wavelength and amplitude are not properties of particles.
Carries matter from one place to another	No Electromagnetic fields do not need matter as they are oscillations in electric and magnetic fields. In mechanical waves, the particles vibrate or move with periodic motion, returning to their original position once the wave has passed.	Yes Particle collisions due to kinetic energy result in the movement of matter from one place to another.



Table 2.3 Comparison between waves and particles

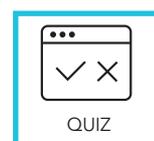
## Section 2.2 questions

### Remembering

- State** the types of electromagnetic radiation that are outside the visible spectrum.
- Recall** the wavelength range of radio waves.
- Recall** the terms for the high-pressure and low-pressure areas of a sound wave.
- Identify** the correct words to complete the following sentences.
  - Pitch is determined by the \_\_\_\_\_ of a wave.
  - Loudness is determined by the \_\_\_\_\_ of a wave.
- Define** the following terms in your own words.
  - Wavelength
  - Frequency
  - Amplitude
  - Pitch

### Understanding

- Explain** how microwaves heat up food.
- Explain** what is meant by the term 'longitudinal wave'.
- Explain** why sound cannot travel through the vacuum of space.
- Explain** why you see the flash of lightning first before you hear the thunder.



**Applying**

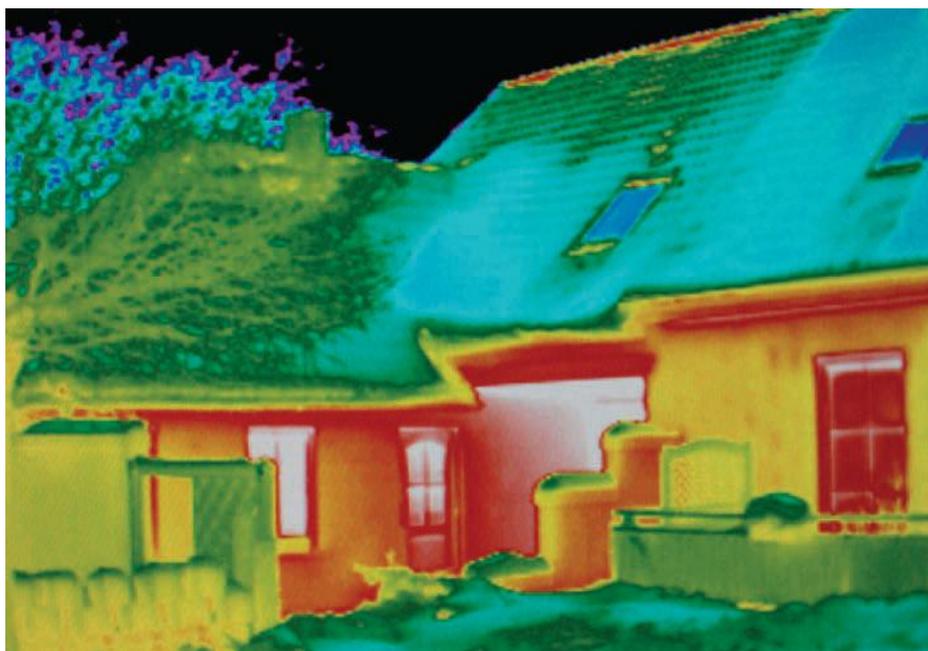
- 10 A sound wave has a frequency of 5 Hz and a wavelength of 3 m. **Interpret** what this means.
- 11 **Compare** microwaves and gamma rays.

**Analysing**

- 12 Use the image below to **determine** why the loudness of a sound decreases as you move away from the source of the sound.

**Evaluating**

- 13 The figure below shows a thermal image of a house, which has been produced by an infrared camera. **Decide** what the different colours mean.



- 14 **Decide** why it is important to find a balance between getting too much or too little UV radiation exposure.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>2.1 I can distinguish between temperature and thermal energy.</b> e.g. Compare temperature and thermal energy.	
<b>2.1 I can describe conduction, convection and radiation.</b> e.g. Describe what happens when heat is applied to the end of a metal bar.	
<b>2.2 I can distinguish between mechanical and electromagnetic waves.</b> e.g. State three types of mechanical wave.	
<b>2.2 I can identify the different parts of a wave.</b> e.g. Construct a labelled diagram of a transverse wave.	
<b>2.2 I can recall the different parts of the electromagnetic spectrum.</b> e.g. Organise the following electromagnetic waves from low frequency to high frequency: X-ray, gamma rays, radio waves, infrared, visible, microwave, ultraviolet.	
<b>2.2 I can describe the differences between transverse and longitudinal waves.</b> e.g. Compare how waves travel down a shaken rope and sound waves travel through the air.	



## Reflections

- 1 What **connections** come to mind when you think about energy transfer and your everyday life?
- 2 What new concepts have **extended** your thinking about the different ways energy is transferred?
- 3 What information did you find **challenging** or confusing?



### Data questions

A 20-year-old took their 80-year-old grandparent for a hearing loss evaluation and decided to take the auditory test as well. An audiogram shows the lowest volume at which a person can hear a sound at a particular frequency. (Note that the values on the vertical axis are in decreasing order.)

The audiogram results for the 20-year-old and the 80-year-old are illustrated in Figure 2.32. Hearing is considered normal if you can hear sound volumes over 30 dB at a particular frequency. Hearing loss is considered moderate if you require volumes of 30 dB to 60 dB, and is severe if you can only hear sound volumes over 60 dB.

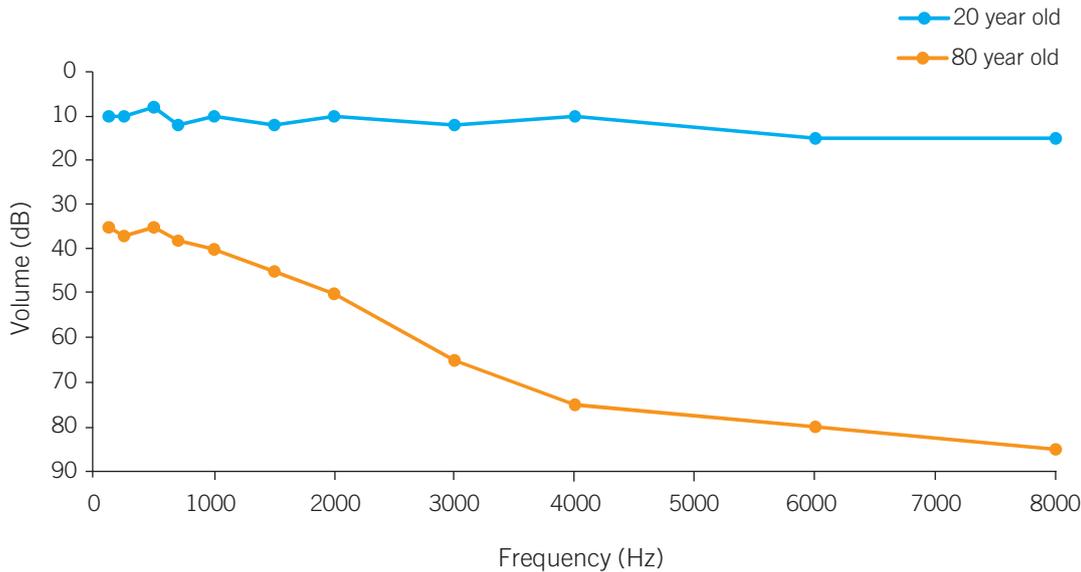


Figure 2.32 Audiogram for a 20-year-old and 80-year-old

- 1 **Identify** which person required a louder sound to hear at a sound wave frequency of 2000 Hz.
- 2 **Determine** the volume of the 1000 Hz sound wave that is the lowest volume that can be heard by the 20-year-old based on the test.
- 3 **Recognise** which person displays hearing loss.
- 4 **Identify** a trend in volume and frequency for both the 20-year-old and 80-year-old.
- 5 **Analyse** the plot for the 80-year-old and find any frequencies where the person suffers from severe hearing loss.
- 6 **Contrast** the two data sets between the frequencies of 1000 Hz and 2000 Hz.
- 7 Following the trend in the data, **deduce** the lowest volume at which the 20-year-old can hear a frequency of 9000 Hz.
- 8 **Predict** whether the 80-year-old would more easily hear a person talking or a higher pitch bird whistle of the same volume.
- 9 The outcome of the test was that the 80-year-old suffers from 'moderate low-pitch hearing loss and severe high-pitch hearing loss'. **Justify** whether this statement is accurate.

## STEM activity: Musical instruments

### Background information

Music is part of most people's lives. Whether you listen to music, play an instrument or even create your own music, it is something that most people encounter every day.

**Design brief:** Design and build a musical instrument from recycled materials.

### Activity instructions

In small groups your task is to design and build a musical instrument. The first step will be to research the main components of musical instruments as well as ways to alter the pitch of a note played.



**Figure 2.33** In musical instruments, vibration produces sound, and this sound is often amplified in the body of the instrument.

### Suggested materials

- plastic containers
- elastic bands
- bottles
- icy-pole sticks
- scissors
- cardboard

### Research and feasibility

- 1 Discuss in your group which type of instrument you will focus on – will you build an instrument that is a woodwind, string or percussion instrument? (It might be difficult to find the resources to build a brass instrument.)
- 2 Research all the components required for the instrument you are going to build, and list all the ways you can change pitch and/or volume of sound.

### Design and sustainability

- 3 As a group, make multiple sketches each and together work out which design would be most effective.
- 4 Design the prototype your group will build and focus on how it can be made using sustainable materials.

### Create

- 5 Build your prototype and test the sound quality produced by your instrument.

### Evaluate and modify

- 6 Discuss the challenges you came across when designing and building your musical instrument, and list the methods you used to overcome these.
- 7 Describe the method by which your instrument produces sound and changes pitch.
- 8 Evaluate how easy or difficult your instrument is to use or to learn.
- 9 Suggest some improvements to your instrument that could make it easier to use.

# Chapter 3

## Motion

### Inquiry questions

How does direction affect the way in which we describe motion?

How do physicists construct, analyse and interpret the motion of objects, using data?

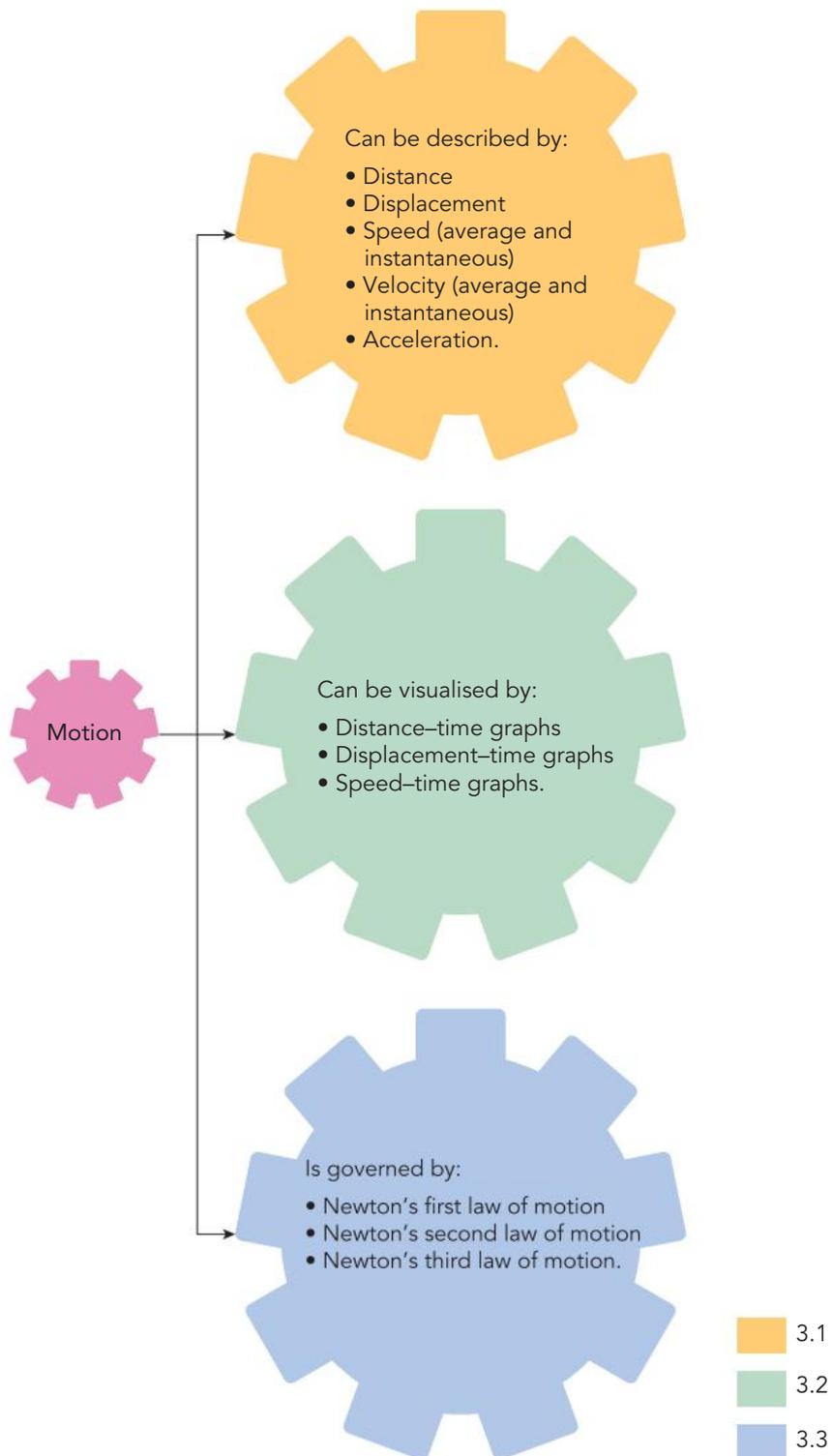
What are Newton's Laws and how are they used to predict an object's change in motion?



### Chapter introduction

This chapter continues our exploration of the science of physics. Have you ever wondered how long it takes for sunlight to reach Earth or how quickly a raindrop falls to the ground? These questions can be answered in the domain of physics – the study of matter, energy and force. One of the most famous areas of physics is the study of how things move. What first comes to mind when you think of the word 'motion'? How do you describe objects that move? You live in a world filled with moving things. This chapter will help you understand the core ideas of how things move, how fast they travel and the forces that are at work.

# Chapter map



# 3.1 Describing motion

## Learning goals

- 1 To explain the relationship between distance, speed and time
- 2 To calculate average speed
- 3 To convert m/s to km/h and vice versa



## Distance

When motion is discussed, **distance** usually refers to how far something has travelled along a path. The symbol  $s$  is used to denote the distance an object has travelled. For example, the soccer ball in Figure 3.1 has travelled a distance of 20 metres.

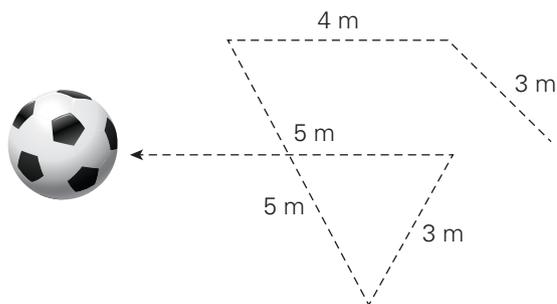


Figure 3.1 Distance travelled by a soccer ball

## Displacement

Unlike distance, **displacement** describes how far and in which direction something has travelled from an initial starting point. Displacement is the change in an object's position from the initial point. Displacement is denoted with the symbol  $\vec{s}$ . The arrow above the symbol denotes that it is a **vector**, meaning that it has both size and a direction. You can remember this by thinking about displacement,  $\vec{s}$ , as relating to spatial location in which distance and direction matter.

Figure 3.2 shows a scenario where the direction of travel matters. Your starting point is the cross in the middle.

**distance**  
total distance travelled;  
measured in metres

**displacement**  
how far you are from where  
you started and what direction  
you are from where you started

**vector**  
a quantity that has both size  
and direction

You might know that you sailed 20 kilometres, but you will not know where you are unless you know the direction you sailed. If you sailed 20 kilometres in the north-west direction, you would

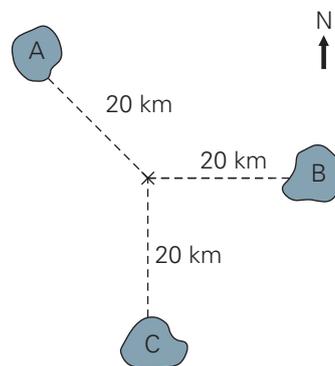


Figure 3.2 If you ended up on Island B, your displacement would be 20 km east from your starting position.

end up on island A; if you sailed east, you would end up on island B; and if you sailed south, you would end up on island C. You can see that sometimes direction matters.

## Distance versus displacement

Often, knowing the displacement is more helpful than knowing the distance something has travelled. Displacement compares the initial position with the final position of an object in motion. If the final position is the same as the initial position, then the displacement is zero. Consider a person who walks six metres forwards from point A to point B, and then two metres backwards to point C. The distance that they have travelled is eight metres. However, since they have only ended up four metres from the starting position, the displacement from their starting point, A, is four metres forwards.

The total distance travelled from A to C is  $s = 6 + 2 = 8$  m.

The displacement from A to C is  $s^d = 6 - 2 = 4$  m to the right.

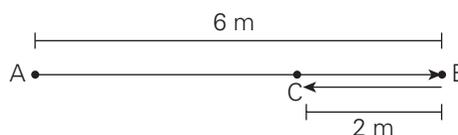


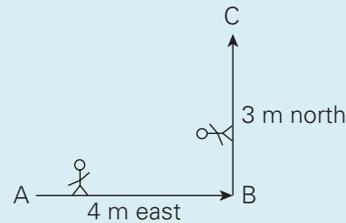
Figure 3.3 The walk described can be represented using arrows, where the length of the arrow symbolises the magnitude, and the direction of the arrow shows the direction of motion.

## Worked example 3.1

**Distance and displacement**

A person walks 4 metres east and then 3 metres north. This can be represented in a simple diagram as follows.

- 1 What is the distance travelled by the person?
- 2 What is the displacement?



Working	Explanation
<p><b>1 Distance</b></p> $s = 3 \text{ m} + 4 \text{ m} = 7 \text{ m}$	<p>Add the two distances travelled to find the total distance that the person has travelled.</p>
<p><b>2 Displacement</b></p> <p>Using Pythagoras's theorem, find the distance from A to C.</p> $\begin{aligned} AC &= \sqrt{4^2 + 3^2} \\ &= \sqrt{16 + 9} \\ &= \sqrt{25} \\ &= 5 \text{ m} \end{aligned}$ <p>To determine the direction requires trigonometry.</p> $\tan \theta = \frac{3}{4}$ $\theta = 36.9^\circ \text{ north of east}$ <p>Therefore, the displacement <math>\vec{s}</math> is 5 m <math>36.9^\circ</math> north of east.</p>	<p>Use Pythagoras's theorem to find the distance from A (the starting point) to C (the end point).</p> $a^2 + b^2 = c^2$ $c = \sqrt{a^2 + b^2}$ <p>Remember that you also need the direction travelled from the starting position to the final position.</p>

## Quick check 3.1

- 1 Define the terms 'distance' and 'displacement' in your own words.
- 2 A classmate travels between classrooms. From their initial classroom, they travel west 100 m and then north 50 m, where they arrive at the intended classroom.
  - a Represent this journey in a diagram.
  - b Calculate the distance travelled by the student.
  - c Calculate the displacement of the student, to the nearest metre. Remember to also give an angle in your answer.
  - d The student then travels back to the initial classroom. Determine their displacement.

## Speed

We have all used words or phrases to describe how quickly something travels, or maybe even to determine how long it will take to get from one place to another.

**Speed** is a general term for how fast something travels. It is a measure of the rate at which an object travels a distance. In other words, speed is the distance ( $s$ ) travelled divided by the amount of time ( $t$ ) it took to travel that distance.

Speed is used to judge how fast something is moving, or how far something will travel in a certain amount of time. Speed is commonly measured in units of metres per second (m/s), or kilometres per hour (km/h). However, depending on the motion, speed may sometimes be measured in m/min, cm/h, or even km/s.

Consider the examples of motion shown in Figure 3.4.

**speed**  
change in distance  
divided by time



A rocket can travel at 11 km/s.



A cheetah can maintain a speed of 31 m/s.



The speed of a snail is more likely to be measured in units of cm/min.



The speed of cars is usually measured in km/h.

**Figure 3.4** Examples of different speeds

Speed is calculated as follows:

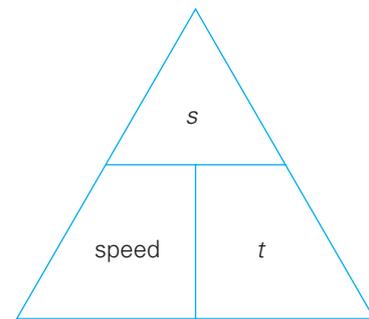
$$\text{average speed (m/s or km/h)} = \frac{\text{distance travelled (m or km)}}{\text{time taken (s or h)}}$$

$$\text{Or speed} = \frac{s}{t}$$

A simple way to remember this equation is by using the average speed triangle shown in Figure 3.5.

Using the average speed triangle, you can derive formulas for:

- $\text{speed} = \frac{s}{t}$
- $\text{change in time } t = \frac{s}{\text{speed}}$
- $\text{change in distance } s = \text{speed} \times t$ .



**Figure 3.5** The average speed triangle

## Worked example 3.2

**Average speed**

Consider two runners who are competing in a 100 m hurdles event. Runner 1 finishes in a time of 12.5 s. Runner 2 runs the race with an average speed of 7 m/s.

- Who wins the race?
- How long does it take Runner 2 to cross the finish line? Round your answer to one decimal place.

Working	Explanation
1 Who wins?	
$s = 100 \text{ m}$ $t = 12.5 \text{ s}$ speed = ?	List the relevant information for runner 1.
$\text{speed} = \frac{s}{t} = \frac{100 \text{ m}}{12.5 \text{ s}}$ $= 8 \text{ m/s}$	Calculate the average speed using the formula for average speed.
Runner 1: speed = 8 m/s Runner 2: speed = 7 m/s Since runner 1 has a higher average speed, they finish before runner 2 does. Therefore, runner 1 wins the race.	Compare the average speed of each runner.
2 Runner 2 time	
$t = ?$ speed = 7 m/s $s = 100 \text{ m}$	List the information that you have for runner 2.
$t = \frac{s}{\text{speed}} = \frac{100 \text{ m}}{7 \text{ m/s}}$ $= 14.3 \text{ s}$	Calculate the time taken for runner 2 to complete the race using a rearranged average speed formula.
It takes 14.3 s for runner 2 to complete the 100 m hurdles race.	Interpret the solution, ensuring that you have correct units and decimal places.

**Converting units**

So far we have only used m/s for speed, but another common unit for speed is kilometres per hour (km/h), which is what most people use in cars. Here is a quick guide for converting units.

$$1 \text{ km} = 1000 \text{ m}$$

$$1 \text{ h} = 3600 \text{ s}$$

$$1 \frac{\text{km}}{\text{h}} = \frac{1000 \text{ m}}{3600 \text{ s}} = \frac{1}{3.6} \frac{\text{m}}{\text{s}}$$

Multiplying both sides by 3.6 and swapping the sides to make 1 m/s the subject gives:

$$1 \text{ m/s} = 3.6 \text{ km/h}$$

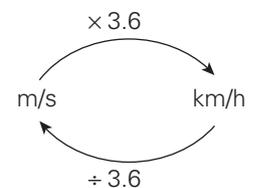


Figure 3.6 Converting m/s into km/h

To convert m/s to km/h, multiply by 3.6.

To convert km/h to m/s, divide by 3.6.

## Try this 3.1

## Converting speed

Next time you are in a car, ask the driver to tell you how fast the car is travelling. Collect three samples at different speeds, and then convert each of them from km/h to m/s.

Are the results what you expected? Can you think of a scenario that would be appropriate to measure speed using m/s instead of km/h?

## Velocity

**Velocity** is a term used to describe how fast something travels in a particular direction. Like speed, the common units associated with velocity are m/s or km/h. However, unlike speed, velocity is a measure of the change in

displacement of an object within a certain amount of time. Velocity includes more

**velocity**  
change in displacement  
divided by change in time

information than speed because it includes direction (indicated by the vector arrow). It is used as a measure of how quickly something travels in a specific direction. Aeroplane pilots and ship captains need to know their velocity so they can accurately navigate towards their destination.

Calculating velocity is similar to using the formula for speed, except distance travelled is replaced by displacement. The main difference between calculating speed and velocity is that direction is important with the velocity, so displacement is used instead of distance.

Mathematically, velocity can be described in the following ways:

$$\text{average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

$$\vec{v}_{av} = \frac{\vec{s}}{t}$$

## Worked example 3.3

## Average speed versus average velocity

Consider the triangle in Figure 3.7 between Adelaide, Brisbane and Alice Springs. Imagine two aeroplanes that need to get from Alice Springs to Brisbane. Plane 1 travels directly to Brisbane. Plane 2 must stop in Adelaide before flying to Brisbane. It takes both planes 4.00 hours to reach Brisbane. The true bearing of Brisbane from Alice Springs is  $106^\circ$  clockwise from north.

- 1 What is the average speed of each plane?
- 2 What is the average velocity of each plane?
- 3 Which plane travels faster in the air?

**Figure 3.7** Travelling between Adelaide, Brisbane and Alice Springs



Working	Explanation
<p>1 Average speed</p> <p>Plane 1:  <math>\text{speed} = \frac{1965}{4.00} = 491 \text{ km/h}</math></p> <p>Plane 2:  <math>\text{speed} = \frac{(1330 + 1603)}{4.00} = 733 \text{ km/h}</math></p>	<p>For average speed, use this formula: <math>\text{speed} = \frac{s}{t}</math></p>

*continued...*

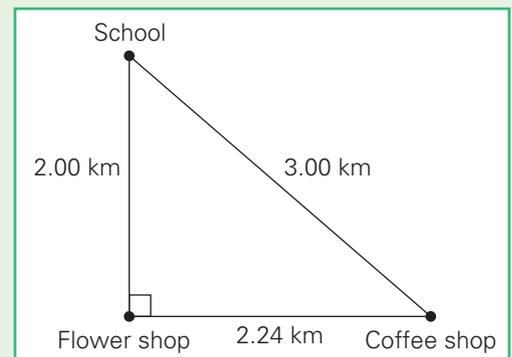
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Working	Explanation
<b>2</b> Average velocity	
Plane 1: $\vec{v}_{av} = \frac{1965}{4.00} = 491 \text{ km/h } 106^\circ \text{ clockwise from north}$ Plane 2: $\vec{v}_{av} = \frac{1965}{4.00} = 491 \text{ km/h } 106^\circ \text{ clockwise from north}$	For average velocity, use this formula: $\vec{v}_{av} = \frac{\vec{s}}{t}$
<b>3</b> Comparing speeds	
Plane 2 is faster in the air.	The plane with the greater average speed travels faster as it covers more ground in the same amount of time.

**Quick check 3.2**

Two students, Mia and Peter, leave school to meet at the local coffee shop. Peter decides to jog to the coffee shop, but also stops at a flower shop along the way. Mia decides to walk from school directly to the coffee shop. They arrive at the coffee shop at the same time, 30 minutes after they leave school. Use the diagram to answer the following questions.

- Calculate how much further Peter travels than Mia.
- If it takes them both half an hour to reach the coffee shop, calculate:
  - Mia's average speed
  - Peter's average speed
  - their average velocities.

**Acceleration**

**Acceleration** can be thought about as 'speeding up' or 'slowing down'. At this stage we will only deal with velocities and accelerations of objects travelling in a straight line, so we won't have to mind the direction.

Consider a car at a set of traffic lights. Initially it is **stationary**; we would say that it has an initial velocity, represented by  $u$ , of 0 km/h. Imagine that when the light turns green the car speeds up to 40 km/h in the next five seconds. This change in velocity means that the car has an acceleration.

Similarly, consider the car reaching another set of lights that have just turned red – it has to slow until it stops. When the car slows down, it decreases its velocity over time; we call this **deceleration** (negative acceleration).

An object that does not change speed and direction is travelling with a **constant velocity**, meaning that the acceleration is zero.

If an object changes its velocity, then it is also accelerating (with positive or negative acceleration). When the object is moving in a straight line (such that the change in velocity is only due to the change in speed), we can calculate its acceleration using the speed, as follows:

$$\text{Acceleration} = \frac{\text{change in speed}}{\text{time taken}} = \frac{\text{final speed}(v) - \text{initial speed}(u)}{\text{time taken}}$$

**acceleration**  
the change in velocity or direction of an object

**stationary**  
not moving

**deceleration**  
when an object is slowing down, defined mathematically as negative acceleration

**constant velocity**  
when an object is travelling at the same speed and direction, and is not accelerating or decelerating

Acceleration ( $\vec{a}$ ) is thus represented by the equation:

$$\vec{a} = \frac{v - u}{t}$$

Using the acceleration triangle in Figure 3.8 is another helpful way to remember the formula for acceleration.

Using this acceleration triangle, you can derive formulas for:

- acceleration  $\vec{a} = \frac{v - u}{t}$
- change in time  $t = \frac{v - u}{\vec{a}}$
- change in speed  $v - u = \vec{a} \times t$

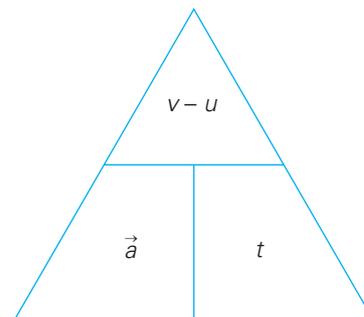


Figure 3.8 The acceleration triangle

### Worked example 3.4

#### Acceleration

Consider the motion of a dirt bike.

- 1 If it speeds up from rest to 54 km/h in a straight line in 3 seconds, calculate the acceleration.
- 2 If that same bike travelling at 54 km/h comes to a stop in a straight line within 5 seconds, what is the acceleration? What does this mean?
- 3 If better brakes were installed on the bike, it could decelerate at a quicker rate of  $10 \text{ m/s}^2$ . Calculate how long it would take to stop if it was initially travelling at a speed of 72 km/h.



Figure 3.9 A dirt bike in motion

Working	Explanation
<b>1 Acceleration</b>	
$u = 0 \text{ m/s}$ $v = 54 \text{ km/h} = 15 \text{ m/s}$ $t = 3 \text{ s}$ $\vec{a} = ?$	List the information that you have. Since the bike begins at rest, the initial speed is zero.
$\vec{a} = \frac{v - u}{t} = \frac{(15 - 0)}{3} = 5 \text{ m/s}^2 \text{ forward}$	Calculate using the acceleration formula by substituting in all of the known values. Remember to include units and a direction.
The bike accelerates at a rate of $5 \text{ m/s}^2$ (5 metres per second, every second)	Interpret the answer.
<b>2 Negative acceleration</b>	
$u = 54 \text{ km/h} = 15 \text{ m/s}$ $v = 0 \text{ m/s}$ $t = 5 \text{ s}$ $\vec{a} = ?$	List the information. In this example, the bike has an initial speed of 54 km/h, and a final velocity of 0 km/h.

*continued...*

...continued

Working	Explanation
$\vec{a} = \frac{v - u}{t} = \frac{(0 - 15)}{5} = -3 \text{ m/s}^2 \text{ forward}$	Substitute the known values.
Since there is a negative acceleration, the bike is decelerating at a rate of $3 \text{ m/s}^2$ forward.	Interpret the solution and remember to include correct units and direction. The bike is still travelling forward (in the positive direction) and so its displacement remains forward despite it slowing down.
<b>3</b> Faster stopping	
$\vec{a} = -10 \text{ m/s}^2$ $v = 0 \text{ m/s}$ $u = 72 \text{ km/h} = 20 \text{ m/s}$ $t = ?$	List the known information.
$-10 = \frac{(0 - 20)}{t}$	Substitute the values into the acceleration formula.
$t = \frac{-20}{-10} = 2 \text{ s}$	Rearrange so that the unknown is the subject of the equation.
It takes the bike 2 seconds to decelerate from $72 \text{ km/h}$ to rest.	Interpret the solution.

**Quick check 3.3**

- Define the terms 'acceleration', 'deceleration' and 'constant speed' in your own words.
- An object increases its speed from  $5.2 \text{ m/s}$  to  $7.7 \text{ m/s}$  in four seconds.
  - Calculate the acceleration of the object.
  - Assume that the object could decelerate at a rate of  $1.5 \text{ m/s}^2$  ( $\vec{a} = -1.5 \text{ m/s}^2$ ). Calculate the time it would take for the object to stop if it was initially travelling at  $10 \text{ m/s}$  ( $u = 10 \text{ m/s}$ ). Give your answer to two decimal places.

**Practical 3.1****Ramps and cars****Aim**

To investigate the effect of ramp height on the average speed of a crash trolley or model car.

**Materials**

- ramp at least  $90 \text{ cm}$  long
- stopwatch
- metre ruler
- books or blocks that can be used to make a ramp
- crash trolley or model car

**Planning**

- Develop a hypothesis by predicting how a change to the height of the ramp will affect the average speed of a model car.
- Identify as many controlled variables as possible and describe how these will be managed to prevent them from affecting the measurements.

*continued...*

...continued

### Procedure

#### Part 1: Prepare the results table

- 1 Draw the table shown in the results section into your science journal.
- 2 Identify and label the independent variables in the table.
- 3 Identify and label the dependent variable in the table.

#### Part 2: Collect the data

Set up the ramp as shown in Figure 3.10.

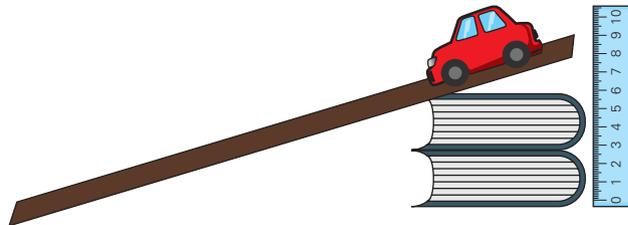


Figure 3.10 Experimental set-up

- 1 Measure the height of the ramp.
- 2 Use the stopwatch to measure how long it takes for a crash trolley or model car to roll down the ramp. Record the results in the results table.
- 3 Repeat steps 1 and 2 three times so you can take the mean of the results.
- 4 Repeat steps 1–3 using some different heights and record your results in the table.

### Results

- 1 Calculate the average time taken for the car to roll down the ramp.
- 2 Draw a scatter plot to analyse the relationship between the **height** and the **speed**.
- 3 Format the graph and insert a copy into your science journal, below the results table.

Independent variable	Dependent variable			
	Trial 1	Trial 2	Trial 3	Mean

### Discussion

- 1 Describe the effect of different ramp heights on the mean speed of a model car.
- 2 Describe any limitations to your investigation and how these may have affected your results.
- 3 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

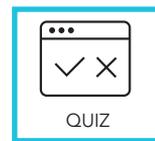
### Conclusion

- 1 State a conclusion as to how increasing the height can affect speed.
- 2 Justify this conclusion using data from your results.

## Section 3.1 questions

## Remembering

- 1 **Recall** the unit or units normally used for distance.
- 2 **List** the unit or units normally used for speed.
- 3 **State** the formula and unit for average acceleration in a straight line.



## Understanding

- 4 **Distinguish** between distance and displacement.
- 5 **Distinguish** between speed and velocity.

## Applying

- 6 The average speed of a galloping horse is 40 km/h. If a horse is already travelling at that speed, **calculate** how far it will travel in 2.3 hours.
- 7 If a person walks at an average speed of 4 km/h, **calculate** how long it will take them to travel 50 m. Round your answer to the nearest second. Hint: First convert 4 km/h into m/s.
- 8 **Determine** the acceleration of a car travelling at a constant speed of 50 km/h.
- 9 A sprinter starts from rest. In the first three seconds they reach a speed of 2 m/s. After the next 10 seconds they reach a speed of 6.5 m/s.
  - a **Calculate** the average acceleration in the first three seconds, and round to two decimal places.
  - b **Calculate** the average acceleration in the last 10 seconds.
  - c **Determine** when the sprinter's acceleration was the greatest: over the first three seconds or the last 10 seconds.
- 10 A car starts from rest and accelerates at a constant rate of 5 m/s<sup>2</sup> for five seconds.
  - a **Calculate** the final speed.
  - b **Calculate** the average speed. Because the speed increases at a constant rate, you can do this by using  $(v_1 + v_2)/2$  to find the average speed.
  - c **Calculate** the displacement of the car after five seconds.
- 11 Consider the times of one of Usain Bolt's record 100 m sprints.

Distance (m)	0	20	40	60	80	100
Time (s)	0	2.87	4.65	6.32	7.96	9.69

- a **Calculate** the average speed of Usain Bolt for the entire 100 m. That is, from  $t = 0$  to  $t = 9.69$ .
- b Does he travel quicker in the first 40 m or the last 40 m? **Give a reason** why.

## Analysing

- 12 **Categorise** the following as either acceleration, deceleration or constant speed.
  - A bike rider slowing down
  - A text book sitting on a desk
  - A sprinter taking off at the start of a race
  - A dog running at 5 m/s forwards
  - A car crashing into a brick wall
  - A car rolling down a hill and gaining speed

## Evaluating

- 13 Imagine you are trying to figure out how efficiently your car uses petrol. **Propose** whether you would use distance travelled or displacement covered with one tank full. **Explain** your reasoning.

## 3.2 Graphing motion

### Learning goals

- 1 To describe the speed of an object from a distance–time graph
- 2 To draw distance–time graphs to show the movement of an object
- 3 To calculate speed from a distance–time graph
- 4 To interpret speed–time graphs to describe the motion of an object



In this section, you will learn how to plot objects in motion onto a graph, and use this to determine the distance travelled, speed and acceleration of the object. If information about direction is included in the question, then displacement and velocity can be determined.

### Distance–time graphs

Distance–time graphs show how far an object moves as time progresses. Distance travelled is on the vertical  $y$ -axis and time is on the horizontal  $x$ -axis. The **gradient** of the line indicates the speed of the object. Recall that:

$$\text{speed} = \frac{s}{t} = \frac{\text{rise}}{\text{run}}$$

Table 3.1 shows some shapes you may see on a distance–time graph.

**gradient**  
the gradient of a graph is the rise over the run

Shape	Explanation	Example
	Horizontal lines indicate that an object is stationary.	The $\frac{\text{rise}}{\text{run}}$ of horizontal lines is zero because the rise is 0 m. So the speed is 0 m/s.
	A straight line with a gradient indicates that the object is moving at a constant speed.	$\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{2 \text{ m}}{2 \text{ s}} = 1 \text{ m/s}$ $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{1 \text{ m}}{2 \text{ s}} = 0.5 \text{ m/s}$ <p>The gradient of the first graph is steeper, which shows that object has a greater speed.</p>

Table 3.1 Two shapes of distance–time graphs

**Worked example 3.5**

**Distance–time graph**

Take a look at the distance–time graph that shows Lin's walk in a straight line for six seconds in Figure 3.11.

- 1 Calculate her speed at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.
- 2 During which time interval is Lin travelling the fastest?

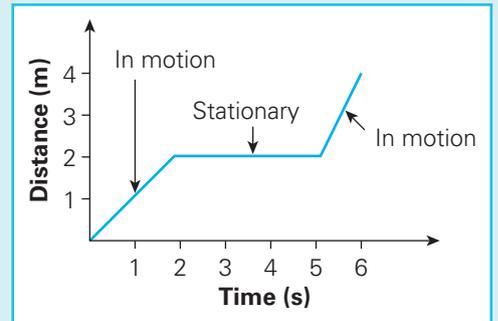


Figure 3.11 Distance–time graph of Lin's walk

Working	Explanation
<b>1 Speed</b>	
0 to 2 seconds: $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{(2 - 0) \text{ m}}{(2 - 0) \text{ s}} = \frac{1 \text{ m}}{1 \text{ s}} = 1 \text{ m/s}$ 2 to 5 seconds: A horizontal line indicates she is stationary. 5 to 6 seconds: $\text{speed} = \frac{\text{rise}}{\text{run}} = \frac{(4 - 2) \text{ m}}{(6 - 5) \text{ s}} = \frac{2 \text{ m}}{1 \text{ s}} = 2 \text{ m/s}$	Select two points from each time interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the speed.
<b>2 Fastest interval</b>	
She travels the fastest from the 5th to the 6th second.	The steeper line indicates a faster speed.

**Quick check 3.4**

Look at the distance–time graph of a moving object in Figure 3.12.

- a Calculate the average speed for each of the sections A, B and C.
- b Describe the motion of the object in the graph.

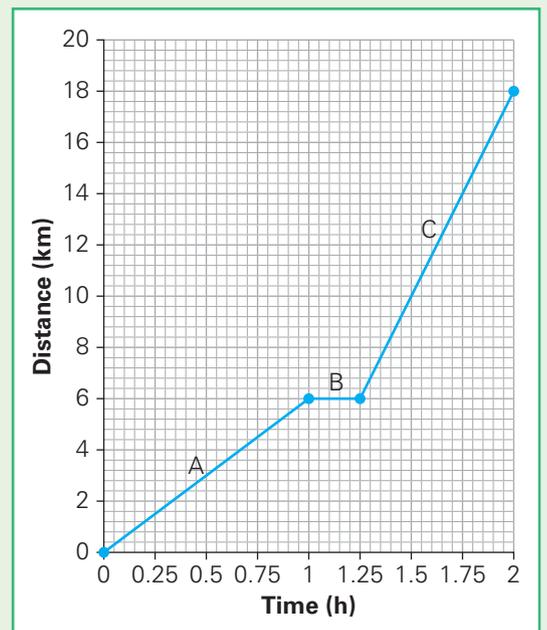


Figure 3.12 Distance–time graph of a moving object

## Displacement–time graphs

Displacement–time graphs are similar to distance–time graphs, but they also show the object's location with respect to a starting point. In other words, they can show whether an object is moving away from, or back towards, its initial

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

position over a period of time. The starting position is always located on the graph at the coordinate (0, 0), and is referred to as the **origin**. The gradient of a displacement–time graph gives the velocity for specific time periods.

### Worked example 3.6

#### Displacement–time graph

Remember the distance–time graph for Lin's walk. Figure 3.13 shows her displacement–time graph for the same motion.

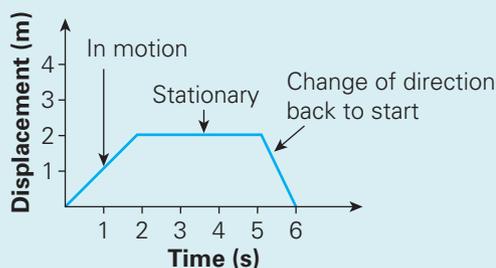


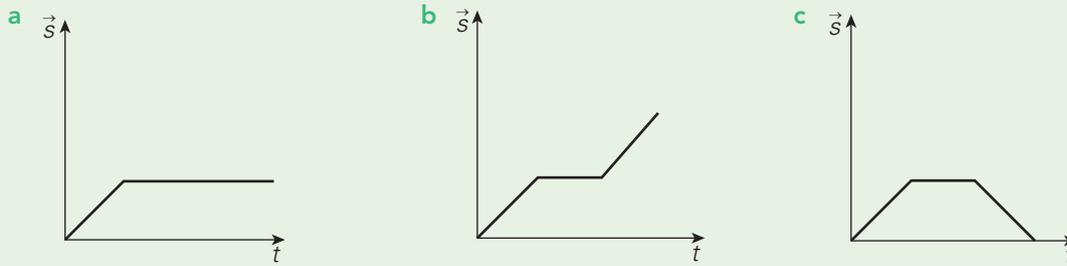
Figure 3.13 Displacement–time graph of Lin's walk

- Describe her movements in relation to her starting point.
- Calculate her velocity at the following time intervals: from 0 to 2 seconds, 2 to 5 seconds and 5 to 6 seconds.

Working	Explanation
<b>1</b> Describing movements	
For the first two seconds, Lin moves away from her starting position by 2 metres. For the next three seconds, she is stationary. In the final second, she increases her velocity moving back to the origin (her starting position).	The displacement y-axis indicates how far from the start she is. In the distance–time graph, you could not tell which direction she was travelling, only that she was moving.
<b>2</b> Velocity	
0 to 2 seconds: $\vec{v} = \frac{\text{rise}}{\text{run}} = \frac{(2 - 0) \text{ m}}{(2 - 0) \text{ s}} = \frac{2 \text{ m}}{2 \text{ s}} = 1 \text{ m/s}$	Select two points from each interval and use $\frac{\text{rise}}{\text{run}}$ to calculate the velocity.
2 to 5 seconds: A horizontal line indicates she is stationary, in other words, $\vec{v} = 0 \text{ m/s}$ .	
5 to 6 seconds: $\vec{v} = \frac{\text{rise}}{\text{run}} = \frac{(0 - 2) \text{ m}}{(6 - 5) \text{ s}} = \frac{-2 \text{ m}}{1 \text{ s}} = -2 \text{ m/s}$	A negative velocity means that she has changed directions and is travelling the opposite direction, in this case, back to the start. She is travelling faster towards her original position (5 to 6 seconds) compared to when she was travelling away from it (0 to 2 seconds).

## Quick check 3.5

Describe the motion of an object according to the following displacement–time graph shapes.



## Speed–time graphs

Speed–time graphs show the speed of a travelling object as time passes. They are quite useful because they can be used to determine the distance travelled, the **instantaneous speed** and the acceleration of a moving object. Speed–time graphs have three important features.

**instantaneous speed**  
the speed at any particular instant

- Instantaneous speed can be read directly from the graph at any particular point in time.
- The gradient between two points on a speed–time graph represents the average acceleration over that time interval of the object in motion.
- The area under a speed–time graph represents the distance that the object has travelled.

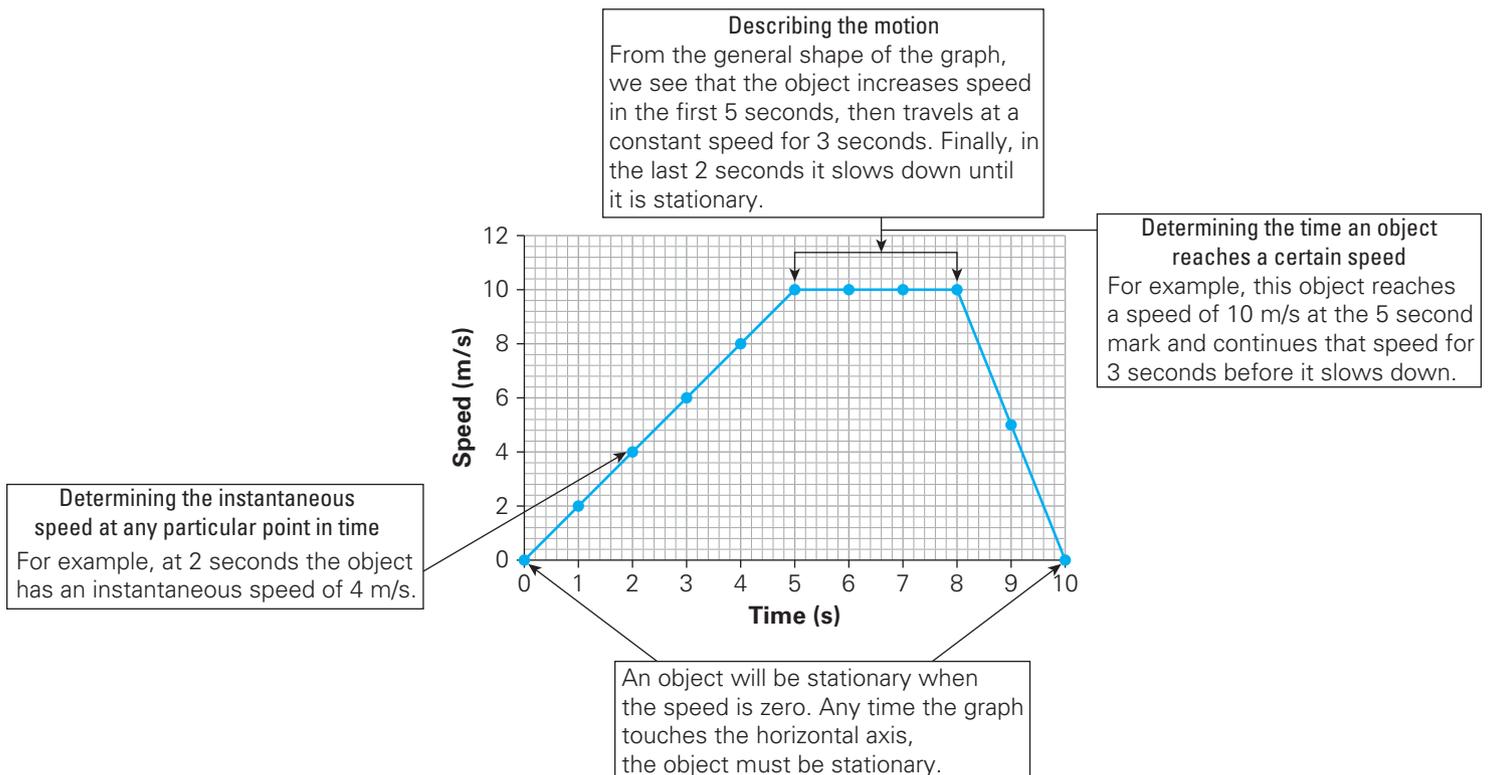


Figure 3.14 A speed–time graph tells you a lot about an object's motion.

### Finding acceleration from the gradient

The three graphs in Table 3.2 help to identify when an object travelling in a straight line of motion (direction is constant) is speeding up (accelerating), when an object is slowing down (decelerating), or when an object is travelling at a constant speed. As the direction is constant only the change in speed is considered.

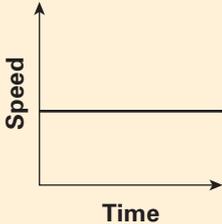
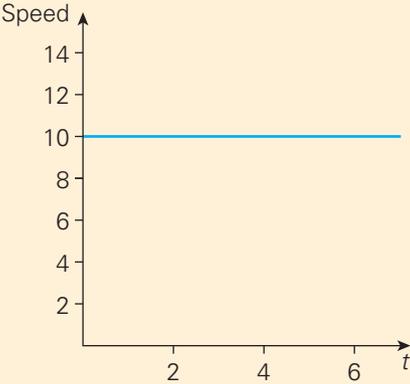
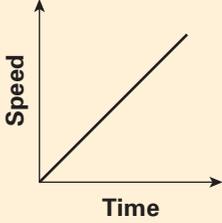
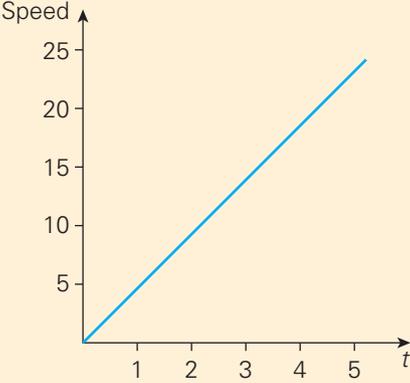
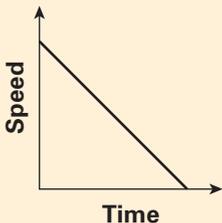
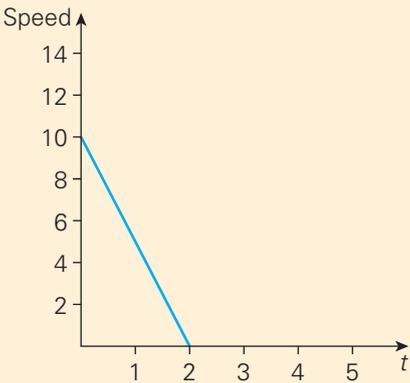
Shape	Explanation	Example
 <p>A speed-time graph with 'Speed' on the vertical axis and 'Time' on the horizontal axis. A horizontal line is drawn at a constant speed value.</p>	Horizontal lines indicate that an object is travelling at a constant speed.	 <p>A speed-time graph with 'Speed' on the vertical axis (0 to 14) and 't' on the horizontal axis (0 to 6). A horizontal line is drawn at a speed of 10 m/s.</p> $\vec{a} = \frac{\text{rise}}{\text{run}} = \frac{0 \text{ m/s}}{10 \text{ s}} = 0 \text{ m/s}^2 \text{ forward}$
 <p>A speed-time graph with 'Speed' on the vertical axis and 'Time' on the horizontal axis. A straight line starts at the origin and goes up and to the right.</p>	Positive gradient means positive acceleration (speeding up). The steeper the gradient the more the object is accelerating.	 <p>A speed-time graph with 'Speed' on the vertical axis (0 to 25) and 't' on the horizontal axis (0 to 5). A straight line starts at the origin (0,0) and goes up to (5,25).</p> $\vec{a} = \frac{\text{rise}}{\text{run}} = \frac{25 \text{ m/s}}{5 \text{ s}} = 5 \text{ m/s}^2 \text{ forward}$
 <p>A speed-time graph with 'Speed' on the vertical axis and 'Time' on the horizontal axis. A straight line starts at a positive speed value and goes down to zero speed.</p>	Negative gradient means negative acceleration (deceleration). The steeper the gradient the quicker the object is decelerating.	 <p>A speed-time graph with 'Speed' on the vertical axis (0 to 14) and 't' on the horizontal axis (0 to 5). A straight line starts at (0,10) and goes down to (2,0).</p> $\vec{a} = \frac{\text{rise}}{\text{run}} = \frac{-10 \text{ m/s}}{2 \text{ s}} = -5 \text{ m/s}^2 \text{ forward}$

Table 3.2 Three different speed-time graphs representing different types of straight-line motion

## Calculating distance travelled

In some problems, you may be given the speed–time graph and asked to work out the distance travelled. The distance an object travels can be calculated by calculating the area under the graph. Often it might be simpler to split the graph into smaller sections.

### Worked example 3.7

#### Calculating the distance

Consider the graph shown in Figure 3.15 of an object in motion.

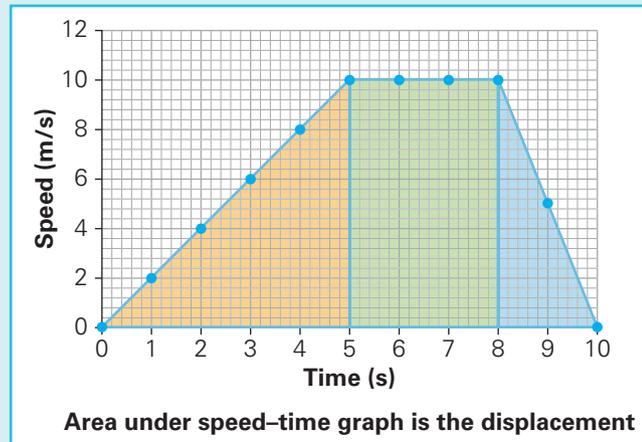
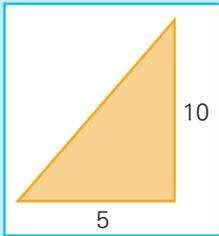
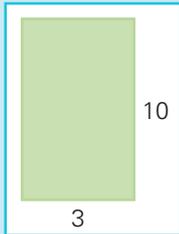


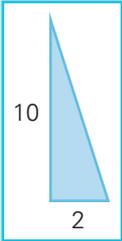
Figure 3.15 Speed–time graph

- 1 Calculate the distance travelled in the first 5 seconds
- 2 Calculate the distance travelled from  $t = 5$  to  $t = 8$ .
- 3 Calculate the distance covered in the final 2 seconds.
- 4 What is the total distance covered by the object, over the entire 10 seconds?

Working	Explanation
<p><b>1</b> Distance in first 5 seconds</p> <p>The area in the first 5 seconds can be described by the following triangle.</p> $A_1 = \frac{1}{2}(5)(10) = 25$ <p>This means that in the first 5 seconds the object travels 25 metres.</p>	 <p>Redraw the shape and label the known sides. The area of a triangle is given by the formula <math>A_1 = \frac{1}{2}bh</math>. Interpret the area, and check that units are correct.</p>
<p><b>2</b> Distance from <math>t = 5</math> to <math>t = 8</math></p> <p>The area under the graph between <math>t = 5</math> and <math>t = 8</math> can be described by the following rectangle.</p> $A_2 = 3 \times 10 = 30$ <p>This means that the distance travelled over this period is 30 metres.</p>	 <p>Redraw the shape and label the known sides. Calculate the area of the rectangle given by the formula <math>A_2 = l \times w</math>. Interpret the solution with correct units.</p>

*continued...*

...continued

Working	Explanation
<p><b>3</b> Distance in final 2 seconds</p> <p>The area under the graphs in the final 2 seconds is represented by the following triangle.</p>  $A_3 = \frac{1}{2}(2)(10) = 10$ <p>In the final 2 seconds the object travels 10 metres.</p>	<p>Redraw and label the shape. Calculate the area. Interpret solution with correct units.</p>
<p><b>4</b> Total distance covered</p> <p>Sum each of the areas for the total distance covered.</p> $\begin{aligned} A_T &= A_1 + A_2 + A_3 \\ &= 25 + 30 + 10 \\ &= 65 \end{aligned}$ <p>Therefore, the total distance covered by the object over the 10 seconds is 65 metres.</p>	<p>Add up all of the area sections under the graph to get the total distance travelled.</p>

### Quick check 3.6

Figure 3.16 shows a speed–time graph of an object travelling in a straight line of motion.

- 1 Describe the motion of the object shown in the graph.
- 2 Calculate the acceleration over the first 2 seconds.
- 3 Determine the acceleration between  $t = 2$  and  $t = 4$ .
- 4 Calculate the distance travelled after the first 2 seconds.
- 5 Determine how far the object travels in 4 seconds.

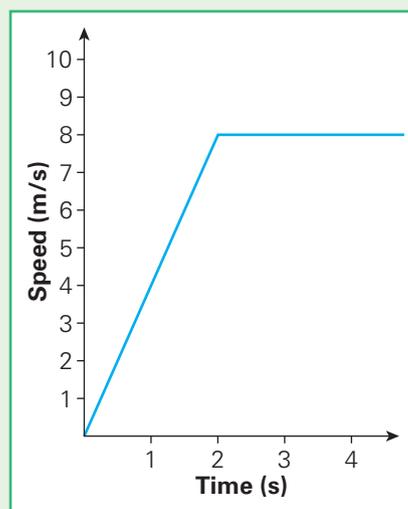


Figure 3.16 A speed–time graph

## Practical 3.2

### Investigating the motion of students over 100 m

#### Procedure

- 1 Copy the results tables below.
- 2 Choose at most five classmates to sprint 100 m.
- 3 Line up the remainder of your classmates at 20 m intervals along the 100 m track. Start the first sprinter.
- 4 Use stopwatches to capture the time from when a sprinter begins, to when they pass each 20 m interval. Ideally, there will be at least two classmates at each interval so that an average of the times can be calculated. Record these results in a table.

#### Results

- 1 Calculate the difference in elapsed time for each 20 m interval.

Results of sprint times at each 20 m interval					
Student name	20 m	40 m	60 m	80 m	100 m

- 2 Calculate the average speed for each interval and complete the table of average speed versus time.

#### Results of speed (m/s) vs time

Student name	20 m	40 m	60 m	80 m	100 m

- 3 Plot the distance–time and average speed–time graphs by drawing smooth trend lines.

#### Discussion

- 1 Are the shapes of the graphs generally similar?
- 2 Describe what is happening at each 20 m interval in terms of speed.
- 3 Propose why it was important to gather data from various classmates instead of just from one.
- 4 Identify some potential sources of error (uncertainties or experimental method faults).
- 5 Imagine if your classmates walked, hopped or crawled. Predict what the graphs would look like.

## Section 3.2 questions

### Remembering

- 1 **Recall** what the gradient of a distance–time graph tells us.
- 2 **Recall** what the gradient of a speed–time graph tells us.
- 3 **Recall** what the area under a speed–time graph tells us.

### Understanding

- 4 **Describe** what the shape of a displacement–time graph can reveal about an object's movements.
- 5 **Describe** what the shape of a speed–time graph can reveal about an object's movements.



**Applying**

- 6 The path of a caveman as he makes the trek to a nearby river, then back to his cave, is shown on this displacement–time graph in Figure 3.17.

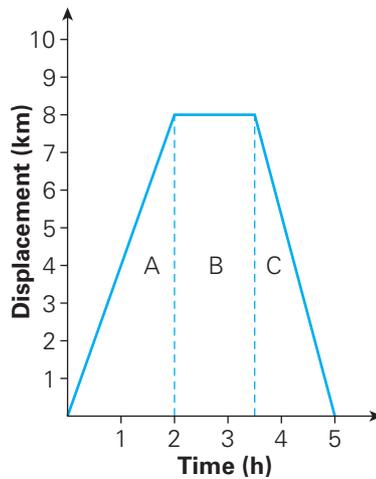


Figure 3.17 Displacement–time graph

- Determine** how far the river is from the cave.
  - Determine** the velocity of the caveman as he walks from his cave to the river (section A).
  - Determine** how long the caveman stops at the river (section B).
  - Calculate** how quickly the caveman returns back to his cave once he leaves the river (section C).
- 7 Consider the speed–time graph in Figure 3.18.

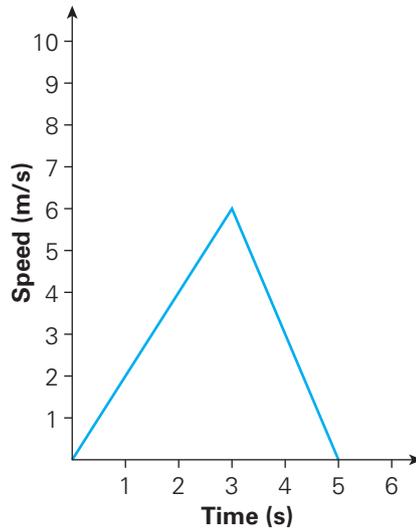


Figure 3.18 Speed–time graph

- Describe** the motion of the object.
- Calculate** the acceleration in the first three seconds.
- Calculate** the acceleration for the next two seconds.
- Calculate** the distance the object has travelled after five seconds.

## Analysing

- 8 Hundreds and thousands of animals in Australia are killed every year by vehicles.

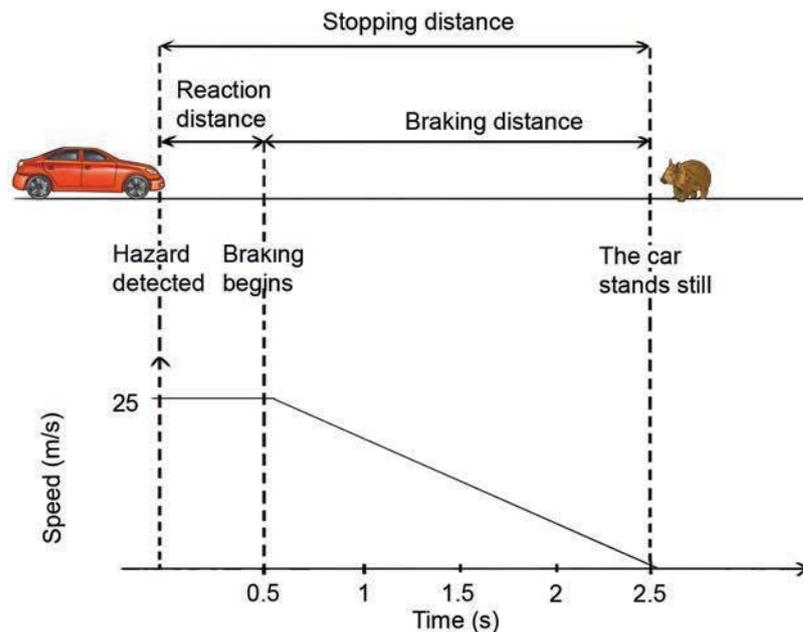


Figure 3.19 Speed–time graph for car travelling along a road

- If a driver travelling at 90 km/h (25 m/s) takes 0.5 seconds to react, and they come to a stop according to the speed–time graph in Figure 3.19, **calculate** the total stopping distance.
- If the reaction time was increased by 0.5 seconds, in other words the reaction time was one second, **calculate** what the stopping distance would be.
- What can you **infer** about reaction times? What things can affect reaction time?

## Evaluating

- 9 Use the following table to draw the distance–time graph of an object. Based on the shape of the graph, what conclusions can we make about the object’s movements? **Evaluate** whether we can tell in which direction the object went and **justify** your response.

Time (s)	Distance (m)
0	0
2	2
5	3
7	3
9	4
10	5

- 10 A car starts from rest and accelerates at a constant rate of  $3 \text{ m/s}^2$  in a straight line for five seconds.

- Calculate** the final speed.
- Calculate** the average speed. Because the speed increases at a constant rate, you can do this by using  $\frac{v + u}{2}$  to find the average speed.
- Calculate** the distance the car had moved after five seconds.
- Construct** the speed–time graph for this scenario and use it to calculate the distance using the area under the graph.
- What can you **conclude** from your answers to part **c** and **d**?

## 3.3

# Forces and Newton's laws of motion

## Learning goals

- 1 To determine the net force acting on an object
- 2 To predict the movement of an object based on the net force acting on it
- 3 To describe the relationship between force, mass and acceleration
- 4 To relate acceleration to a change in speed and/or direction as a result of a net force
- 5 To analyse everyday situations involving motion in terms of Newton's laws



WORKSHEET

## Sir Isaac Newton's three laws of motion

### Newton's first law of motion

Newton's first law of motion, also known as the law of **inertia**, states:

VIDEO  
Newton's first law

An object will remain at rest or in constant motion in the same direction unless it is acted upon by an external unbalanced force.

#### Newton's first law of motion

an object will remain at rest or in constant motion in the same direction unless acted upon by an external unbalanced force

#### inertia

a property of matter that keeps something in the same position or moving in the same direction unless acted upon by an external force

#### force

any interaction that, when unopposed, will change the motion of an object

#### net force

the sum of all the forces acting on an object

As you might remember from previous years of study, a force is a push or pull acting on an object. Put simply, a **force** is any interaction with an object that, if left unopposed, will cause a change in the motion of the object. At any given time, multiple forces may act on any single object. These forces determine if the object will accelerate, continue to travel

at a constant speed or remain at rest. Force has both magnitude and direction; it can be represented using the symbol  $\vec{F}$ , and is generally measured in newtons (N).

If the forces acting on an object are balanced, meaning equal in magnitude (size) and in opposite directions, then the object will not change its motion.

That is, if the object is at rest it will stay at rest, and if an object is travelling at a constant speed, it will continue at a constant speed in the same direction. The term **net force** is used to describe the sum of all forces acting on an object. When the net force is zero ( $\vec{F}_{\text{net}} = 0$ ), it means that the forces are balanced and will not change the motion of the object. However, if the forces applied to an object are unbalanced ( $\vec{F}_{\text{net}} \neq 0$ ), then the object will either accelerate or decelerate or change direction.

$\vec{F}_{\text{net}} = 0$	$\vec{F}_{\text{net}} \neq 0$
The forces acting on an object are balanced and sum to zero. The motion of the object is not changed in speed or direction.	The forces acting on the object are unbalanced and sum to either a positive or negative number. The motion of the object changes. It either speeds up or slows down or changes direction depending on the direction of the net force.

**Table 3.3** The effect of balanced and unbalanced forces

Inertia is responsible for the feeling that you get when you suddenly change motion in a car, train, aeroplane or on a bike. At times when we travel at a constant speed, we hardly even recognise that we are moving. But when the vehicle that we are travelling in suddenly stops, turns a sharp corner or accelerates, we notice that our body moves unexpectedly. This is inertia. It is the tendency for objects to either stay at rest or continue travelling at a constant speed in the same direction.



**Figure 3.20** Consider travelling in a car at a constant speed. When the brakes are suddenly pressed, the car quickly slows down, but our body continues to move forwards at the original speed. If it were not for seatbelts, we would continue our motion towards the front window of the car.

### Newton's second law of motion

**Newton's second law of motion** is a mathematical formula that describes the relationship between net force, mass and acceleration. Newton's second law states:

The net force acting on an object equals the mass of the object multiplied by the acceleration.

It can also be written as:

net force = mass  $\times$  acceleration

$$\vec{F}_{\text{net}} = m\vec{a}$$

From this equation, the following four statements can be generated:

- 1 The more massive the object, the greater the force needed to accelerate it.
- 2 The greater the force applied to an object, the quicker it will accelerate.
- 3 If the same force is applied to a more massive object, the acceleration will be less.
- 4 If there is an acceleration, then there is a net force.



VIDEO  
Newton's  
second law

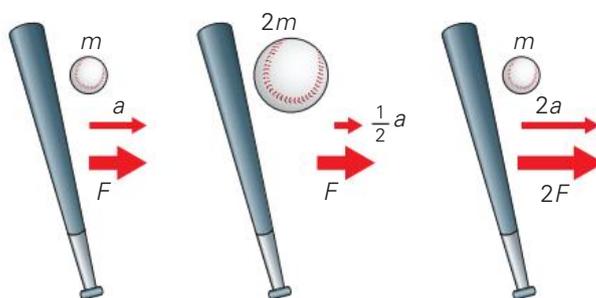


WIDGET  
Newton's  
second law

Imagine hitting a baseball with a bat as in Figure 3.21. When a net force is applied to the ball, it will accelerate. Consider what would happen if we were to swap the baseball with a larger baseball with twice the mass. Newton's second law tells us that if the same force were applied to a larger baseball with twice the mass, it would not accelerate as much as the smaller baseball because of the difference in mass. Lastly, if we were to apply a greater force on the baseball, it would increase the acceleration.

#### Newton's second law of motion

an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force, and inversely proportional to the mass of the object



**Figure 3.21** A baseball hit by a bat follows Newton's second law of motion.

### Practical 3.3

#### Force and mass

##### Aim

To investigate the effects of force and mass on acceleration.

##### Materials

- crash trolley
- elastic bands
- weights
- tape
- stopwatch

*continued...*

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### Procedure

Design an experiment that investigates the effects of force and mass on acceleration. You can use increasing numbers of elastic bands to demonstrate increased force applied on the trolley.

### Results

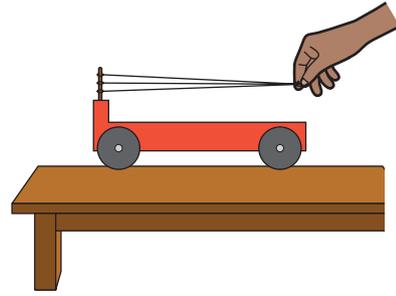
Record your data in a table.

### Discussion

- 1 As you increase force, what happens to acceleration?
- 2 As you increase mass, what happens to acceleration?
- 3 How can your experimental design be improved?
- 4 Identify any sources of error (experimental uncertainty or experimental faults).

### Conclusion

- 1 Make a claim about force, mass and acceleration based on this experiment.
- 2 Support the statement by using the data you gathered and include potential sources of error (experimental uncertainty or experimental faults).
- 3 Explain how the data supports the statement.



## Newton's third law of motion

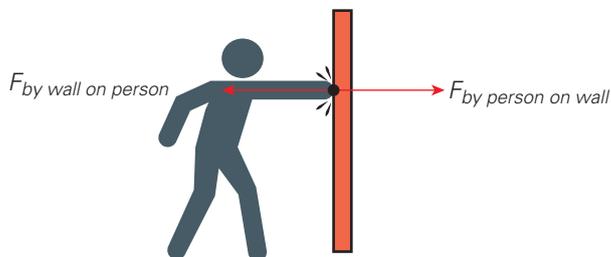
Newton's first two laws examine the forces acting on a single object. **Newton's third law of motion** describes what happens to an object when it is acted upon by another object. The third law suggests that all forces come in pairs: an action force that acts on one object and a reaction force that acts on the other object. For

**Newton's third law of motion**  
for every action, there is an equal and opposite reaction

example, if you were to push on a wall, the wall pushes back just as hard – if it did

not you would fall through (Figure 3.22)! Newton's third law states:

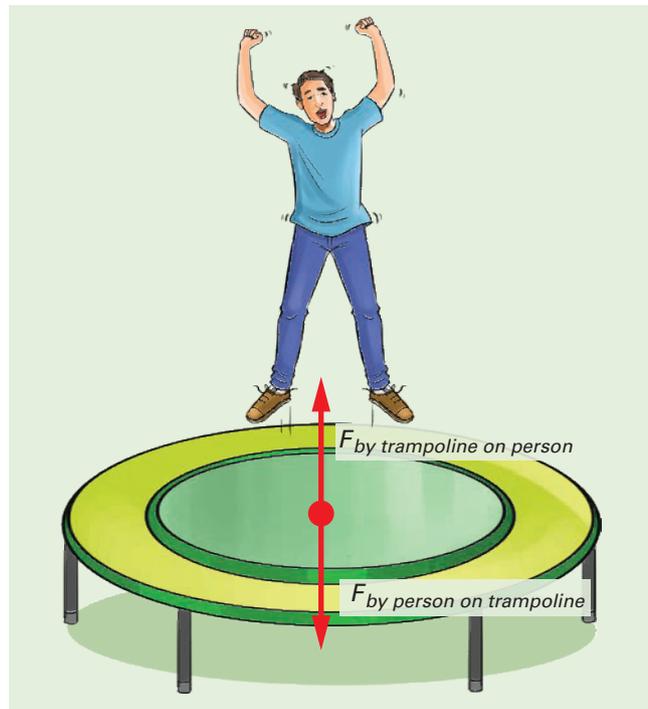
For every action, there is an equal and opposite reaction.



**Figure 3.22** The action of pushing against a wall has a reaction force that pushes back on the person with the same magnitude.

There are many examples of action–reaction pairs. Action–reaction pairs always act on different objects. For example, if the action force is the force the person's feet exert on the ground (a contact force) then the

reaction force is the contact force that the ground pushes up on the person's feet (or vice versa). The action–reaction forces always act on different objects, in opposite directions and have the same magnitude. This means that an apple pulls Earth up with exactly the same force that Earth pulls the apple down!



**Figure 3.23** As a person jumps down on a trampoline, they exert a force downwards on the mat when in contact with the mat. The mat then pushes back up with an equal but opposite force. This can cause the person to bounce back into the air.

## Quick check 3.7

Copy the diagram in Figure 3.24 and label with the action force and the reaction force.

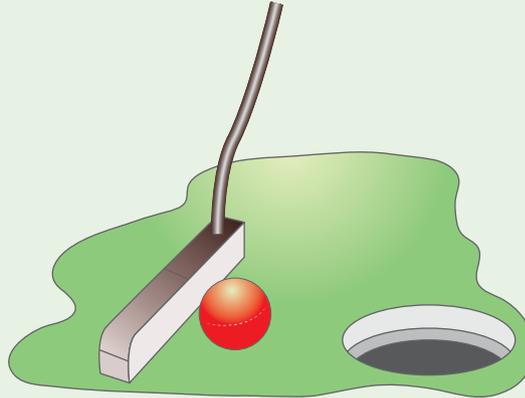


Figure 3.24 Forces involved in putting a golf ball

## Explore! 3.1

## Projectiles and throwing devices

Aboriginal and Torres Strait Islander peoples have used spears, spear-throwers and bows and arrows for millennia prior to European settlement. They recognised patterns in the data and had an understanding of the relationship between the mass of the projectile (spear/arrow), the force that the throwing device (spear-thrower/bow) applied to it, and the effect on its velocity, range and impact force. Use your preferred search engine to investigate how Aboriginal and Torres Strait Islander peoples achieved an increase in velocity and subsequent impact force by using spear-throwers and bows.

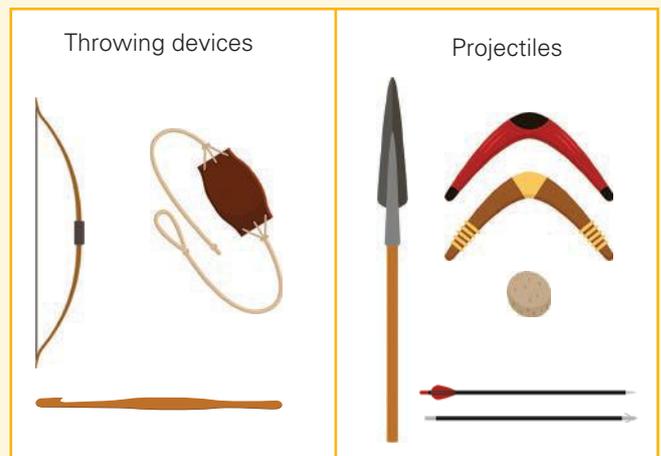


Figure 3.25 What is the throwing device of the boomerang?  
The human arm

## Practical 3.4

## Crash-test eggs

## Aim

To design and build a car with safety features that will protect an egg from breaking during a collision.

## Materials

As chosen by students but may include:

- rubber bands
- wheels
- icy-pole craft sticks
- dowels
- plastic cups
- straws
- rubber bands
- string

*continued...*

...continued

- springs
- balloons
- toilet paper or paper towel rolls
- cardboard boxes (varying sizes)
- plastic bottles
- flat cardboard
- sticky tape

### Procedure

- 1 Research information on vehicle collisions, safety features of cars and the forces involved during a collision.
- 2 Based on your research, design and build a vehicle or device that has safety features to protect an egg during a collision.
- 3 Test your design by competing as a class to see whose crash-test egg survives.

### Results

Take a high-speed video of your collision and slow it down to see the forces in effect.

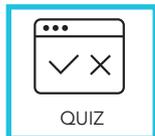
### Discussion

- 1 Compare your safety device to a safety feature in a car.
- 2 Draw the forces acting on the egg during the collision.
- 3 What difficulties or errors did you encounter during this experiment? How could you improve the experiment to avoid these in the future?

### Conclusion

- 1 Make a claim about safety based on this activity.
- 2 Support the statement by using your observations and include potential sources of error.
- 3 Explain how your observations support the statement.

## Section 3.3 questions



### Remembering

- 1 **Describe** what is meant by the term inertia.
- 2 **Describe** the term 'net force'.

### Understanding

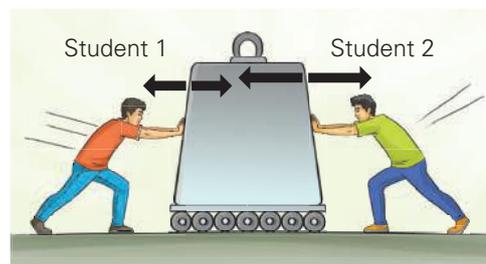
- 3 If there is zero net force applied to an object that is travelling at a constant speed in a straight line, **outline** what happens to the object. Which of Newton's laws applies to the situation?

### Applying

- 4 A 50 kg person sits on a chair with feet dangling above the ground. **Construct** a diagram to represent the action–reaction pair of forces acting on the scenario and include labels to indicate the force quantities. (Remember that acceleration due to gravity is  $g = 9.8 \text{ m/s}^2$ .)

### Analysing

- 5 Consider the action–reaction forces in the following scenario. Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass and Student 2 exerts a force of 220 N. Ignore frictional forces.
  - a **Determine** the net force acting on the mass.
  - b **Determine** the direction the mass will move.



**Figure 3.26** Two students are trying to push a mass towards each other. Student 1 on the left exerts a force of 155 N on the mass and Student 2 exerts a force of 220 N.

### Evaluating

- 6 **Evaluate** whether there are other action–reaction pairs in the system from the previous question. Can you quantify the forces?

# Chapter review

## Chapter checklist

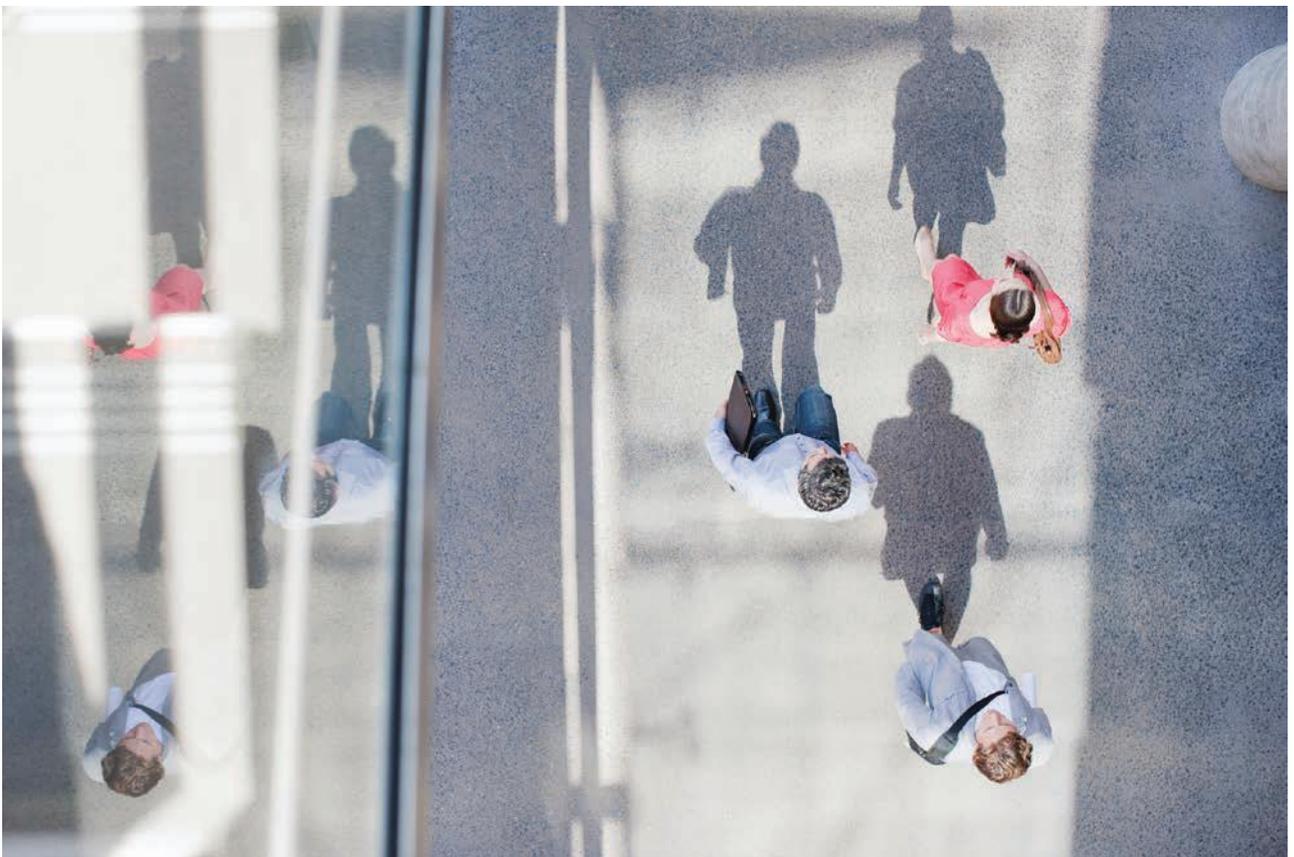
You can download this checklist from the Interactive Textbook to complete it.

Success criteria	Check
<b>3.1 I can distinguish between distance and displacement.</b> e.g. Define the term 'displacement' in your own words.	
<b>3.1 I can calculate the speed of an object.</b> e.g. State the equation for speed.	
<b>3.1 I can distinguish between speed and velocity.</b> e.g. State the equation for velocity.	
<b>3.2 I can use speed–time, distance–time and displacement–time graphs to communicate an object's motion.</b> e.g. Recall what a positive gradient on a speed–time graph represents.	
<b>3.3 I can explain Newton's three laws of motion.</b> e.g. Explain Newton's second law of motion.	



## Reflections

- 1 What **connections** come to mind when you think about motion and your everyday life?
- 2 What new concepts have **extended** your thinking about describing and quantifying motion?
- 3 What information did you find **challenging** or confusing?



## Data questions

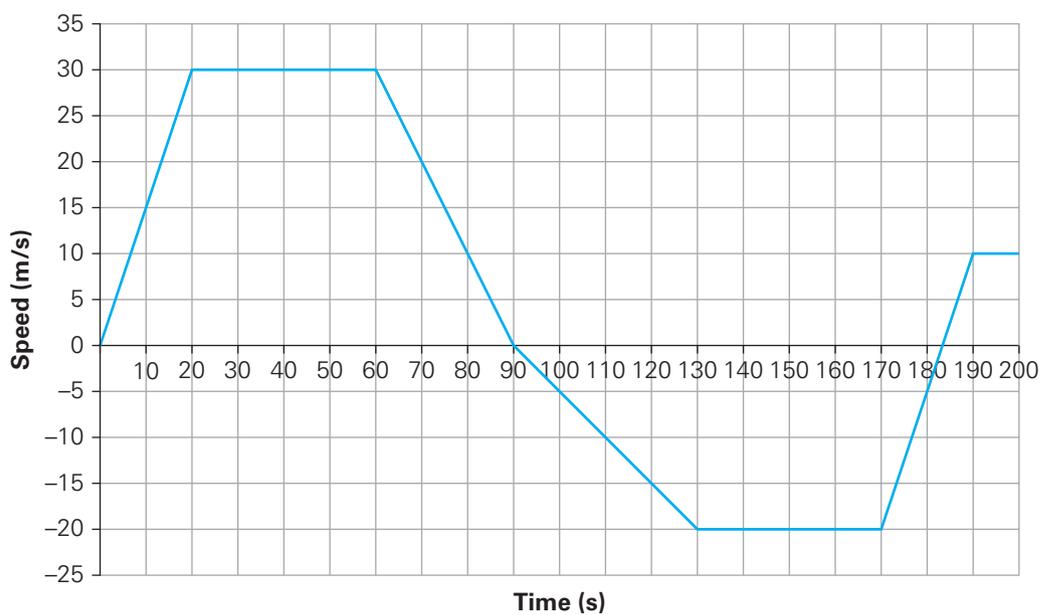


Figure 3.27 Speed–time graph of unknown object

- 1 Using the speed–time graph in Figure 3.27, **identify** the speed of the object at the 10, 40, 90 and 140 second marks.
- 2 **Calculate** the acceleration of the object at the 10, 40, 80 and 110 second marks.
- 3 **Calculate** the distance travelled of the object after 170 seconds.
- 4 **Interpret** the speed–time graph to describe the motion of the object in words.
- 5 **Deduce** a potential identity of the object.
- 6 **Deduce** why it is unlikely to be a standard car.

# STEM activity: Preventing motion sickness

## Background Information

Motion sickness is a common condition usually experienced by people who are travelling. About one in three people are susceptible to motion sickness while driving or flying, and around 10 per cent of those sufferers are highly sensitive to motion.

The mechanisms responsible for motion sickness are not fully understood, but researchers suggest that motion sickness results from an interaction between the vestibular and the visual system. Evidence suggests that motion sickness occurs when there is a conflict between the movement detected by the vestibular system and the visual input.



**Figure 3.28** The driver of a car (left) is least likely to suffer from motion sickness because their sensory information (visual, sensory and even touch) all indicate accurate information. An aeroplane passenger (right) is susceptible to motion sickness as they are often caught unaware by sudden changes in the plane's motion.

**Design brief:** Design a product as a solution for motion sickness.

## Activity instructions

In this activity, you will work in groups (three to four maximum) to brainstorm and attempt to design potential solutions and products that could assist people with severe motion sickness symptoms. You should focus on solutions to prevent sensory conflict, and the consequent motion sickness.

Importantly, your design should be non-ingestible (not swallowed) and non-invasive (nothing is put inside the body), and it must not involve passing electric shocks. Consider cost and aim to make your design as affordable as possible.

## Suggested materials

- big pieces of paper
- markers
- access to the internet
- cardboard
- tape
- straws
- balloons
- ziplock plastic bags
- string

## Research and feasibility

- 1 Discuss with your classmates the effect of different modes of transport on motion sickness. For example, on which modes of transport (car, train, aeroplane, boat) have you experienced motion sickness? Why might someone experience motion sickness in a small boat but not on a cruise? Use the following terms: acceleration, deceleration, change in motion, sensory or stimuli.

## Design and sustainability

- 2 Research some of the current solutions that do not involve medication or electric shocks. Describe how you could make these solutions more affordable or viable for use now.

## Create

- 3 Propose a design and a method of building or developing your product. Your product could be conceptual, but a physical product is preferred. If your design can be built, then build a prototype.
- 4 Create a poster showcasing your solution and pitch it to the class as if you were seeking for investors. Ensure your pitch takes three minutes and explains:
  - why the product is needed
  - what the product is
  - what is unique about the product
  - why people will want to use it.

## Evaluate and modify

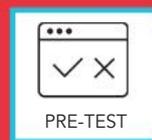
- 5 What questions might your 'investors' ask? How could you modify your design to address potential issues?

# Chapter 4

# Electricity

## Inquiry questions

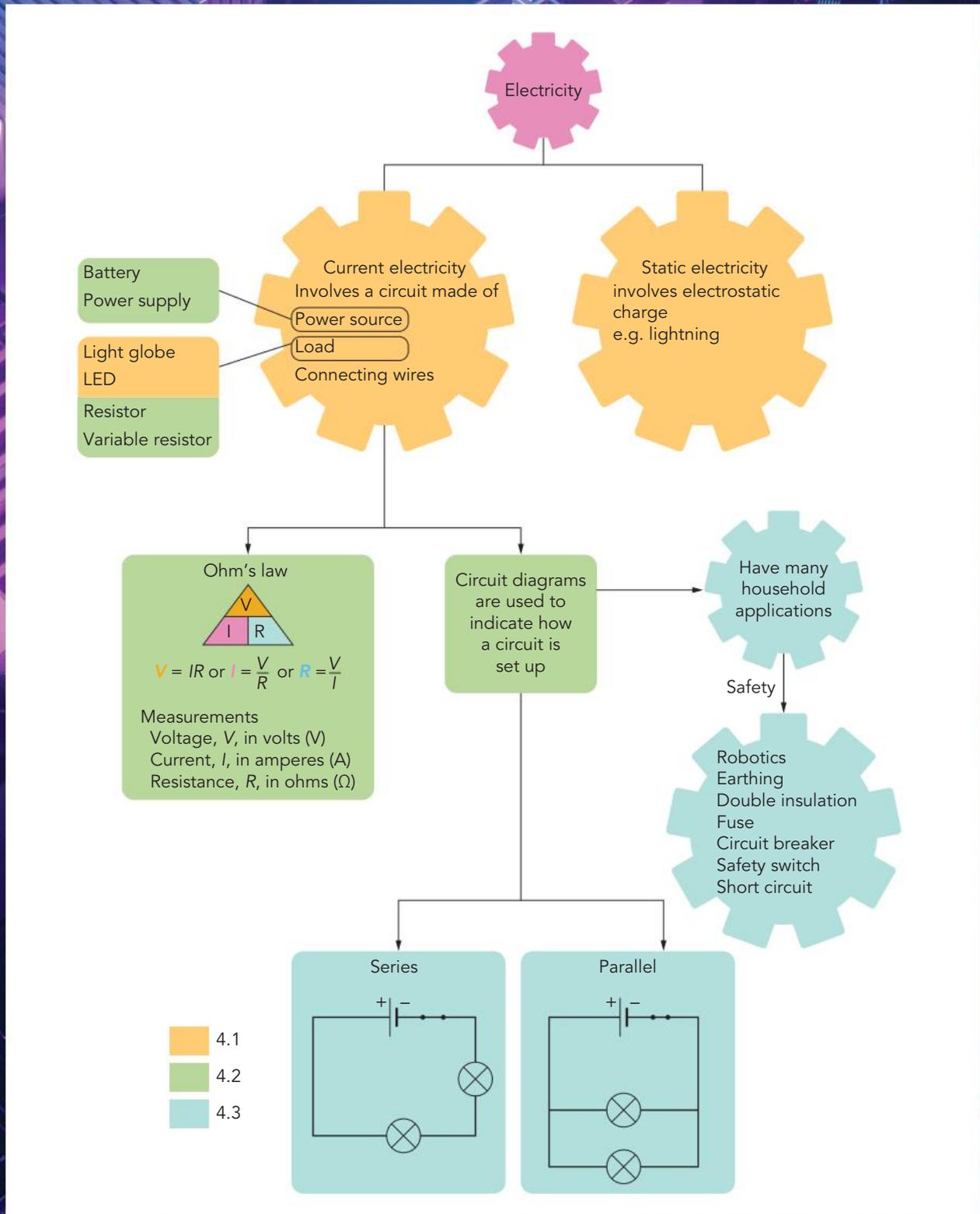
- What happens to the energy in a circuit?
- Why do some lights get hotter than others?
- How do we protect ourselves when using electricity?



## Chapter introduction

Many household appliances rely on electricity to operate. The way they function depends on how the electrical components within them are arranged; this is called their electrical circuit. In this chapter, you will learn about what electricity is and how electricity flows in a circuit. You will learn about various components in an electrical circuit and how using different electrical circuits and components changes the outcome.

# Chapter map



# 4.1 What is electricity?

## Learning goals

- 1 To recall the structure of the atom and the charge of protons, neutrons and electrons
- 2 To describe the generation of electrostatic charge in terms of the movement of charged particles
- 3 To recall the requirements of an electric circuit



**electricity**  
a form of energy that results from either the accumulation of charge or the flow of charge

**static electricity**  
an imbalance of charge on objects

**electrostatic charge**  
charge that stays on an object



VIDEO  
Example  
of static  
electricity at  
work

**Electricity** is a form of energy that results from either the accumulation of charge or the flow of charge. It is generally the movement of the negatively charged electrons that results in movement and separation of charge.

## Static electricity and charge

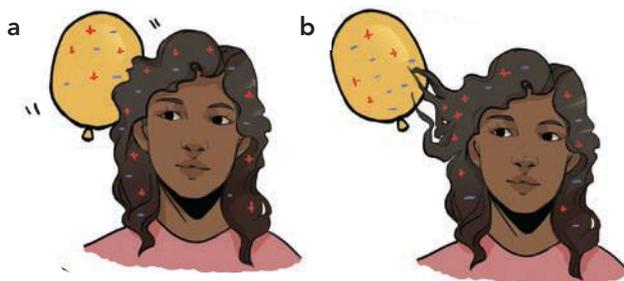
**Static electricity** is created when there is an imbalance of charge on objects; that is, there is a build-up of positive or negative charge. You may have experienced the effects of static electricity when

you have combed your hair, or you may have received a small shock when you got out of the car and touched the metal door. The charge build-up is called **electrostatic charge** because it stays on the object ('static' means stationary or still). One of the most dramatic

demonstrations of the energy of static electricity is seen during a thunderstorm. A bolt of lightning releases an enormous amount of energy in an electrical discharge.

## Try this 4.1

Blow up a balloon and tie it up. Rub it against your hair or find a friend who has fine hair and ask them to rub the balloon against their hair. What do you observe? Can you explain what happened in terms of movement of charge?



**Figure 4.1 (a–b)** When a balloon is rubbed against hair, electrons from the hair transfer to the surface of the balloon, giving the balloon an overall negative charge, while the hair now has a positive charge. Recall that like charges repel and opposite charges attract, so the hair (+) is now attracted to the balloon (–).

## Did you know? 4.1

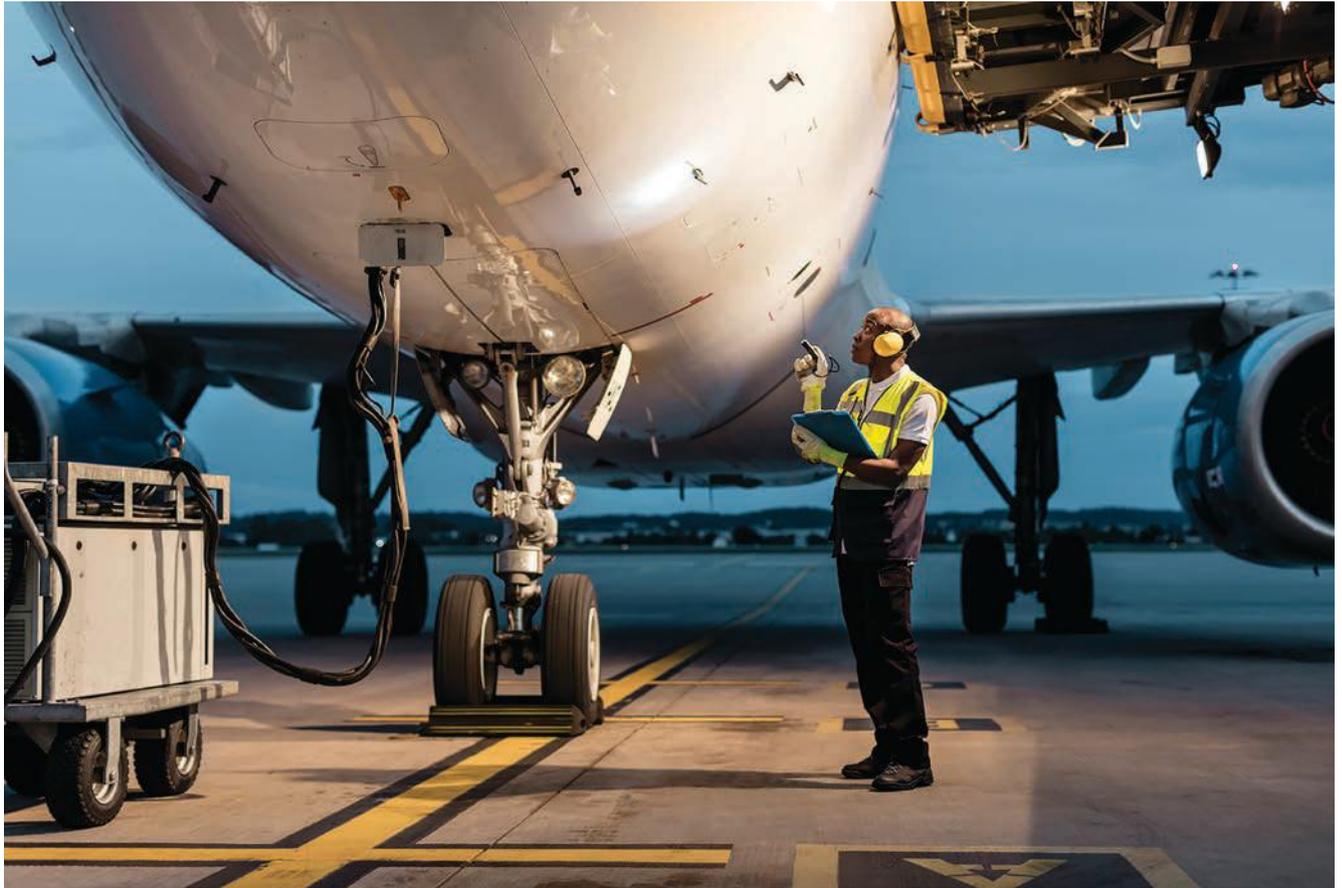
### History of static electricity

The ancient Greek philosopher Thales of Miletus, writing at around 600 BCE, was the first to describe a form of static electricity. Using a piece of amber (fossilised tree resin), which he rubbed on fur, Thales noted that he could attract light objects such as hair, straw and small pieces of wood shavings. More vigorous rubbing of the amber even managed to produce small electrical sparks. In Ancient Greek, the word for amber is *elektron*, which gave its name to the electron and electricity.



**Figure 4.2** Amber was rubbed on fur to produce static electricity.

The presence of electrostatic charge can be dangerous. Aeroplanes being refuelled must be ‘grounded’ (that is, connected by wires to the earth) so that static electricity does not cause a spark and an explosion (see Figure 4.3).



**Figure 4.3** The aeroplane is connected to earthing wires during refuelling to avoid sparks and a possible explosion.

### Quick check 4.1

- 1 Outline the structure of an atom.
- 2 Define the following terms in your own words.
  - a Electricity
  - b Charge
  - c Static electricity
- 3 How does rubbing two different materials together sometimes create static electricity?
- 4 How is static electricity created by combing your hair?

## Current electricity

While static electricity is when charge gathers in one place, in **current** electricity, charges move and may continue moving in a steady manner for a period of time. These charges are electrons. When the charge passes through an electrical **component**, such as a light

globe, it transfers energy to that component. Depending on what the component is, it converts that energy into other forms of energy like movement, light and heat.

**current**  
the flow of electric charge, which may continue in a steady manner for a period of time

**component**  
part of a circuit

## Try this 4.2



**Figure 4.4** Electricity is used to run many household items.

What are some electrical appliances you see used in the classroom or at home? In each case, what is electrical energy being converted into? What does a remote control convert electrical energy into?

## Circuits

You use electrical **circuits** all the time, whether it is in simply turning on a torch or using a computer. Electrical circuits can be simple (for example, a torch) or complex (for example, a computer's central processing unit), but they all consist of the same basic components and

follow the same principles in their operation.

It is current electricity that moves in a circuit. If there is a break in the loop, then the electricity stops flowing. Electrons need a path out of and back to the power source

to continue moving around the circuit. An electrical circuit always has these three components:

- a power source (that provides energy to electrons – like a battery or power pack)
- a **load** (that uses the energy – like a light globe)
- connecting wires (that carry the moving electrons).

### Power source

The **cell** is the power source of a circuit. It supplies the energy to the electrons, which are then pushed around the circuit. Because there is an imbalance of charge, when the two terminals are connected via a circuit, electrons flow from the negative to the positive terminal. An everyday **battery**, like you might have in a torch, is an electrochemical cell (something that derives electrical

**circuit**  
structure through which charges can move

**load**  
something that uses energy in a circuit

**cell**  
a single electrical energy source that produces a current

**battery**  
a portable source of power

energy from chemical reactions). In this text, we use battery in a general sense to mean a portable source of power (so, including cells, batteries or power packs).

Never connect a wire directly from the positive to the negative terminal of a battery! As there is no energy user or load, the wire will become very hot and the battery could be flattened or damaged.

### Load

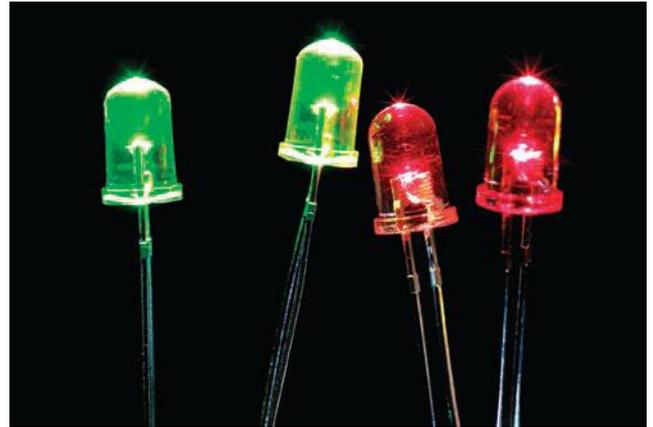
A load is a component of an electrical circuit that uses or dissipates energy. Electrons moving through a circuit carry energy from the power source to components that can transform that energy into other forms of energy as the electrons pass. For example, in incandescent light globes, the energy being carried by the electrons is transformed into light and thermal energy.

Only a small amount of the energy is transformed into light energy – around 96% is wasted as thermal energy. Incandescent light globes, which are not very energy efficient, can get quite hot!

### LEDs

Light emitting diodes (LEDs) are tiny light globes that transform electrical energy into light energy much more efficiently than incandescent light globes, with only 20% of the energy lost as thermal energy. The lifespan of LEDs is also much longer than that of incandescent

light globes. LEDs are often used in appliances such as watches, microwaves, calculators, traffic lights and TV screens.



**Figure 4.5** LEDs (light emitting diodes) are tiny light globes that fit into electric circuits.

### Connecting wires

Connecting wires or conductors are essential components in a circuit and are needed to carry the current from the power source to a load and back again.

#### Quick check 4.2

- 1 Contrast current and static electricity.
- 2 Identify what flows in the connecting wires of an electrical circuit.
- 3 Why must a circuit be 'closed' or complete (free of breaks) for it to work?

## Advances in science 4.1

### Electric cars

There are many reasons why electric cars are becoming more mainstream worldwide. They do not release any exhaust gases and have the potential to dramatically reduce air pollution in large cities. They are quiet and efficient. An electric car powered by rechargeable batteries uses electric motors to drive all four wheels. These motors can also become efficient electrical generators when the car is braking. This 'regenerative' braking system can recoup up to 60% of the car's energy of motion and turn it back into electricity!

Additionally, electric cars are being designed so that their batteries can be fully or partially recharged by renewable resources, such as domestic solar energy. There is no point driving an environmentally friendly electric car if you are charging up with electric power made from highly polluting coal-fired power stations!

While electric cars are ideal for city and suburban runs (having a typical range of approximately 200–300 kilometres), they cannot yet manage long-distance journeys. Petrol and diesel cars can typically do 500–800 km on a tank and can be refilled in 10 minutes at numerous petrol stations along the highways. Electric recharge stations are still few and far between in Australia, especially when you think that the first Australian-built electric

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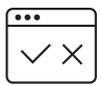


**Figure 4.6** Fast charging an electric car. The 85 kWh battery pack has a mass of 540 kilograms (kg) and contains 7104 lithium-ion battery cells in 16 modules wired in series.

car began production in 2008! The infrastructure required needs a critical number of electric cars to make it economically feasible. Electric cars also take a longer time to recharge (from 15 to 60 minutes for a fast recharge).

A Sydney to Broken Hill car trip (approximately 900 km) might involve two enforced extended recharges. Although possibly inconvenient, such a recharge break may inadvertently save lives as drivers are forced to take a rest break – driver fatigue on such long trips is a factor in serious accidents.

### Section 4.1 questions



QUIZ

#### Remembering

- 1 **Name** the charged particles that carry an electric current through a circuit.
- 2 **List** the three components that an electricity circuit needs.

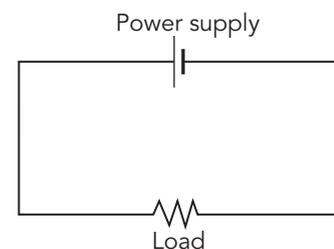
#### Understanding

- 3 **Explain** how rubbing amber produces electric sparks.

- 4 **Contrast** static and current electricity.

#### Applying

- 5 Your body relies on electricity to function. Your nervous system sends electric signals through your body. Redraw the simple electric circuit on the right and **label** with what you propose would be the energy source, connecting wires and load in your body.



### Analysing

- 6 It is often difficult to completely empty the plastic bag that contains your breakfast muesli as small flakes of oats seem to get stuck to the inside of the bag. **Propose** a possible explanation for this effect.
- 7 Modern laser printers use static electricity as part of the printing process. The printing process is a 4-step process as follows (note that step 3 is missing):
- Step 1. The laser beam scans back and forth on a cylindrical drum inside the printer and creates a pattern of static electricity on the drum.
- Step 2. A very fine powdered ink (normally black but can be any designated colour) called the toner is inserted near the drum.
- Step 3. \_\_\_\_\_
- Step 4. Finally, a fuser unit binds the toner to the paper.
- Deduce** what you think happens to the toner in step 3 of the process.

### Evaluating

- 8 An electrostatic smoke stack is used to remove pollutants from the smoke before they are released into the environment.
- a **Explain** how neutral particles can be attracted to the statically charged rods hanging in the smoke stack.
- b **Explain** why it is good practice to remove the particles from industrial smokestacks.
- 9 Lightning bolts contain large amounts of electrical energy. **Propose** reasons why the electricity from lightning bolts is not captured for our electrical needs.
- 10 **Propose** three arguments supporting, and three arguments against, the widespread adoption and use of electric cars in Australia.



## 4.2 Simple circuits

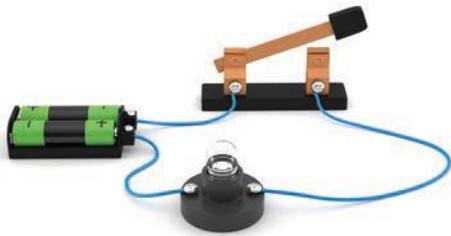
### Learning goals

- 1 To draw circuit diagrams using conventional symbols
- 2 To describe voltage, current and resistance in terms of energy applied, carried and dissipated
- 3 To outline the role of conductors and insulators in relation to their effect on the flow of current
- 4 Additional: To explain the relationship between resistance, voltage and current using Ohm's law
- 5 Additional: To apply numerical procedures to calculate resistance using Ohm's law formula



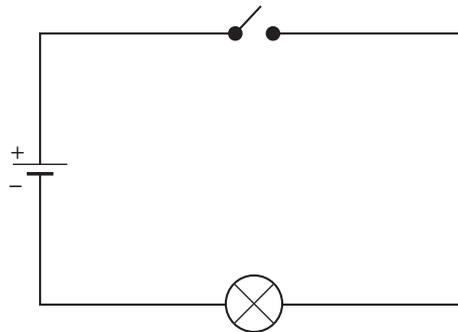
### Circuit diagrams

The circuit in Figure 4.7 shows a battery pack connected to a light globe with connecting wires and a switch. When the switch is pressed down, it completes the circuit, so electrons can flow from the negative terminal of the battery through the circuit and back to the positive terminal.



**Figure 4.7** A simple circuit can be made with a power source, light globe and switch.

Many circuits are better represented in the form of a diagram in which each symbol represents a different electrical component. Figure 4.8 shows the circuit from Figure 4.7 in the form of a circuit diagram using symbols.



**Figure 4.8** To create a diagram of the simple circuit shown in Figure 4.7, join the symbols for a power source, a light globe and a switch together with straight lines that represent the wires.

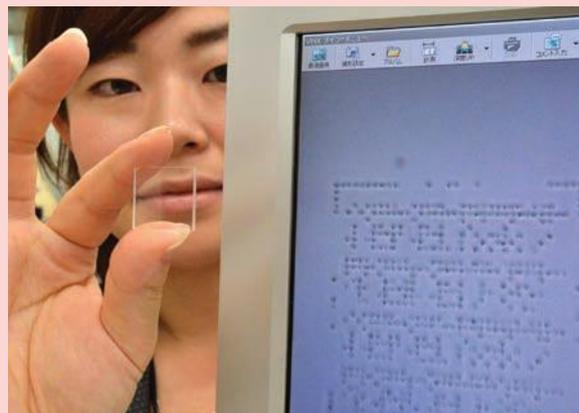
### Advances in science 4.2

#### Crystal circuits

In 2017, scientists found a way to engrave an electrical circuit into a crystal. By accident, physicists from Washington State University found that if a crystal is heated and then left exposed to light, it can conduct electricity. A circuit can be engraved into the crystal using a laser.

Even better, it was found that the circuit can be erased by heating it on a hot plate. This means the circuits can be erased and reconfigured numerous times, like the drawings on an Etch a Sketch.

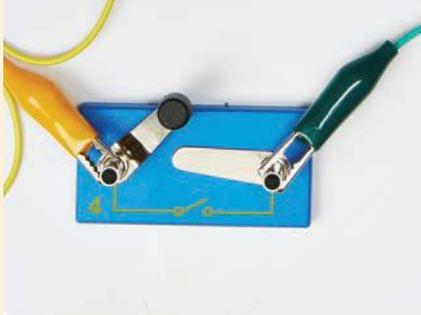
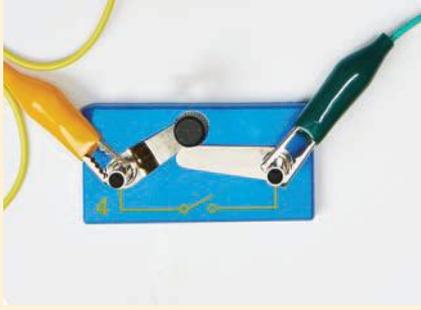
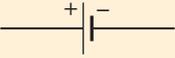
An electrical circuit in a crystal would be transparent, opening up opportunities to embed electronics in windows.



**Figure 4.9** Laser beams create dots on glass in order to store data.

## Circuit symbols

You have already seen some common electrical components and their circuit symbols above (battery, load and connecting wires). Table 4.1 shows several other useful electrical components and their circuit symbols.

Component	Image	Symbol
Connecting wire		
Switch open		
Switch closed		
Cell		

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**Table 4.1** Some common electrical components and their circuit symbols.

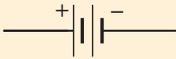
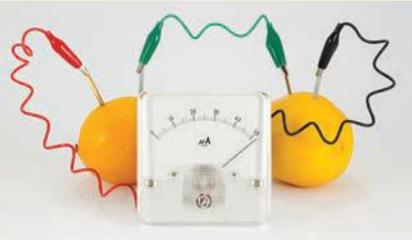
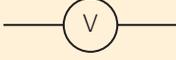
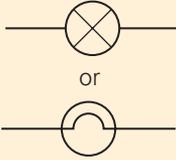
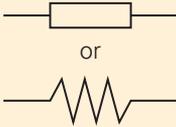
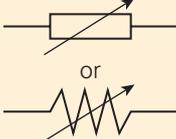
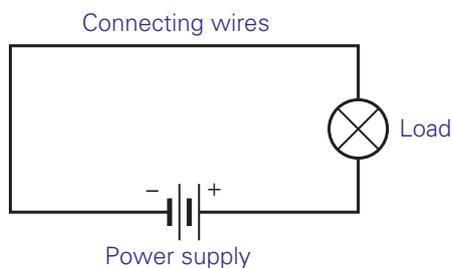
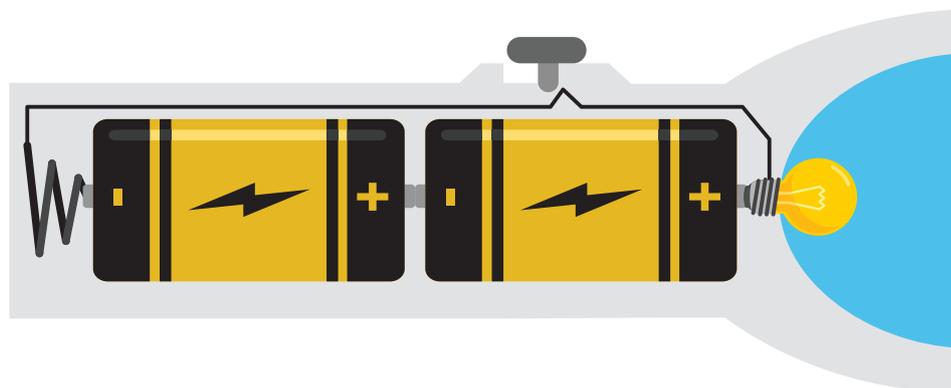
Component	Image	Symbol
Power supply or battery pack		
Ammeter		 <p><b>ammeter</b> a device for measuring electric current</p>
Voltmeter		<p><b>voltmeter</b> a device for measuring voltage between two points on an electric circuit</p> 
Load: light globe		 <p>or</p>
Load: resistor		 <p>or</p>
Load: variable resistor		 <p>or</p>

Table 4.1 (Continued)

### Drawing circuit diagrams

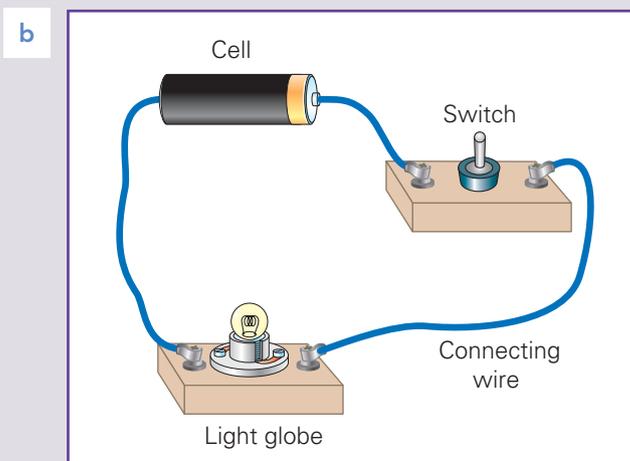
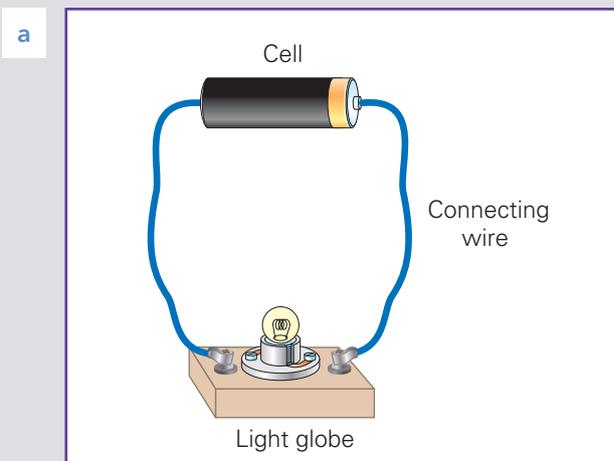
A circuit diagram is a diagrammatical representation of an electrical circuit using basic symbols. Circuit diagrams should always be drawn with a ruler and pencil. All lines should be straight and joined at right angles.



**Figure 4.10** The top drawing shows the inside of a torch, but you use a simplified diagram like the bottom one to represent the circuit. The batteries are the energy source and the light globe is the load. Can you think of one component that needs to be added to the diagram?

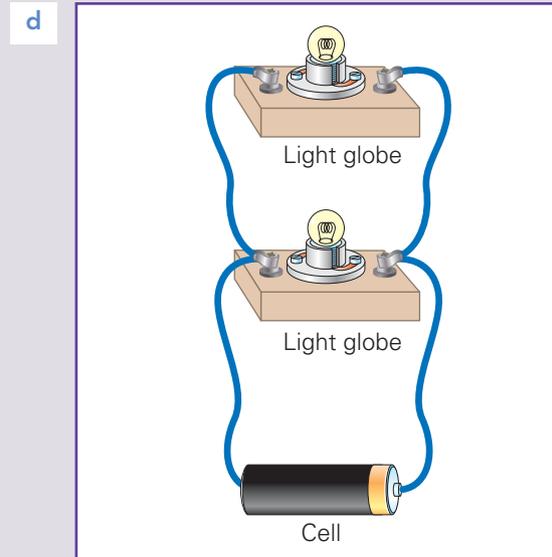
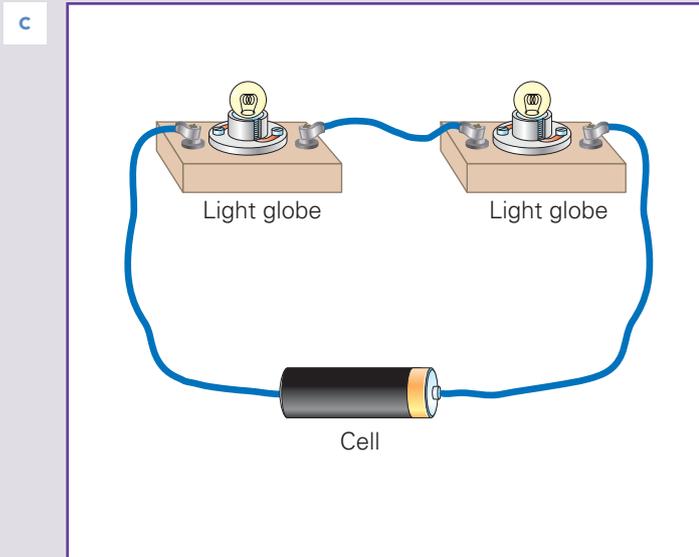
### Try this 4.3

Draw circuit diagrams for the following circuits.



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...continued



### Quick check 4.3

- 1 List five components that could be included in a circuit.
- 2 For the list from question 1, draw the circuit symbol for each.
- 3 Explain why circuit diagrams are used.
- 4 List the rules that apply to drawing a circuit diagram.

## Voltage

**Voltage** is supplied by the power source of a circuit and is a measurement of how much energy each electron (charge) is given. For example, a 1.5 V battery supplies 1.5 joules of energy to each unit of charge. Components such as light globes and speakers transform the energy supplied by charges into light, heat and sound. The difference in the amount of energy the charges carry before and after the light globe or speaker is called a **voltage drop**. The voltage of a battery is usually standardised for its particular purpose. Car batteries used for starting petrol cars are virtually all

standardised at 12 V. In Australia, power points supply 230 V. Some appliances contain a transformer that reduces the voltage to a more suitable number.

**voltage**  
a measurement of how much energy each charge carrier is given

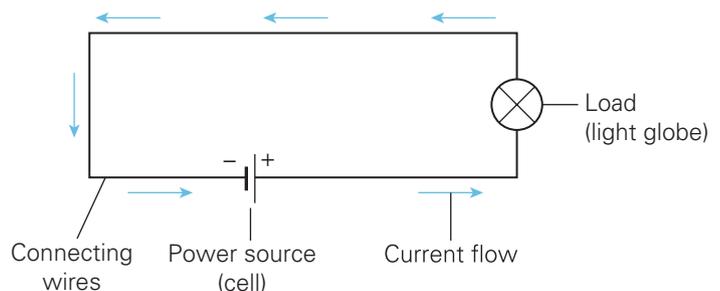
**voltage drop**  
the difference in energy the charges carry before and after a load

Voltage is measured in volts (V) using a voltmeter.

A voltmeter can measure the voltage provided by the power supply or the voltage drop across components of the circuit. In a circuit, a voltmeter must be connected to the start and the end of the component whose voltage you are measuring so as to measure the voltage drop **across** the component as shown in Figure 4.12. This is called connecting in parallel to the circuit.

## Current

Current is the movement of electrons around a circuit. The electrons flow from the negative terminal to the positive terminal (referred to as electron flow or electron current). However, the current in circuit diagrams is shown as going in the opposite direction; that is, from the positive terminal to the negative terminal of the power source. This is called conventional current, and follows the direction defined in the 1700s.

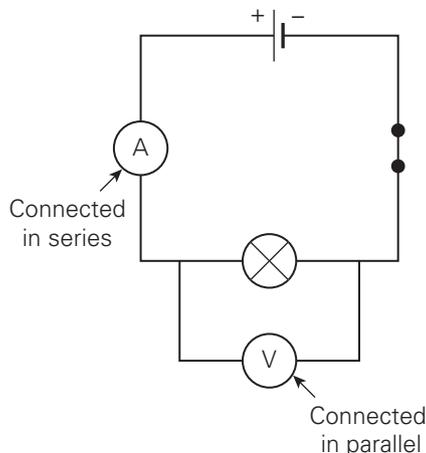


**Figure 4.11** Conventional current is indicated in this simple circuit as flowing from the positive terminal to the negative terminal of a cell. The connecting wires are drawn as straight lines.

It is possible to measure the rate at which charge passes any point in a circuit. Imagine being able to see the electrons moving along a conductor carrying an electric current. You could count the number which pass any particular point in 1 second and use that number as a measure of the current (in electrons per second).

The unit of current is defined this way: 1 **coulomb** per second is 1 **ampere** (A), or amp for short. A coulomb can be described as the amount of charge transferred in 1 second with a current of 1 amp. You can increase the electric current flowing through a circuit by increasing the voltage or energy supplied to each charge.

To measure the current in specific locations of a circuit, an ammeter is used. An ammeter is connected in line to measure the current **through** a circuit as shown in Figure 4.12. This is called connecting in series with the circuit.



**Figure 4.12** When building a circuit, ammeters need to be placed in series and voltmeters need to be placed in parallel.

#### Quick check 4.4

- 1 Define the following terms in your own words.
  - a Voltage
  - b Voltage drop
  - c Voltmeter
  - d Current
  - e Ampere
  - f Ammeter
- 2 How does current differ in a circuit when the switch is open and closed? Explain your answer.

## Resistance

The **resistance** in an electric circuit is how difficult it is for the current to flow through a material or component.

Resistance is measured using the unit **ohm**. The unit symbol for ohms is the symbol for the last letter in the Greek alphabet, omega, represented by  $\Omega$ . A resistor is a component of a circuit intentionally added to control or reduce the amount of current by increasing the resistance, making it more difficult for the current to flow.

A digital multimeter is a tool often used to measure current, voltage and resistance.

## Conductors

Materials through which current can flow easily have a low resistance and are called **conductors**. Metals are a good example of conductors.

Some metals are much better at conducting electricity than others. Copper is an excellent conductor of electricity. It is used in electrical wiring, electrical motors, telecommunications and electric cars. Gold is also an excellent conductor of electricity; however, due to its cost it is used in small amounts in critical electronic components such as computer chips and spacecraft electronics.

**coulomb**  
unit of electric charge; the amount of charge transferred in 1 second with a current of 1 amp

**ampere**  
one coulomb per second

**resistance**  
the degree to which a substance resists the flow of an electric current through it

**ohm**  
the unit of resistance

**conductor (electricity)**  
a material that allows electric current to flow easily



**Figure 4.13** Digital multimeters can measure current, voltage and resistance.

## Did you know? 4.2

## Saving lives

A defibrillator is a device that treats life-threatening heart problems by delivering a measured dose of electric current to the heart. When the heart does not beat as it should, blood is not circulated around the body. To get the heart pumping, an electric shock is delivered to the heart. An automatic external defibrillator (AED) can be used by untrained people and significantly improves survival rates in people having a heart attack.



Figure 4.14 An AED can increase the chance of survival during a heart attack.

## Insulators

Some materials have such high resistance that they block electric current almost completely. Such materials are called **insulators**. Examples of good electrical insulators are various plastics, glass, ceramics, wood and rubber.

**insulator**  
a material through which current cannot flow easily

## Variable resistors

Fixed resistors are used in circuits to control the amount of current that flows, while variable resistors can be adjusted and are used to control the volumes on stereos and televisions, or the brightness of the lights through the use of dimmer switches. These variable resistors may have a slider or dial that can be used to adjust the resistance and therefore the current in the circuit.

A light-dependent resistor (LDR) is a special type of variable resistor because its resistance changes depending on the amount of light falling on it. As light intensity increases, resistance decreases. LDRs are used in light-sensitive electronic circuits and act as light-sensitive switches; for example, they are used for lights that turn on automatically when it gets dark.

Thermistors, another special type of variable resistor, act in the same way except that their resistance changes as the temperature increases or decreases. Thermistors regulate the temperature in air conditioners and refrigerators using the relationship between voltage and resistance.

## Explore! 4.1

## Electrical engineering as a career

Electrical engineering is a career that deals with the principles of electricity, electronics and electromagnetism. One of the jobs of electrical engineers is to maintain the delivery of power to homes and businesses; that means maintaining power lines and transmission towers. Power lines are the most efficient way to transmit large amounts of electrical energy. You may notice that power lines are bare – the air insulates them. However, utility poles and transmission towers need insulation. Conduct some research to answer the following questions.

- 1 Identify the material used in insulators for high-voltage power transmissions.
- 2 Some electric utilities have begun converting to polymer composite materials for some types of insulators. Identify what these are made of and deduce why they are useful as an alternative to other insulators.



Figure 4.15 This electrical engineer is carrying a high-voltage electrical insulator ready for installation.

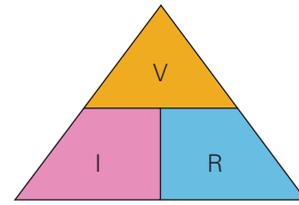
## Quick check 4.5

- 1 Define the term 'resistance' in your own words.
- 2 Compare a conductor and an insulator and give an example of each.

## Ohm's law

Georg Simon Ohm was a German physicist who, through his research, observed that electric current had direct proportionality with the voltage applied across some conductors; that is, if you double the voltage you double the current. There was also inverse proportionality between resistance and current; that is, if you double the resistance, you halve the current. This relationship is known as **Ohm's law**, where  $R$  is the resistance in ohms ( $\Omega$ ),  $V$  is the voltage in volts (V) and  $I$  is the current in amperes (A).

$$V = IR \text{ or } I = \frac{V}{R} \text{ or } R = \frac{V}{I}$$



**Figure 4.16** The Ohm's law triangle describes the relationship between voltage, current and resistance.

For example, if you have a circuit with a 2.5 V power source and a 1  $\Omega$  resistor, the current would be  $I = \frac{2.5 \text{ V}}{1 \Omega} = 2.5 \text{ A}$ . If the resistor is changed to having 2  $\Omega$  resistance while keeping the voltage the same at 2.5 V, then the current is decreased to  $I = \frac{2.5 \text{ V}}{2 \Omega} = 1.25 \text{ A}$ .

Recall that resistance is how difficult it is for electrons to travel around a circuit. So, if you increase resistance, the current must decrease.

**Ohm's law**  
the law that states there is a direct proportionality between the voltage applied across some conductors and the resultant electric current

## Quick check 4.6

- 1 Explain the relationship between current and voltage as stated in Ohm's law.
- 2 Using the formula  $V = IR$ , calculate the following.
  - a The resistance of a circuit where the voltage supplied is 6 V and the current is 2 A
  - b The current in a circuit where the resistance is 50  $\Omega$  and the voltage is 25 V
  - c The voltage in a circuit where the resistance is 100  $\Omega$  and the current in the circuit is 0.5 A
- 3 Explain how a variable resistor works and give an example of how it may be used in your home.

## Practical 4.1

## Investigating resistance

## Aim

To investigate how the length of a wire affects its resistance.

## Materials

- heat mat
- DC power supply (6 V)
- 6 connecting leads
- resistance wire such as constantan or nichrome
- alligator clips
- ammeter
- voltmeter
- metre ruler

## Planning

- 1 Write a paragraph about the factors that affect resistance.
- 2 Create a relevant and specific research question for this investigation.
- 3 Identify the independent, dependent and controlled variables for this investigation.

## Be careful

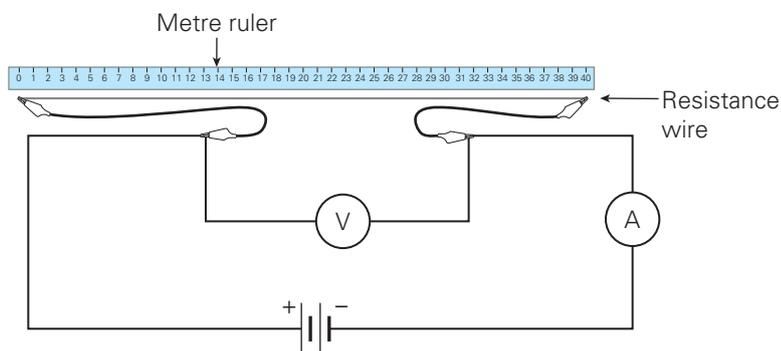
Electrical shocks may occur.  
Ensure the voltage output does not exceed 6 V. Power supply is to be turned off when changing the circuit.  
Resistance/nichrome wire gets very hot if the voltage is too high, or if the power supply is left on for too long.  
Ensure that no flammable materials are in contact with the wire.  
Use a heat mat to prevent scorching your bench.

*continued...*

...continued

### Procedure

- 1 Connect the circuit shown in the diagram. For ease, follow these instructions.
  - i Start on the positive side of the power supply.
  - ii Connect a lead from the positive socket to the positive side of the ammeter.
  - iii Connect a lead from the negative side of the ammeter to the alligator clip attached to the resistance wire at the zero end of the ruler.
  - iv Connect another lead from the other alligator clip to the negative side of the battery. This lead will be used to connect to the other side of the resistance wire and disconnect the power supply between taking readings.
  - v Connect a lead from the positive side of the voltmeter to the alligator clip that you connected to the ammeter.
  - vi Connect a lead from the negative side of the voltmeter to the other alligator clip attached to the disconnection lead.



- 2 Draw a suitable results table. Hint: you should have four columns.
- 3 Record the length of the wire between the alligator clips, and the readings on the ammeter and voltmeter in your results table.
- 4 Move the alligator clip attached to the disconnection lead to different points on the resistance wire, recording the ammeter and voltmeter readings at each length of wire. The voltmeter readings may not change.

### Results

Record your results in your results table.

### Discussion

- 1 Calculate and record the resistance for each length of wire using the Ohm's law equation.
- 2 Plot a graph of length of wire (metres) against resistance ( $\Omega$ ), including a straight line of best fit.
- 3 Identify any trends, patterns or relationships in your results.
- 4 Explain your results using your own scientific knowledge.
- 5 Your line of best fit may not go through the origin. Explain where the extra resistance came from.

### Conclusion

Draw a conclusion from this experiment regarding length of wire and resistance, using data to support your statement.

## Practical 4.2

### Current and resistance

#### Aim

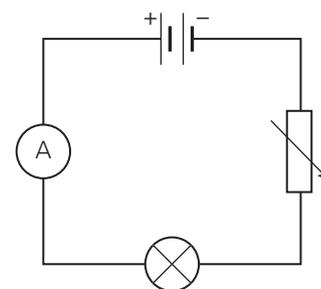
To investigate the relationship between current and resistance using a variable resistor.

#### Materials

- 6 V power supply
- 6 V light globe
- variable resistor
- 4 connecting wires and connectors
- ammeter

#### Procedure

- 1 Draw the results table below.
- 2 Set up the circuit as shown in the diagram at right 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.



#### Be careful

Electrical shocks may occur.  
Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

#### Results

Brightness of globe	Current (A)
Brightest	
Bright	
Dim	
Dimmest	

#### Discussion

- 1 Describe what happens to the current in the circuit as the resistance of the variable resistor increases.
- 2 Describe what happens to the brightness of the globe as the resistance is increased.
- 3 Predict what is happening to the voltage across the globe as it gets dimmer.

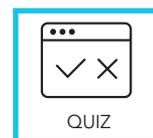
#### Conclusion

Draw a conclusion from this experiment regarding current and resistance.

## Section 4.2 questions

### Remembering

- 1 Draw the symbols for the following electrical components.
  - a Single cell
  - b Three batteries in a row
  - c Open switch
  - d Resistor
  - e Globe



- 2 **Define** the following terms in your own words and give an example of each.
  - a Conductor
  - b Insulator
  - c Resistor
  - d Variable resistor
- 3 **Recall** the device that measures current and the units that it is measured in.
- 4 **Recall** the device that measures voltage and the units that it is measured in.
- 5 **State** Ohm's law.

### Understanding

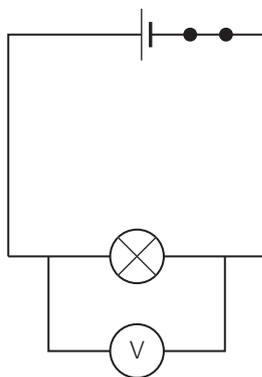
- 6 a **Explain** why an ammeter needs to be connected in line with the other components of a circuit (this is called being 'in series').
  - b **Explain** why a voltmeter needs to be connected across the component whose voltage you are measuring in a circuit (this is called being 'in parallel').
- 7 **Contrast** the terms 'voltage' and 'voltage drop'.
- 8 **Describe** how a variable resistor works.

### Applying

- 9 Both gold and copper conduct electricity. **Identify** which one of these two conducting metals would you most likely find in the following. **Propose** reasons why.
  - a In household wiring
  - b In critical electronic components
- 10 a For a certain electrical circuit, 20 coulomb of charge flows past a point in 5 seconds. **Define** the term 'current' in your own words and **calculate** the current in ampere.
  - b For a certain electrical circuit, there is 20 joules of electrical energy per coulomb of charge. **Define** the term 'voltage' in your own words and **calculate** the voltage of this circuit in volts.
- 11 Use your knowledge of thermistors and light-dependent resistors to **propose** a household appliance that uses them.

### Analysing

- 12 The circuit below was constructed by a student using a 6 V battery, a switch, a 6 V globe and a voltmeter.



- a **Identify** each of the electrical components on the diagram.
- b **Label** which side of the battery is positive on the diagram.

### Evaluating

- 13 Light dependent resistors are variable resistors that can be controlled by the amount of light that it is exposed to. **Propose** a household appliance that uses them.

## 4.3

## More circuits and their applications

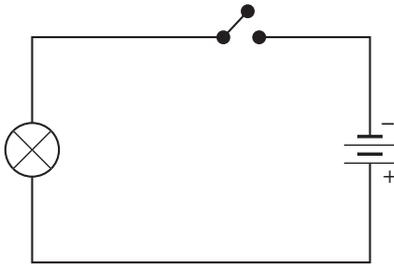
## Learning goals

- 1 To compare the characteristics and application of series and parallel circuits
- 2 To learn how to connect ammeters and voltmeters
- 3 To investigate the effect of adding globes in series and parallel
- 4 To discuss when and why a circuit would be set up in series or parallel

## Series circuits

A torch circuit where the batteries, the switch and the globe are all connected one after the other is an example of a **series circuit** (see Figure 4.17).

Series circuits are easy to make and connect. However, if any one part of the circuit fails, the circuit will not work because there will be a break in the path. In the example of the torch circuit, any one or more of a flat



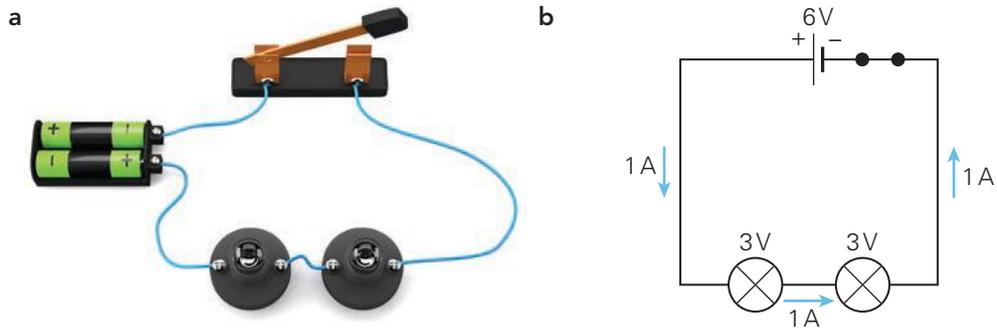
**Figure 4.17** A series circuit diagram of a torch contains the symbols for a power source, light globe and switch.

battery, a faulty switch or a faulty globe would cause the circuit to stop working. Troubleshooting a faulty torch circuit would require systematically looking at each of these three components in turn. Would you use a series circuit for car headlights? Consider what would happen if one headlight globe burned out – both headlights would stop working. This would be extremely dangerous if you were travelling at 80 kilometres per hour around a corner on a country road on a dark night.

In a series circuit the current is the same throughout the circuit, and therefore the voltage, or energy, is shared among the load. For example, in Figure 4.18, if the light globes are identical, the voltage across each is half that of the power source.



**series circuit**  
a circuit in which the batteries and other components are all connected one after the other



**Figure 4.18** (a) Car headlight circuit modelled as a series circuit. (b) Matching circuit diagram with a 6 V power source and identical globes.

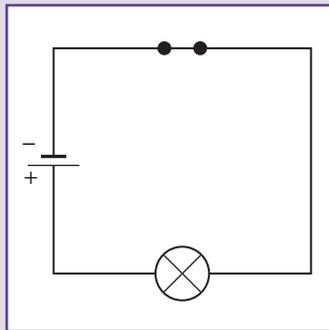
## Try this 4.4

## Series circuits

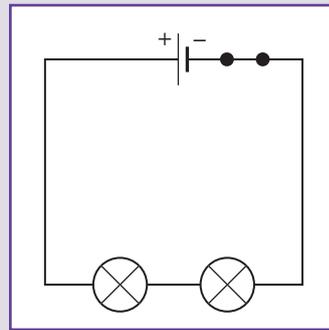
Two circuits have been set up for you by your teacher.

Circuit 1 is shown below. Note the brightness of the globe.

Now look at circuit 2 where the two globes are connected in series.



Circuit 1 – Single globe



Circuit 2 – Two globes in series

- 1 Do the globes in circuit 2 glow as brightly as the globe in circuit 1? Explain why or why not.
- 2 Predict what will happen if you disconnect the lead between the two globes in circuit 2.
- 3 Turn off the power. Disconnect the lead and turn the power on again. Note what happens. Explain what you observe.
- 4 What happens if you add another globe in series? Explain what you observe.

## Parallel circuits

An alternative car headlight circuit could be constructed using the same components as you used previously, but in a way that will prevent both lights from turning off if one blows. In this instance, you will model the

**parallel circuit**  
a circuit in which each component is connected in a separate conducting path

headlight circuit using a **parallel circuit**, as shown in Figure 4.19.

In a parallel circuit, the current is split at each branching point. For example, if the light globes in Figure 4.19 are identical, the current in each branch is half that of

the current from the main wire coming from the power source. The voltage across each component is the same.

Now, if one headlight fails, the other one will still work as there is a clear connecting path between the battery and the other headlight when the switch is on.

In a parallel circuit each component is connected in a separate conducting path. This means that if one load component of the circuit is faulty, the other load components will still work.

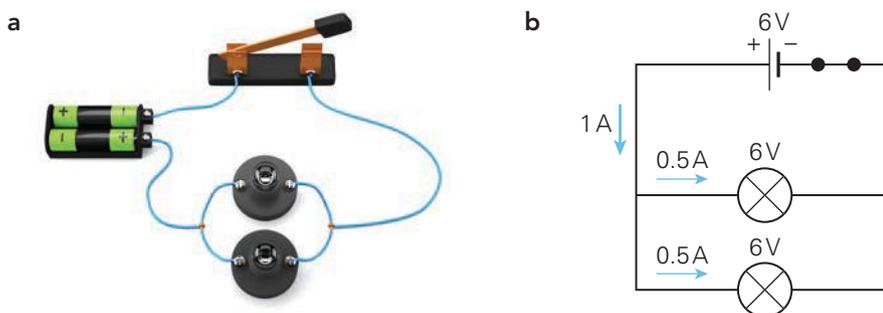


Figure 4.19 (a) Car headlight circuit modelled as a parallel circuit (b) Matching circuit diagram with the blue arrows indicating current split

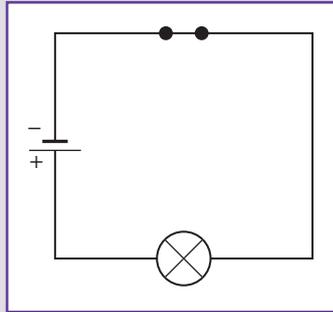
Try this 4.5

**Parallel circuits**

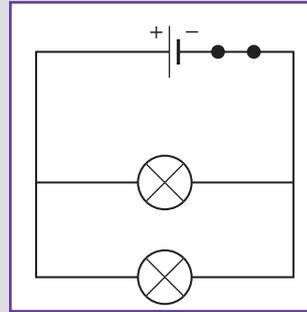
Two circuits have been set up for you by your teacher.

Circuit 1 is shown below. Note the brightness of the globe.

Then look at circuit 2 where the two globes are connected in parallel.



Circuit 1 – Single globe

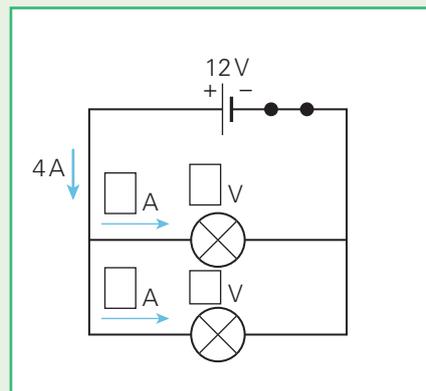
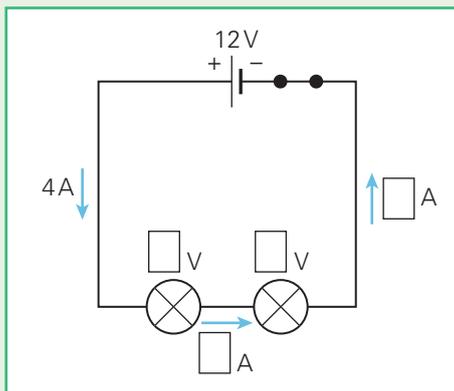


Circuit 2 – Two globes in parallel

- 1 Are the globes in circuit 2 glowing as brightly as the globes in circuit 1? Explain what you observe.
- 2 Predict what will happen if you disconnect the bottom globe in circuit 2.
- 3 Turn the power off. Disconnect the lead and turn the power on again. What happens to the brightness of the other globe? Explain what you observe.
- 4 What happens if you add another globe in parallel? Explain what you observe.
- 5 What happens if you add another globe in series with the bottom globe? Explain what you observe.

Quick check 4.7

- 1 Describe the differences between a series and a parallel circuit.
- 2 Explain why you would not wire your house in series configuration.
- 3 How does the brightness of globes compare in series and parallel circuits?
- 4 Assuming that each light globe is identical, copy and complete the values in the following diagrams.



## Practical 4.3

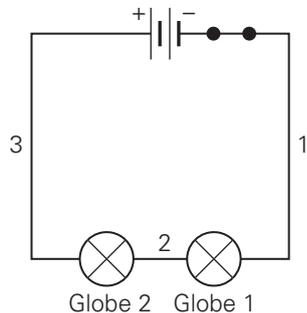
## Series and parallel circuits

## Aim

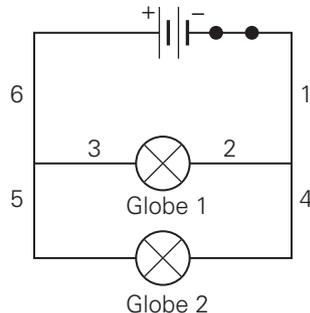
To observe and compare the values of current and voltage in series and parallel circuits.

## Materials

- DC power supply (6 V)
- 2 × 6 V light globes and 2 × 6 V globe holders
- connecting leads (alligator clips)
- ammeter
- voltmeter



Circuit 1 – Two globes in series



Circuit 2 – Two globes in parallel

**Be careful**

Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

## Procedure

Draw the results tables below.

**Series**

- 1 Set up circuit 1 so that the two globes are connected in series.
- 2 Measure the current at the three numbered positions. Then measure the voltage across the power pack, across globe 1 and across globe 2. Record the readings in your results tables.

**Parallel**

- 1 Set up circuit 2 so that the two globes are connected in parallel.
- 2 Measure and record the current at the six numbered positions. Then measure the voltage across each globe and the power source. Record the readings in your results tables.

## Results

**Current**

Series circuit	
Position	Current (A)
1	
2	
3	
Parallel circuit	
Position	Current (A)
1	
2	
3	
4	
5	
6	

*continued...*

...continued

**Voltage**

Series circuit	
Component	Voltage (V)
Power source	
Globe 1	
Globe 2	
Parallel circuit	
Component	Voltage (V)
Power source	
Globe 1	
Globe 2	

**Discussion**

- 1 Explain your observations regarding the current values in the series circuit.
- 2 Explain your observations regarding the current values in the parallel circuit.
- 3 Explain your observations regarding the voltage values in the series circuit.
- 4 Explain your observations regarding the voltage values in the parallel circuit.

## Household electricity

In your household, all your electrical appliances and lights transform the electrical energy into other forms of energy as the electrons flow through the different components. In Australia, electricity is usually supplied to homes at a voltage of 230 V and is referred to as the **mains electricity**.

Power points (sockets) in the home have three slots: active, neutral and earth. When you plug in an electrical device and switch the power on, current flows between slots at the top through the appliance (between the active and the neutral via the appliance). In appliances that are **earthed**, there is a third slot which is the earth slot. It is normally connected to a metal pipe in the ground; that is, directly connected locally to the earth.

## Safety

### Earthing

Earthing certain appliances is essential. For example, if your toaster has a metal casing, and there is a fault in the appliance, the metal casing might accidentally become 'live'. By earthing your toaster, the bottom earth pin fits into the earth socket, and thus the electric current will



**Figure 4.20** An Australian power point has three slots: active, neutral and earth.

flow via the earth pin to the ground. This prevents the current going through the body of a person who might be touching the metal case of the toaster.

**mains electricity**

the electricity that is supplied to homes

**earthed**

having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

### Electrical hazards

The mains electricity supply in Australia presents a potential hazard to life. Even a relatively small current passing through the human body can be deadly.

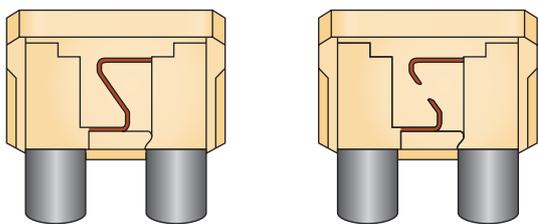
Anyone using electricity should be aware of the dangers associated with using it. All electrical work should be carried out only by qualified electricians. One of the main causes of **electrocution** in the home is the use of damaged cords and plugs. Frayed cords and plugs can expose the active, neutral and earth wires inside. As Table 4.2 shows, the human body is very sensitive to relatively small currents. You can feel one thousandth of an amp (1 mA), and a current of only 20 mA involuntarily contracts your muscles – you cannot let go of the wire! If someone grabs you to save you, they will most likely paralyse their muscles as well, placing two people at risk of electrocution.

Current (mA)	Effect on the human body
1	Can be felt
10	Causes pain
20	Paralysed muscles – very difficult to let go
50	Severe shock
90	Breathing is affected
150	Breathing is very difficult
200	Death is likely
500	Serious burning, breathing stops, death inevitable

**Table 4.2** The size of the current determines the effect it has on the human body.

### Fuses and circuit breakers

A **fuse** is a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit. Many fuses used in cars are designed this way. Look at Figure 4.21 – notice the fuse on the right no longer provides an electrical connection.



**Figure 4.21** The wire inside a fuse will break if the current passing through it gets too high.

Most modern houses have replaced fuses with circuit breakers. A **circuit breaker** (see Figure 4.22) carries out the same function as a fuse by breaking the circuit when the current exceeds some safety limit, such as 20 A.

Safety switches (also known as residual current devices, RCDs) are different to circuit breakers. RCDs detect when current ‘leaks’ from circuits, possibly into a person. When 30 mA leaks from a circuit, these devices trip the power, preventing an electric shock.

**electrocution**  
electric current passing through the body

**fuse**  
a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

**circuit breaker**  
carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

**short circuit**  
when the current is allowed to flow from one conductor to another with little or no resistance



**Figure 4.22** Circuit breakers protect electrical systems in the house and safety switches protect people against electric shock.

### Short circuit

A **short circuit** can occur when frayed electrical cords or faulty electrical appliances allow the current to flow from one conductor to another (for example, from active to neutral or from active to earth) with little or no resistance. The current increases rapidly, causing the wires to get hot and possibly cause a fire.

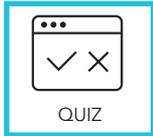


**Figure 4.23** A short circuit can cause a fire.

## Quick check 4.8

- 1 Recall the voltage of mains electricity in Australia.
- 2 State the purpose of the third socket of a power plug.

## Section 4.3 questions



## Remembering

- 1 Using the labels switch, earth, active and neutral, redraw and then correctly **label** the electrical power point shown at right. Is the switch OFF or ON? **Explain** how you can tell.



- 2 **Describe** the differences between series and parallel circuits.

## Understanding

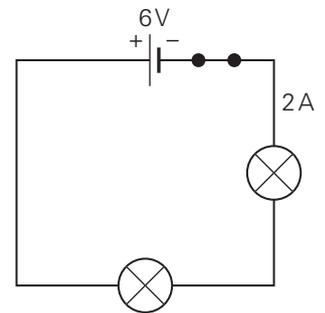
- 3 **a Describe** the main disadvantage of a series circuit.
- b Describe** two advantages of a parallel circuit.
- 4 **Explain** why some electrical appliances are earthed.
- 5 **Describe** how electrical faults can cause house fires.

## Applying

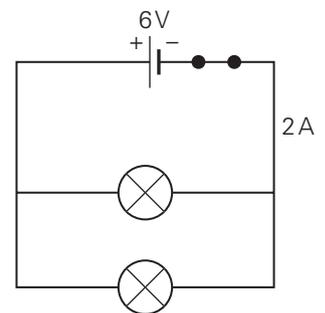
- 6 **Draw** a diagram to show how four 1.5 V batteries can be connected in parallel. What is the total voltage provided by this battery circuit? **Label** the positive and negative terminals of each battery.
- 7 **a Explain** what happens to your muscles when you experience a current of 20 mA from a live wire from the mains electricity. **Draw** a simple diagram modelling this scenario and label the components.
- b Explain** reasons why you should not grab a person who is being electrocuted by a current of 20 mA.
- 8 **Explain** the function of an RCI circuit breaker in an electrical circuit.

## Analysing

- 9 A student constructs circuit 1 as shown, using a 6 V battery and two identical globes, and measures the current through the circuit as 2 A.
  - Identify** whether this a series or parallel circuit. **Justify** your answer.
  - Determine** the voltage drop across each globe.
  - Calculate** the resistance of one globe.
- 10 A student constructs circuit 2 as shown below. The circuit contains a 6 V battery and two identical globes of higher resistance than in question 9.
  - Identify** whether this a series or parallel circuit. **Justify** your answer.
  - Determine** the voltage drop across each globe.
  - Calculate** the resistance of one globe.

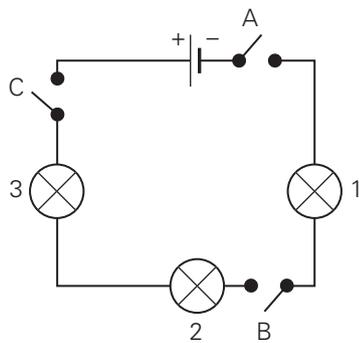


Circuit 1



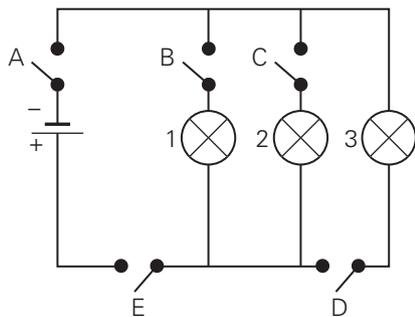
Circuit 2

11 a Copy and **complete** the following table regarding the circuit shown below.



Switches turned on	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
A			
B and C			
A, B and C			

b Copy and **complete** the following table regarding the circuit shown below.

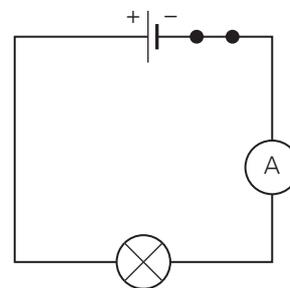


Switches turned on	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
A, B, C and D			
A, B and E			
A, C, D and E			
A, B, D and E			

12 The following circuit has been constructed using a 6 V battery, a switch, a 6 V light globe with a resistance of 5 Ω and an ammeter.

Copy the following table, **indicating** the current flowing through the circuit when the switch is open and closed for different positions of the ammeter.

Position of the ammeter	Switch open current	Switch closed current
Between power source and switch		
Between switch and globe		
Between globe and power		



**Evaluating**

13 **Propose** reasons why household electrical wires are coated in plastic.

14 **Evaluate** why household circuits supplying your lights, television, computers, washing machines and suchlike, are wired in parallel, while the fuses (and circuit breakers) to these circuits are wired in series with the circuits.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>4.1 I can describe electricity as either the accumulation of charge or the flow of charge.</b> e.g. Define the term 'electricity' in your own words.	
<b>4.2 I can construct circuit diagrams.</b> e.g. Construct a circuit diagram that shows a power supply, two lamps, an ammeter and a voltmeter.	
<b>4.2 I can define voltage.</b> e.g. Describe how voltage can be measured.	
<b>4.2 I can define current.</b> e.g. Describe how current can be measured.	
<b>4.2 I can calculate the resistance of a circuit using the Ohm's law equation.</b> e.g. Calculate the resistance of a circuit that has a voltage of 20 V and a current of 15 A.	
<b>4.3 I can distinguish between series and parallel circuits.</b> e.g. Recall what you would observe happening to the current in a parallel circuit.	
<b>4.3 I can describe the safety aspects of household electricity.</b> e.g. Discuss the safety aspects of electrical equipment used in the home.	



## Reflections

- 1 What **connections** come to mind when you think about electricity and your everyday life?
- 2 What new concepts have **extended** your thinking about electricity?
- 3 What information did you find **challenging** or confusing?



### Data questions

A group of students is testing the advertising claims of 10 different AA battery brands. A fresh AA battery is claimed to provide at least 1.50 V. The initial voltage for three new batteries for each brand was recorded by preparing a circuit with a multimeter, and the data is presented in Table 4.3.

Battery brand	Initial voltage of first battery (V)	Initial voltage of second battery (V)	Initial voltage of 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 4.3** Recorded voltage for three new AA batteries of different brands

- Identify** the battery with the highest initial voltage.
- 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.
- For the first battery tested of each brand, remove any flat batteries as outliers and **calculate** the mean initial AA battery voltage.
- With respect to the initial voltage claim of at least 1.5 V, **identify** any patterns that appear in the observed initial voltages.
- 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.
- 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).
- Battery brand 9 also claims to have the 'longest lasting AA battery'. **Justify** whether the data in Table 4.3 supports this claim.
- 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 4.3.
- Based on the data presented in Table 4.3, **predict** whether a fourth battery of brand 3 is likely to meet the claim of an initial voltage of 1.5 V. Consider the sample size when thinking about this question.

## STEM activity: Can you see the renewables?

### Background information

Your local council has just informed its residents that they wish to invest some capital to secure the energy needs for its residents for the next 20 years. One local company, Coal Co., has lobbied heavily for funds to expand an old open-cut coal mine in the region. On the other hand, a new start-up business, Argus Renewables, has hired your team to create a 60-second video to gain support from residents for the development of a large solar farm in the region.

**Design brief:** Design and create a 60-second infomercial promoting the use of renewable energy to be shared in your local area.

### Activity instructions

In teams (maximum of 4 people), you will use the digital storytelling process (described below) to create a short 60-second video to answer a specific scenario. It is recommended that you and your colleagues think about assigning roles and tasks for this project (for example, videographer, researcher, movie editor) so everyone has the chance to develop and use different skills.

### Suggested materials

- mobile device, camera to record footage
- laptop or tablet with a video editor
- paper to create a storyboard
- your imagination!

### Research and feasibility

- 1 Discuss within your group who your target group is going to be. Include thinking about your local area.
- 2 Research advantages of renewable energy over non-renewable energy that should be communicated to your audience through the infomercial, and make a table to rank them in order of importance for your project.

	Rank of importance	Comments when considering target audience

- 3 Research the population of your local area. Discuss and then list important information about your target audience. Considering this information about your target audience, add comments to your advantages and disadvantages research.

### Design and sustainability

- 4 As a group, decide the key issues you are going to present in your infomercial. Then write the script for the video, assign roles to individual members and reflect on what is required to achieve the goal.
- 5 Design a storyboard to put the script together with a visual representation.

### Create

- 6 Create the video by recording the storyboard sections. As a group, gather short clips and images, and/or record your own video using a mobile device.
- 7 Put it all together using video-editing tools such as iMovie, Windows Movie Maker or Adobe Spark (recommended) to put your ideas into video format.

### Evaluate and modify

- 8 Discuss with your group members the challenges you encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.
- 9 Evaluate the effectiveness of your infomercial by sharing with your target audience.
- 10 Create a range of evaluative questions to use to gauge the success of your infomercial. After showing your infomercial to a target audience, use the questions to test its effectiveness.

# Chapter 5

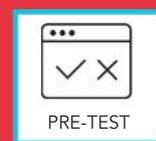
## Conservation of energy

### Inquiry questions

Why are energy transfers not 100% efficient?

What happens to wasted energy?

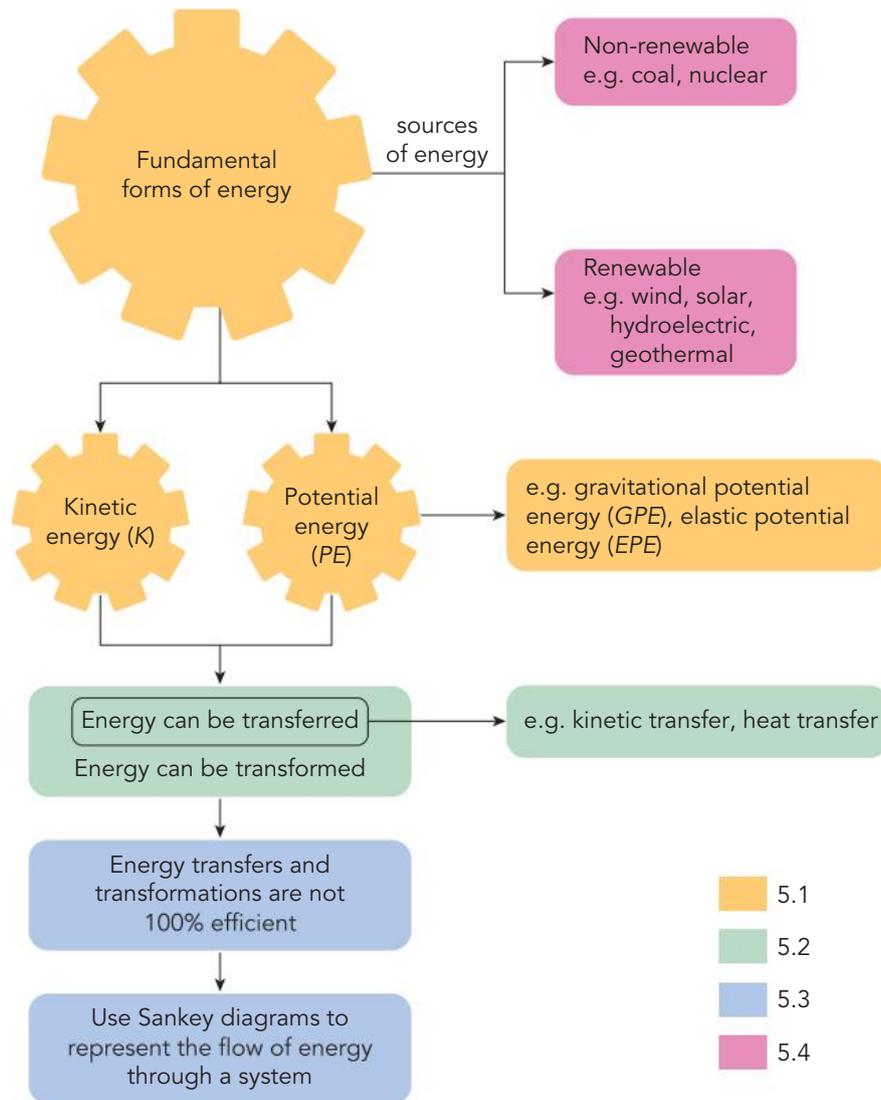
Why is it crucial to find alternate energy sources to fossil fuels?



### Chapter introduction

Energy is all around us – radiating from the Sun, transporting us to where we need to go, powering our many devices, and even stored in the food we eat. Much of our use of energy results in a loss of useful energy; thus, there is increasing pressure to be less wasteful and more efficient in our use of energy. This chapter will expand your knowledge on energy and its different forms. We will look at energy transfers and transformations as well as energy efficiency by applying the law of conservation of energy.

# Chapter map



# 5.1 Forms of energy

## Learning goals

- 1 To recall different types and forms of energy
- 2 To describe everyday situations which involve energy changes or transfers



**Energy** is the ability to do work or make things happen. It can't be created or destroyed; that is, the amount of energy in our universe is always the same.



However, energy can change form, be transferred from one object to another, or it can be stored for later use. For all the different types of energy, the unit of measurement is the **joule** (J).

### energy

the capacity to do work; the total amount of energy is conserved in any process

### joule

the unit of energy or work done

### kinetic energy

energy possessed by an object due to its motion

There are several different forms of energy; however, the two fundamental types of energy are kinetic energy and potential energy.

## Kinetic energy

When a force is applied to an object that then causes that object to move, work is being done – energy is being transferred. The energy transferred is known as **kinetic energy** ( $K$ ) and is the energy an object has due to its motion. The amount of kinetic energy that an object has depends on its mass and its speed, where the faster an object moves the more kinetic energy it has.

To calculate how much kinetic energy an object has, we use the following equation:

$$K = \frac{1}{2} mv^2$$

Here,  $K$  is kinetic energy, measured in joules (J);  $m$  is the mass of the object in motion, measured in kilograms (kg); and  $v$  is the speed at which the object is moving, measured in metres per second (m/s or  $\text{ms}^{-1}$ ).

## Worked example 5.1

### Kinetic energy

A motorcycle has a mass of 120 kg and is travelling at 150 km/h. How much kinetic energy does the motorcycle have?



Figure 5.1 A motorcycle in motion possesses kinetic energy.

*continued...*

...continued

Working	Explanation
$m = 120 \text{ kg}, v = 150 \text{ km/h}$	List the relevant data that has been provided.
$150 \text{ km/h} \div 3.6$ $v = 41.67 \text{ m/s}$	Convert units to the SI base units (Standard International units) used in the equation. (Note that in this conversion the calculation has been rounded to 4 significant figures.)
$K = \frac{1}{2}mv^2$	Recall the definition of kinetic energy and the equation.
$K = \frac{1}{2} \times (120 \text{ kg}) \times (41.67 \text{ m/s})^2$	Substitute the relevant data into the equation.
$K = 104\,183.33 \text{ J}$ $= 104.2 \text{ kJ}$	Solve the problem, giving an answer with appropriate units. (Note that if the conversion to m/s is done as part of the substitution, the calculation will give 104 166.67 J. Rounding it to 4 significant figures gives 104.2 kJ.)

### Quick check 5.1

- 1 Identify two factors that affect the amount of kinetic energy an object has and the effect they have.
- 2 A cricket player bowls a 160 g cricket ball at a speed of 150 km/h. Calculate how much kinetic energy is transferred to the ball.

## Potential energy

**Potential energy** (*PE*) is energy that is stored in an object or person due to its composition or position.

### Gravitational potential energy

**Gravitational potential energy** is the energy stored in an object due to its position above the surface of Earth.

**potential energy**  
energy that is stored in an object due to its position and other factors, such as its mass, electric charge and internal stresses

**gravitational potential energy**  
energy stored in an object due to its position above the surface of Earth

Anything that is positioned above the surface of Earth has the potential to fall due to the effect of gravity. Therefore, the higher an object is above the surface of Earth, the more gravitational potential energy it has.

To calculate how much gravitational potential energy an object has, we use the following equation:

$$GPE = mgh$$

where *GPE* is the gravitational potential energy (also may be represented as  $E_p$ ,  $\Delta U$  or  $U_g$ ), measured in joules (J); *m* is the mass of the object, measured in kilograms (kg); *g* is the gravitational acceleration experienced by the object due to the strength of the Earth's gravitational field ( $9.8 \text{ m/s}^2$  or  $\text{ms}^{-2}$ ); and *h* is the height of the object above the surface of Earth, measured in metres (m).



**Figure 5.2** As you ride on a rollercoaster the amount of gravitational potential energy that you have is constantly changing, as is your kinetic energy.

## Worked example 5.2

**Gravitational potential energy**

A diver on the diving board has a mass of 60 kg.

- 1 If the diving board is 10 m above the ground, what is the diver's gravitational potential energy?
- 2 When the diver is 0 m above the ground, what is his gravitational potential energy?
- 3 What does this mean in terms of work done  $W = \Delta GPE$  if the diver wants to go from 0 m back to the diving board 10 m above the ground?



**Figure 5.3** A diver waiting to dive has gravitational potential energy due to his position relative to Earth's surface.

Working	Explanation
<b>a</b> $m = 60 \text{ kg}$ , $h = 10 \text{ m}$ , $g = 9.8 \text{ m/s}^2$ $GPE = mgh$	<b>1</b> List the relevant data that has been provided. Recall the definition of gravitational potential energy and the equation.
$GPE = 60 \text{ kg} \times 9.8 \text{ m/s}^2 \times 10 \text{ m}$	Substitute the relevant data into the equation.
$GPE = 5880 \text{ J}$ $= 5.88 \text{ kJ}$	Solve the problem, giving an answer with appropriate units.
<b>b</b> GPE at ground level = ? GPE at ground level = 0 J	<b>2</b> At $h = 0 \text{ m}$ , the gravitational potential energy is 0 J.
<b>c</b> Work done to climb back up to the board = ? Work done to climb back up to the board = 5.88 kJ	<b>3</b> This means that if he wants to climb back up from the ground to a height of 10 m, there will have to be work done of 5.88 kJ as that is the difference in gravitational potential energy, $\Delta GPE$ .

**Elastic potential energy**

**Elastic potential energy** (*EPE*) is the energy stored in an object due to its shape, and it usually results from the object

either being compressed or stretched. When stretched or compressed, some materials store more energy than others.

**elastic potential energy**  
energy stored in an object due to its shape, usually resulting from the object either being compressed or stretched

To calculate the amount of elastic potential energy an object has, we use this formula:

$$EPE = \frac{1}{2} kx^2$$

where *EPE* is the elastic potential energy (also may be represented as  $E_e$ ), measured in joules (J); *k* is the elasticity constant, which is an indication of the object's stiffness; and *x* is the linear length that it has been expanded or compressed relative to its equilibrium position, measured in metres (m).

## Worked example 5.3

**Elastic potential energy**

A bow has an elasticity constant of 2000 N/m. It is stretched by 30 cm. How much elastic potential energy does the bow store?

Working	Explanation
$k = 2000 \text{ N/m}$ , $x = 0.30 \text{ m}$	List the relevant data that has been provided.
$EPE = \frac{1}{2}kx^2$	Recall the definition of elastic potential energy and the equation.
$EPE = \frac{1}{2} \times (2000 \text{ N/m}) \times (0.30 \text{ m})^2$	Substitute the relevant data into the equation.
$EPE = 90 \text{ J}$	Solve the problem, giving an answer with appropriate units.



**Figure 5.4** A stretched bow stores elastic potential energy.

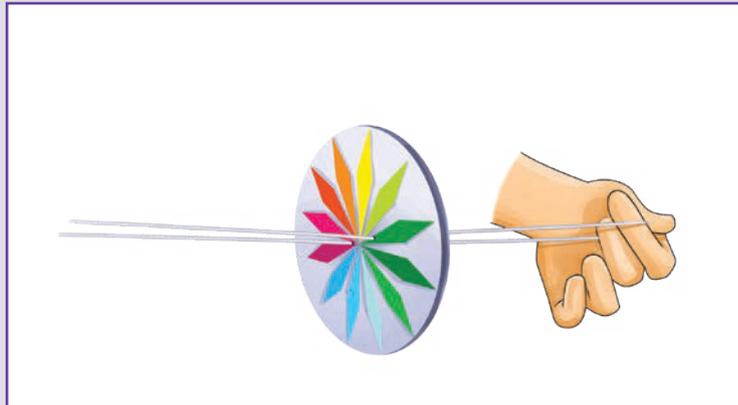
Form of energy	Description
Thermal energy	The energy in an object due to the random motion of its particles
Wave energy	The energy carried by a wave
Sound energy	The energy carried by a sound wave
Light energy	The energy carried by light waves (electromagnetic energy)
Kinetic energy	The energy possessed by an object due to its motion
Gravitational potential energy (GPE)	Energy stored when an object is lifted off the ground; energy released when the object falls
Electrical (potential) energy	Energy stored in electrostatic situations (e.g. thunderclouds, capacitors); energy released when current flows (includes sparks like lightning)
Chemical potential energy	Energy stored in chemicals such as fuel and in batteries (when connected to an electric circuit, the chemical energy is converted to electrical energy)
Elastic potential energy ( <i>EPE</i> )	Energy stored when an object is stretched or compressed; energy released when an object returns to original size and shape
Nuclear energy	Energy stored in unstable (radioactive) atoms; energy released when atoms decay or undergo fission or fusion in unstable (radioactive) atoms

**Table 5.1** A summary of various forms of energy

### Try this 5.1

Recreate this 'fidget spinner' in four simple steps.

- 1 Find a button with a diameter of at least 5 cm (a piece of cardboard with two small holes about 1 cm apart will do too).
- 2 Thread about 60–80 cm of string through two of the holes in the button and tie it off, forming a loop like the one shown in Figure 5.5.

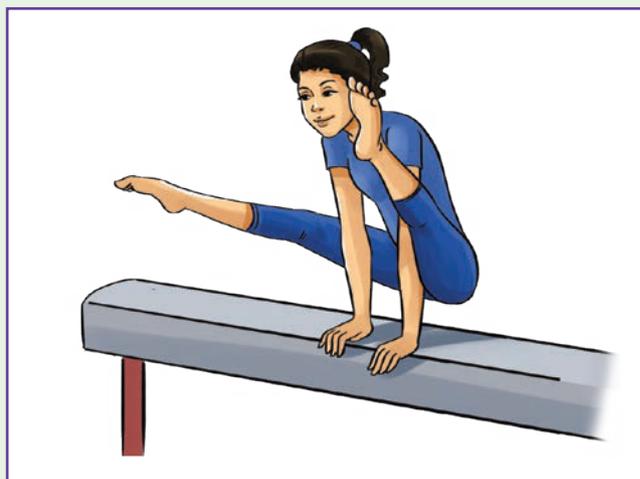


**Figure 5.5** A paper spinner or 'woer woer' is a toy that uses elastic potential energy to create motion and sound.

- 3 Wind up your spinner by holding onto the strings and positioning the button in the middle. Then, using your wrists, swing the button in a vertical loop.
- 4 Release the potential energy with alternating high and low tensions in the string (created by moving your hands closer and pulling them further away from each other).

### Quick check 5.2

- 1 Describe what the word 'potential' in potential energy means.
- 2 Other than gravitational and elastic, state two other forms of potential energy and give an example of each.
- 3 A gymnast on a balance beam has a weight of 500 N. If the beam is 1.25 m above the ground, calculate her gravitational potential energy.



**Figure 5.6** What is the gravitational potential energy of a gymnast?

## Practical 5.1

### Jumping paper frogs

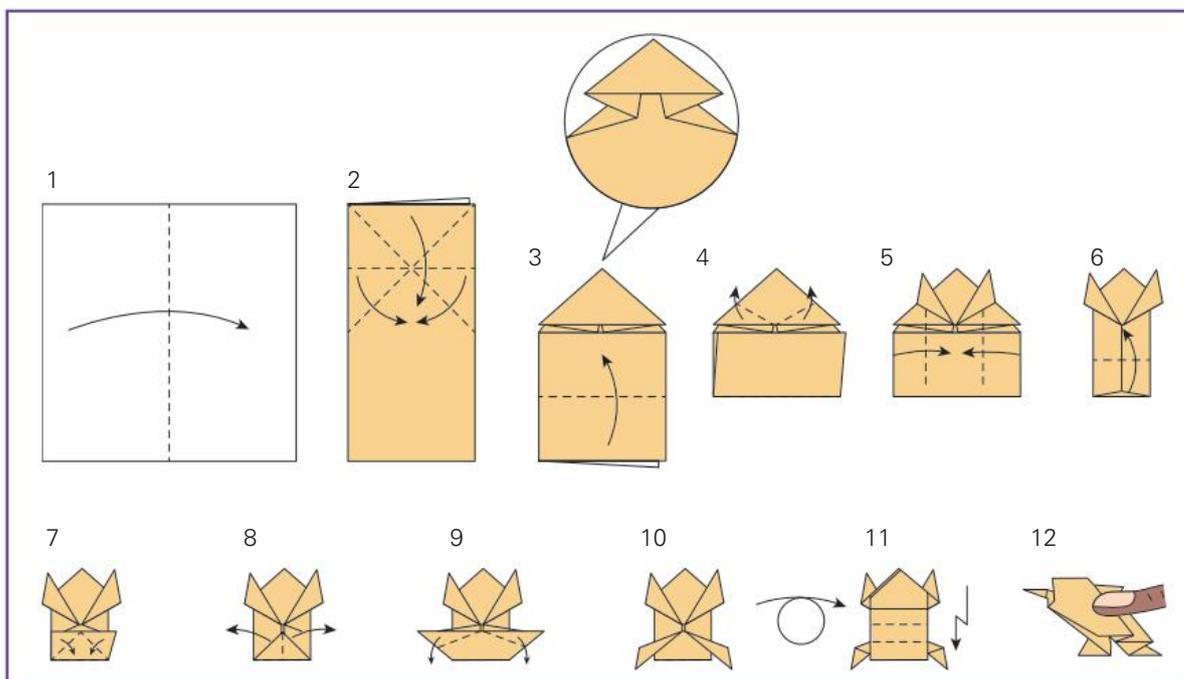
Create an origami frog to demonstrate the conversion of elastic potential energy to kinetic energy and gravitational potential energy.

#### Materials

- origami paper
- ruler

#### Procedure

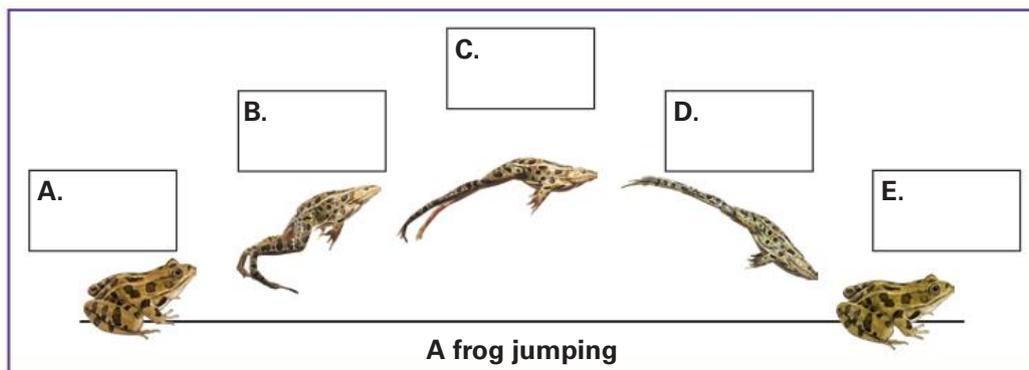
- 1 Use the following steps to create your own jumping frog.



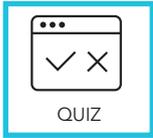
- 2 Press down on your frog to make it jump and record both the height and distance it jumped.
- 3 Explore ways to change the amount of energy your frog has so it can jump different heights and/or distances.

#### Discussion

- 1 Where does the energy that enables your frog to move come from?
- 2 Complete the illustration below by indicating the form of energy (kinetic, gravitational potential or elastic potential) possessed by the frog at different stages of its jump.



## Section 5.1 questions



## Remembering

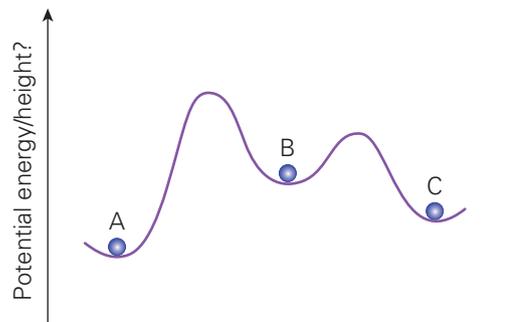
- 1 **Define** the term 'energy' in your own words.
- 2 **Describe** what kinetic energy is.
- 3 **List** three everyday objects that have elastic potential energy.

## Understanding

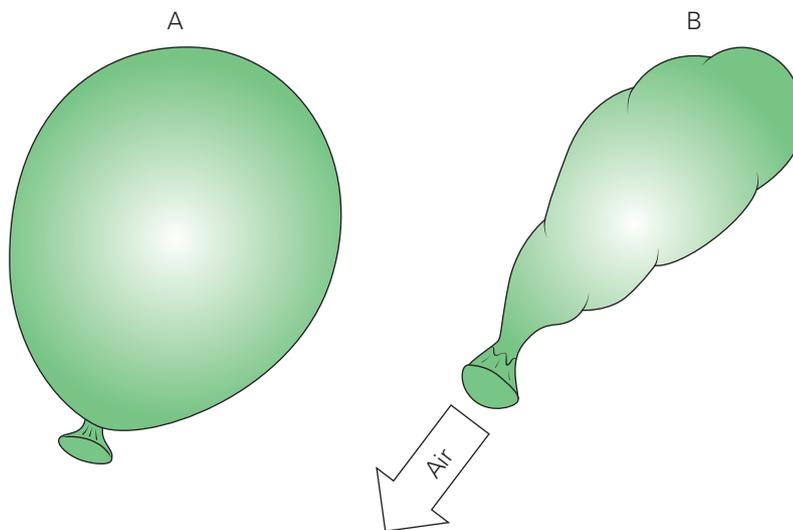
- 4 **Classify** the following as either possessing kinetic energy or potential energy:
  - a the moving (or spinning) blades in a blender
  - b books sitting in a bookshelf
  - c hot water in a kettle
  - d the sound coming from a radio
  - e a cheeseburger.
- 5 **Compare** gravitational and elastic potential energy.

## Applying

- 6 Look at the diagram below which illustrates the change in gravitational potential energy (*GPE*) as it changes position and use it to answer the following questions.

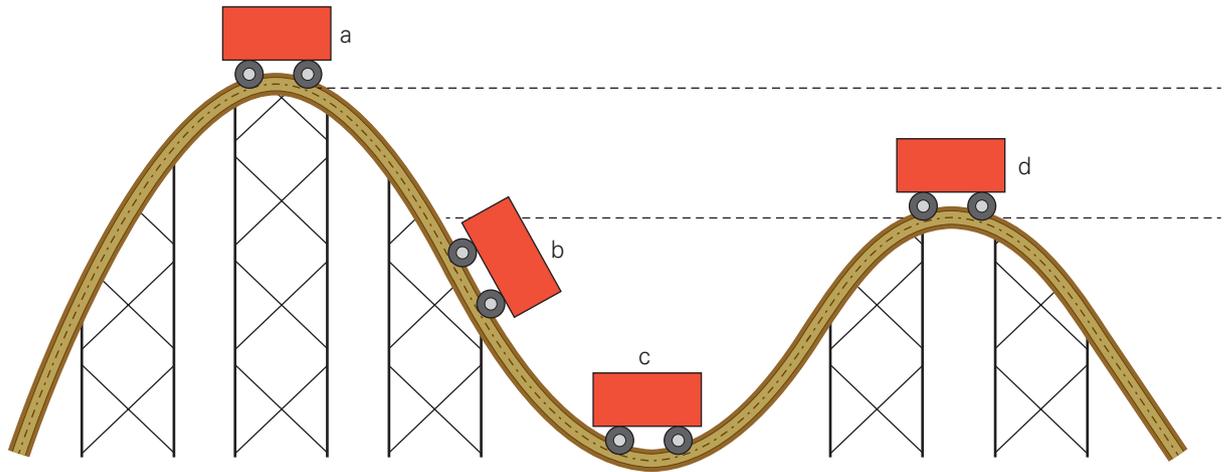


- a **Identify** which letter represents the position where the ball has the most gravitational potential energy.
  - b If the ball moved from C to A, **determine** if there would be an overall gain or loss of gravitational potential energy.
- 7 **Explain** which balloon in the image below, has the most elastic potential energy.



**Analysing**

8 **Outline** the energy changes in the roller coaster below at points a, b, c and d.



9 **Arrange** the following items from having the most to the least amount of gravitational potential energy:

- a an apple hanging in a tall tree
- b an apple lying under a tree
- c an apple in a fruit bowl on a table.

**Evaluating**

10 **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, **state** the form of energy used as the input (that operates them) and the forms of energy that they output (include the 'useful' output as well as the outputs that represent wasted energy).



## 5.2 Energy transfers and transformations

### Learning goals

- 1 To recall that energy can be transferred from one object to another or transformed into other types
- 2 To describe everyday situations which involve energy transfers or transformations
- 3 To use flow diagrams to outline energy transformations in everyday situations



Energy is constantly changing from one form to another. For example, the characteristic lights and sounds produced by fireworks are the result of such energy transformations. When a firework explodes, thermal energy, in the form of a lit fuse, in addition to chemical potential energy, is transformed into heat, light and sound energy, as well as kinetic and gravitational potential energy.

Not all energy transformations are this complex. A toaster, for example, transforms electrical energy to thermal energy which toasts the bread by radiation. Regardless of how simple or complex the transformations are, energy is conserved in all energy conversions. This is to say, all conversions abide by

#### law of conservation of energy

the law that explains how the total amount of energy in an isolated system is constant

#### energy transfer

the movement of energy from one place or object to another

the **law of conservation of energy** in that energy is neither created nor destroyed, and so the total amount of energy in an isolated system remains constant.

Figure 5.7 Fireworks are the result of many energy transformations.



### Explore! 5.1

#### Nanotechnology improving energy transfer efficiencies

Nanotechnology is a combination of science and engineering that manipulates and uses individual atoms and molecules as its building blocks and moving parts. Nano refers to the nanoscale, about 1 to 100 nanometres, or 1 to 100 billionths of a metre. Research how new technologies in this area are helping to improve the efficiency of producing and transferring energy. For example:

- 1 high efficiency light bulbs
- 2 stronger and lighter windmill blades
- 3 generating electricity from waste heat or friction
- 4 cheaper solar cells.

### Energy transfer

#### Kinetic transfer

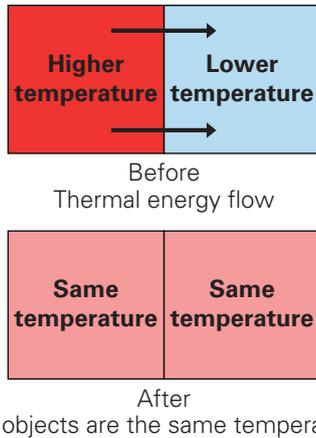
**Energy transfer** is the movement of energy from one place or object to another. For example, a golf club has kinetic energy when it swings through the air. When the club hits a golf ball, this kinetic energy is transferred to the ball, making it move.



Figure 5.8 When a golfer hits a golf ball, they transfer kinetic energy from the golf club to the ball.

### Heat transfer

Thermal energy is another type of energy that can be transferred. If an object of high temperature is placed next to an object of lower temperature, thermal energy will flow from the object of higher to that of lower temperature. This will continue until the objects are the same temperature. This flow of energy is always from high to low temperature, never the other way around.



**Figure 5.9** 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

As opposed to energy transfers, where the type or form of energy stays the same and moves from one object to another, **energy transformations** occur when energy is converted from one form to another. Combustion involves burning, and converts chemical energy into thermal energy and light. Machines use fuel or electrical energy and convert it into kinetic energy. **Generators**, powered by steam **turbines**, can convert kinetic energy into electrical energy. In leaves, the biological processes in photosynthesis convert light energy from the Sun into

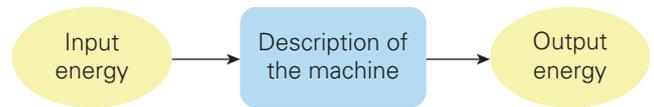
chemical energy in the form of carbohydrates, such as sugars. Thermal energy is often produced as a by-product of energy transfers.

**energy transformation**  
the change in type or form of energy

**generator**  
a rotary mechanical device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

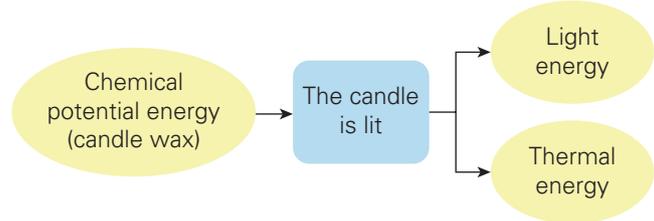
**turbine**  
a device that converts the kinetic energy of a moving substance into useful work, for example a windmill

Energy transformations can be represented in a flow diagram (see Figure 5.10). On the left-hand side of the flow diagram are the energy inputs, and the energy outputs are on the right. 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.



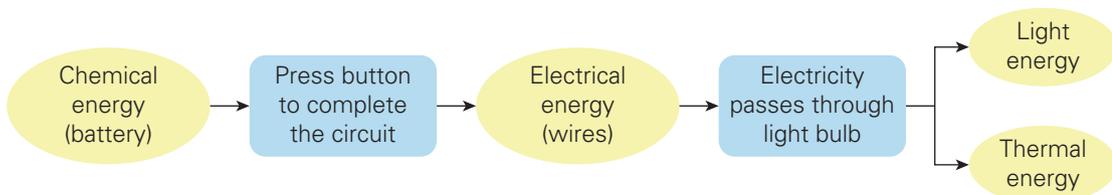
**Figure 5.10** A simple energy flow diagram

For example, Figure 5.11 shows the energy flow diagram for a candle that has been lit.



**Figure 5.11** 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 5.12).



**Figure 5.12** 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 5.13 An electric kettle converts electrical energy into thermal energy.

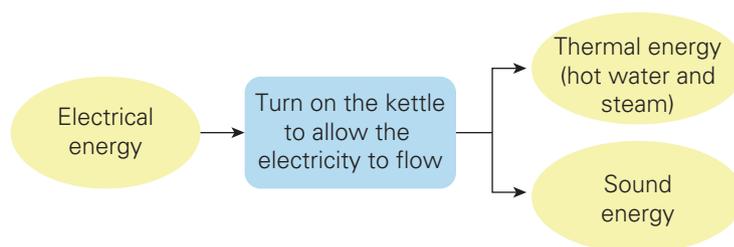


Figure 5.14 Energy flow diagram for an electric kettle

#### Quick check 5.3

- 1 Explain what occurs during an energy transformation.
- 2 Provide two examples of an appliance that transforms energy.

### Investigating a hot air balloon

The operation of a hot air balloon involves two energy changes. When the hot air balloon first takes off, chemical potential energy is stored in the form of natural gas (in the gas cylinder in the basket of the balloon). When the gas is burned, it releases thermal energy, which heats the air in the balloon. The air in the balloon expands as it warms up, and this makes the air inside the balloon lighter than the air around the balloon. The balloon then rises, due to buoyancy forces, gaining kinetic energy and gravitational potential energy as it gains altitude.

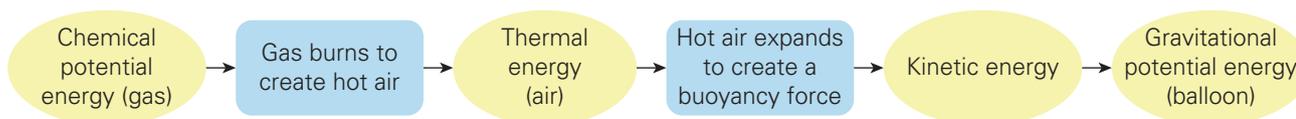


Figure 5.15 Energy flow diagram for a hot air balloon



**Figure 5.16** A hot air balloon flying over the Hunter Valley in NSW. The balloon converts chemical energy to thermal energy, then kinetic energy as it moves, then gravitational potential energy as it gets higher.

### Investigating an aircraft taking off

Sometimes a machine can convert a source of energy into two forms at the same time. When an aircraft takes off, it starts moving slowly from one end of the runway and then accelerates under full power until it leaves the ground at the other end. When it first starts its take-off, the jet has chemical potential energy stored in the form of aviation fuel in its tanks. The fuel is ignited in the jet engines to create a force that accelerates the aircraft along the runway, gaining kinetic energy as it does so. When the aircraft reaches sufficient speed, it lifts off and gains gravitational potential energy as it rises into the air.

Look closely at the picture of the aircraft taking off, and you can see that the air behind the aircraft's engines is blurred. This is because it is at a high temperature, heated by the energy produced by the aircraft's engines, and that energy should be added to the energy flow diagram. Aircraft are also very noisy when taking off, so sound energy is also produced.



**Figure 5.17** An aircraft converts chemical potential energy to kinetic energy and gravitational potential energy.

**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

**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



WIDGET  
Energy forms  
and  
transformations

**output energy** when **waste energy** is included.

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

In Figure 5.18, 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

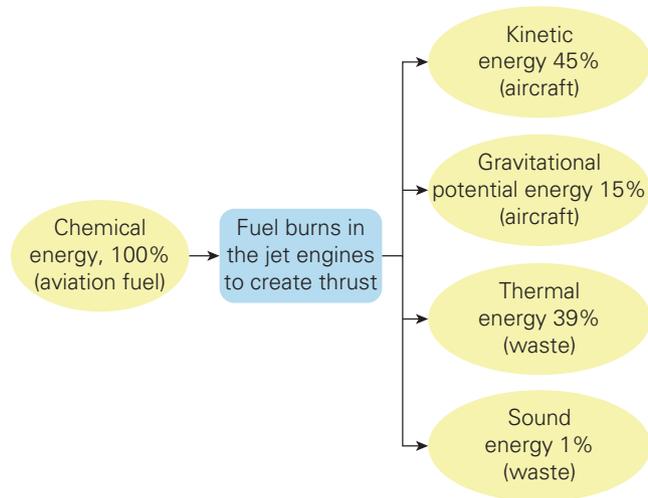


Figure 5.18 Energy flow diagram for a jet aircraft taking off

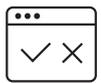
the aircraft's engines is 60%. The other 40% is wasted through thermal and sound energy.

### Quick check 5.4

Draw flow diagrams for the following energy transformations.

- A television converting electrical energy to sound, thermal and light energy
- A light bulb converting electrical energy to light and thermal energy
- A human converting chemical potential energy from food into kinetic energy when moving

### Section 5.2 questions



QUIZ

#### Remembering

- Recall** the energy transformations that occur when fireworks explode.
- Describe** the difference between an energy transfer and an energy transformation.

#### Understanding

- Using the law of conservation of energy, **explain** why a light bulb gives off thermal energy.
- Describe** the energy transformation that occurs in the Sun.

#### Applying

- State** the energy transformations that occur when someone climbs a set of stairs.
- Draw** an energy flow diagram for each of the following situations.
  - A stone is dropped from the top of a building.
  - A car is slowing down as it moves up a hill.
  - A charcoal fire is burning in a barbeque.
  - A bungee jumper jumps from the top of the jump to the bottom.
  - An electric tram starts from rest and builds up to full speed.
  - A person rides on an escalator from the bottom to the top.
  - A sheepdog runs up a hill.

**Analysing**

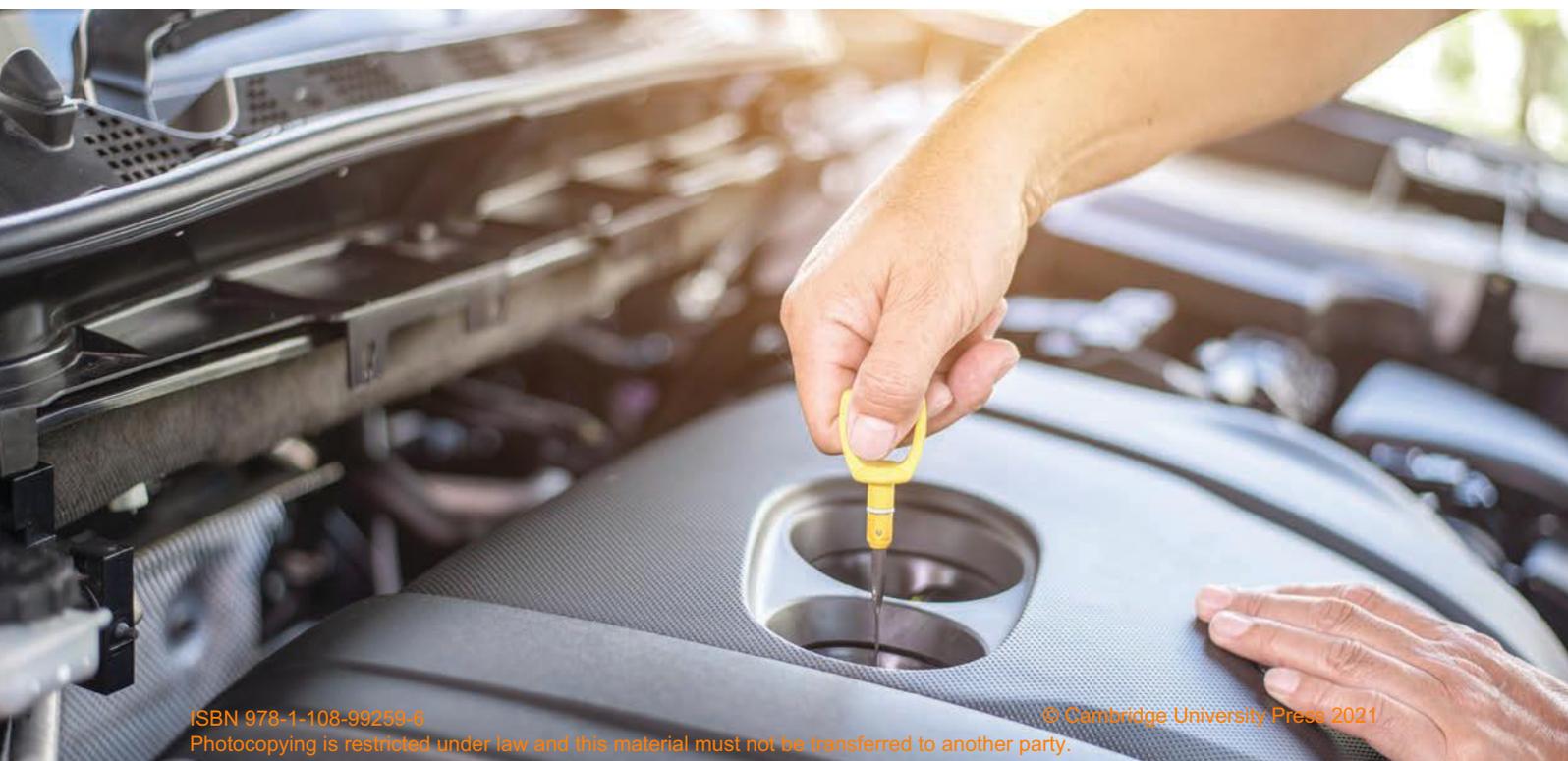
- 7 Think about all the different types of energy we encounter every day – driving a car is one example. Pick another example and **suggest** how you can make the process more energy efficient.
- 8 Look closely at the image below of a children's playground.



- a **Identify** the components of the playground that involve gravitational potential energy.
- b **Suggest** ways in which elastic potential energy could be incorporated into this playground setting.

**Evaluating**

- 9 Cars are energy inefficient. State the input form of energy and the useful and wasted forms of energy. **Propose** some other forms of transport that are more energy efficient.



## 5.3 Energy efficiency

### Learning goals

- 1 To apply the Law of Conservation of Energy to account for the total energy involved in energy transfers/transformations
- 2 To discuss how usable energy reduces in electricity transfers and that systems are not 100% efficient
- 3 To perform calculations to determine the efficiency of a system taking into account useful and wasted energy

Hardly any energy transfer or conversion is 100% efficient – energy in some form is always lost to the system as wasted energy. Consider a rubber ball being dropped from a height onto a concrete surface. At its maximum height, the ball possesses a large amount of gravitational potential energy. When the ball is dropped, this gravitational potential energy is converted to kinetic energy, which reaches a maximum just before the ball hits the ground. As the ball hits the ground, the kinetic energy is converted

creates a sound and there is also friction between the ball and the ground. Thus, energy is lost due to the inefficient conversion between  $K$  and  $GPE$  and back again. Therefore, with each successive bounce, the ball has less energy than the preceding bounce. As a result, the ball slows down before coming to a stop when all of the energy initially possessed by the ball is lost to the system.

### Calculating efficiency

The **efficiency** of a system, in terms of its ability to convert energy, is a measure of its ability to produce useful energy.

**Useful energy** is defined as energy that can be used for a specific purpose. In the example of the bouncing ball, kinetic energy and elastic potential energy are useful forms of energy. In contrast, heat and sound energy are by-products of the energy conversion (that is, wasted energy). Wasted energy is usually lost to the environment and generally cannot be used to do work.

Energy efficiency is most commonly expressed as a percentage and can be calculated using the following equation:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$

**efficiency**  
a measure of the ability to produce useful energy

**useful energy**  
energy that can be used for a specific purpose

into elastic potential energy. This is converted back into kinetic energy as the ball bounces up again. If this system was 100% efficient,

the ball would bounce back up to its starting height and have the same amount of gravitational potential energy as before being dropped. We know that this is not the case as with each bounce, the ball reaches a lower maximum height until eventually the ball comes to a stop.

Let's look at how energy is lost from this system. First, as the ball is falling towards the ground it is encountering air particles. Contact with these particles results in friction and heat – thus energy is lost as heat to the surrounding air particles. When the ball bounces, it

### Worked example 5.4

#### Efficiency

What is the efficiency of a light globe if 75 J of energy is put in but only 12 J of light energy is produced?

Working	Explanation
Useful energy output = 12 J, Energy input = 75 J	List the relevant data that has been provided.
Efficiency = (useful energy output/energy input) $\times$ 100	Recall the definition of efficiency energy and the equation.
Efficiency = $\frac{12 \text{ J}}{75 \text{ J}} \times 100$	Substitute the relevant data into the equation.
Efficiency = 16%	Solve the problem, giving an answer with appropriate units.

## Practical 5.2

### Investigating the efficiency of bouncing balls

#### Aim

To calculate and compare the efficiencies of balls that bounce.

#### Prior understanding

Different factors can affect a ball's efficiency. For example, temperature, inflation level of the ball, surface area and the material that a ball is made from can all have an impact.

#### Useful formula

$$\text{Percentage efficiency} = \frac{\text{Final potential energy}}{\text{Initial potential energy}} \times 100$$

#### Materials

As chosen by students but most likely to include:

- a variety of balls
- equipment to measure the height of the bounce
- other equipment as requested

#### Planning

- 1 Identify the independent variable from the clue in the aim and describe the different groups that will be set up for the experiment.
- 2 Define the dependent variable (calculated) and how it will be measured.
- 3 Define the controlled variables and describe how these will be managed to prevent any controlled variables from affecting the measurements.
- 4 Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.

#### Procedure

##### *Design a method*

- 1 Design a method that will allow you to calculate the efficiency of a variety of balls that bounce by measuring the rebound height.
- 2 Complete a risk assessment, considering at least two significant risks.

##### *Test and modify the method*

- 1 Test out your original method using a trial run to collect data.
- 2 Adjust steps in the method to address any issues identified.

##### *Undertake your modified method*

- 1 Follow the steps in your method to collect multiple trials of data.
- 2 Make note of any issues that may need to be discussed in your evaluation.

#### Results

Calculate the percentage efficiency for each of the balls you tested.

#### Discussion

- 1 Compare the efficiency of the different types of balls. Justify your response using data.
- 2 Identify which bouncy ball is the most efficient.
- 3 Discuss how this data can be related to energy transformation and wasted energy.
- 4 How much variation in the measurement was observed between different student groups within the class?

*continued...*

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- 5 Were other variables that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning with data.
- 6 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments. Include calculations such as confidence limits that would help validate your findings.
- 7 Write out an improved version of the method based on the answers to the above evaluation questions. Include instructions on how to control variables for validity.

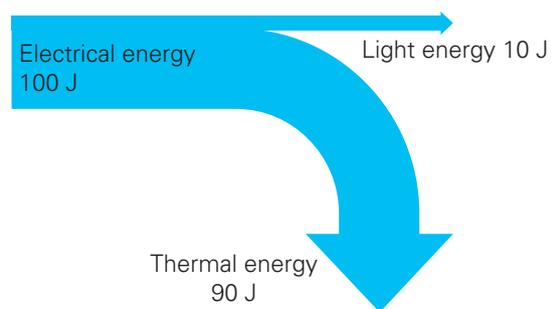
### Sankey diagrams

A **Sankey diagram** is a flow chart that represents the flow of energy through a system. A Sankey diagram has a wide arrow at its base, which represents the energy input into a system. The flow diagram then branches off into two or more arrow heads, the size and thickness of which are directly proportional to the amount of output energy in that form. For example, Figure 5.19

**Sankey diagram**  
flow chart that represents the flow of energy through a system

shows a Sankey diagram for an incandescent light globe, where only 10% of output energy is in a useful form.

arrow) rather than light, which is a useful form of energy output. The thermal energy produced is said to be lost or wasted energy.



**Figure 5.19** A Sankey diagram for an incandescent light globe showing the amount of input energy (100 J) as well as the amount of output energy in its various forms.

The Sankey diagram shows that most of the electrical energy is transformed into thermal energy (thicker

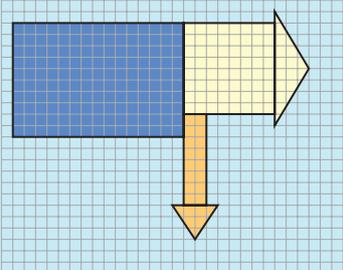
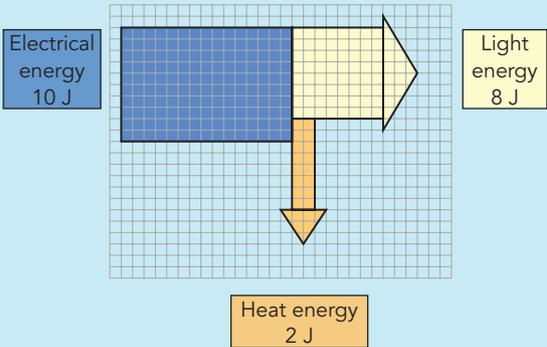
### Worked example 5.5

Draw the Sankey diagram of an energy efficient light bulb with an input energy of 10 J, an output energy of 8 J in the form of light and wasted output of 2 J in the form of heat.

Working	Explanation
	The height of the box represents the amount of energy that is put in. In this case it is 10 J, so it should be 10 units in height. Note that the length of the box does not matter.
	The height of the next box represents the amount of useful energy. In this case, it is 8 units in height.
	The height of the final box represents the amount of wasted energy. In this case, it is 2 units in height.

continued...

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Working	Explanation
	<p>The wasted energy should be rotated 90 degrees clockwise so it points down. This shows that it is wasted energy.</p> <p>Add arrows to the output boxes.</p>
	<p>Finally, add the labels.</p>

### Quick check 5.5

- Outline the energy changes that take place when you jump on a trampoline, and explain why you do not bounce back up to the same height after successive bounces.
- Calculate the efficiency of an electric stove that has an input of 1500 J of energy and produces 200 J of light energy and 1300 J of thermal energy.
- Draw a Sankey diagram for the electric stove in Question 2.

### Section 5.3 questions

#### Remembering

- Define** the term 'useful energy' in your own words.
- State** what usually happens to wasted energy.

#### Understanding

- A car has an energy efficiency of 35%. **Explain** what this means in terms of energy.
- Incandescent light globes convert 10% of their input energy into light energy, while LEDs (light-emitting diodes) convert 60% of their input energy into light energy. **Determine** which type of light globe is more energy efficient.
- As Jane slides down a playground slide, the amount of kinetic energy that she gains is less than the amount of gravitational energy that she loses.
  - Predict** where the missing energy goes.
  - Consider** what Jane can do to minimise the amount of wasted energy.

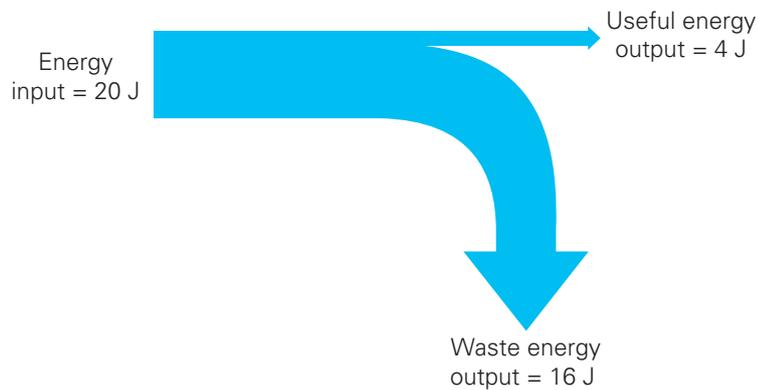


**Applying**

- 6 An organism uses 500 J of chemical potential energy stored in its body to produce 125 J of kinetic energy to climb a tree. **Calculate** the organism's efficiency.
- 7 **Explain** what the term 'efficiency' means.

**Analysing**

- 8 A kettle has an energy efficiency of 89%. **Calculate** how much electrical energy is required to produce 1068 J of thermal energy.
- 9 The Sankey diagram below is of a light globe.



- a **Identify** the useful energy output that the light bulb is designed to produce.
- b **Describe** the effect that the wasted energy has on the surrounding air.
- c **Calculate** the efficiency of this light bulb.

**Evaluating**

- 10 **Explain** how the law of conservation of energy still applies to a system despite energy being 'lost' during a transformation.
- 11 On cold days, some of the heat transferred from a hot car engine is used to warm the air inside the car. **Describe** the effect that this has on the overall efficiency of the car engine. Justify your answer.

**Figure 5.20** Car heater used to warm a driver's hand



## 5.4 Energy problems

### Learning goals

- 1 To recall the nature of renewable and non-renewable sources of energy
- 2 To compare the efficiency, advantages and disadvantages of electricity generation by different methods
- 3 To discuss developments designed to improve the efficiency in electricity generation
- 4 To discuss using examples, how the values and needs of contemporary society can influence the focus of scientific research in the area of increasing efficiency of the use of electricity by individuals and society
- 5 To discuss viewpoints and choices in making decisions about the use of non-renewable energy resources
- 6 To research recent examples where scientific or technological developments have involved specialist teams from different branches of science, engineering and technology, e.g. low-emissions electricity generation

You may remember from Stage 4 that some energy sources, such as wind and solar, will never run out. Methods of energy production that do not use up natural resources or will never run out, such as solar and wind, are called **renewable** energy sources. Other energy sources, such as coal, oil and gas, are not renewable. Once these sources are used, they cannot be replaced within a human lifetime, and as such, once they run out, they are effectively gone forever.

Another major consideration in choosing an energy source is the effect it has on the environment. Some methods of energy production, such as burning coal, create pollution that damages the environment. In addition, when wood, oil, gas or coal is burned, greenhouse gases, which have the potential to cause climate change, are created. Methods of energy production that are non-polluting or have a small effect on the environment are called **sustainable**.

The demand for energy has increased steadily since the Industrial Revolution 300 years ago, and it is still increasing today as more countries become industrialised. Scientists are constantly looking for ways to make the production of energy more efficient and to reduce its effect on the environment. Some of the main methods of generating energy are summarised below.

### Non-renewable sources of energy

#### Coal

**Fossil fuels** are a **non-renewable** source of energy. Most deposits of coal formed 300 million years ago during the

Carboniferous Period. This was 100 million years before the dinosaurs, when the Earth was warm, wet and covered with giant forests. Eventually the forests died and layers of sand, which later turned into rock, covered the dead trees. Deep underground and under high temperature and pressure, the remains of the forest trees changed into coal.

Coal is mined and then transported to a power station where it is used to generate electricity. When all the coal has been used up, there will be no more left. That is why coal is considered non-renewable.

**renewable**  
can be produced as quickly as it is used

**sustainable**  
causing little or no damage to the environment and therefore able to continue for a long time

**fossil fuel**  
a non-renewable energy source such as oil, coal or natural gas

**non-renewable**  
existing in limited quantities that cannot be replaced after they have all been used



**Figure 5.21** The Loy Yang power station converts the chemical potential energy in coal into electrical energy.

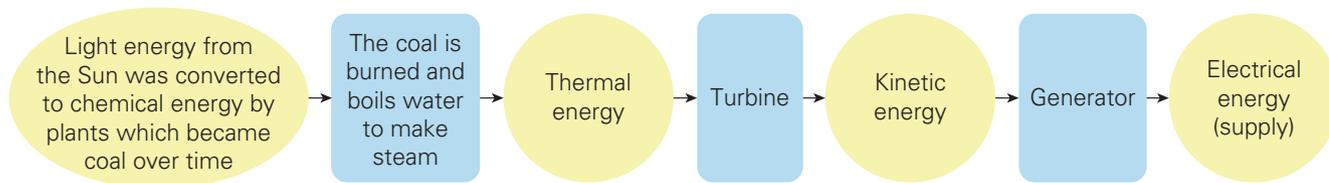


Figure 5.22 Energy flow diagram for a coal-fired power station

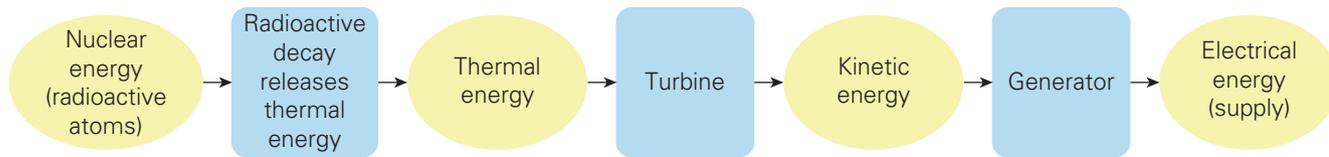


Figure 5.23 Energy flow diagram for a nuclear power station

## Nuclear energy

Nuclear energy is an option for countries that have the technology to build nuclear power stations. Unlike all other forms of energy production, nuclear energy does not rely ultimately on the Sun. Instead, the fuel comes from radioactive materials, mainly uranium, found within the Earth's crust. These materials were inside the Earth when it formed, around 4.5 billion years ago. The mass of fuel required is a tiny fraction of that required to run a coal-burning power station. Although the materials used in nuclear power generation are not

renewable, it is unlikely that the world will ever run out of nuclear fuel. Nuclear power stations do not release greenhouse gases.

Although nuclear energy has the potential to supply the world's energy needs when fossil fuels start to run out, there are also some potential problems, such as leaking radioactivity, that need to be taken into account.

### Did you know? 5.1

#### Australian uranium

Australia is the world's third-largest uranium producer, after Kazakhstan and Canada. All the uranium mined in Australia is exported, because there is no nuclear power plant here to use it. However, there is a nuclear reactor at Lucas Heights on the outskirts of Sydney, operated by the Australian Nuclear Science and Technology Organisation. It is used for research and nuclear medicine purposes.

### Quick check 5.6

- 1 Define the term 'non-renewable' in your own words.
- 2 Recall the types of non-renewable energy sources used in Australia.
- 3 State where in Australia non-renewable energy sources can be found.
- 4 State how and why the demand for energy has changed over the years.

## Renewable energy sources

### Wind energy

Wind energy is a renewable energy source in which electrical energy is generated using large wind turbines, usually built in groups called wind farms. The advantage of wind energy is that once the wind turbine has been built, wind energy is free, non-polluting and available at night. The main disadvantage is that it depends on the availability of the wind. For this reason, the energy that wind turbines produce is intermittent and must be combined with a storage capability, such as a battery, to provide a continuous energy supply.



Figure 5.24 Wind turbines are a striking sight in the countryside.

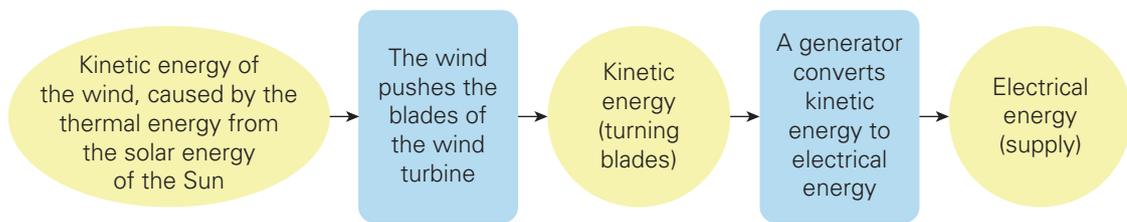


Figure 5.25 Energy flow diagram for a wind turbine



Figure 5.26 Solar panels convert sunlight into electricity.

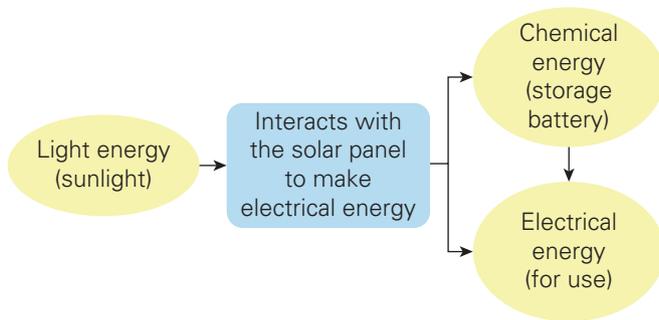


Figure 5.27 Energy flow diagram for a photovoltaic solar panel with a storage battery

### Solar energy

Solar energy is a renewable energy source. Solar panels are used to convert the energy in sunlight directly into electrical energy and can also supply energy to provide hot water. The advantages of solar panels are that the energy they produce is free once the initial cost is met, and they are non-polluting to use. When solar panels are combined with storage batteries, they can provide a constant supply of energy, as the batteries store energy during the day and release it at night.

### Hydroelectric power

**Hydroelectric power** is generated by using the gravitational potential energy of water held in dams to drive turbines that generate electricity. The dam's surface is as high above the turbines and generators as possible. The water's gravitational potential energy is converted to kinetic energy by turbines at the base of the dam or as far below it as possible. These turbines turn generators that convert this kinetic energy into electrical energy.

**hydroelectric power**  
a renewable source of energy harnessing the gravitational potential energy of water to generate electrical energy

Some countries are mountainous and are well suited to hydroelectric energy generation. Norway, for example, generates around 95% of its energy in this way. In Australia, hydroelectric energy accounts for around 6% of total energy production. The biggest single producer of hydroelectric power in Australia is the Snowy Mountains Scheme.



### Geothermal energy

Geothermal energy is both sustainable and renewable.

**geothermal energy**  
thermal energy that originates from inside the Earth

It is thermal energy left over from the Earth's formation, as well as radioactive decay. Where the Earth's crust may be fractured or thin, it is possible to drill down to find rocks hot enough to boil water. Cold water is pumped down to this hot rock. The water boils, producing steam, which is brought to the surface and used to generate electrical energy.

**Figure 5.28** In this hydroelectric power station in the Snowy Mountains, water is carried by gravity through the pipes shown, from a dam located near the top of the mountain down to turbines and generators in the power station, converting gravitational potential energy into electrical energy.



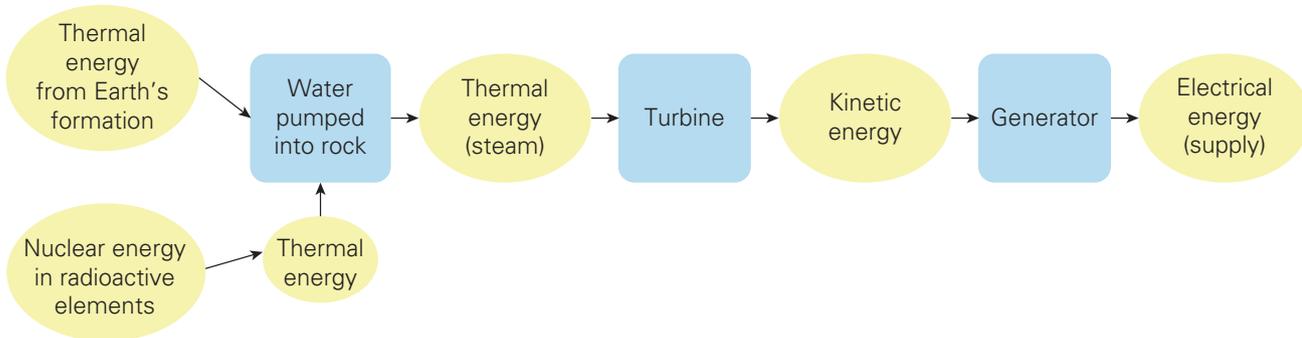
**Figure 5.29** Energy flow diagram for hydroelectricity generation



### Quick check 5.7

- 1 Define the term 'renewable energy source' in your own words.
- 2 Recall some different types of renewable energy.
- 3 Draw a flow diagram to show the energy transformations that occur while producing electricity from wind turbines.

**Figure 5.30** The Wairakei Power Station in New Zealand uses geothermal energy to produce electricity.



**Figure 5.31** Energy flow diagram for geothermal energy

## Explore! 5.2

**Providing technology to remote communities**

Approximately one in five Aboriginal and Torres Strait Islander peoples are located in remote and isolated parts of Australia. Providing access to basic services such as electricity and clean water in these areas is very difficult, let alone modern technology such as mobile phone and internet coverage. Despite these difficulties, individuals remain in these areas as they have a connection to the land.

- 1 Research what is being done to provide basic modern services to remote communities, including any new technology such as solar thermal collectors and battery banks.
- 2 What are the economic and ethical implications of providing these services to small groups of people at such remote locations?



**Figure 5.32** Around 10% of Alice Spring's energy is generated from renewables. The challenge is serving communities that are as far as 130 km from the town.

## Explore! 5.3

**Turning waste into energy**

A lot of energy in modern life goes unused in the form of food scraps and animal wastes. A UK-based company is trying to change that by harnessing the power of detritus (waste material). Use the website of SEaB Energy (a UK company that converts organic waste into energy) to answer the following questions.

- 1 Why is food and animal waste such an issue for the world and the environment?
- 2 Explain how SEaB Energy's two main products, the Muckbuster® and the Flexibuster®, work.
- 3 Draw a flow diagram showing the energy transformations that would occur in harnessing energy from food and animal waste.

## Advances in science 5.1

**The power of evaporation**

A key challenge for current renewable energy resources is intermittency. Wind turbines and solar photovoltaic cells, for example, only produce power when wind and sunlight, respectively, are available. To power the electrical grid from renewable energy sources, we need a stable supply of energy and we also need to store energy to keep up with periods of high demand.

Water in nature is in constant transformation, and because water covers 70% of Earth's surface, the water cycle involves enormous amounts of energy, which is a potential resource. Up until now we have been able to harness energy from water falling from the clouds or from a height, but researchers at Columbia University in the United States looked for a way to harness the energy involved in evaporation of water – and they found it!



**Figure 5.33** Evaporation from lakes and oceans is an untapped energy source that could be the solution to our inconsistent power supply.

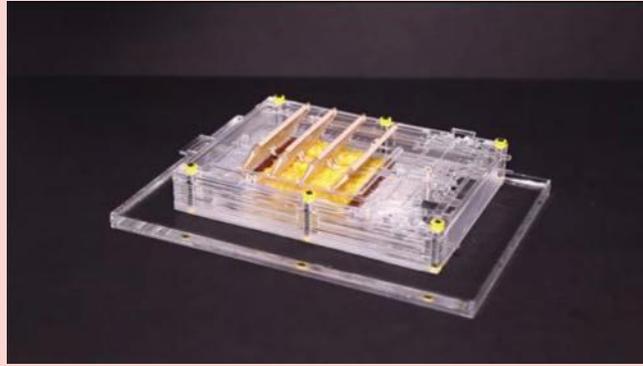
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In 2015, the researchers discovered a way to harness the process of evaporation to create a seemingly endless, controllable, renewable energy resource. The secret to their discovery was the property possessed by bacterial spores whereby they expand when exposed to water and contract as they dry out. This expansion and contraction is similar to muscle movement and can be controlled by adjusting the humidity.

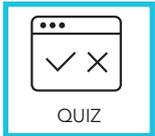
The scientists used their research findings to create an evaporation engine using material coated with bacterial spores that behaved like muscles. The evaporation engine sits on the water surface, and as moisture from the water enters the device it changes the shape of the muscles. The movement of these muscles was coupled to shutters, which allow moisture to escape when they are open. Because the moisture escapes, the muscles dry out and contract. This closes the shutters, so the humidity builds up again – and the cycle of the engine continues.

The advantage of this renewable resource is that you can store up the moist air and release it in a controlled fashion over time. This gives you a continuous power output that can keep up with our power demands.



**Figure 5.34** The evaporation engine floats on the surface of water and creates a piston-like back and forth movement as the water evaporates from the surface.

## Section 5.4 questions



### Remembering

- 1 **List** the fossil fuels used to provide energy in Australia.
- 2 **Recall** approximately how many years ago coal deposits were formed.
- 3 **State** some sources of energy that harness water.
- 4 **Describe** the main reason behind switching to renewable energy sources.

### Understanding

- 5 **Explain** how energy is produced using thermal energy from the Earth.
- 6 **Draw** an energy flow diagram for a hydroelectric power station.
- 7 **Explain** the difference between the terms 'renewable' and 'sustainable'.
- 8 **Explain** why nuclear energy is not considered renewable.
- 9 **Explain** how non-renewable energy sources are causing global warming.
- 10 **Explain** why each of the renewable sources of energy is considered 'renewable'.

### Applying

- 11 **Draw** an energy flow diagram for a petrol engine car travelling at a constant speed on a flat road.
- 12 Make a list of ways in which you can make your house more energy efficient. For each suggestion, **explain** how it works.
- 13 A cyclist used 1000 kJ of energy riding to work. Of this, 250 kJ was transformed into kinetic energy to move his muscles. The other 750 kJ was transformed into heat. **Calculate** the energy efficiency of the cyclist.

### Analysing

- 14 Consider the Sun's role in life on Earth. **Explain** why there would be no life on Earth without the Sun.

- 15 Some people use wood-burning stoves to heat their homes. **Conclude** whether this source of energy is renewable and/or sustainable. Explain your answer.



Figure 5.35 A wood-burning stove

### Evaluating

- 16 **Suggest** one drawback of using solar energy as an energy source.
- 17 **Suggest** two reasons why coal may not be suitable as a long-term energy source.
- 18 **Suggest** why inner city trains and trams are powered by electrical energy.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>5.1 I can recognise the relationship between energy and work.</b> e.g. Recall the definition for energy.	
<b>5.1 I can identify different forms of energy.</b> e.g. Name five types of potential energy.	
<b>5.1 I can calculate the kinetic energy of an object.</b> e.g. State the equation for kinetic energy.	
<b>5.1 I can calculate the gravitational potential energy of an object.</b> e.g. State the equation for gravitational potential energy.	
<b>5.1 I can calculate the elastic potential energy of an object.</b> e.g. State the equation for elastic potential energy.	
<b>5.2 I can recall the law of conservation of energy.</b> e.g. Recall the law of conservation of energy.	
<b>5.2 I can describe how energy is transferred and transformed.</b> e.g. Explain what occurs during an energy transformation.	
<b>5.3 I can calculate the efficiency of different machines.</b> e.g. A toaster uses 131 500 J of electrical energy: 80 650 J is used to produce heat to toast bread. Calculate the efficiency of the toaster.	
<b>5.3 I can describe energy transfers and transformations.</b> e.g. Explain why energy transfers are not 100% efficient.	
<b>5.3 I can calculate and diagrammatically represent the efficiency of energy transfers.</b> e.g. Using a Sankey diagram, represent an energy transfer which is 78% efficient.	
<b>5.3 I can consider energy in different systems.</b> e.g. Discuss the energy changes that occur when an aeroplane takes off, in terms of useful and wasted energy.	
<b>5.4 I can compare the efficiency, and advantages and disadvantages of electricity generation by different methods.</b> e.g. Explain the advantages and disadvantages of wind as an energy source.	

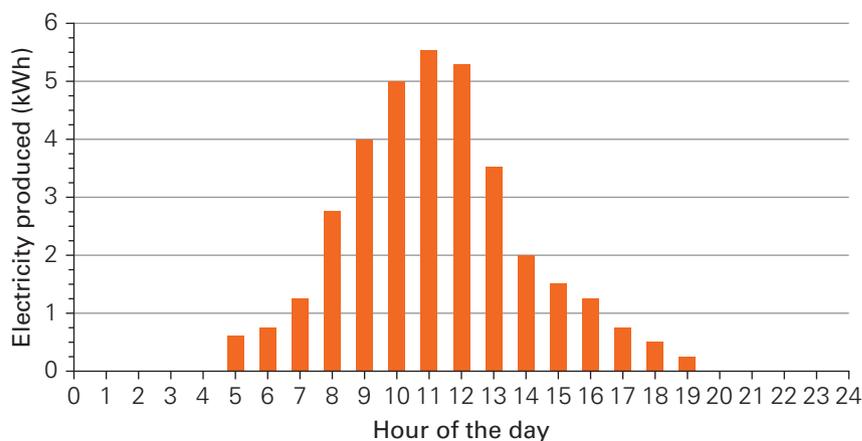


## Reflections

- 1 What **connections** come to mind when you think about how energy is conserved in your everyday life?
- 2 What new concepts have **extended** your thinking about the conservation of energy?
- 3 What information did you find **challenging** or confusing?

## Data questions

Solar panels are used across Australia to convert the energy provided by sunlight into electricity. The electricity produced by a typical commercial solar panel in NSW throughout a sunny day is shown in Figure 5.36. The efficiency and price of six different solar panel models is also shown in Table 5.2.



**Figure 5.36** Electricity produced, in kilowatt hours, by a typical commercial solar panel throughout a sunny day

Solar panel model	Efficiency (%)	Estimated price (\$ / m <sup>2</sup> )
A	46	> 2 000 000
B	44	> 1 000 000
C	37	> 100 000
D	22	120
E	17	80
F	15	70

**Table 5.2** Efficiency and cost of different solar panel models

- Identify** the time of the day the solar panel presented in Figure 5.36 produces the most electricity.
- Calculate** how many hours per day the solar panel can produce electricity.
- Identify** the pattern of electricity production throughout a sunny day.
- Refer to Table 5.2 and **identify** the trend between the efficiency of a solar panel and the price per square metre.
- Infer** whether the cost of a solar panel is directly proportional to the efficiency.
- Deduce** why electricity is not produced between midnight and 4 a.m. and again between 8 p.m and midnight.
- Predict** the effect on the data in Figure 5.36 if the weather was an overcast and rainy day.
- A domestic household owner in NSW would like to install solar panels on the roof of their home. The owner would like a solar panel with an efficiency above 20% to cover 3 m<sup>2</sup>. **Deduce** the type of solar panel and the lowest price that the homeowner could pay for these requirements.
- Based on the general shape of the data presented in Figure 5.36, **justify** why the angle at which the solar panel is oriented on a roof is important for a higher electricity production.

## STEM activity: Wind power

### Background information

Wind power has been used for generations as a method of generating usable energy. Wind turns the turbine and generates mechanical energy, which has been used for many things over the years. From providing energy to pump water from a reservoir to electricity generation, wind power has many uses, and a major benefit is its ability to be generated in remote areas.

**Design brief:** Design a wind turbine capable of lifting an object.

### Activity instructions

In groups you will design and construct a simple wind turbine capable of lifting weights from the floor up to bench height. Your turbine must be efficient in its energy conversion and sustainable in its design.

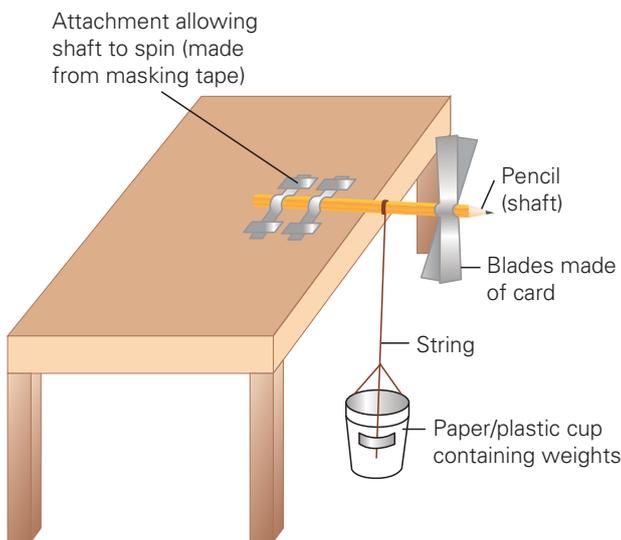


Figure 5.37 You can build ideas around this basic design.

### 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
- weights (you can use Lego® characters as well)
- electronic scale (optional)

### Research and feasibility

- 1 Research and discuss in your group how wind turbine blades are shaped to capture the maximum amount of wind. Consider the materials used in construction, different shaped turbines, and their use in high/low wind areas.
- 2 Discuss in your group the constraints of your building materials and testing area.

### Design and sustainability

- 3 Sketch and label multiple turbine designs within your group and discuss the effectiveness of the design features based on research.
- 4 Propose a measure of design efficiency. Think about how you can quantitatively measure how effective one design/prototype is compared with another. This may include measures for sturdiness, speed of lift, and maximum capacity. Discuss in your group the relationship between blade shape and blade spin for your design.
- 5 Design a table you can use to test different designs and to find the optimal shape for the wind conditions you are testing for. Trial different fan speeds to see their effect.
- 6 Discuss how sustainable your design is, and its effect on the environment. Does blade design affect this?

**Create**

- 7 Build your design and test using the weights.

Blade length	Blade width	Blade thickness	Blade angle	Fan speed	Weight being lifted	Time to lift weight

**Evaluate and modify**

- 8 Discuss and suggest three possible solutions to the problems you encounter.
- 9 Predict what would happen to the cup if you turn the fan (wind) off when the cup is halfway between the floor and the tabletop. Now test this scenario and write down your observations. Does it match your prediction?
- 10 Evaluate and present the most effective design to the class, and discuss why you believed this to be the most effective wind turbine design in this situation.



# Chapter 6

## The universe

### Inquiry questions

Why have technological developments furthered our understanding of the universe?

How do dimmer stars live longer?

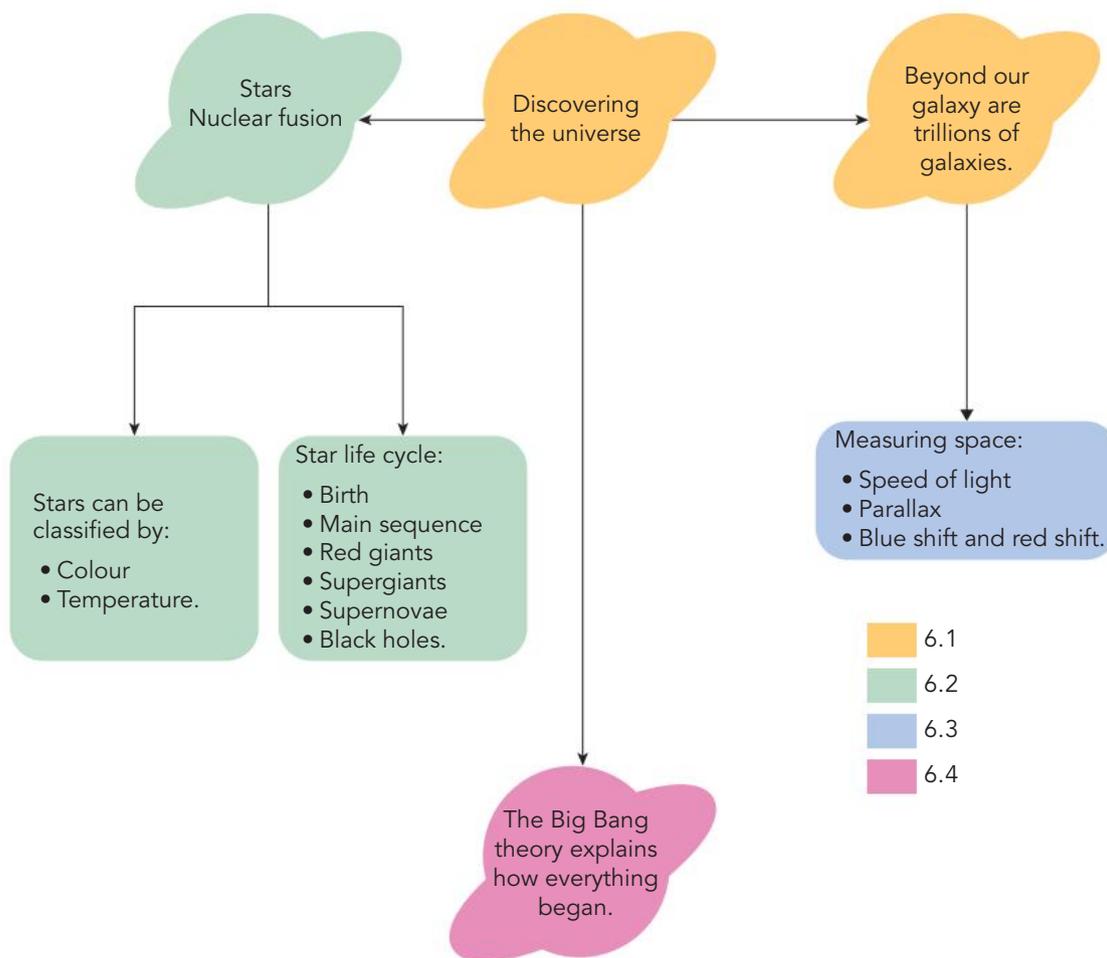
What evidence supports the Big Bang?



### Chapter introduction

Humans have always been inspired by the universe. The movement of the Sun, stars, Moon and planets has been studied for centuries, and there is still so much unknown. Advances in technology have let us see further and further into space to discover more about how the universe began and what it is made of. There can be a certain feeling of insignificance as well as awe that people experience when they think about the enormous size of our expanding universe. In this chapter, you will learn about what can be observed in the night sky and what information can be gathered from stars and galaxies to find out about how it all began.

# Chapter map



# 6.1 Discovering the universe

## Learning goals

- 1 To appreciate how scientific thinking is refined over time
- 2 To recall the different technologies that have helped with our understanding of the universe
- 3 To explain how technological developments have furthered our understanding of the universe



Aboriginal and Torres Strait Islander peoples have been observing and documenting the night sky to pass the knowledge on through the generations, since well before European settlement in 1788. They have a deep understanding of the movements of celestial bodies (objects in the sky) and are sometimes called the ‘world’s first astronomers’.

Many **constellations** are associated with stories, and different communities have different stories. Australia’s First Nations peoples not only identify stars and constellations by their brightness, but also from patterns originating from the dark clouds.

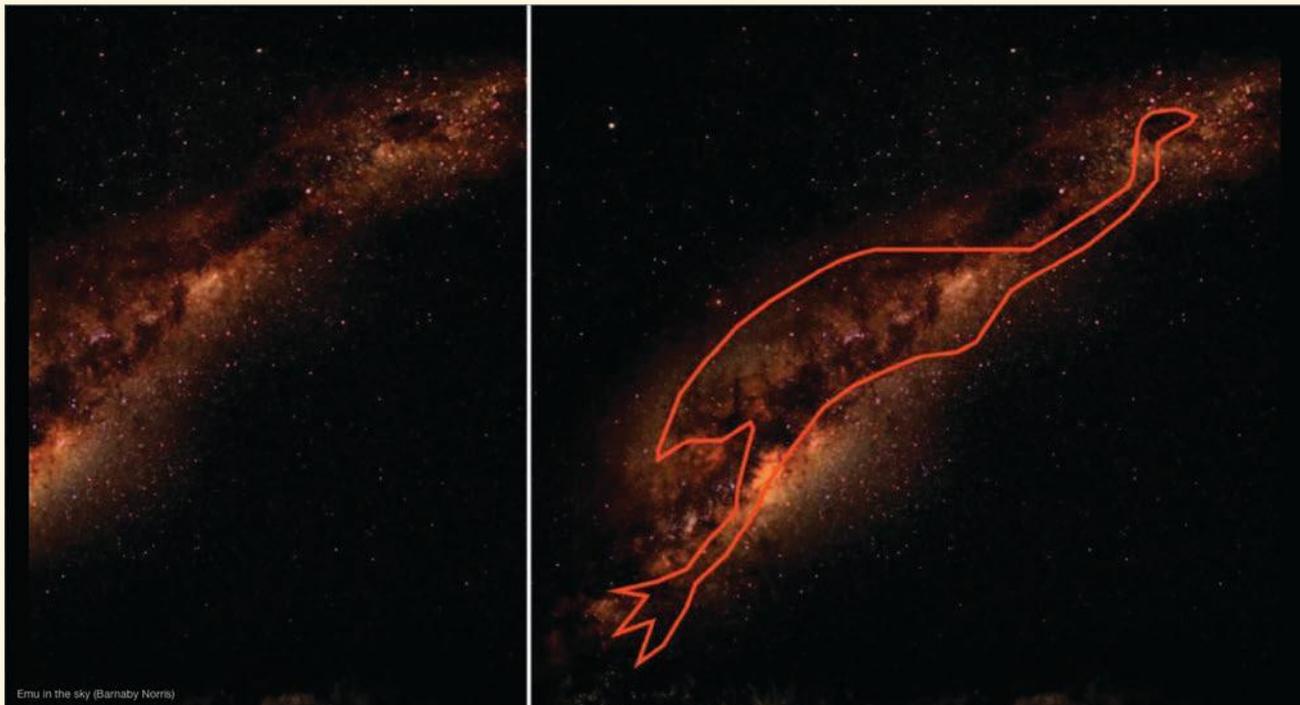
**constellation**  
a group of stars as seen from Earth that appear to form a familiar shape



## Explore! 6.1

### Constellations

The story of the Emu in the Sky is a common one. However, different Aboriginal and Torres Strait Islander communities have different stories or images associated with the part of the Milky Way shown in Figure 6.1. Use your preferred search engine to find out some of the other names and stories from different communities and what significance each plays in indicating changing seasons or the community’s practices throughout the year.



**Figure 6.1** The dark patches in the Milky Way make up the body of the Emu in the Sky, a story common to many Aboriginal groups. The orientation of the emu, sitting or running, indicates the start of different seasons, timing of ceremonies and even when it is time to hunt emus or collect emu eggs.

## Early astronomers

The early astronomers relied on the naked eye to make observations about the positions of celestial objects and how they moved over time.

Claudius Ptolemy was an astronomer from the second century who suggested that Earth was at the centre of the universe. He proposed a **geocentric** model in which all celestial objects orbited around Earth. It is easy to see why he suggested this model, given that the Sun, stars and Moon all appear to rise in the east, follow a circular pattern while they are up, and then set in the west.

There was one main problem with Ptolemy's geocentric model. At different points in the year, the motion of the planets across the sky appears to go backwards for a few days. It is called **retrograde motion** and could not happen if the planets orbited Earth.

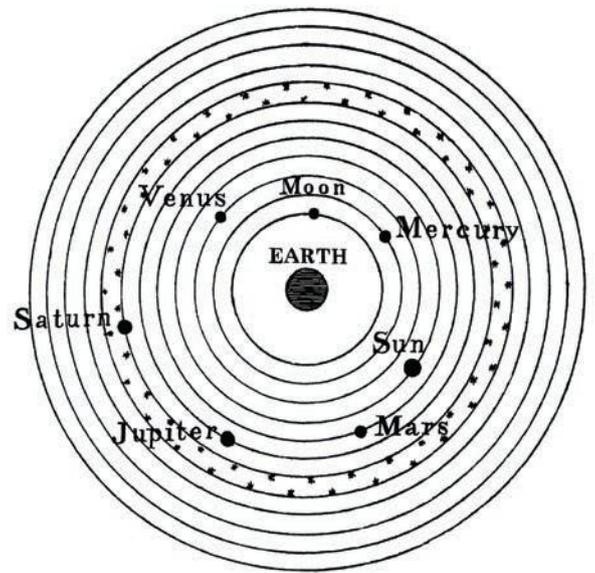
In the early 1500s, Nicolaus Copernicus proposed a **heliocentric** model of the solar system, in which the

**geocentric**  
a model of the solar system with Earth at the centre

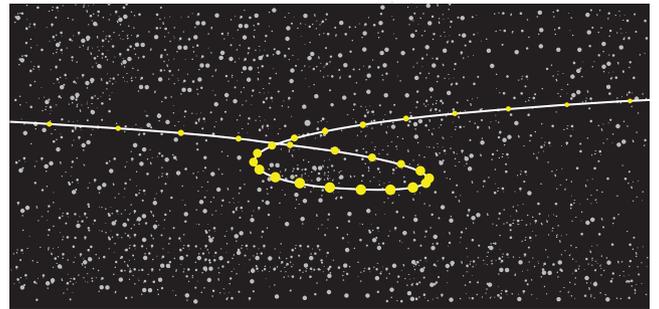
**retrograde motion**  
apparent backwards motion of a planet as seen from Earth

**heliocentric**  
a model of the solar system with the Sun at the centre

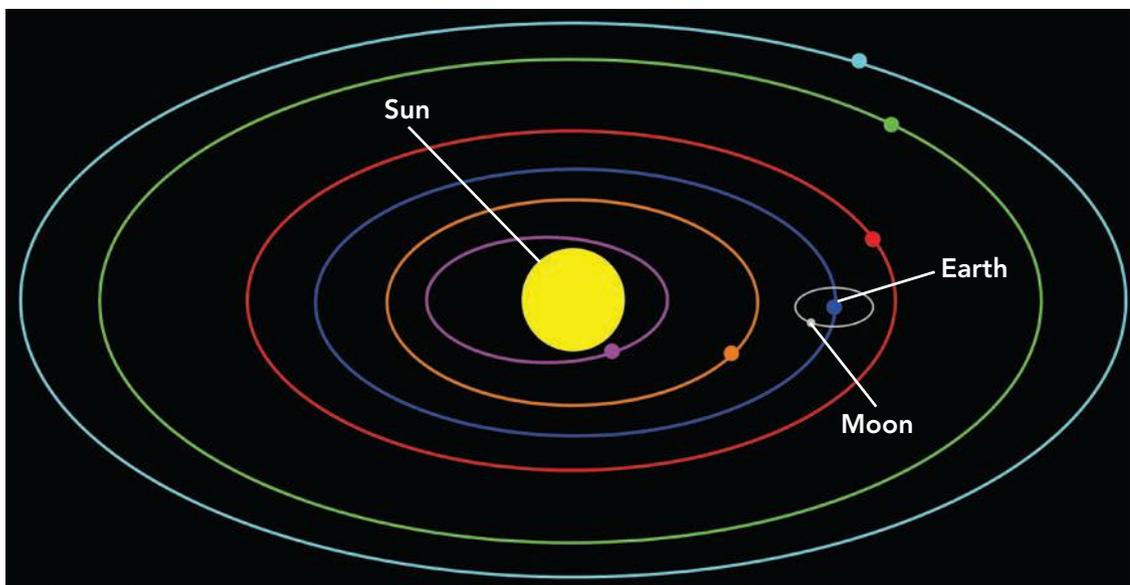
planets revolved around the Sun. This could explain the retrograde motion of the planets, occurring when a faster moving planet catches up with a slower moving planet and then passes it.



**Figure 6.2** The geocentric model proposed that Earth was the centre of the universe, with the planets and stars orbiting around it.



**Figure 6.3** Retrograde motion of Mars across the sky as seen from Earth



**Figure 6.4** The heliocentric model proposes that planets revolve around the Sun, rather than Earth.

With the invention of the telescope in the 1600s, Galileo Galilei was able to observe the four largest moons of Jupiter and could confirm that they were orbiting that planet.

Telescopes changed the world of astronomy in a huge way. They have allowed us to see the outer planets of the solar system, the moons of other planets, millions more stars and distant galaxies.

### Quick check 6.1

- 1 What celestial object is at the centre of a geocentric model?
- 2 What celestial object is at the centre of a heliocentric model?
- 3 How can the circular path of the Sun and stars across our sky each day be explained?

## Modern day astronomy

Modern day astronomers have amazing technology to work with. Modern telescopes have become larger and larger to allow us to see further into space. In 1995, the Hubble Space Telescope was pointed towards a region

of space previously thought to be empty. The photo produced after two days showed multitudes of galaxies that had never been observed before. Known as the ‘Hubble Deep Field’, this image further demonstrated the enormous size of the universe.

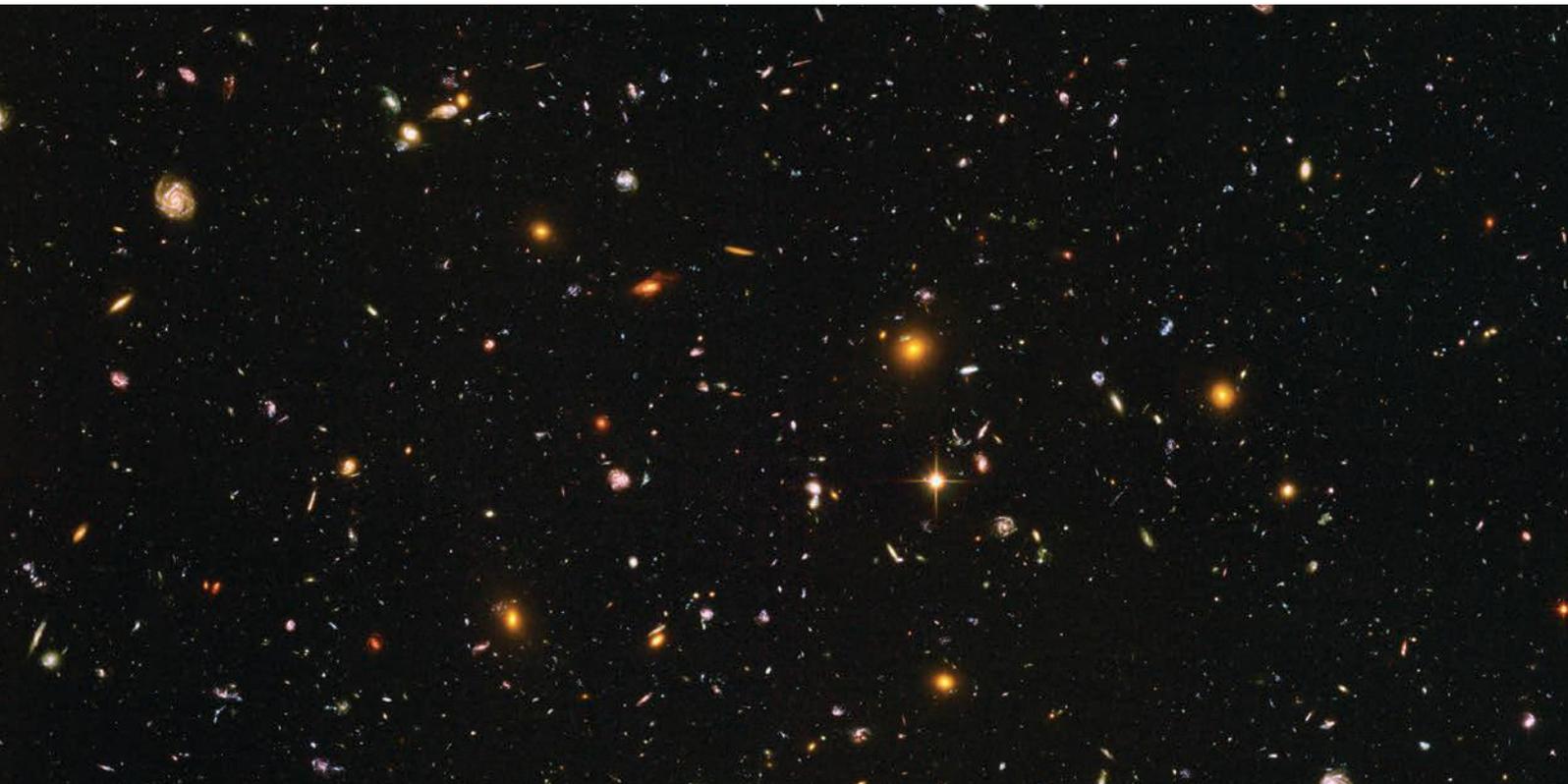
To minimise the effects of light pollution and the distorting effects of the atmosphere completely, the Hubble Space Telescope was launched into Earth’s orbit and is controlled remotely from the ground. It has been instrumental in developing our understanding of the universe and the Big Bang theory.

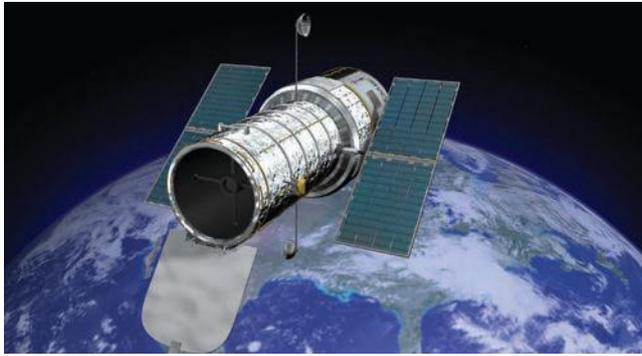
## Telescopes and technology

The first telescopes were **optical telescopes**, which use lenses to collect light and focus it for the eye to see. The larger the diameter of the lens, the more light that can be collected and the further you can see. But, as telescopes got larger, the size of the glass lenses required reached the point where they would be too big to support their own weight, so polished mirrors were used instead to collect and focus light.

**optical telescope**  
a device that collects and focuses light from the visible spectrum to form an image

**Figure 6.5** This figure shows a portion of the Hubble Ultra-Deep Field image, taken over a period of months from 2003–04. More detailed than the original Deep Field from 1995, the full image covers only a tiny portion of the sky and yet shows approximately 10 000 galaxies, many of which contain billions of stars each. The full-sized image can be viewed online.





**Figure 6.6** The Hubble Space Telescope can observe the light from distant galaxies without the dimming effects of Earth's atmosphere.

**Radio telescopes** gather information in the form of radio waves. Radio telescopes follow the same principle as optical telescopes, in that they collect signals and reflect them inwards to focus them, but the reflective surfaces do not need to be polished mirrors. This means that radio telescopes can be made much larger than optical telescopes. Multiple radio telescopes can also be linked together to look even further into space. The Square Kilometre Array radio telescope, which is expected to be completed in Western Australia in 2028, will be made up of thousands of dishes whose total

collection area will be bigger than one square kilometre (or one million square metres). An artist's impression of what it might look like is shown in Figure 6.7.

**radio telescope**  
a device that receives radio waves emitted by stars and other celestial objects



**Figure 6.7** The Square Kilometre Array will have the potential to look further into space than has ever been possible before.

### Quick check 6.2

Name the two main types of telescopes and recall which part of the electromagnetic spectrum they detect.

### Did you know? 6.1

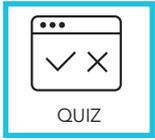
#### The Parkes radio telescope

The Parkes radio telescope in New South Wales was instrumental in the 1969 Moon landing mission. It was used to relay footage back to Earth for the live television broadcast. NASA had intended to swap between the signals relayed from three different radio telescopes in order to sustain the best-quality signal available, but when they changed over to the Parkes signal they found it to be so superior to the other signals that it was used for the entire 2.5-hour live broadcast.



**Figure 6.8** The Parkes radio telescope in New South Wales

## Section 6.1 questions

**Remembering**

1 **Recall** the reason that most observatories are located remotely and at high altitudes.

**Understanding**

2 **Describe** the evidence that Ptolemy used to explain his geocentric model.



Figure 6.9 An artist's engraving of Ptolemy looking to the sky

3 **Describe** the evidence that Copernicus used to disprove the geocentric model.

**Applying**

4 **Determine** the purpose of the large dish on the Parkes radio telescope. You may like to draw a diagram in your answer.

**Analysing**

5 **Contrast** the geocentric and heliocentric models, and explain why the motion of the planets as observed on Earth supports the heliocentric model.

6 **Compare** and **contrast** optical and radio telescopes.



Figure 6.10 The Milky Way over a radio telescope in New Mexico, USA

**Evaluating**

7 **Explain** the advantages and disadvantages of having a telescope in space.

8 **Consider** the improvements in technology since early astronomers that have allowed us to look further and further into space.

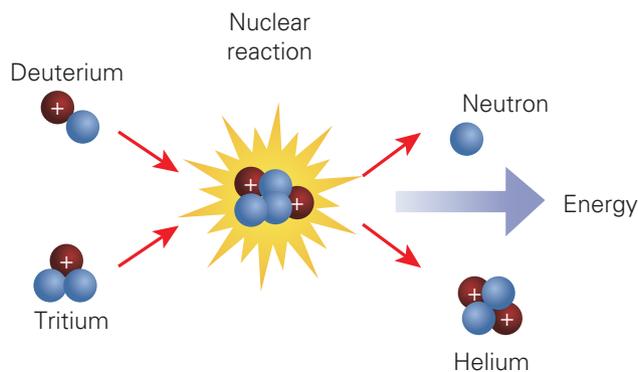
## 6.2 Solar systems, stars and nebulae

### Learning goals

- 1 To describe the features of nebulae and solar systems
- 2 To outline the stages in the lifecycle of a star
- 3 To relate the colours of stars to their age, size and distance from Earth

The universe is made up of many different features, including solar systems and nebulae. Solar systems comprise a Sun and the bodies orbiting it. Nebulae are clouds of dust and gas, often visible in the night sky, where new stars are being formed. Other nebulae contain the remains of dead or dying stars.

It is amazing to think that all of the atoms that make up all of the molecules that make up all of the cells in your body were formed in distant stars well before Earth, the Sun and our solar system even existed. Carl Sagan (the American astronomer who popularised science



**Figure 6.11** One step in the fusion of hydrogen happens when the isotopes deuterium (one proton and one neutron) and tritium (one proton and two neutrons) fuse together. A neutron is released and a helium nucleus is formed (two protons and two neutrons).

in the 1980s TV series *Cosmos*) once said, ‘We’re made of star-stuff’, and he was right!



### Nuclear fusion

Nuclear fusion occurs when two atoms combine (or fuse) to create a new element. Because it is so hot inside the cores of stars, hydrogen nuclei have enough energy to overcome the electrostatic repulsion between their protons. They fuse together to form helium and an enormous amount of energy is released in the process.



### Star colour and temperature

When you look at stars in the night sky, you will notice that they vary in colour. The colour of a star is related to its temperature: blue stars are the hottest and red stars are the coolest. Stars are given a **spectral class** letter based on their temperature and colour. As you can see in Table 6.1, our Sun is a relatively small yellow star with a surface temperature of around 6000 K, so a G-type star.

**spectral class**  
a group into which stars are classified based on their spectra/colour

Colour	Star temperature (kelvin)	Spectral class
Blue	>30 000	O
Blue white	10 000 to 30 000	B
White	7 500 to 10 000	A
Yellow white	6 000 to 7 500	F
Yellow	5 200 to 6 000	G
Orange	3 700 to 5 200	K
Red	2 400 to 3 700	M

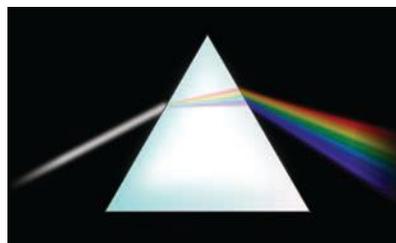
**Table 6.1** Temperatures and spectral classes of the star colours

**Quick check 6.3**

- 1 What is the name of the process that occurs inside stars?
- 2 Recall what the colour of a star tells us.

**Light from stars**

All stars emit a full range of wavelengths from the visible spectrum (colours). This means you would observe a complete rainbow if you were to split the star's light into different colours using a prism. However, a star's spectrum peaks at a certain colour, and this is the colour that we observe the star to be.



**Figure 6.12** White light consists of the full range of wavelengths (colours) from the visible spectrum.

**Practical 6.1****Flame tests and observing emission spectra****Aim**

To investigate how emission spectra can be used to determine the metal in unknown substances.

**Materials**

- solutions of copper chloride, potassium chloride, sodium chloride, barium chloride and calcium chloride
- unknown solutions labelled A, B and C (A, B and C should each contain one of the known solutions above)
- wooden splints
- Bunsen burner
- bench mat
- matches
- emission spectrometer

**Procedure****Part 1: Prepare the results table**

Draw the table shown in the results section into your science journal.

**Part 2: Test the known solutions**

- 1 Set up the Bunsen burner with bench mat and attach the Bunsen burner to the gas.
- 2 Turn on the Bunsen burner and adjust to a blue flame.
- 3 Dip the wooden splint into the first solution and place in the flame.
- 4 Observe the colour and record.
- 5 Dip the same splint into the same solution and have your partner observe the flame through the emission spectrometer.
- 6 Draw lines on the results table to match the spectral lines shown through the emission spectrometer. Take note of the very faint dark lines, the most notable being at wavelengths of 4.9 and 5.2 (in hundreds of nanometres).
- 7 Repeat steps 4–6 with the other known solutions using a new wooden splint for each solution.

**Part 3: Test the unknown solutions**

Repeat steps 4–6 and record the colour and emission spectra for the unknown solutions.

*continued...*

**Be careful**

Ensure appropriate personal protective equipment is worn. Be careful not to set the splints alight. Wear safety glasses. Wash hands after practical.

...continued

### Results

Determine the metal present in the unknown solutions, labelled A, B and C and record in the table by drawing lines that match the colours you see. The first row has been completed as an example.

Solution	Flame test	Spectroscope						
	Colour in flame	Colours (wavelength in hundreds of nm)						
		4	4.5	5	5.5	6	6.5	7
<b>Known solution</b>								
Copper chloride	Blue or bluish-green							
Barium chloride								
Calcium chloride								
Sodium chloride								
Potassium chloride								
<b>Unknown solution</b>								
A								
B								
C								

### Discussion

- 1 Determine the identity of the three unknown solutions. Justify your statements with data.
- 2 At which wavelengths would you observe dark lines in the Sun's spectrum? Research which elements are found in the Sun's atmosphere that coincide with spectral lines at those wavelengths.

## Luminosity

When you look at stars in the night sky, you will notice that they also vary in brightness. Astronomers call this **luminosity** and define it as the rate at which a star

**luminosity**  
the intrinsic brightness of a celestial object; the rate at which a star produces energy

produces energy. The scale of luminosity is based around our Sun, which is given a

luminosity of 1. Stars that are brighter than the Sun have a luminosity of greater than 1, and stars that are less bright than the Sun are given a luminosity of less than 1. For example, a star with a luminosity of 100 is 100 times brighter than the Sun. We might assume that the brighter a star is in the sky the closer it is to us. This is often the

case, but not always. Read on to find out what can also affect the brightness of a star.

## Star life cycle

Stars do not have a limitless fuel source. At some point, each star will run out of material to burn and will come to the end of its lifetime. The changes that stars go through in their life time are predictable and depend on their size. A star's life cycle is therefore dependent on its mass as well as the rate at which it is using up its fuel: we can determine this by measuring its luminosity. Generally, the more massive a star, the quicker it uses up its fuel and so the shorter its lifetime. We can also assume that the more luminous a star the shorter its lifetime.

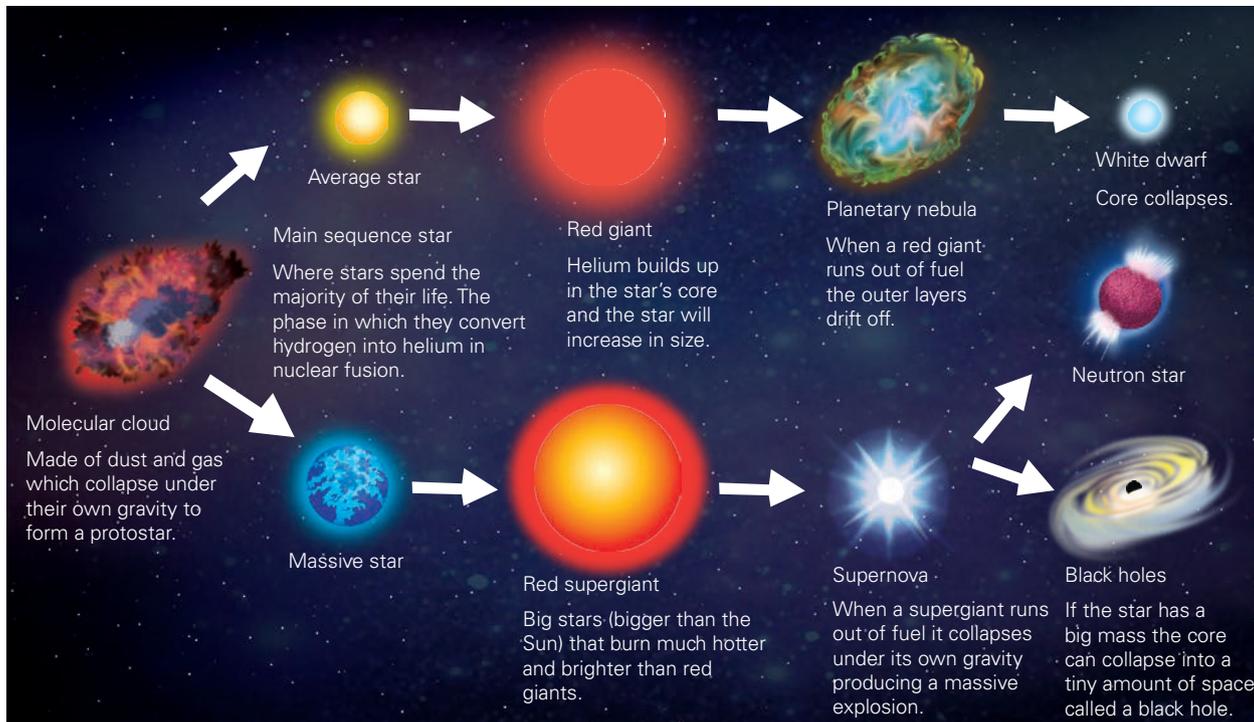


Figure 6.13 The life cycle of stars. How stars change over time depends on their size.

## Explore! 6.2

### Spaghettification and worm holes

Black holes have captured the imagination of astronomy enthusiasts, science fiction writers and astrophysicists alike since their existence was hypothesised in the early 1900s. There are many theories surrounding black holes and how light and matter can interact with them.

- 1 Research the ideas behind spaghettification and worm holes and summarise the main concepts in a few paragraphs.
- 2 Propose what it might look like to watch something travel into a black hole.

## Advances in science 6.1

### The first image of a black hole

#### black hole

the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing, not even light, can escape

#### galaxy

a gravitationally bound system of gas, dust and millions or billions of stars and solar systems

Figure 6.14 shows the first 'image' of a **black hole**, released on 10 April 2019. This is not a photograph, but an image created by the Event Horizon Telescope (EHT) project. A network of eight radio observatories

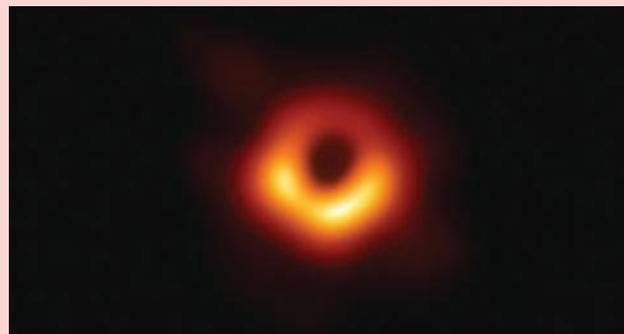


Figure 6.14 The black hole at the centre of galaxy Messier 87

on four continents collected data of a black hole in a supergiant elliptical **galaxy** for 10 days in order to capture the image. Scientist Dr Katie Bouman developed an algorithm called CHIRP to sift through the enormous amount of data gathered by the EHT project. The algorithm created an image using the data.

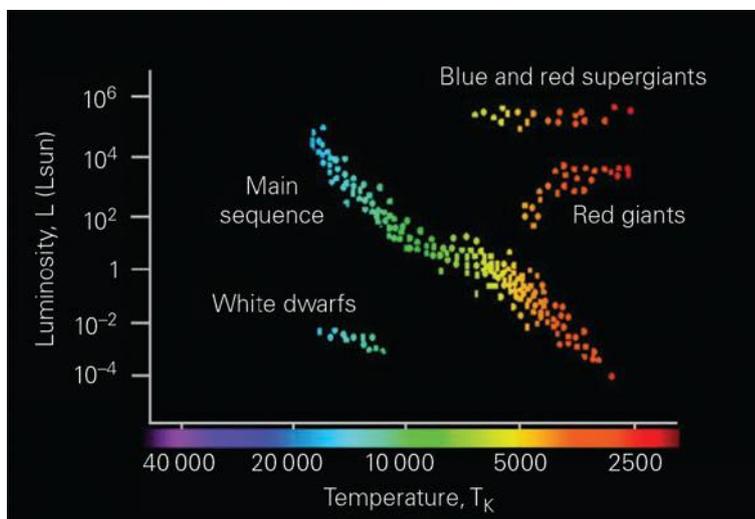
The black hole itself is unseeable, as it's impossible for light to escape from it; what we can see is its event horizon, or the golden ring in the image. The event horizon is the boundary around a black hole beyond which no light or other radiation can escape the massive gravitational pull of the black hole. Objects that pass into the event horizon go through spaghettification (refer back to your research in Explore! 6.2).

## Hertzsprung–Russell diagrams

**H–R diagram**  
a graph where the star luminosity is plotted against spectral type/temperature (Hertzsprung–Russell diagram)

A Hertzsprung–Russell or **H–R diagram** is a plot of star brightness (measured as luminosity) against star temperature/colour. In Figure 6.15, you can see a diagonal band of coloured dots that represent stars in the main sequence. Red giants, supergiants and white dwarfs make up their own section of the graph.

Remember, the luminosity scale gives us an idea of how bright a star is compared to our Sun. Stars with a luminosity of 1 are as bright as our Sun.



**Figure 6.15** A Hertzsprung–Russell diagram plots star brightness (luminosity) against surface temperature.

### Section 6.2 questions

#### Remembering

- 1 **Recall** the temperature and luminosity of our Sun.

#### Understanding

- 2 **Describe** the process by which a star forms.
- 3 **Explain** the two factors that determine how bright a star appears from Earth.

#### Applying

- 4 Obtain a copy of a H–R diagram and plot the following stars on it:

Star	Temperature (K)	Luminosity (Sun = 1)
Sirius	9940	25.4
Canopus	7350	10700
Arcturus	4290	170
Alpha Centauri	5790	1.5
Vega	9602	40
Rigel	11 000	120 000
Betelgeuse	3500	140 000

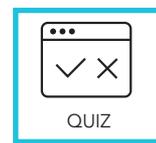
- a **Identify** which of the stars you have plotted is a red supergiant.
  - b **Identify** which of the stars you have plotted is most like our Sun.
  - c **Determine** the colour of Canopus. How do you know?
  - d **Determine** approximately how many times brighter Sirius is compared to the Sun.
  - e Will Rigel's lifetime be longer or shorter than the Sun's? **Explain** your answer.
- 5 **Describe** the relationship between star brightness, size and length of lifetime. **Explain** why this is the case.

#### Analysing

- 6 **Propose** a reason why nobody has ever seen a black hole. How do we know that they are there?

#### Evaluating

- 7 **Consider** the observable features of stars and how they relate to each other.



## 6.3 Beyond the Milky Way

### Learning goals

- 1 To classify galaxies in terms of their shape
- 2 To describe the differences in sizes and distances between structures in the universe



All the stars that you can see in the night sky are within the Milky Way. It is mind-boggling to imagine the immense distances in space unless some things are put in perspective. Our closest star is the Sun and it takes 500 seconds (about eight minutes) for light to travel from the Sun to Earth (a distance of 150 000 000 km).



The closest star to our solar system is Alpha Centauri. Light takes 4.4 years to travel from Alpha Centauri to Earth. Our solar system is positioned on an outer arm of the Milky Way Galaxy and it takes light 106 000 years to travel across it.

How do galaxies stay together if the stars and planets are so far away from each other? Gravity is what keeps them together. Every object in the universe exerts a gravitational force on all other objects. Although the attraction is weak, this is what keeps planets in orbit and galaxies together.

### Galaxies

Galaxies are classified by their shape, according to the Hubble galaxy classification scheme. Galaxies can be classified as elliptical, lenticular, spiral or irregular.

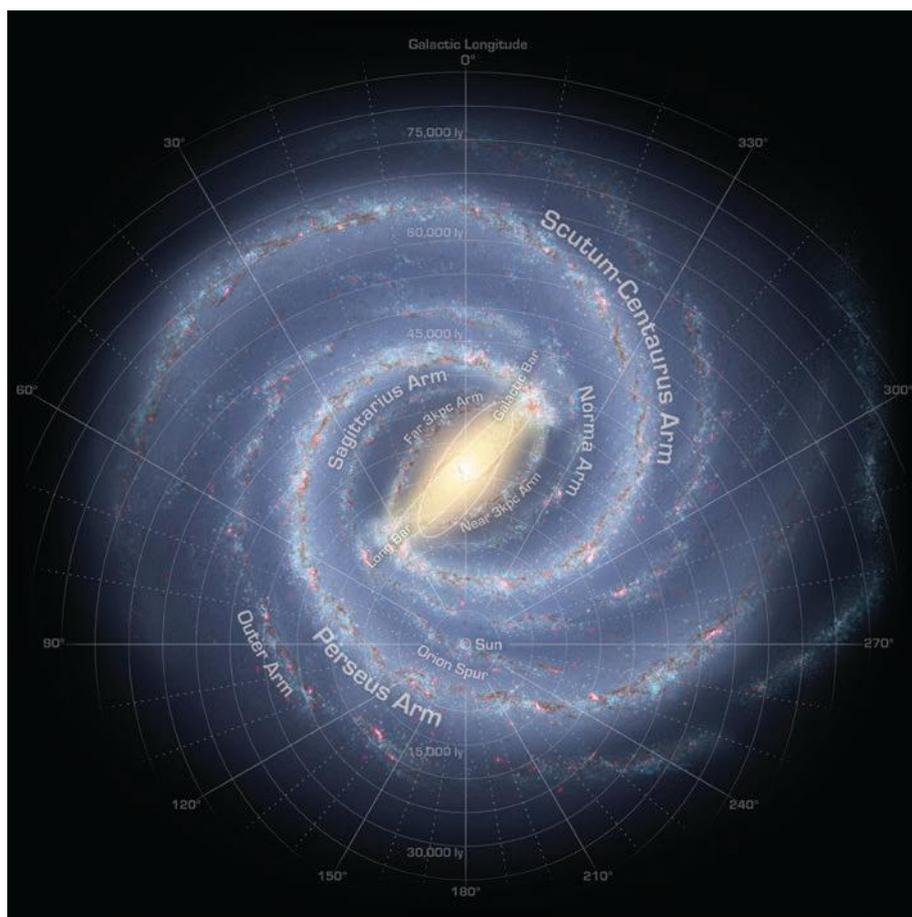


Figure 6.16 Our solar system sits on the Orion arm of the Milky Way.

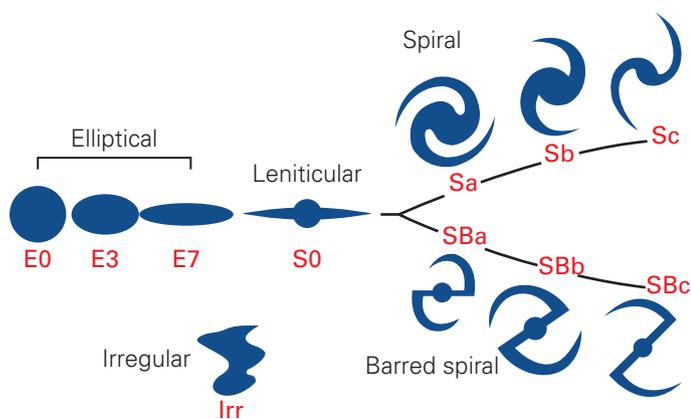


Figure 6.17 Hubble's galaxy classification scheme

### Try this 6.1

#### Classifying galaxies

Astronomers now have so many photos of galaxies that they simply do not have the time to classify them all. A group of astronomers has set up a crowd-sourced astronomy project called Galaxy Zoo that allows anyone to take part in some real science. You can try this too.

Search for Zooniverse Galaxy Zoo on the internet and you can have a go at classifying galaxies for yourself. You will be shown a galaxy and asked a series of questions about what you can see and the shape of the galaxy. Do not be afraid that you will get it wrong – the galaxies are shown about 30 different times to make sure that the responses are consistent.

### Quick check 6.4

Classify the following galaxies using Hubble's classification scheme.



### Astronomical distances and the speed of light

Light travels at a speed of 300 million metres every second, or  $3 \times 10^8$  m/s. A **light year** is a unit of distance equivalent to how far light travels in a year, which is equal to 9.46 trillion kilometres.

**light year**  
the distance that light travels in one year (about 10 trillion km)

### Try this 6.2

#### Cheese and light

Use your microwave to calculate the speed of light!

- 1 Open your microwave and remove the rotating platform.
- 2 Line a dinner plate with cheese singles and place it in the microwave.
- 3 Turn on the microwave for about 10 seconds or until small hotspots start to form on the layer of cheese.
- 4 Take the plate out of the microwave and measure the distance between two of the hotspots. This value will be half of the wavelength of the microwave radiation.
- 5 Locate the frequency of your microwave, in hertz (Hz), which should be listed inside the door.
- 6 Use the formula  $v = f\lambda$ , where  $v$  is the speed in m/s,  $f$  is the frequency in Hz and  $\lambda$  is the wavelength in m, to calculate the speed of light (remember to multiply your hotspot measurement by two to get the wavelength). Compare it to the actual value.

#### Be careful

Handle with care as cheese may be extremely hot.

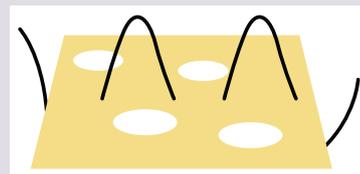


Figure 6.18 A microwave wave heating up a slice of cheese

## Parallax

If you hold your index finger in front of you at arm's length and close one eye, then swap eyes and close the other one, your finger will appear to move because you

### parallax

the effect by which the position of an object seems to change when it is observed from different locations

### astronomical unit

the distance between Earth and the Sun

### baseline

a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

### parsec

the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

are essentially observing your finger from a different location. The same thing happens when we look at the stars in the night sky from a different position in space. As Earth travels around the Sun, our position in space changes and we see the stars arranged slightly differently. We can measure the angle between the apparent location of a nearby star and a 'fixed' distant star. This is called the **parallax**

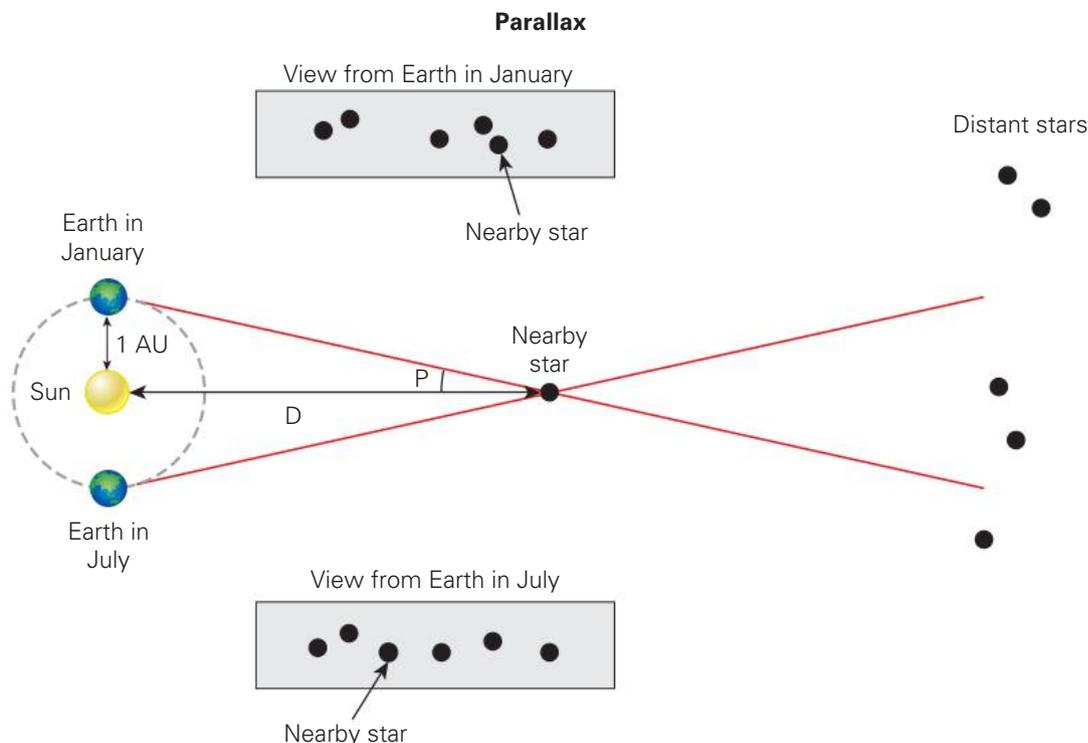
angle. Using the distance between Earth and the Sun (the **astronomical unit** or AU) as the **baseline** and some trigonometry, we can work out how far the star is from Earth.

This technique enables us to measure distant stars in **parsecs** (pc): one parsec is equal to 3.26 light years or 30 trillion kilometres.

Using parsecs to measure distance makes it easier to calculate distances with the following formula:

$$\text{Distance to star (in pc)} = \frac{1}{\text{parallax angle (in arcseconds)}}$$

The further away a star is, the less it appears to move due to parallax, and the smaller the parallax angle becomes. This gives a limit to the distance that we can measure using the parallax method, because when stars are too far away, their parallax angle is too small to measure.



**Figure 6.19** Astronomers can work out the distance to nearby stars by comparing their apparent location relative to the background of distant stars (which are unaffected by parallax).

### Quick check 6.5

- 1 Does a light year measure time or distance?
- 2 Will a closer star have a larger or smaller parallax angle?

## Practical 6.2

### Parallax

#### Aim

To investigate the use of parallax angles to reliably calculate distance.

#### Materials

- an 'object' (something that can be placed in the middle of the school oval and be visible from the perimeter)
- 2 rulers
- large protractor
- trundle wheel

#### Procedure

##### Part 1: Prepare the results table

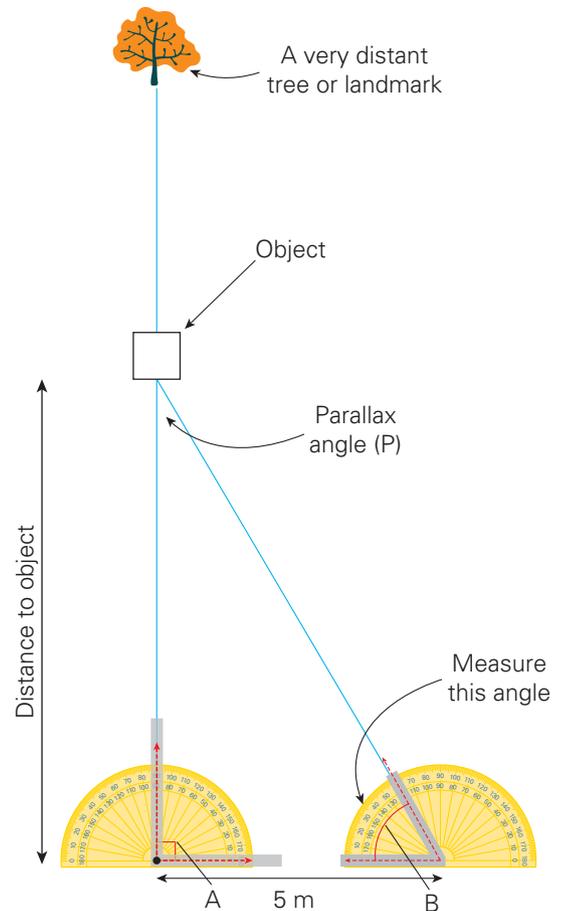
Draw the table shown in the results section into your science journal. You will be collating your results with the class to analyse the reliability of this method.

##### Part 2: Set up the distances

- 1 Your teacher will place an object in the middle of the school oval (the whole class will determine the distance to this one object).
- 2 Find a location near the perimeter of the oval where the object lines up with a distant landmark; for example, a tree, the edge of a fence, a gate, the edge of a building or a flagpole.
- 3 At this location, use the two rulers and protractor to make a right angle, angle (A) perpendicular to the line going through the object and the landmark, as shown in the diagram.
- 4 Measure out a 5 m line along this perpendicular direction (this will be your baseline).
- 5 At the end of the 5 m line, use the two rulers and protractor to measure angle (B) (between the base line and the ruler directed towards the object). (You may have to lie on your stomach to line up the objects by sight.)

#### Results

- 1 Calculate the parallax angle ( $P$ ) by subtracting the angle (B) from  $90^\circ$ .
- 2 Use trigonometry  $D = \frac{5}{\tan(P)}$  to calculate the distance ( $D$ ) to the object.
- 3 Use the trundle wheel to measure the actual distance to the object.
- 4 Calculate the relative error.
- 5 Combine data on a class board or spreadsheet.
- 6 Draw a scatter plot to analyse the relationship between the distance to the object and its parallax angle.
- 7 Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.



*continued...*

...continued

	Baseline distance (m)	Angle B (°)	Angle P = 90 – Angle B (°)	Calculated distance to the object (m)	Measured distance to the object (m)	Relative error $\frac{\text{Measured distance} - \text{Calculated distance}}{\text{Measured distance}} \times 100$
Group 1	5					
Group 2	5					
Group 3	5					
Group 4	5					
Group 5	5					
Group 6	5					
Mean	5					

**Discussion**

- 1 Describe the relationship between the parallax angle and the calculated distance.
- 2 Describe the amount of relative error for your own calculations and the mean relative error for the class group.
- 3 Instrument error is one factor that could affect the precision of the experiment. Were other factors that could affect the validity of the results successfully controlled during the experiment? Justify your reasoning.
- 4 Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

**Doppler effect**

a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer

**blue shift**

a spectrum shifted towards shorter wavelengths

**red shift**

a spectrum shifted towards longer wavelengths

**The Doppler effect**

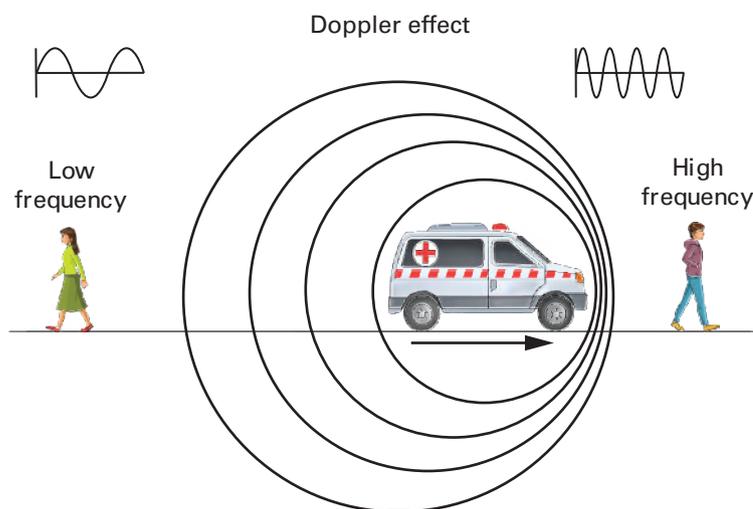
When you hear an ambulance travelling past you, the pitch of the siren changes as it passes. When the ambulance is travelling towards you, the sound wave is a little more squashed than usual and results in a higher frequency wave. You hear it

as a higher pitch. When the ambulance is travelling away from you, the sound wave is a little more stretched than usual and

results in a lower frequency wave. You hear it as a lower pitch. This phenomenon is called the **Doppler effect**.

The same phenomenon happens with light waves if an object is travelling fast enough. When the object is travelling towards you, the light it emits is of a higher frequency, which translates to the light appearing more blue. This is called **blue shift**. When the object is travelling away from you, the light it emits is of a lower frequency, which translates to the light appearing more red. This is called **red shift**.

When astronomers look at spectra from distant galaxies, they find that the emission lines are almost always shifted towards the red part of the spectrum. This tells us that the vast majority of galaxies in the universe are moving away from us.



**Figure 6.20** Sound waves are squashed together as the ambulance travels into them, so we hear a higher pitch. Sound waves are spread out as the ambulance moves away from them, so we hear a lower pitch.

## Travelling large distances

Interstellar travel (that is, travelling outside our solar system) throws up quite a few problems. These problems relate to the vast distances that we would need to travel in order to find and inhabit a new planet. Light takes just over four years to reach the closest star to our solar system, Alpha Centauri. We cannot travel even remotely

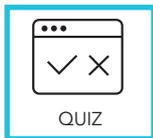
near the speed of light with current technology. Even if we develop such technology in the future, travelling close to the speed of light has its own problems: it would not only require an enormous amount of energy to accelerate a conventional space ship leaving the earth to 99% of the speed of light, but an equally enormous amount of energy to decelerate at journey's end.

### Advances in science 6.2

#### Dr Abigail Allwood

Dr Abigail Allwood is the first female and first Australian principal investigator on a NASA Mars Rover mission searching for evidence of life on Mars. She grew up in Brisbane and studied stromatolites, detection of life on other planets and evolution of life on early Earth at Queensland University of Technology and Macquarie University in Sydney.

## Section 6.3 questions



### Remembering

- 1 **Define** the term 'light year' in your own words.
- 2 **Recall** the units used to measure parallax angle and star distance.

### Understanding

- 3 **Explain** why an ambulance siren changes to a slightly lower pitch as it drives past you.

### Applying

- 4 An astronomer collects data from a star in January and then again in July and finds that its parallax angle is 0.8 arcseconds. **Calculate** the distance to the star. Express your answer in parsecs and light years.

### Analysing

- 5 **Explain** what happens to the colour of light when stars move towards one another.

### Evaluating

- 6 An astronomer finds that the spectral lines from a distant galaxy are shifted towards the red part of the spectrum. **Propose** what this tells us about the galaxy and what it implies about the universe.

## 6.4 The Big Bang

### Learning goals

- 1 To appreciate how scientific thinking is refined over time
- 2 To recall how the universe began
- 3 To describe the evidence to support the Big Bang theory
- 4 To explain how this evidence supports the Big Bang theory

### The beginnings of a theory

Albert Einstein, a theoretical physicist, developed the theory of General Relativity between 1907 and 1915. He proposed the existence of a ‘cosmological constant’, a term that he pioneered in 1917. The implication of it was that the universe was static or non-evolving.

In 1927, Georges Lemaître, a Catholic priest, astronomer, mathematician and cosmologist, published a solution to the equations of General Relativity that built the case for an expanding universe. This was radically different to what the scientific community believed at that time.



**Figure 6.21** Georges Lemaître was also a professor of physics at the Catholic University of Louvain in Belgium.

In 1929, Edwin Hubble and his team published a paper demonstrating that other visible galaxies seemed to

be speeding away. This supported Lemaître’s views.

At this point, Einstein revised his equations,

dropping the cosmological constant and accepted the expanding universe.

By 1930, the expanding model of the universe was generally accepted by cosmologists to be unsatisfactory. As you can see, the scientific community is constantly reviewing their knowledge base with each new discovery and advances in technology.

Lemaître explored the consequences of the expanding universe even further. He reasoned that since the universe was expanding, then at some point in the past, it must have originated from an initial point. He proposed that the beginning of the universe came from a single point he called the ‘Primeval Atom’. It was a bold proposal, and the scientific community met it with scepticism. Yet this idea was the start of what we are now familiar with: the Big Bang theory.

The term ‘big bang’ was first used by steady state astronomer Fred Hoyle while he was on a radio talk show for the BBC in 1949. The term stuck. However, it took another thirty years for the expanding universe to be generally accepted. It was the discovery of **cosmic microwave background radiation** in 1964, by Arno Penzias and Robert Wilson, both radio astronomers, that proved conclusive. Lemaître died in 1966 and lived just long enough to see his theory finally accepted.

Our present theories about the origin of the universe continue to evolve. The inflationary model, dark energy and dark matter are all currently being investigated, and a new generation of telescopes (e.g. the James Webb Space Telescope) are being built. Over the last 100 years the scientific community has been constantly reviewing and refining theories about the origin of the universe in accordance with new discoveries.

**cosmic microwave background radiation**  
electromagnetic radiation left over from the early stages of the universe

**Quick check 6.6**

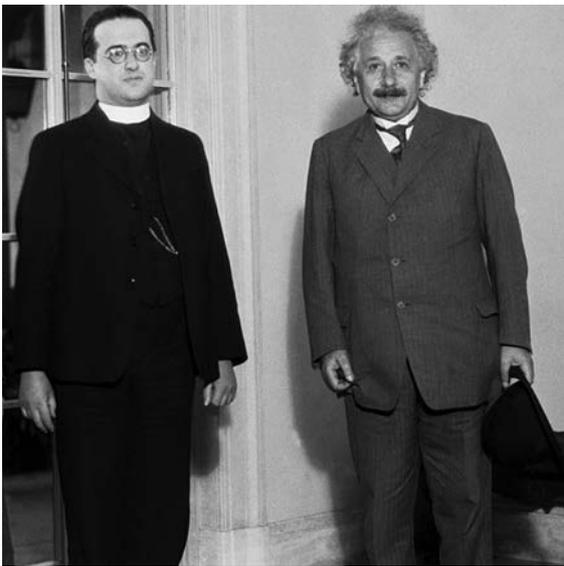
What discoveries supported Lemaître's model of the expanding universe?

**Explore! 6.3****Contributions of countless many**

It would be impossible to name every single individual involved in shaping our understanding of the universe to what it is today. Conduct some research on Jocelyn Bell Burnell and Alan Guth and summarise their contributions. How does their work link directly or indirectly to the Big Bang theory?



**Figure 6.22** Jocelyn Bell Burnell (left) and Alan Guth (right) are two of the countless great minds in the modern era.



**Figure 6.23** Lemaître and Einstein met on several occasions, one of which was at Lemaître's lecture at the California Institute of Technology.

**Evidence for the Big Bang**

The Big Bang theory suggests that the universe was created 13.7 billion years ago from a very small, yet very dense **singularity**. Three main pieces of evidence support the Big Bang theory:

- Almost all galaxies are red shifted, which means that almost all galaxies are travelling away from each other. This suggests that the universe is expanding.
- The abundance of smaller elements in the universe is

consistent with them being created in a Big Bang and not inside stars through nuclear fusion.

- Radiation left over from the Big Bang, called cosmic microwave background radiation, is consistent with the rate of cooling calculated from such an explosion.

**Cosmic microwave background**

Radiation is the name that we give to all frequencies of the electromagnetic spectrum. Radiation was emitted from the Big Bang, and we can still observe that radiation today. It exists in the form of very low-frequency waves, even lower frequency than radio waves, and was discovered in the 1960s, almost by accident. Two radio astronomers noticed a subtle continuous buzzing that came from the skies and initially thought that it was some type of interference coming from their antenna. They soon realised they were detecting the cosmic microwave background.

**singularity**  
a point at which infinitely dense matter occupies an infinitely small space

When discrete particles of radiation (photons) are emitted in space, they continue to radiate outwards forever. This is just like if you threw a tennis ball in space – it would continue its motion forever according to Newton's first law. For example, when we look at the light from Alpha Centauri, it has taken 4.4 years to reach

Earth, so we are actually looking 4.4 years back in time. So, when we observe cosmic microwave background radiation, we are looking back in time to the earliest observable light in the universe. These photons were emitted just under 13.7 billion years ago!

#### dark energy

a theoretical force responsible for accelerating the expansion of the universe

### Dark energy

We know that the universe is expanding because of the fact that light from other

galaxies is red shifted. What is really interesting is that galaxies are not just moving away from all other galaxies, but they are doing so at an accelerating rate. It seems that there is some sort of unobservable pressure that is making the universe expansion rate accelerate. This unknown pressure has been termed **dark energy**. It is amazing to think that in the future, the universe may have expanded so vastly that all other galaxies will be outside our observable universe, so we will not actually be able to see anything beyond our own galaxy!

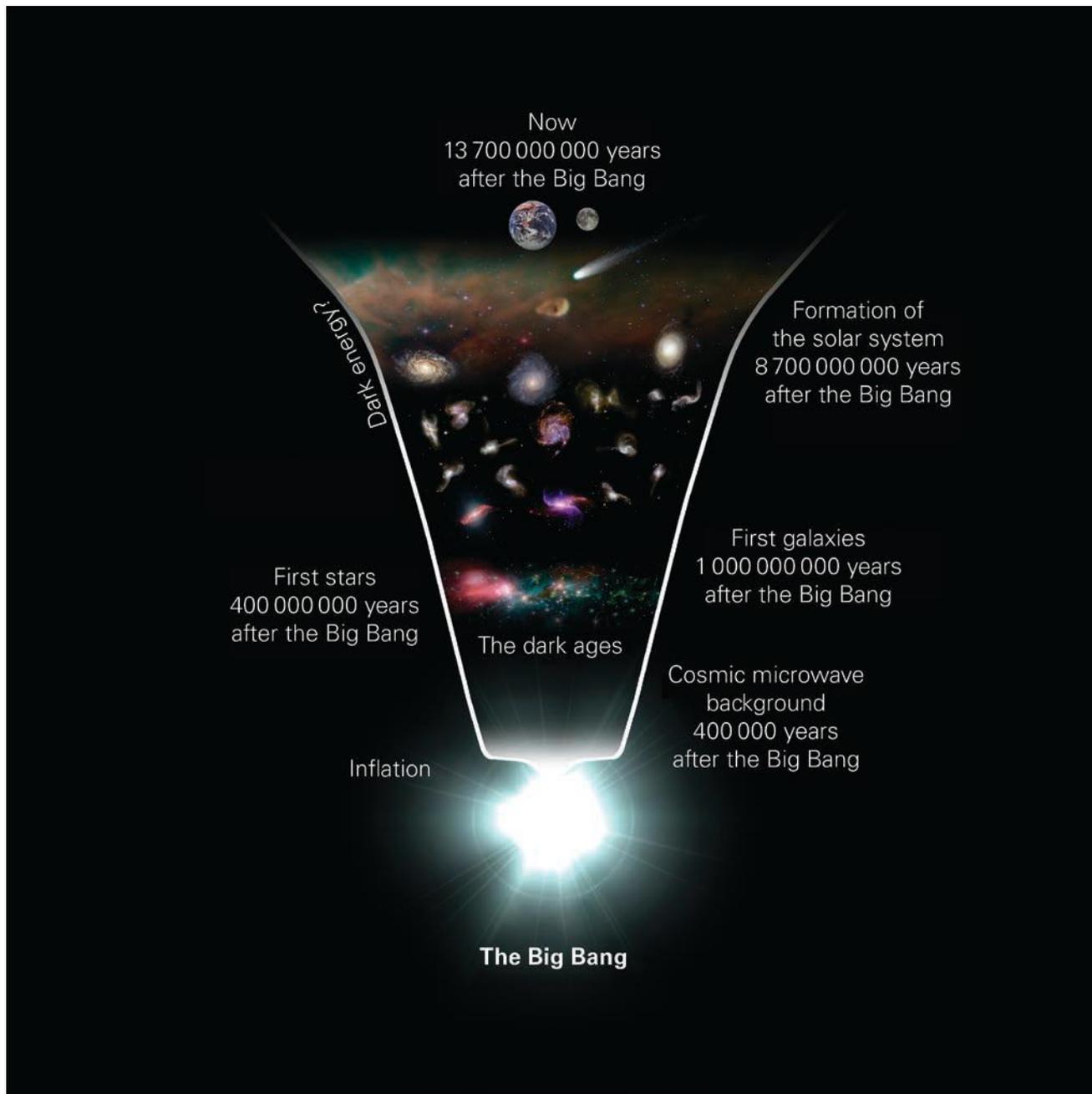
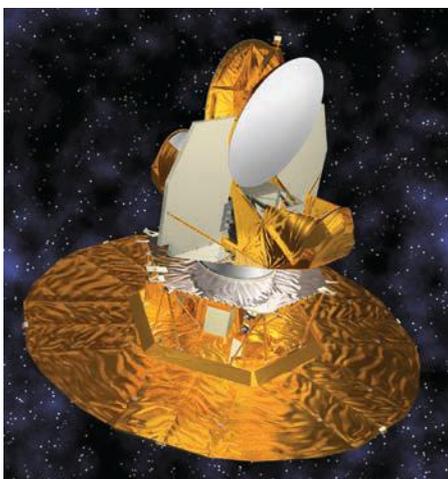
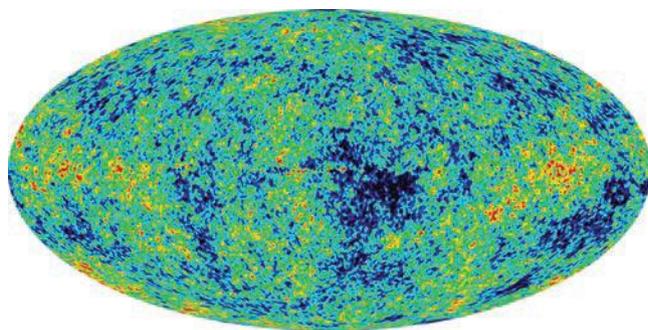


Figure 6.24 The history of the universe



**Figure 6.25** The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft operated in the early 2000s to collect temperature data from the cosmic microwave background.



**Figure 6.26** Data collected from WMAP was used to give a temperature map of what the universe looked like shortly after the Big Bang.

### Advances in science 6.3

#### Professor Brian Schmidt

Professor Brian Schmidt, Australian National University, was one of the scientists who discovered that the universe's expansion rate is accelerating rather than decelerating. He received the Nobel Prize in Physics in 2011 for his discovery.



**Figure 6.27** Nobel Prize laureate, Professor Brian Schmidt

#### Age of the universe

Edwin Hubble made his observations about galaxies in the 1920s, and observed that many 'clouds' of dust and gas were actually distant galaxies. He noticed that these distant galaxies were different sizes and concluded that the smaller ones must be further away. While this assumes that all galaxies are the same size, which they are not, it is nevertheless a pretty good approximation at these distances.

Hubble calculated the **recessional velocity** of the galaxies (that is, the speed that they are travelling away from us) by recording the red shift of their spectra. The further the spectral lines are shifted towards red, the faster the galaxy is moving. Hubble found that the further a galaxy is from us, the faster it is travelling away from us, so he proposed a relationship between distance and recessional velocity. This relationship is called **Hubble's law**.

**recessional velocity**  
the relative rate at which a star is moving away from Earth

**Hubble's law**  
the further away a galaxy is, the faster it is moving away from Earth



**Figure 6.28** Edwin Hubble, one of the most important astronomers of all time

Hubble's law demonstrates that the universe is not just expanding outwards from Earth, but rather it is expanding from everywhere. If it was only expanding away from Earth, then the recessional velocity would be the same for all galaxies.

### Practical 6.3

#### Modelling the expanding universe

##### Aim

To model the expanding universe with a balloon and evaluate the limitations of the model.

##### Materials

- balloon
- small dot stickers
- permanent marker
- piece of string around 40 cm long
- ruler
- paperclip
- stopwatch

##### Procedure

##### Part 1: Prepare the results table

Draw the table shown in the results section into your science journal.

##### Part 2: Set up the model

- 1 Partially blow up the balloon to about 10 cm in diameter and secure the end with a paperclip (do not tie the balloon as you will need to further inflate it later).
- 2 Stick six dots on the balloon at random points and label one H (for home) and the others A, B, C, D and E. The home dot represents the Milky Way and the other dots represent neighbouring galaxies. You may add more than five neighbouring galaxy dots if you like.

##### Part 3: Measure the variables

- 1 Use the string and ruler to measure the distances HA, HB, HC, HD and HE, and record them in the results table under  $D_1$ .
- 2 Remove the paperclip, then fully inflate the balloon, timing how long it takes you to do this with the stopwatch. Tie the balloon off.
- 3 Measure the five distances again and record them in the results table under  $D_2$ .

##### Results

Position on balloon	$D_1$ (cm)	$D_2$ (cm)	Mean speed (cm/s) $= \frac{(D_2 - D_1)}{t}$
HA			
HB			
HC			
HD			
HE			

- 1 Calculate the mean speed that each dot was moving away from the home dot in the time ( $t$ ) it took you to blow up the balloon, by using mean speed  $= \frac{(D_2 - D_1)}{t}$ .
- 2 Draw a scatter plot to analyse the relationship between mean speed (on the y-axis) and the  $D_2$  (on the x-axis).
- 3 Add a line of best fit to the graph if possible. Note the type of line that fits best to reflect the relationship between the two variables.

*continued...*

...continued

### Discussion

- 1 Describe the trend or pattern that is found when the line of best fit was applied to the graph. What type of relationship was found?
- 2 Suggest how you apply this relationship to understanding the movement of galaxies and expansion of the universe.
- 3 Predict the misconception that might arise if you drew the galaxies on with the marker rather than using stickers.
- 4 Evaluate the limitations of using a balloon as a model for 3D space and suggest a better model.
- 5 Can a valid conclusion regarding the expansion of the universe be drawn from modelled experiments such as this one? Support your statement using data and limitations of the model.
- 6 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 reliability or validity of the data.

## Section 6.4 questions

### Remembering

- 1 **Recall** the age of the universe.
- 2 **List** the evidence that supports the Big Bang theory.

### Understanding

- 3 **Discuss** the assumption that Hubble made about galaxies and what he concluded about galaxies that appeared smaller than others.

### Applying

- 4 **Explain** why the abundance of smaller elements in the universe gives evidence for the Big Bang.

### Analysing

- 5 **Describe** the relationship between dark energy and the Big Bang theory.

### Evaluating

- 6 Imagine a Year 6 student asked you how big the universe is. **Propose** one way to demonstrate the enormous size of the universe.
- 7 **Propose** how theories and discoveries work together to refine scientific thinking. Use how we think about the origin of the universe as an example.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>6.1 I can summarise the changes in the model of the universe that have been proposed over time.</b> e.g. Contrast the heliocentric and geocentric models of the universe.	
<b>6.2 I can describe the formation and life cycle of different stars.</b> e.g. Recall how a red giant is formed.	
<b>6.3 I can determine the distance that stars and galaxies are from Earth.</b> e.g. Recall how parallax can be used to measure distances in space.	
<b>6.3 I can describe the Doppler effect.</b> e.g. Contrast red shift and blue shift.	
<b>6.4 I can describe the Big Bang.</b> e.g. Explain how cosmic microwave background is considered evidence for the Big Bang.	



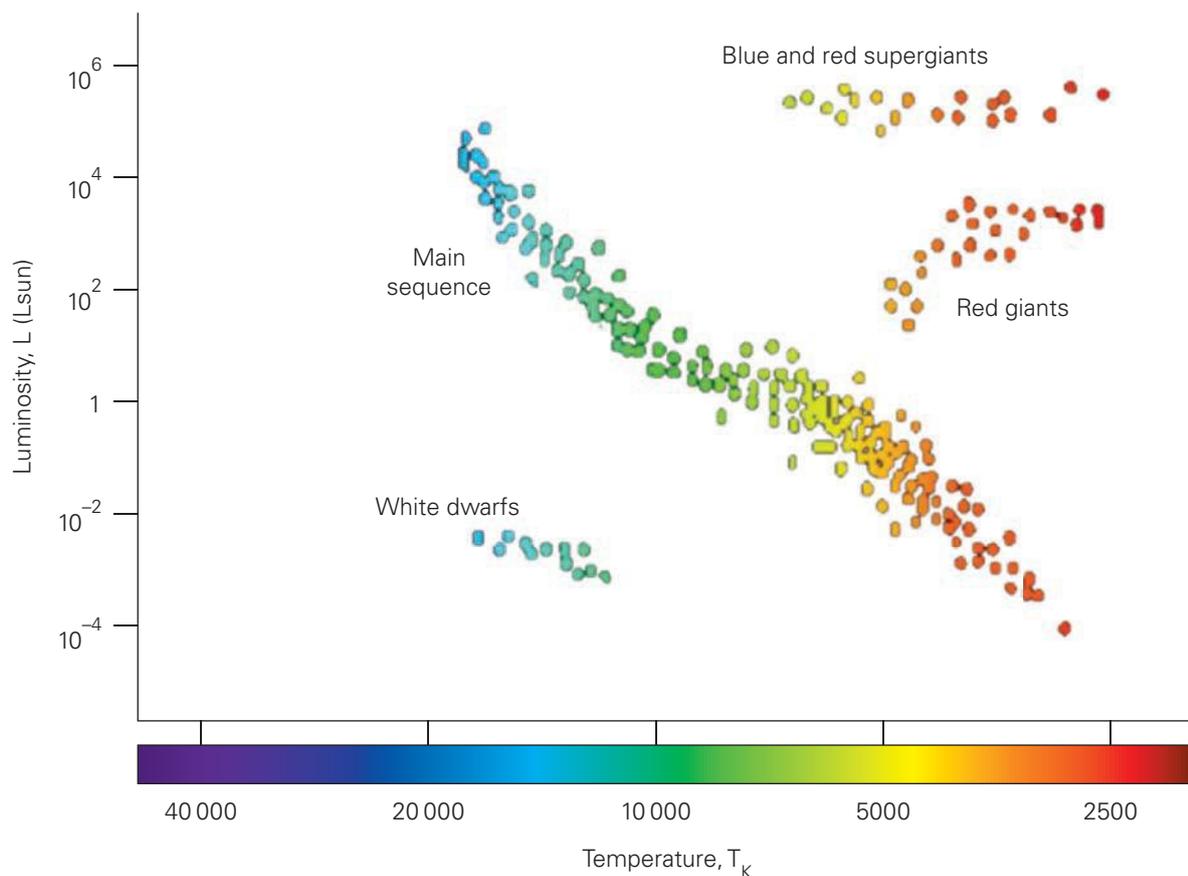
## Reflections

- 1 What **connections** come to mind when you think about the universe and your everyday life?
- 2 What new concepts have **extended** your thinking about the universe?
- 3 What information did you find **challenging** or confusing?



## Data questions

The universe is home to billions of stars, many much larger and much brighter than the star we call 'the Sun'. Figure 6.29 presents a selection of stars in our universe and shows their surface temperature and luminosity. As a reference, the Sun has a luminosity of 1 and a surface temperature of approximately 5800 K. The stars in Figure 6.29 belong to four different categories depending on their properties: the main sequence, white dwarfs, red giants, and blue and red supergiants.



**Figure 6.29** A Hertzsprung–Russell diagram illustrating the surface temperature and luminosity of various stars in the universe

- Identify** the category of star to which our Sun would belong.
- Determine** which category of star is most luminous.
- The x-axis provides the star surface temperature in units of kelvin ( $^{\circ}\text{C} = \text{K} - 273$ ). Given the surface temperature of the Sun is 5800 K, **calculate** the surface temperature in  $^{\circ}\text{C}$ .
- Identify** the trend of surface temperature and luminosity of stars in the main sequence.
- Contrast** the properties of white dwarfs and red giants.
- Identify** any patterns occurring in the properties of blue and red supergiants.
- A large star has been discovered and classified as a main sequence star with a surface temperature of 25 000 K. **Deduce** the luminosity of this star compared to the Sun.
- New data have suggested that this new star (from Question 7) is almost 100 000 years old, its surface temperature is cooling and it is becoming slightly more luminous. **Predict** the category this star will belong to as it changes properties from the main sequence.
- Compare** the properties of all four categories of star. Do you think the size of a main sequence star will ultimately determine whether it becomes a supergiant/giant/dwarf?

## STEM activity: Creating a representation of our solar system to scale

### Activity instructions

The scale of the universe is immense. In this activity you will collaborate in groups to create a representation of our planetary system to scale, using hands-on materials, while recording your journey. The scale model must include all the planets and known

dwarf planets. You will need to make sure that your scale model helps others gain a better idea of the vastness/true size of our solar system. To do this, you will need to make sure that you find a way (for example, a formula) to convert distances and diameters of planets into something humans can comprehend.

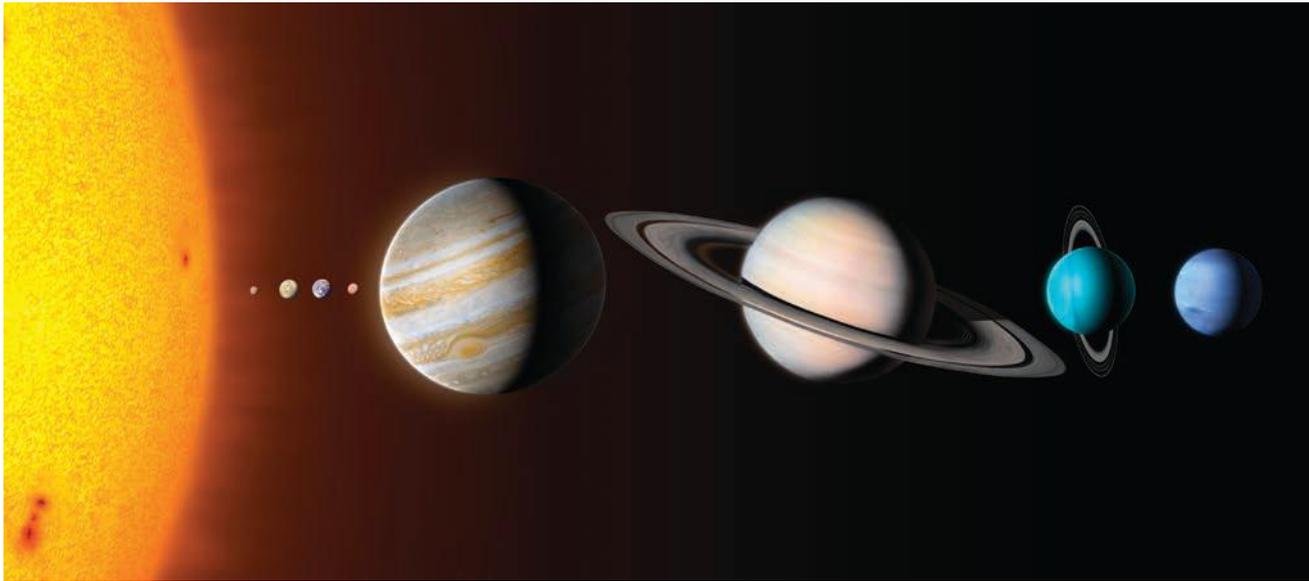


Figure 6.30 A representation of our solar system where the distances are not to scale, but the sizes are to scale.

**Design brief:** Design a scale model of the universe and present this information in the form of a vlog (video blog or video log).

### Suggested materials

#### Model

- a basketball or soccer ball (the Sun)
- large reel of measuring tape
- colouring pencils, cardboard and paper to create your planets
- protractor
- scissors
- movie-maker software and recording device

Note: You may need to use the school oval to really represent the distances involved.

### Research and feasibility

- 1 Using the information in Table 6.2 on the following page, research how you could create a formula to assist you to convert all values from millions of kilometres to more manageable units (metres or centimetres). What skills do you need to perform that task? Record all information on your vlog.
- 2 Discuss in your group the feasibility of presenting the scale model within the restrictions of school. List your ideas of how to demonstrate the vast size of the solar system.

- 3 Record your research and results as the Research and feasibility section of your vlog.

### Design and sustainability

- 4 Analyse Table 6.2 and make a statement about how the orbital period of a celestial body is affected by its distance from the Sun. Explain your reasoning.
- 5 The dwarf planet Haumea has been described as 'eccentric' by its discoverers. Analyse Table 6.2 and determine which bit of data shows how

this dwarf planet is very different from other dwarf planets.

- 6 Planets orbit around the Sun on elliptic orbits.
- Compare and contrast the average distance from the Sun of planets and dwarf planets.
  - How do the orbits of dwarf planets compare (visually) to the orbit of inner planets in our solar system? You can draw or sketch your answer if you like.
- 7 Record your analysis as a Design and sustainability section of your vlog.

Name of planet	Average distance from Sun (km)	Diameter (km)	Time to spin on axis	Time to orbit Sun	Distance scale (m)	Diameter scale (cm)
Mercury	57 900 000	4878	59 days	88 days		
Venus	108 160 000	12 104	243 days	224 days		
Earth	149 600 000	12 756	23 hours, 56 mins	365.25 days	2	10
Mars	227 936 640	6 794	24 hours, 37 mins	687 days		
Jupiter	778 369 000	142 984	9 hours, 55 mins	11.86 years		
Saturn	1 427 034 000	120 536	10 hours, 39 mins	29 years		
Uranus	2 870 658 186	51 118	17 hours, 14 mins	84 years		
Neptune	4 496 976 000	49 532	16 hours, 7 mins	164.8 years		
<b>Dwarf planets</b>						
Ceres	413 900 000	950	9 hours, 5 minutes	4 years, 220 days		
Pluto	4 436 820 000 to 7 375 930 000	2370	6 days, 9 hours	248 years		
Haumea	5 260 000 000 to 7 708 000 000	1960 × 1518 × 996	4 hours	258 years		
Eris	5 665 500 000 to 14 634 000 000	2326	7 hours, 46 minutes	557 years		

**Table 6.2** Some information about planets and dwarf planets within our solar system

### Create

- 8 Create your 2D solar system model. Make sure to include your scale.
- 9 Record the whole creation of your 2D model in the Create section of your vlog.

### Evaluate and modify

- 10 Edit your vlog into a video file that can be shared.
- 11 Reflect on how effective your vlog is in demonstrating the vastness of our solar system.
- 12 Present your vlog to the class and discuss the use of vlogs to share information, and the effectiveness of its use.

# Chapter 7

## Our changing Earth

### Inquiry questions

How does the movement of tectonic plates affect the Earth?

Why do tectonic plates move?

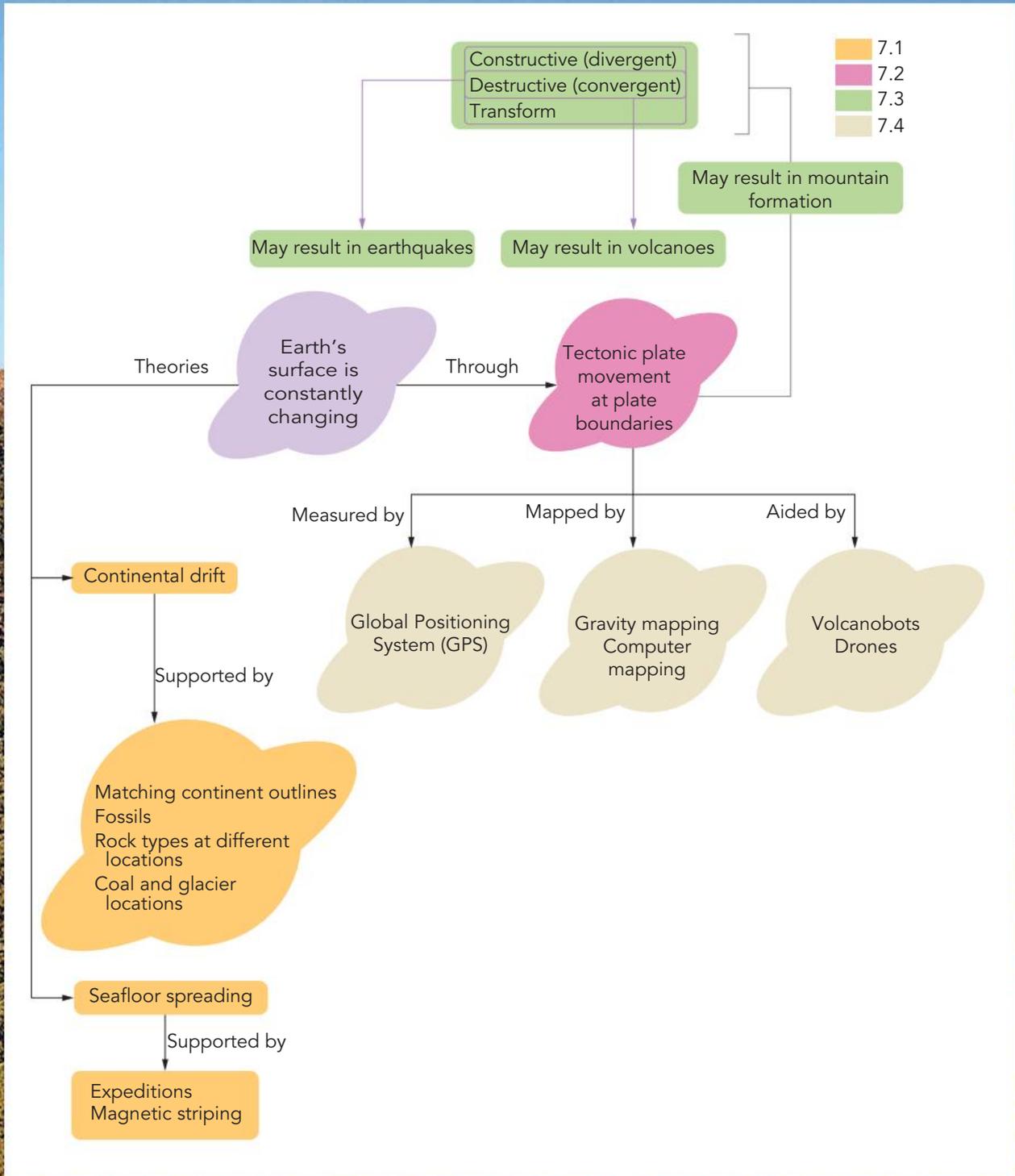
Why have technological developments improved our understanding of geological activity?



### Chapter introduction

Our knowledge of how the world works continuously improves and deepens with the addition of new information from discoveries and experiments. It was not so long ago that it was thought that Earth's surface was like the skin of an apple – unbroken. In this chapter, you will learn how changing ideas about the structure of Earth have led to a greater understanding of why geological natural disasters occur. You will look at the impact of these natural disasters and how early detection methods using modern technology have reduced their impacts.

# Chapter map



# 7.1 Continent movement theories

## Learning goals

- 1 To recall the theory of continental drift and the evidence supplied for this theory
- 2 To describe how sea-floor spreading contributed to our understanding of plate tectonics
- 3 To explain how patterns in rock magnetism give evidence for plate tectonics



Since the late sixteenth century, scientists have speculated that continents may have drifted on the Earth's surface. In this section, you will learn about the contribution that various scientists have made to the understanding of the theory of continental drift.

## Alfred Wegener – continental drift

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



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*Alfred Wegener.*

1880–1930

Figure 7.1 Alfred Wegener

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

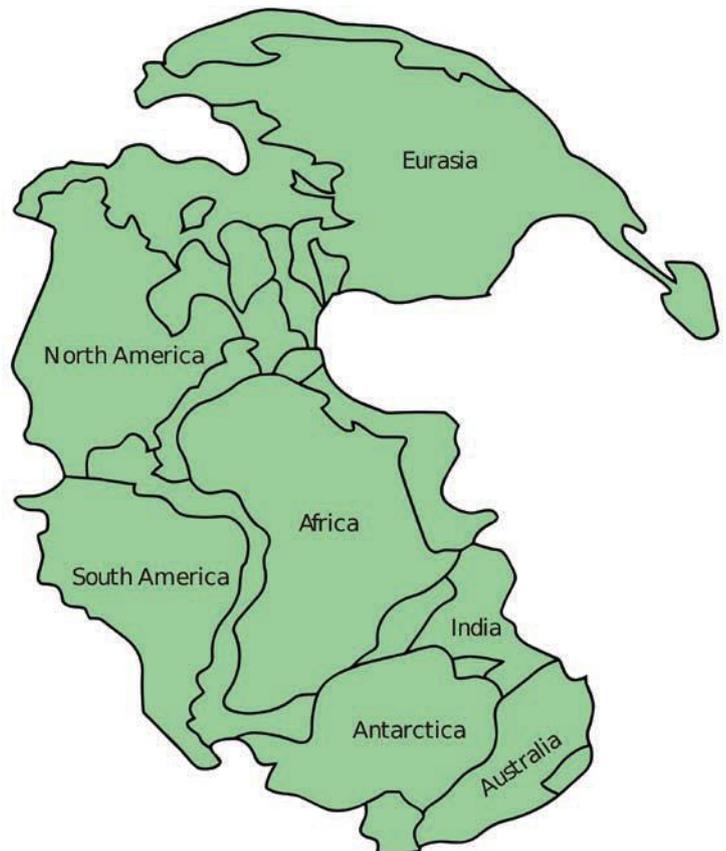


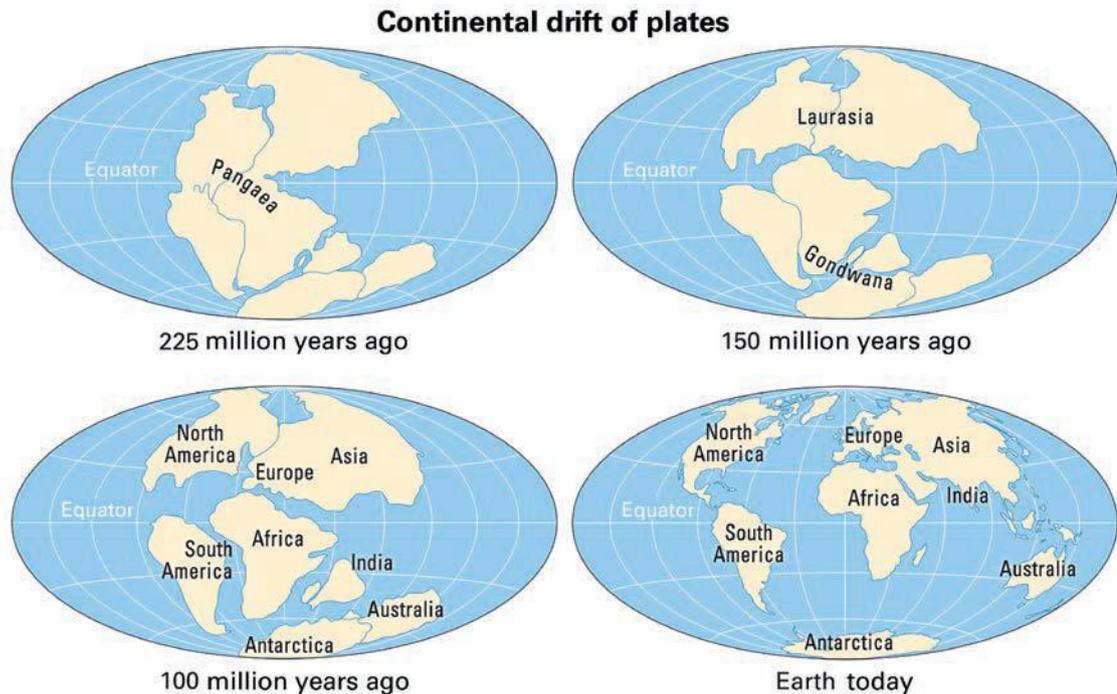
Figure 7.2 Wegener proposed that all the continents were once together in a giant landmass called Pangaea.

Over time, this giant landmass broke up and drifted apart to form the continents that you know today. Figure 7.3 shows how the continents have moved over millions of years.

Follow the movement of Australia to see how far we have moved in that time.

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

**Pangaea**  
the supercontinent which has since broken into pieces and drifted apart

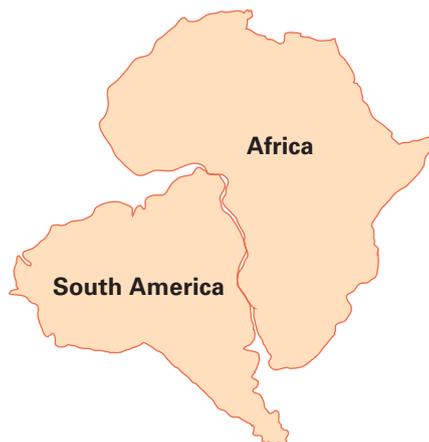


**Figure 7.3** The movement of the continents from a single landmass (Pangaea) to their current locations

A scientific theory cannot arise without evidence. So how did Wegener justify his theory to the scientific community? Wegener put forward four different pieces of evidence to support his theory.

### 1 Continental outlines matched

You can see from Figure 7.4 that, when put together, some of the existing continents look like they fit into each other – just like pieces of a broken jigsaw puzzle. You could argue that this is just a coincidence, so Wegener needed more evidence to back up his theory.



**Figure 7.4** The outlines of Africa and South America fit together like pieces in a jigsaw puzzle.

### 2 Similar fossils were found on different continents

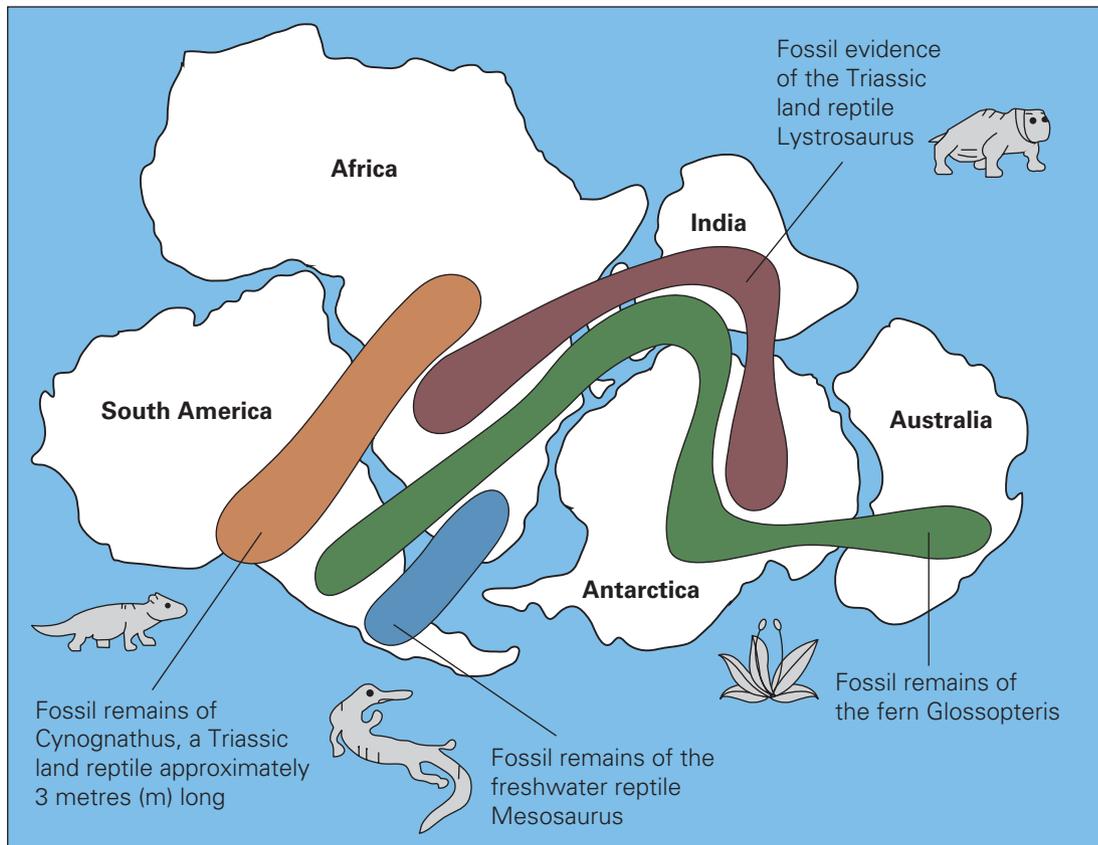
When observing the types of fossils on different continents, Wegener found examples of the same prehistoric land-based creatures on continents that are now separated by oceans. He stated that the land masses must have been together at some stage (as shown in Figure 7.5) because these animals could not 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

When Wegener put the continents together, he also found that bands of different rock types matched up, giving further weight to his theory.

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

Coal only forms in hot and humid areas, and glaciers only form in cold areas, so how could there be coal in cold areas and evidence of past glaciers in regions that are now hot? Wegener concluded that this land could



**Figure 7.5** Wegener found that fossils on different continents matched up, supporting his theory of continental drift.

have once been part of the same landmass and in 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 7.6** Coal only forms in hot, swampy areas; glaciers only form in cold areas.

### Quick check 7.1

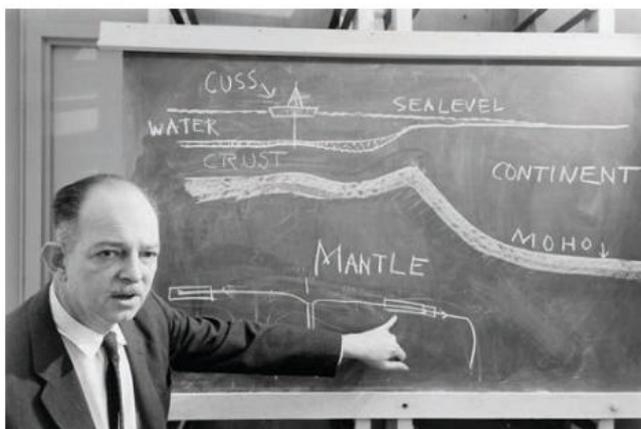
- 1 What is the name of the scientist who is best known for proposing the theory of continental drift?
- 2 List the four different pieces of evidence he used to support his theory.
- 3 Outline why his theory was not accepted at the time.

The story of Alfred Wegener is a tragic one. In 1930, he and another team member were caught in a blizzard on an expedition in Greenland and did not survive. At the time, his hypothesis was still yet to be accepted by the scientific community.

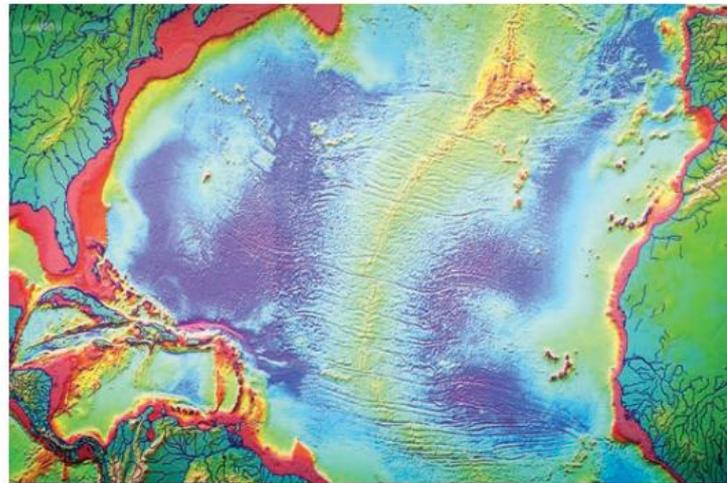
### Harry Hess – seafloor spreading

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 which 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.

Most people at that time thought that the ocean floor was flat. However, when Hess mapped the ocean floor, he



**Figure 7.7** Harry Hess, a professor of geology who mapped the ocean floor



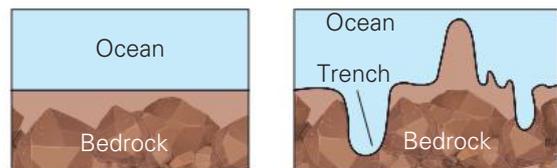
**Figure 7.8** A map of the Mid-Atlantic Ridge and its volcanoes running down the middle of the Atlantic Ocean

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 kilometres (km) above the flat sea floor.

In his book *The History of Ocean Basins*, Hess wrote that volcanoes lining up along these ocean ridges bring up molten rock from under Earth's crust. This molten rock cools and forms new oceanic rock. As more and more

**seafloor spreading**  
a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

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 the old ocean floor was sinking in a process called subduction, forming ocean trenches, (as shown in Figure 7.9). You will look at subduction in more detail in the next section.



What people expected the ocean floor to look like

Harry Hess's map of the ocean floor

**Figure 7.9** The sea floor is more interesting than was previously thought.

### Advances in science 7.1

#### Journey to the bottom of the sea

The Challenger Deep, located in the Mariana Trench in the western Pacific Ocean, is the deepest known point in the Earth's ocean, measuring a depth of 10994 metres.

The first people to reach the bottom of the Challenger Deep were Don Walsh and Jacques Piccard. Having found the deepest part of the trench by blowing up TNT and timing how long it took them to hear the sound, they climbed into a steel cabin that was very cramped for two adults and descended. About 9400 m down, they heard a loud bang, but as there appeared to be nothing wrong they carried on. Later they found out that a window had cracked.

Walsh and Piccard descended for nearly 5 hours, passing glowing creatures as they went. Finally, the cabin touched the ground, stirring the ocean floor beneath it. They waited for 20 minutes and then started the long ascent, which took 3 hours and 15 minutes, back to the surface.



Figure 7.10 Trieste II was a deep-diving manned submarine built in 1964.



Figure 7.11 Don Walsh (second from right) reached the bottom of the Mariana Trench in 1960.

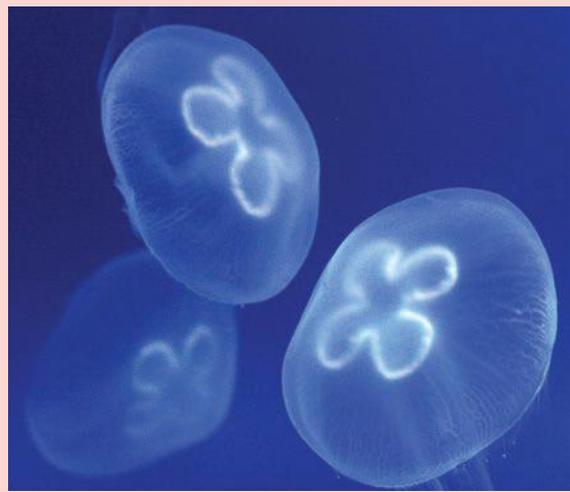


Figure 7.12 The only light that can be observed in the ocean depths is created by the animals that live there. This is called bioluminescence.

### Did you know? 7.1

#### Extreme exploration

In 2020, former NASA astronaut Kathryn Sullivan became the first person to both walk in space and descend to the deepest known point on Earth, after making the 11-kilometre ocean dive to the Challenger Deep. Her 3.5-hour space walk was in 1984.

### Quick check 7.2

- 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.

## Fredrick Vine, Drummond Matthews and Lawrence Morley – reading the ocean floor

A few years after Hess proposed his theory of sea-floor spreading, further evidence was discovered to support his theory. Fredrick Vine and Drummond Matthews were British geologists who first worked together when Vine was a PhD student under Matthews at the

University of Cambridge in the late 1950s. Their 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 ridge. At the same time Canadian geologist Lawrence Morley also came up with the same idea. Vine and Matthews however were the first to publish their findings in 1963.

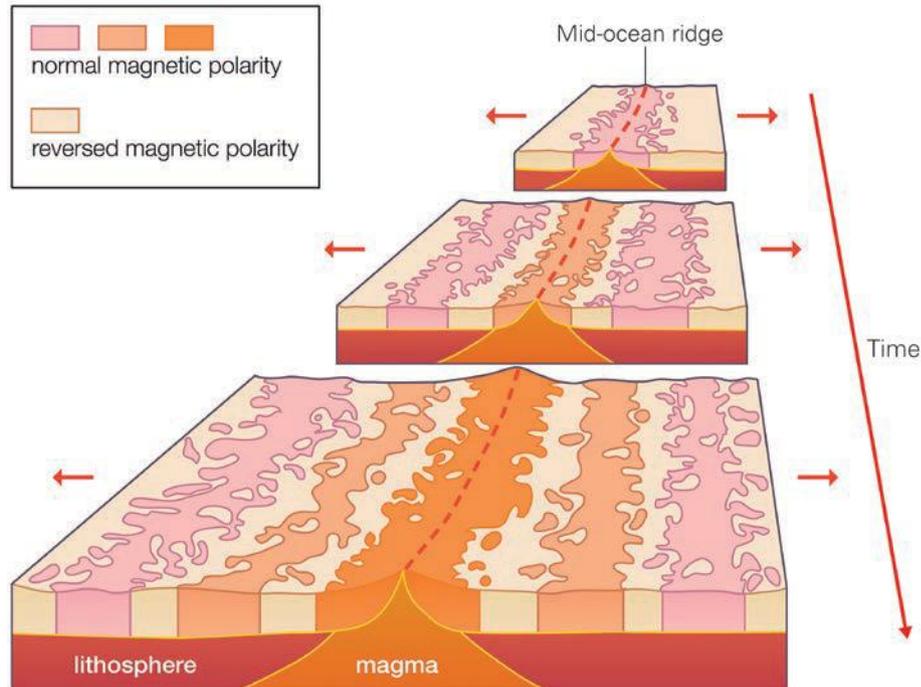


Figure 7.13 The pattern of magnetic stripes on the ocean floor

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 magnetic field, with its magnetic poles matching the Earth's magnetic poles. On average, Earth's magnetic field reverses direction every 450 000 years, and the cooling rock preserves the record of Earth's polarity at that time.

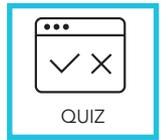
For rocks to have their magnetic minerals aligned in different directions, they must have formed at different times. As the pattern of magnetic stripes leading away from the mid-ocean ridges is symmetrical, this led to Vine and Matthews to conclude that new sea floor was being added equally to each side of the ridge. At around the same time, but quite independently, Canadian geologist Lawrence Morley also saw the significance of



## Section 7.1 questions

## Remembering

- 1 **Name** the theory proposed by each of the following scientists.
  - a Alfred Wegener
  - b Harry Hess.
- 2 **Describe** one piece of evidence that Wegener used to back up his theory.
- 3 **Recall** the piece of evidence that proved Harry Hess was correct.



## Understanding

- 4 **Explain** why Wegener's theory was not accepted during his lifetime.
- 5 **Show** using labelled diagrams the results of Harry Hess's mapping of the ocean floor.
- 6 **Describe** how sonar works.
- 7 **Outline** the evidence that supports Harry Hess's theory of seafloor spreading.

## Applying

- 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 landmass, 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 even volcanoes.

## Analysing

- 9 **Distinguish** between magnetic striping and magnetic field reversal.
- 10 **Compare** and contrast 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 from a ridge.
  - c The continents drifted away from one another.
  - d Rock types on different continents match up with one another.

## Evaluating

- 12 **Deduce** what would happen to a compass if Earth's magnetic field was to change direction now.
- 13 **Demonstrate** by use of a diagram how Earth's magnetic field has switched over time.
- 14 With the example of Alfred Wegener and Harry Hess, **assess** the impact of current scientific ideas with the willingness to adopt new theories.

## 7.2 Plate tectonics and plate movement

### Learning goals

- 1 To recall the three types of plate boundaries
- 2 To describe the key features of each plate boundary
- 3 To explain how convection currents and gravitational forces cause plate movement

With the help of Harry Hess, Fredrick 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 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 crust is made of two different types of rock; 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 continental crust.

Scientists first proposed the theory of **plate tectonics** in the late 1950s and early 1960s. They said that Earth's surface is split into **tectonic plates**, gigantic slabs of rigid rock, which float on the Earth's surface.

#### crust

the top layer of Earth which supports all life on Earth

#### mantle

the layer of the Earth underneath the crust which is made up of mostly solid rock and is where convection currents take place

#### 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

#### plate tectonics

the theory that the 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

Earth's lithosphere is split into gigantic slabs of rigid rock which float on the Earth's surface

### Quick check 7.4

- 1 List the layers of the Earth from the surface to the centre of Earth.
- 2 Describe the differences between oceanic and continental crusts.
- 3 State the name given to the giant slabs of rock that make up Earth's crust.

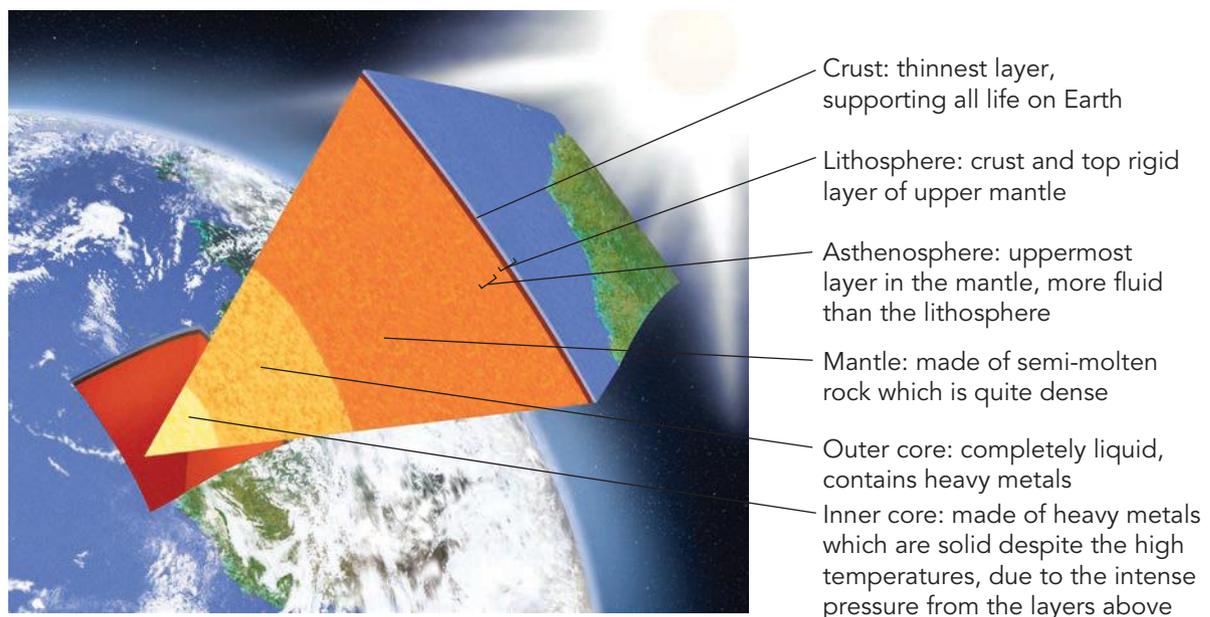
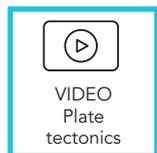


Figure 7.15 Earth's layers

## Tectonic plates

As you can see from Figure 7.16, 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 the Earth.



Figure 7.16 The major and some minor tectonic plates on Earth's surface

## How do the plates move?

Tectonic plates, which are made from pieces of the crust and the topmost rigid layer of the upper mantle (referred to as the lithosphere), float on top of the asthenosphere, the next layer down in the upper mantle. In the top layer of the upper mantle the rock is hard, but lower down in the asthenosphere, the rock is softer and beginning to melt in places, a little bit like toffee when it is heated.

There are three main driving forces for the movement of tectonic plates:

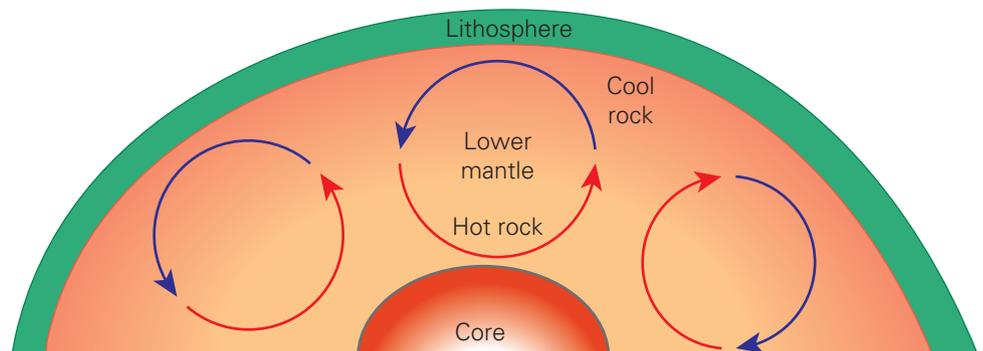


Figure 7.17 Convection currents in Earth's mantle drive the movement of the tectonic plates.

- convection currents in the mantle
- gravitational forces
- the rotation of Earth.

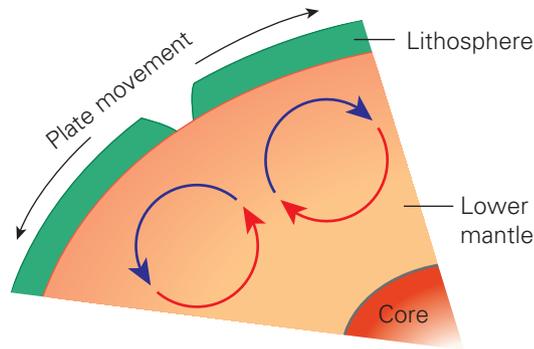
The convection currents in the mantle are the most widely studied aspect of tectonic plate movement.

The temperature increases as you move down through the mantle and get closer to the core. The heat created by the core 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 and falls back towards the core, as shown in Figure 7.17. This cycle of hot rock rising and cooler rock sinking is called a convection cycle and is caused by **convection currents** in Earth's lower mantle.

At the top of each cycle, the sideways movement of the cooling rock in the mantle causes the movement of the tectonic plates above it. Figure 7.18 shows what can

**convection currents**  
movement of rocks within Earth's mantle due to temperature differences between the upper and lower layers

happen when the sideways movements of rocks in the mantle are in opposite directions.



**Figure 7.18** The sideways movement of rock in this example causes the tectonic plates to move in opposite directions, away from each other.

Gravity is another driving force for the movement of tectonic plates. Gravitational forces cause older material on the peaks and ridges to sink towards the ocean floor, aiding the movement of the plates. This is because the sinking dense crust drags the rest of the tectonic plates and is the main cause of plate motion.

### Quick check 7.5

- 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 7.1

#### Observing convection currents

##### Aim

To observe convection currents.

##### Materials

- dark food colouring
- cold water
- 250 mL beaker
- ice cube tray
- Bunsen burner
- gauze mat
- tripod
- heatproof mat

##### Procedure

- 1 Mix 100 mL of water with some food colouring in a beaker (the darker the 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.

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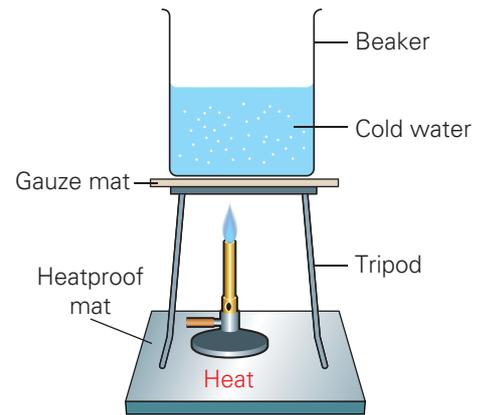
- 4 Set up your equipment as shown in the diagram.
- 5 Set the Bunsen burner to a blue flame and concentrate the heat on one corner of the beaker.
- 6 Drop an ice cube into the beaker and observe the water.

**Results**

Record your observations.

**Discussion**

- 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.



**What happens at plate boundaries?**

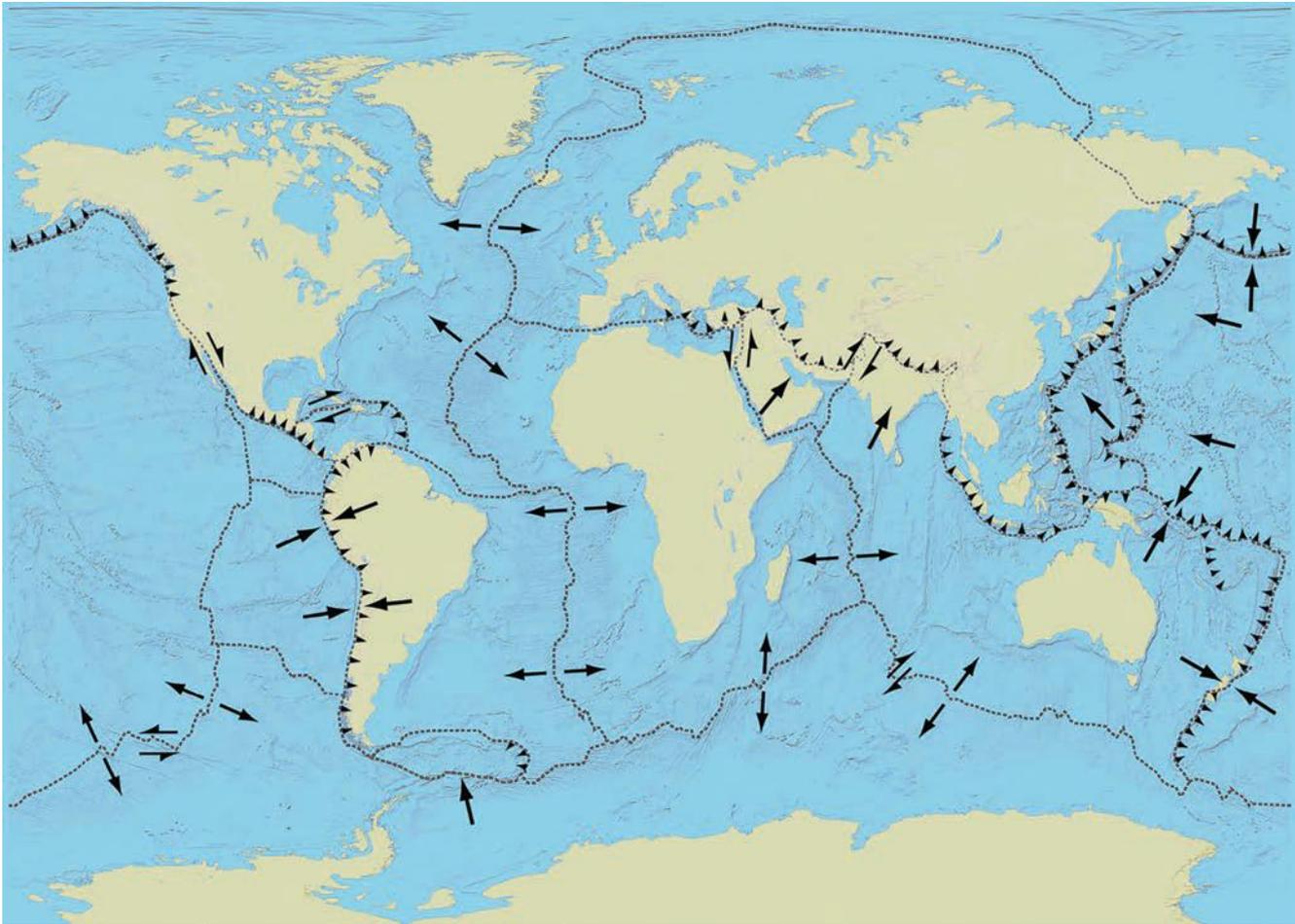
The direction of plate movement causes different types of **plate boundaries** to form. Figure 7.19 shows the major tectonic plates and the direction they are travelling. There are three types of plate boundaries: destructive (convergent), constructive (divergent) and transform (conservative), relating to the movement of plates towards, away and alongside each other.

**plate boundaries**  
the edges where two tectonic plates meet

Table 7.1 summaries the three types of plate boundaries, the type of movement shown by each, and key features and examples of these from around the world.

Type of boundary and movement	Diagram and what happens to the crust?	Key features	Example
Destructive (convergent) Plates move towards each other	 Crust is destroyed	Mountains Trenches Subduction zones Volcanoes Earthquakes	Hikurangi subduction zone, North Island, New Zealand; Himalayan mountain range
Constructive (divergent) Plates move away from each other	 Crust is created	Volcanoes Rifts Ocean ridges	Mid-Atlantic Ridge (underwater volcanoes)
Transform (conservative) Plates move parallel in opposite directions	 Crust is conserved	Earthquakes	San Andreas Fault, California

**Table 7.1** A summary of each type of plate boundary



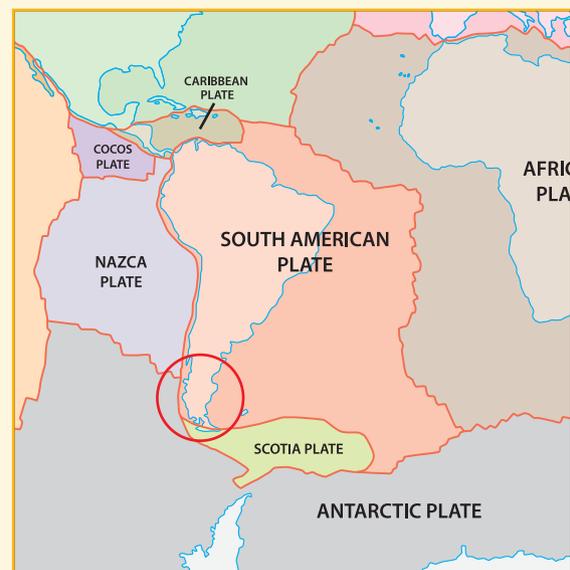
**Figure 7.19** The major tectonic plates and their direction of travel. The small triangles on the lines indicate a convergent plate boundary.

### Explore! 7.1

#### 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 your preferred search engine to answer the following questions.

- 1 List which three tectonic plates meet at the Chile Triple Junction.
- 2 Discuss why the triple junction is unusual.



**Figure 7.20** The Chile Triple Junction

## Destructive boundaries

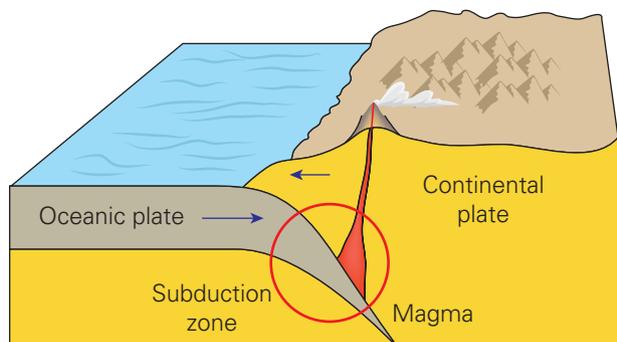
The effects and the features that form at destructive boundaries depend on what the two plates are made from. You have already learned that there are two types of crust: oceanic and continental. Oceanic crust is thin and dense; in comparison, continental crust is thicker and less dense. So, what happens when plates with two different types of crust on top of the upper mantle collide?

### Quick check 7.6

- 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

As the plate with the oceanic crust is denser than the plate with the continental crust, when they collide, the denser oceanic plate will sink underneath the continental plate in a process called **subduction**. As the oceanic plate sinks deeper and deeper into the mantle, it begins to melt, forming **magma**. This magma can rise up through the continental plate to form volcanoes.



**Figure 7.21** A subduction zone forms when the denser oceanic plate subducts underneath the less dense continental plate.

Mountains and deep ocean trenches also form at this type of destructive boundary.

### Quick check 7.7

- 1 State the term which 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.

## When two continental plates meet

When two continental plates meet, both plates have the same density, so when they collide, subduction does not take place. Instead, the crust buckles and breaks down. The pressure of the collision forces the damaged crust upwards, eventually forming mountains.

### subduction

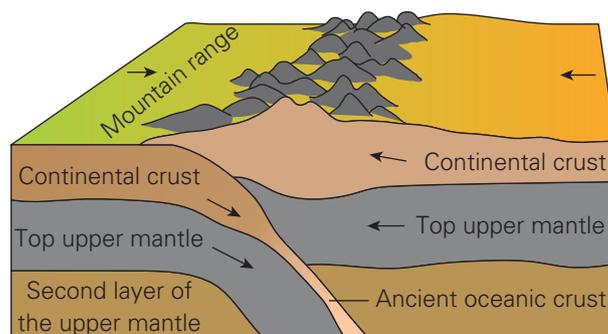
when the denser oceanic plate sinks underneath less dense continental plate

### magma

hot liquid rock found just below the surface of the Earth

## When two oceanic plates meet

Several events 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.



**Figure 7.22** The formation of mountains when two continental plates collide



**Figure 7.23** The Himalayan mountain range, the highest in the world, was formed and is continuing to form at a destructive plate boundary.

## Practical 7.2

### 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

#### Procedure

- 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<sup>3</sup>) in the results table. (Note: 1 mL = 1 cm<sup>3</sup>)
- 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 <sup>3</sup> )			Mean volume (cm <sup>3</sup> )	Density (g/cm <sup>3</sup> )
		1	2	3		
Basalt						
Granite						
Sandstone						
Chalk						

#### Discussion

- 1 Organise the rocks from most to least dense.
- 2 Explain why the experiment was conducted three times for each rock type.
- 3 Explain why you should always measure at the bottom of the meniscus when measuring water levels.
- 4 Compare the density of each rock that you calculated to densities obtained from secondary sources on the internet. How close were you to those values?

#### Conclusion

- 1 Identify which rock was the most dense and which rock was the least dense.
- 2 Using your results, explain why oceanic crusts made of basalt subduct underneath continental crust made predominantly of granite at destructive plate boundaries.

**Did you know? 7.2**

As the Eurasian and Indian plates are constantly moving towards each other, Mount Everest – the highest mountain in the world at 8850 m tall – is actually getting taller each year, by 4 millimetres (mm) in fact. If your ambition is to climb Mount Everest, then you had better do it sooner, rather than later, if you do not want to have to climb even further!

**Constructive boundaries**

Plates moving away from one another are called constructive plate boundaries.

**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.



**Figure 7.24** A volcanic crater of basalt rocks near Portugal



VIDEO  
Describe what  
causes an  
earthquake

**On land**

Constructive plate boundaries that occur on land form rift zones. An active rift zone is currently dividing Eastern Africa from the rest of Africa. This rift will eventually be filled with ocean, creating a new island version of East Africa.

**Quick check 7.8**

- 1 Describe the movement of plates at a constructive plate boundary.
- 2 List some of the features which can form at this type of boundary.
- 3 Why are constructive plate boundaries also known as divergent boundaries?

**Transform boundaries**

When plates move parallel to one another, but in opposite directions, a tremendous amount of force can build up in the form of friction, which stops the plates from moving. When the force of the plate movement overcomes the friction that is stopping them from moving, the pressure is released in the form of earthquakes. Transform boundaries are also known as conservative boundaries as land is neither created nor destroyed.



**Figure 7.25** Thingvellir in Iceland is part of another fissure zone running through the country, which is situated on the tectonic plate boundaries of the Mid-Atlantic Ridge.



**Figure 7.26** 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.

### Quick check 7.9

- 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?

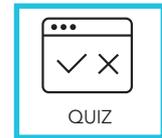


WIDGET  
Plate  
movement at  
boundaries

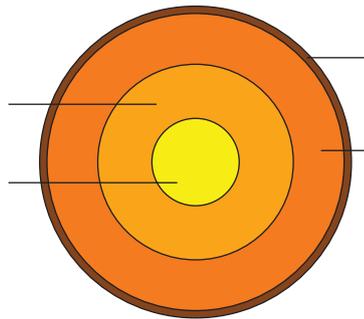
### Section 7.2 questions

#### Remembering

- 1 **Identify** the names of the three types of plate boundaries.
- 2 **State** the name of the mechanism which causes tectonic plates to move.
- 3 **Label** the following diagram showing the structure of the Earth.



QUIZ



- 4 **Match** the layer of the Earth (A–D) to its physical properties (1–4).

<b>A</b> Crust	<b>1</b> Made of metals (iron and nickel) Very hot temperatures Under intense pressure from the layers above so is a solid structure
<b>B</b> Mantle	<b>2</b> Made of dense solid rock which flows in the hot temperatures
<b>C</b> Outer core	<b>3</b> Thinnest layer Supports all the life on Earth
<b>D</b> Inner core	<b>4</b> Made of metals (iron and nickel) Very hot temperatures Liquid

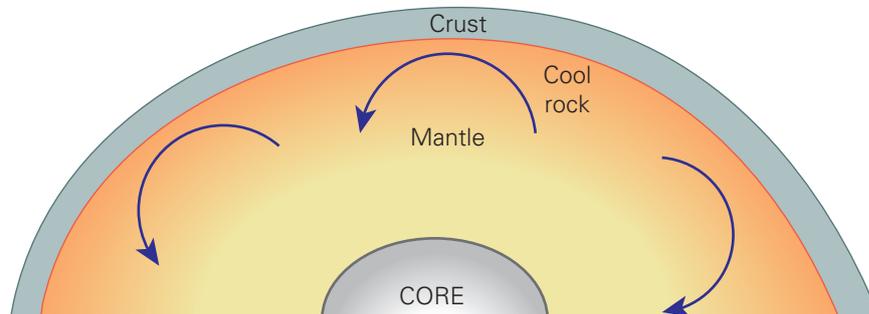
- 5 **Name** a real-life example of each of the three types of plate boundaries.  
 6 **Name** two types of crust.

### Understanding

- 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 the Earth has stayed the same despite this destruction.  
 10 **Outline** how magma forms at a subduction zone.

### Applying

- 11 **Construct** a labelled diagram to show an oceanic plate subducting underneath a continental plate.  
 12 **Identify** the type of plate boundary where the following features would occur:  
 a trenches  
 b mountains  
 c earthquakes  
 d volcanoes  
 e ridges  
 f rifts  
 g subduction zones.  
 13 Using the diagram below, **model** how convection currents in the mantle move tectonic plates.



### Analysing

- 14 **Compare** and contrast oceanic and continental crusts.  
 15 **Analyse** why mountains and trenches continue to increase in size.

### Evaluating

- 16 **Propose** reasons why countries like Australia do not experience significant amounts of geological activity.  
 17 **Explain** why tectonic plates move across the surface of the Earth.  
 18 **Propose** your own reasons why some tectonic plates move faster than others.

## 7.3 The effects of plate movement

### Learning goals

- 1 To describe how earthquakes and volcanoes occur
- 2 To outline how the theory of plate tectonics explains the formation of new landforms

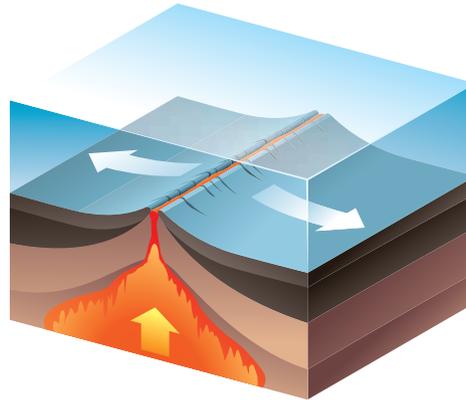
If you live near a plate boundary, you are at risk of experiencing some of the geological activity discussed. In this section, you will examine the reasons for, and effects of, three types of disasters that can occur at plate boundaries.

### Volcanoes

#### Where do volcanoes form?

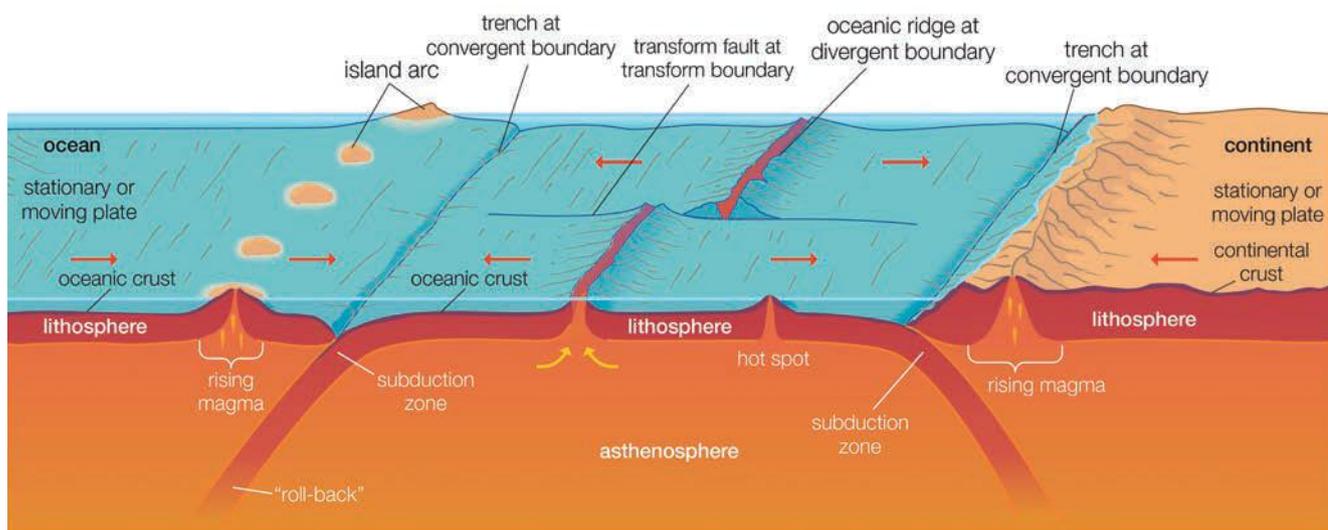
Volcanoes can form at two types of plate boundaries. When two plates move apart at a constructive plate boundary, magma rises and seeps into the gap, as in Figure 7.27.

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 7.27** A constructive plate boundary forms 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 7.28 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 7.28** Volcanoes can form at destructive (convergent) and constructive (divergent) plate boundaries.

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 7.29.

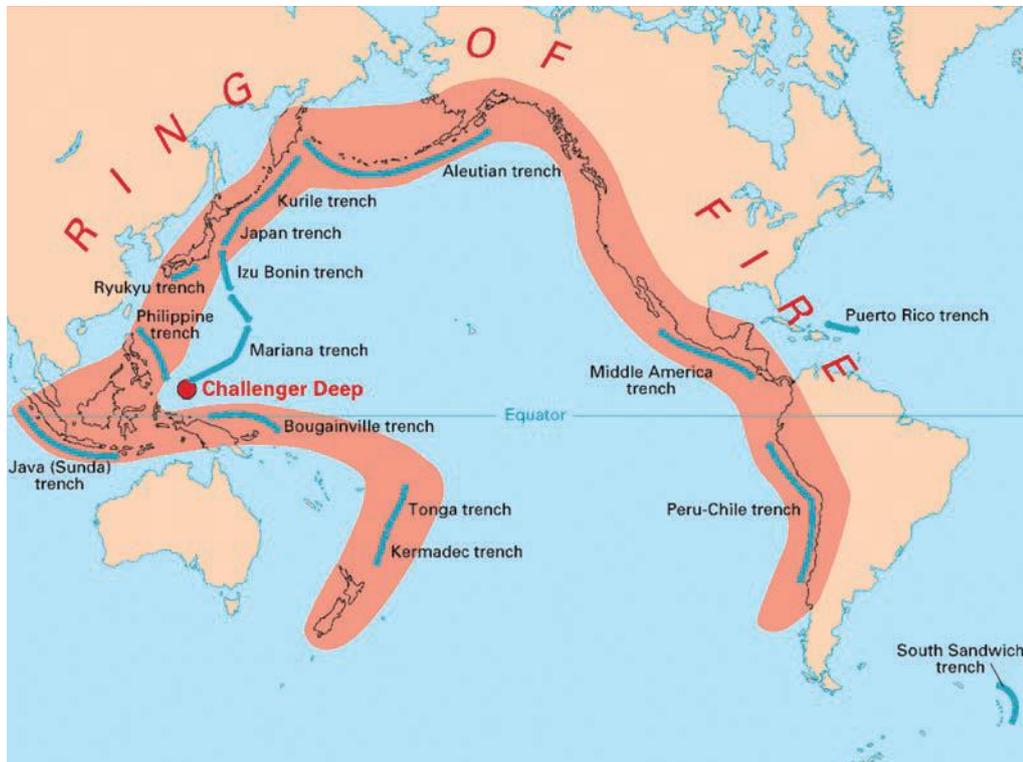


Figure 7.29 The Ring of Fire is an active area of many subduction zones around the Pacific Ocean.

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.

**hotspot**  
a pocket of magma that sits just underneath the crust

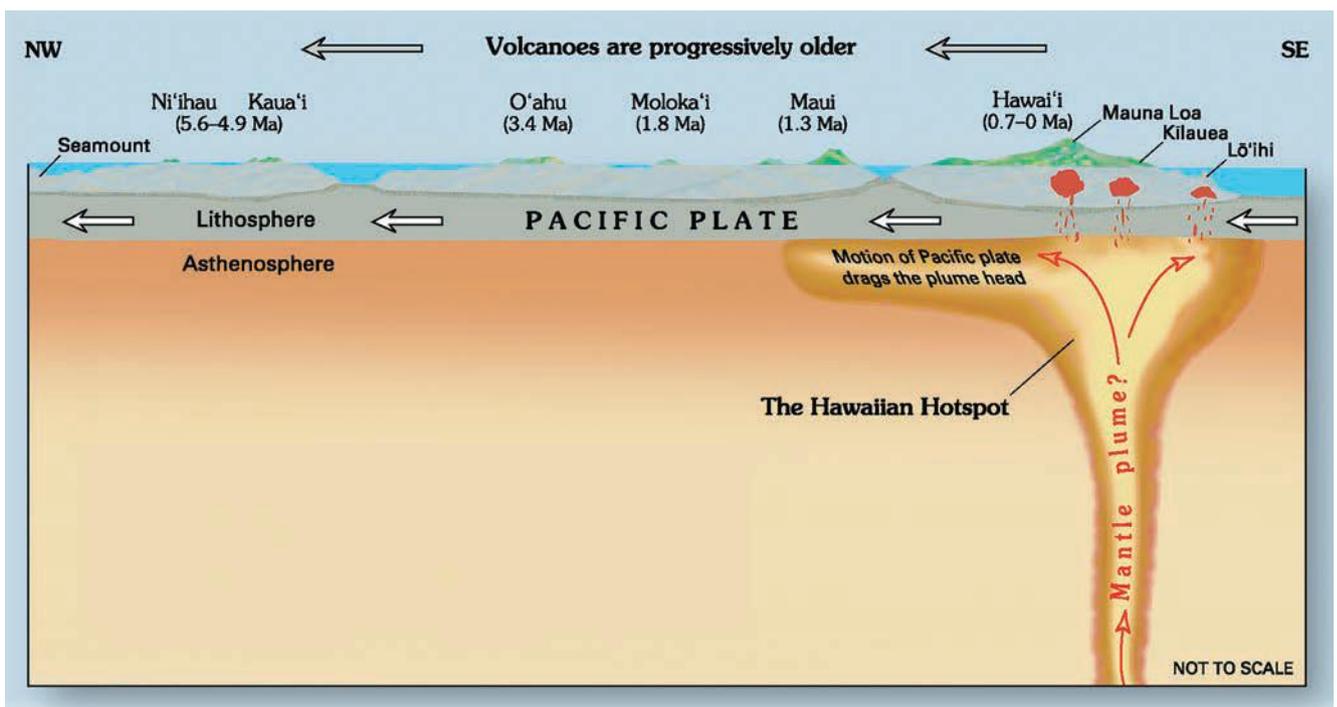


Figure 7.30 The Hawaiian island chain formed as the Pacific plate moves across a hotspot. The oldest island, Ni'ihau, formed around 5.6 million years ago ('Ma'); the top of the newest volcano, Lō'ihi, is less than 1000 m below the sea surface.

## Quick check 7.10

- 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.

## Explore! 7.2

## Iceland's Eyjafjallajökull volcanic eruption in 2010

In 2010, the Eyjafjallajökull volcano in Iceland erupted, throwing volcanic ash several kilometres into the air. Conduct some research to answer the following questions.

- 1 Recall how long the volcano was dormant before it erupted in 2010.
- 2 The volcano is completely covered by an ice cap. Describe how this affected residents in the area when the volcano erupted.
- 3 Outline the most significant consequence of this volcanic eruption.
- 4 Explain whether volcanic eruptions only affect the surrounding area. Use this case study as an example in your answer.

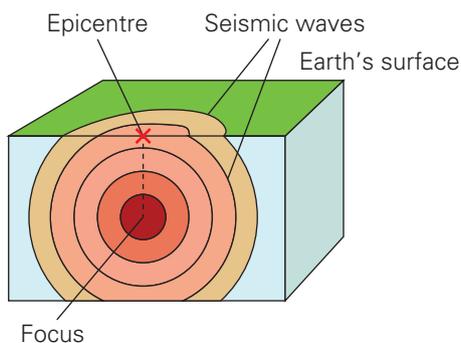


**Figure 7.31** This satellite image shows the volcanic ash thrown out of Iceland's Eyjafjallajökull volcano in 2010 from the force of the eruption.

## Earthquakes and tsunamis

## Where do earthquakes occur?

Earthquakes occur when there is a sudden movement of land. This can happen at a transform 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 the Earth where the earthquake occurs is called the **focus**. The point directly above the focus, on the surface of the Earth is called the **epicentre**.



**Figure 7.32** A diagram showing the location of an earthquake's focus and epicentre

## How are earthquakes detected?

Earthquakes are detected by using an instrument called a **seismometer**. A simple seismometer is shown in Figure 7.33. Its basic structure uses a weight hanging from a spring suspended from a frame which moves along with the motion of Earth. A rotating drum is attached to the frame and a pen 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 resulting pattern is called a **seismogram**. Note that digital seismometers are also available for many smartphones.

**seismic wave**  
wave that moves through Earth during an earthquake

**focus**  
the exact point under the surface of the Earth where the earthquake occurs

**epicentre**  
the location on Earth's surface directly above the focus of an earthquake

**seismometer**  
an instrument that measures the intensity and duration of seismic waves during an earthquake

**seismogram**  
the pattern produced when seismic activity is recorded by a seismometer

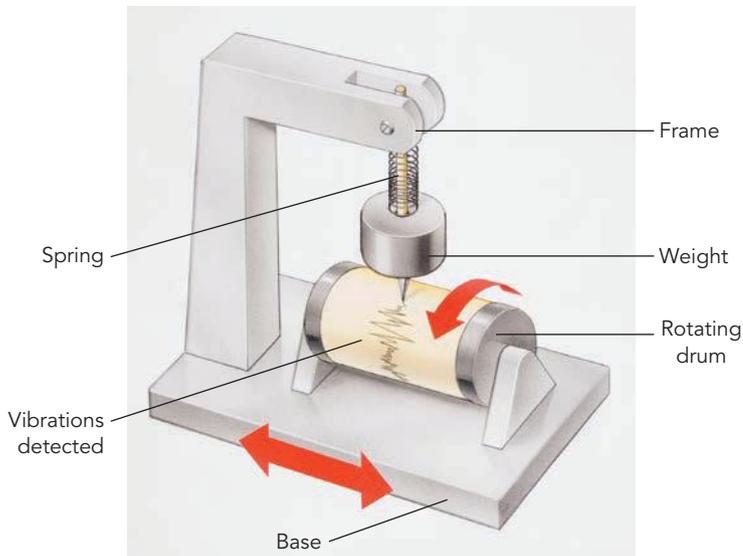


Figure 7.33 A simple seismometer

The two main types of seismic waves produced by an earthquake are primary (P) waves and secondary (S) waves (see Figure 7.34). The properties of these waves are summarised in Table 7.2.

	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 to buildings from up and down movements	Very destructive due to side to side movements

Table 7.2 The properties of P and S waves

As P waves are the faster of the two waves, they are detected by the seismometer first. You can see the first seismic activity detected by the seismometer on the seismogram in Figure 7.35 is the P wave. The S waves are slower and so arrive second. They are also the most intense and so register larger movements on the seismogram.

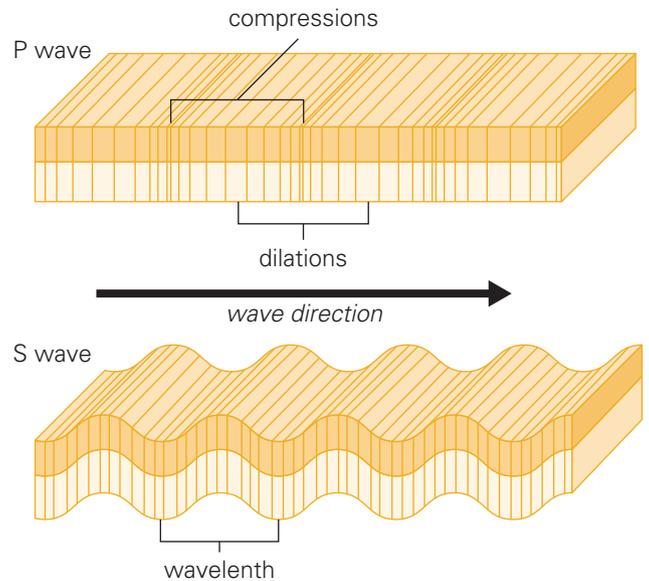


Figure 7.34 P and S waves travelling through the Earth

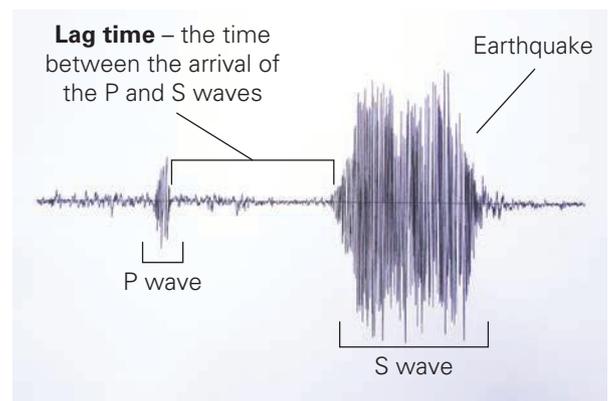


Figure 7.35 A seismogram of seismic activity within the Earth

### Quick check 7.11

- 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 following an earthquake?

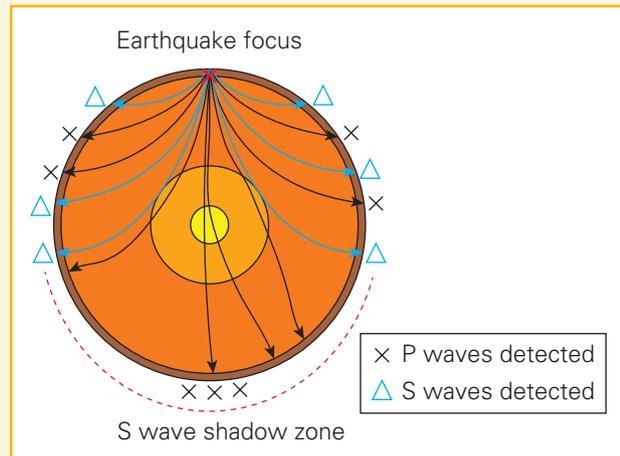
**lag time**  
the time between the arrival of the P and S waves

## Explore! 7.3

**How do P and S waves give us evidence for the structure of the Earth?**

The properties of P waves and S waves generated by an earthquake can be used to determine the properties of the layers of the Earth. Danish scientist Inge Lehmann discovered that the Earth has a solid inner core inside a molten outer core in 1936 after she analysed data from seismic stations around the world. She noticed some irregularities in the data that disproved the accepted idea that the core was entirely molten. It wasn't until 1970 that her theory was confirmed!

- 1 What can you conclude about the movements of P and S waves through Earth using the diagram in Figure 7.36?
- 2 Interpret the properties of the seismic waves listed in Table 7.2 to make conclusions about the physical properties of the outer core and the mantle.
- 3 When P waves travel through the inner core and outer core they appear to bend. Discuss why you think this is.
- 4 What is the S wave shadow zone? Deduce why it occurs.



**Figure 7.36** The pattern of seismic activity away from an earthquake's focus

**Is Australia at risk?**

Australia is located in the middle of the Australian plate and therefore is not directly at risk from major earthquakes and volcanoes. However, because the Australian plate is moving gradually northwards and colliding with the Eurasian plate, a significant amount of pressure is building up at the boundary between these plates. This build-up of pressure can cause earthquakes in Australia.

In fact, Australia has more earthquakes than other regions that sit in the middle of tectonic plates. In 1989, an earthquake of magnitude 5.6 hit Newcastle in New South Wales, killing 13 people. In Victoria, Red Rock is a young volcano located to Melbourne's south-west. The whole province between Ballarat and Geelong is volcanically active, and a new volcano could form anywhere at any time.

**Figure 7.37** Rescue workers trying to find survivors under the rubble beneath the Kent Hotel in Hamilton, Newcastle, after the 1989 earthquake



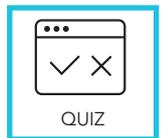


**Figure 7.38** The lower slope of Mount Noorat, Victoria, a volcano that last erupted between 5000 and 20000 years ago. It is Australia's largest dry volcanic crater and was a traditional meeting and bartering place for the Kirrae Wuurong people.

### Section 7.3 questions

#### Remembering

- 1 **Name** the equipment used to measure the seismic activity of the Earth.
- 2 **Name** the point on Earth's surface directly above the focus of an earthquake.
- 3 **Recall** the name of the volcanoes that can form away from a plate boundary.

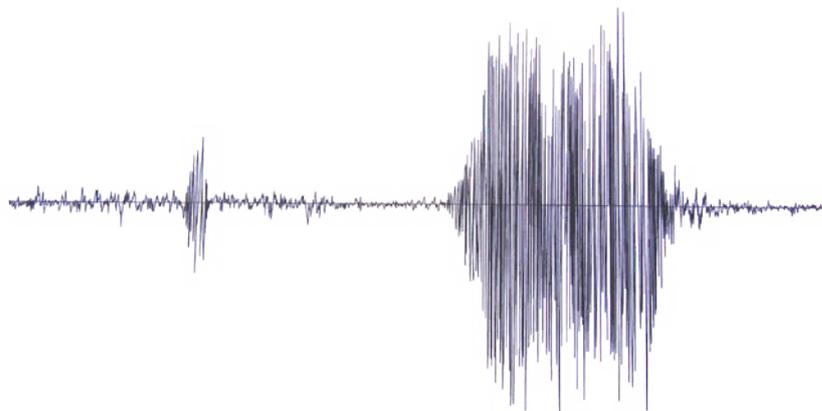


#### Understanding

- 4 **Describe** the three types of plate boundaries and how they affect the amount of crust.
- 5 **Explain** how mid-ocean ridges form.
- 6 **Explain** why plates at a transform or destructive plate boundary do not slide past each other all the time.
- 7 **Outline** the reasons why the Ring of Fire in the Pacific is so volcanically active.

#### Applying

- 8 On the seismogram below, **identify** which is the P wave and which is the S wave.



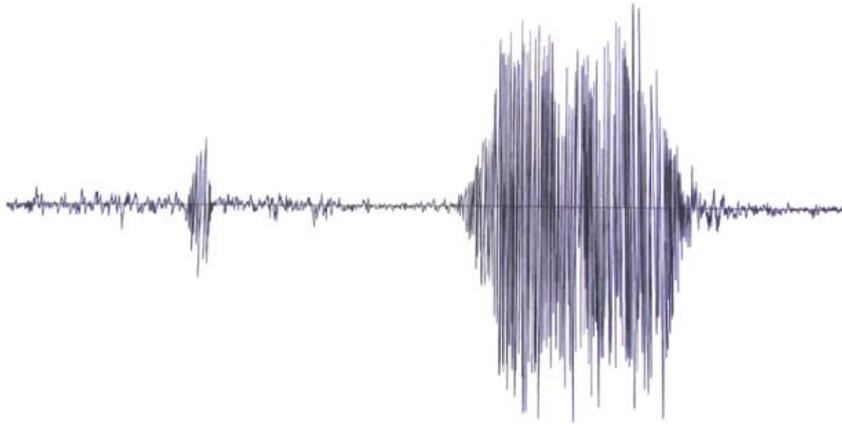
- 9 **Identify** the type of seismic wave from the description:
- A transverse wave which cannot travel through liquids
  - A longitudinal wave that can be detected on the opposite side of Earth to the epicentre of an earthquake.

### Analysing

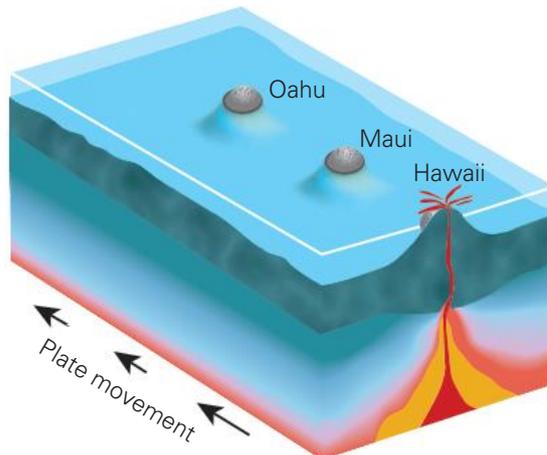
- 10 Hannah says that volcanoes only affect the people who live in the country of the eruption. Rob thinks that volcanic eruptions can affect many countries. **State** who is right and **examine** the reasons why.
- 11 **Compare** and contrast the properties of P waves and S waves.

### Evaluating

- 12 There are many different types of volcanoes. **Deduce** definitions for the following types of volcanoes:
- dormant
  - extinct
  - active.
- 13 **Deduce** what the term 'lag time' is in relation to seismic waves and identify this on the seismograph below.



- 14 **Determine** which island is the oldest from the diagram below. What type of volcano is shown in the diagram?



- 15 **Decide** whether more geological activity is experienced by countries in the middle of a plate boundary or by countries on a plate boundary. **Outline** your reasoning.
- 16 **Discuss** the intensity and frequency of geological activity in Australia.

# 7.4 Technologies and natural disasters

## Learning goals

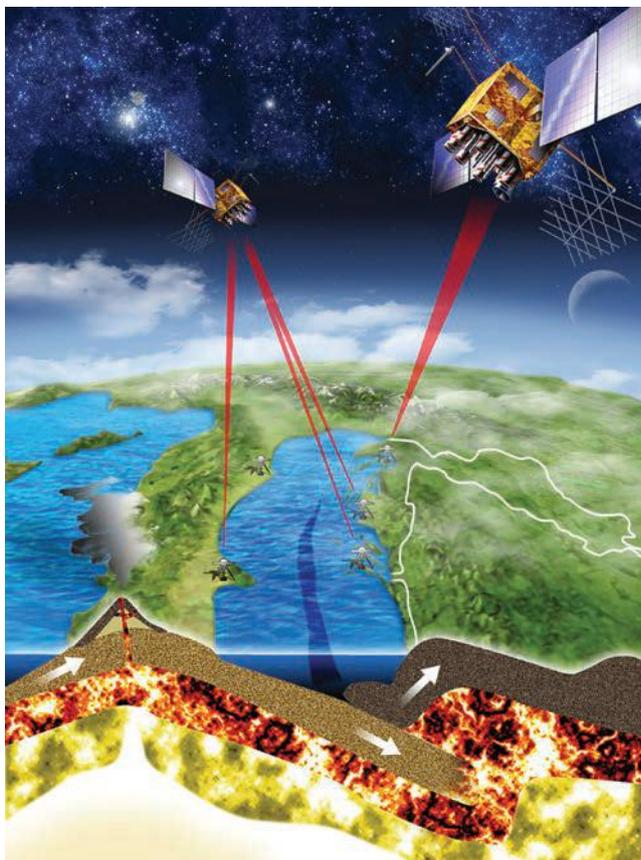
- 1 To recall technological developments that improve understanding of geological activity
- 2 To describe how these developments have increased scientific understanding
- 3 To give examples of developments in the Asia–Pacific region

As technology improves, so does 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 plate movement

### 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 the



**Figure 7.39** GPS is used to measure position and therefore the rate of movement of tectonic plates.

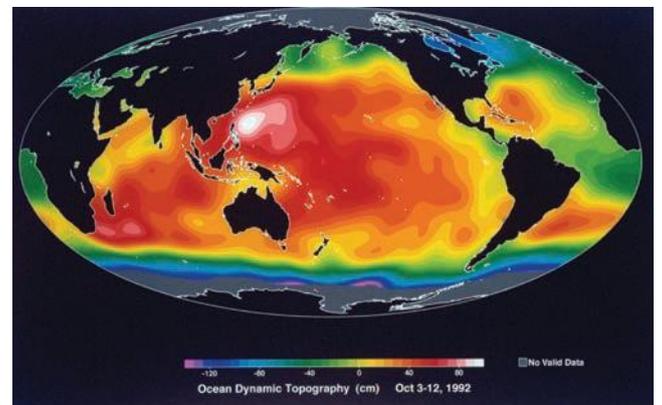
Earth as well as GPS receivers on the ground which detect the radio signals from the satellites. To determine precise locations on Earth, the GPS receiver must receive signals from at least four different satellites. GPS receivers used for plate boundary observation can determine their location to a precision equal to the size of a grain of rice.



### Gravity mapping

Gravity can be stronger and weaker at different points of Earth's surface. The 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. Scientists can create a gravitational map of Earth, called a **geoid**, using these gravitational measurements.

**geoid**  
a model of the 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 7.40** A geoid of the Earth

### Computer modelling

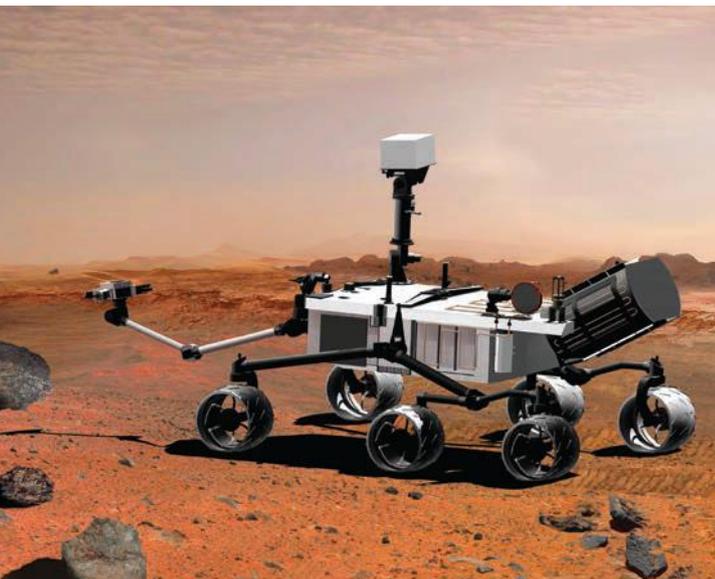
Computer models that simulate the way tectonic plates move are becoming more and more accurate. A new model built by scientists in 2012 was found to be highly accurate in predicting plate motion and the way in which plate boundaries deform.



**Figure 7.41** 3D visualisation and geological modelling suite being used by geologists to interpret seismic data from an oilfield

### Quick check 7.12

- 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?



**Figure 7.42** Robots similar to the one used in the mission to Mars are being created to explore areas of volcanoes that humans could never access.

## Predicting and responding to natural disasters

### NASA volcanobots

Studying active volcanoes is dangerous. Volcanologists (scientists who study volcanoes) working together with robotics engineers are therefore developing robots that will be able to go into crevices in volcanoes that no human could access. *VolcanoBot 1*, 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.

### Drones

Drones can make finding survivors faster and easier than ever before. If people can be found within half an hour of a natural disaster, their chances of survival are 90%. After 24 hours, this survival rate drops to 80%. Not only do drones help find survivors, they can also quickly map the areas in greatest need of aid, no matter how remote they are. This allows rescue teams and aid to be deployed first to those who need it the most.



**Figure 7.43** Drones are being used to search for survivors following natural disasters.

### Quick check 7.13

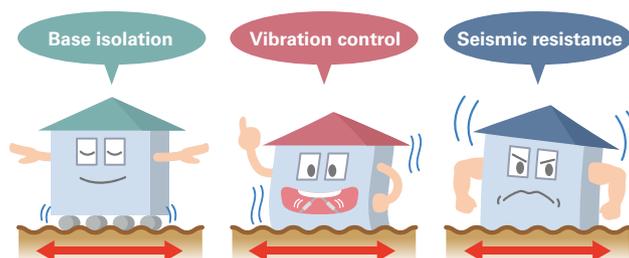
- 1 State the name given to scientists that study volcanoes.
- 2 Give one use of drones after an earthquake.

## 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.

- 1 Base isolation:** buildings do not sit directly on the ground, but are supported by ball bearings and springs, which act like shock absorbers.
- 2 Vibration control:** mass dampers are built to sway in the opposite direction to the building's sway during an earthquake.
- 3 Seismic resistance:** the walls, roof and foundations are tied together into a rigid box that holds together when shaken by an earthquake.

## Earthquake-resistant house



**Figure 7.44** Buildings can be made earthquake proof by three different methods.

### Quick check 7.14

- 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.

## Advances in science 7.2

### Levitating houses!

Air Danshin, a company in Japan, has invented levitating homes. Inventor Shoichi Sakamoto developed a remarkably simple technology to raise a whole house during an earthquake until the tremors stop. This has already been deployed in nearly 90 sites across Japan. The house is separated from its foundations by an air chamber. When an earthquake hits, air fills the chamber lifting the whole structure about 3 cm off the ground. A sensor detects when the shaking stops, and the house gently falls back into position. Although it seems like an excellent solution to protect against earthquakes, it offers no protection if a tsunami hits: in fact, it makes a house completely defenceless to such a large wave.



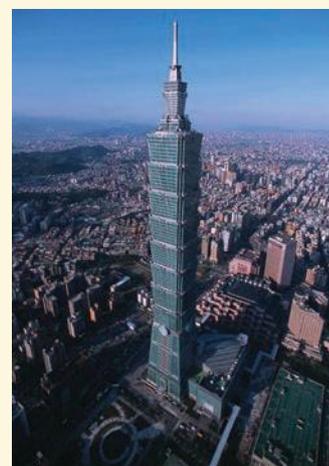
**Figure 7.45** Would you want to live in a floating house?

## Explore! 7.4

### The Taipei 101

This building in Taiwan (previously called the Taipei World Financial Center) is designed to withstand earthquakes and typhoons. Answer the following questions by researching the structure of the building.

- 1 How tall is the building?
- 2 It was once the tallest building in the world. Identify the building that overtook it to be the tallest in 2010.
- 3 Distinguish which of the three methods of earthquake proofing is used in the building.
- 4 Explain the function of the pendulum that is suspended between the 89th and 92nd floors.
- 5 In August 2015, the swinging of the pendulum set a world record when Typhoon Soudelor hit. How far did it shift?



### Practical 7.3

#### Investigating how earthquakes affect buildings

##### Aim

To investigate how earthquakes affect buildings of different heights.

##### Planning

Complete some research and summarise the effects of earthquakes on buildings of different heights.

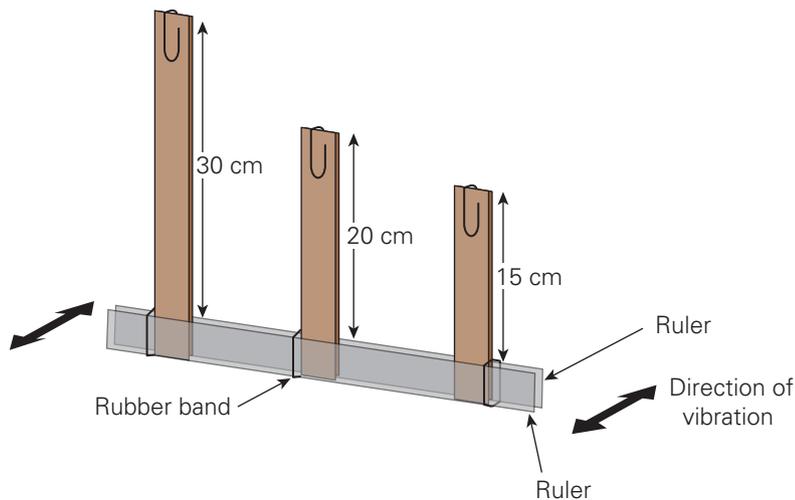
HINT: research the 1985 Mexico City earthquake.

##### Materials

- 2 rulers
- elastic bands
- pieces of card
- paper clips

##### Procedure

- 1 Draw the results table below.
- 2 Set up the experiment as shown in the diagram below. Each 'tower' is made of 4 card strips held together at the top by a paper clip and 2 rulers at the bottom. The rulers are held in place using rubber 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 shortest cardboard strip begins 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 for each strip.
- 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...*

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- 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.

#### Discussion

- 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.
- 3 Identify any potential sources of error in this experiment.
- 4 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.

### Practical 7.4: Student design

#### Designing earthquake-proof building bases

##### Aim

To observe the effect of base isolation on damage to buildings during an earthquake.

##### Materials

- 100 gram (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.

##### Procedure

- 1 Using the equipment provided, except for the wooden block, dowels and pens, design 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)	

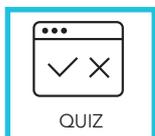
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### Discussion

- 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.

## Section 7.4 questions



### Remembering

- 1 **Recall** what GPS stands for.
- 2 **List** the three methods of earthquake-proofing buildings.
- 3 **Identify** the name of NASA's first robot used to explore volcanoes.
- 4 **Outline** why scientists need to study the inside of volcanoes.

### Understanding

- 5 **Explain** how GPS can map the position of tectonic plates.
- 6 **Summarise** the advantages of using drones after an earthquake.
- 7 **Describe** two examples of technological developments that have been used to reduce damage from earthquakes in the Asia–Pacific region.

### Applying

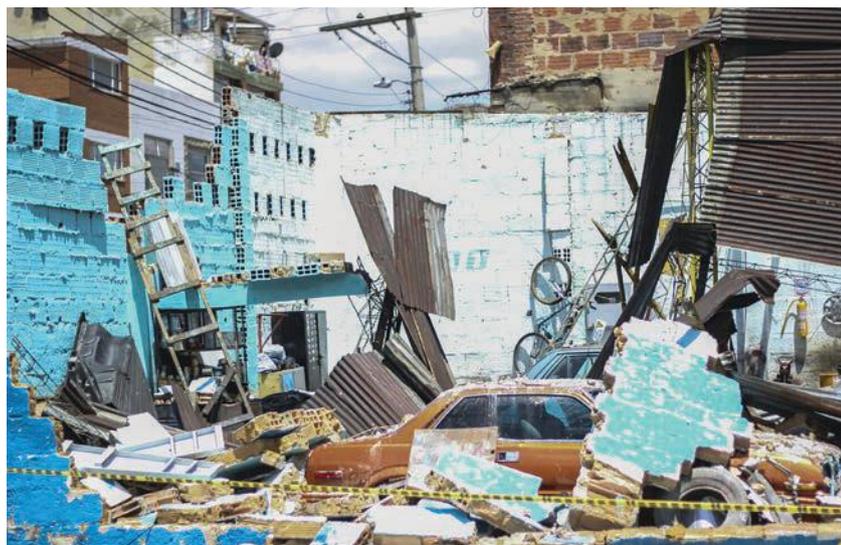
- 8 Apply your knowledge of tsunamis to **explain** why levitating homes are not effective in preventing damage caused by them.

### Analysing

- 9 **Compare** and contrast the three methods of protecting buildings from earthquakes.

### Evaluating

- 10 **Propose** reasons why humans cannot enter some parts of volcanoes.
- 11 **Suggest** benefits and shortcomings of using technologies to map plate movement and Earth's geology, by using examples.
- 12 Recall the various earthquake-proofing methods you have learned about. **Propose** which earthquake-proofing method you would choose and **justify** your choice.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>7.1 I can discuss the evidence surrounding continental drift.</b> e.g. Discuss the evidence that Alfred Wegener proposed regarding continental drift.	
<b>7.2 I can describe the structure of the Earth.</b> e.g. Construct a labelled diagram that shows the different layers of the Earth.	
<b>7.2 I can explain the theory of plate tectonics.</b> e.g. Describe how convection currents cause the movement of tectonic plates.	
<b>7.2 I can describe the effects of tectonic plates interacting with each other.</b> e.g. Describe the effect of a destructive plate boundary.	
<b>7.3 I can explain how earthquakes and volcanoes form.</b> e.g. Define the term 'hotspot' in your own words.	
<b>7.3 I can explain how technological developments have increased our scientific understanding.</b> e.g. Describe one technology that helps in detecting or responding to natural disasters.	



## Reflections

- 1 What **connections** come to mind when you think about plate tectonics and your everyday life?
- 2 What new concepts have **extended** your thinking about how the earth changes?
- 3 What information did you find **challenging** or confusing?



## 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 7.3). The magnitudes of ten New Zealand earthquakes from 2010 to 2019 are presented in Table 7.4.

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

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 7.3** Severity of earthquake observed with Richter scale value

**Table 7.4** The magnitude on the Richter scale of ten earthquakes that occurred in New Zealand between 2010 and 2019

- Identify** the most severe earthquake recorded in Table 7.4.
- Determine** the earthquakes that had a high risk of damage to buildings.
- 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.
- Categorise** the earthquakes presented in Table 7.4 as 'not felt' or 'felt'.
- Identify** a trend in the Richter scale and severity of earthquakes.
- Based only on the ten earthquakes presented, **infer** whether there is a higher chance that an earthquake in New Zealand would not be felt or would damage buildings.
- There are over 10 000 earthquakes a year in New Zealand. **Justify** whether your answer to question 6 would be reliable.
- 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.
- The media in New Zealand are reporting a mild earthquake that caused a tremor that did not damage buildings but moved furniture in buildings in the area. **Deduce** the magnitude of this earthquake on the Richter scale.

## STEM activity: Earthquake-proof structures

### Background information

Experts have demonstrated that most deaths in earthquakes occur because buildings and dwellings collapse due to poor construction.

Papua New Guinea (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.

**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.

### Activity instructions

In groups (maximum of four people), you will investigate how housing design can affect the stability of a building.

Role	Responsibility
Project manager	Making sure the project is on time and within a budget.
Engineer	Conducting research on the current models, finding new ways to improve design
Builder	Creating the proposed design and checking that the design is functional
Presenter	Researching on cultural awareness of the local community and how to effectively present the design

### 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 and design the format you will use for your presentation design 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.
  - B Weight test:** Compare how it behaves when 0.5 kilogram (kg) masses are placed on top of it.
  - C Combination test:** Repeat tests **A** and **B** at the same time.
- 9 Reflect and, if there is time, create and test another design. Reflect on how the second design performed.
- 10 Create the presentation while building and testing your design.

### Evaluate and modify

- 11 Evaluate the effectiveness and cost of materials of your design. It is important to remember who your target audience is throughout this project.
- 12 Give your presentation to the class and reflect on how it demonstrates cultural awareness and how well it communicates effective building methods.

# Chapter 8

## Global systems



### Inquiry questions

How do global systems rely on interactions in chemical spheres?

Why is the carbon cycle important?

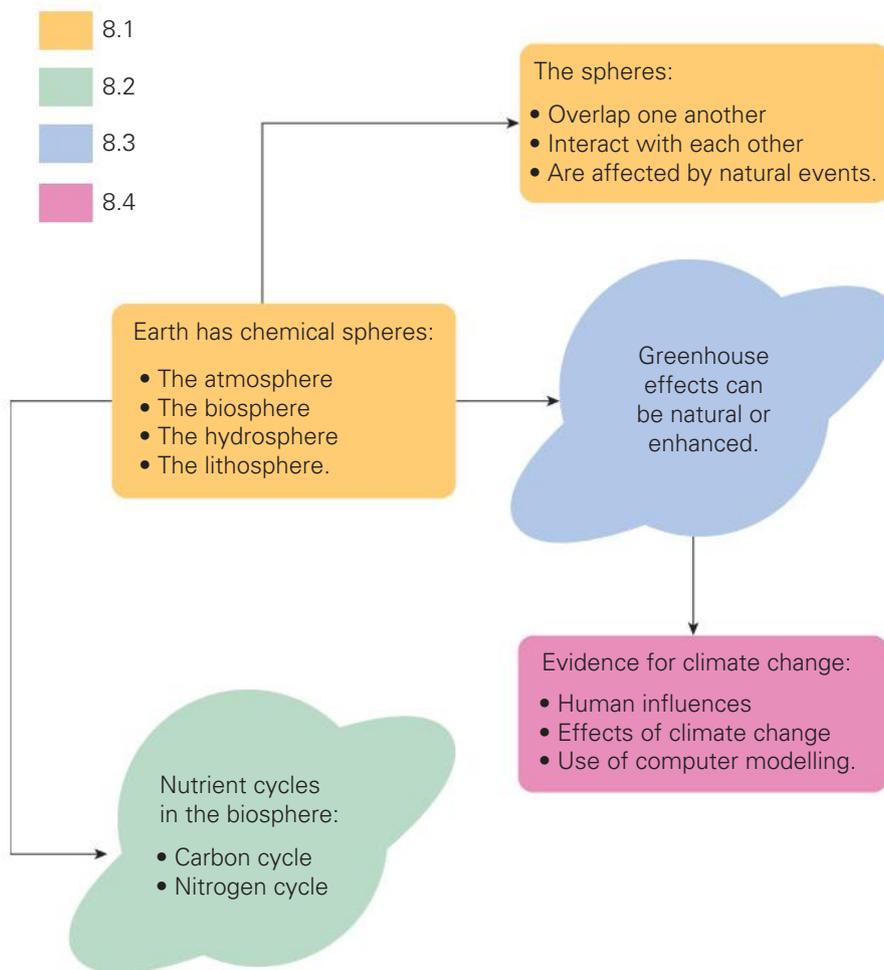
How does the Earth stay warm to sustain life?



### Chapter introduction

The first time people had a glimpse of Earth from space was in October 1946, when a film camera set to take photos every 1.5 seconds was launched on a rocket. Earth was photographed in greater detail in December 1968 by Apollo 8 astronauts on their trip to orbit the Moon. This encouraged us to understand Earth from a different perspective: as a global system. Earth is a dynamic and ever-changing planet consisting of interconnecting spheres. In this chapter, you will learn about Earth's chemical spheres and how they interact. You will understand how humans are disrupting the balance and how scientists can make predictions about our future. It is the interactions between Earth's systems, both natural and enhanced, that have shaped its history and will continue to shape its future.

# Chapter map



# 8.1 Earth's interacting spheres

## Learning goals

- 1 To recall the features of each of Earth's chemical spheres
- 2 To understand how global systems rely on interactions between chemical spheres
- 3 To describe some impacts of natural events on Earth's chemical spheres



WORKSHEET



VIDEO  
Name and briefly explain Earth's spheres

## Chemical spheres

To make it easier to describe the movement of matter around Earth, scientists have split the planet into four major systems called spheres. Despite their name, they are not spherical in shape. These spheres are the atmosphere, biosphere, lithosphere and hydrosphere.

### The atmosphere

The **atmosphere** consists of all the gases above Earth's surface – without it there would be no life on Earth. Two main gases make up our atmosphere: nitrogen and oxygen. There are also smaller proportions of other gases.

#### atmosphere

the mixture of gases above the surface of Earth

#### troposphere

a layer of Earth's atmosphere which is closest to Earth's surface and where most of the weather occurs

#### stratosphere

a layer of Earth's atmosphere above the troposphere containing the ozone layer

Our atmosphere in total is about 500 km thick and contains five layers: the **troposphere**, **stratosphere**, mesosphere, thermosphere and exosphere. These layers allow us and other living things to breathe, protect us from the Sun's harmful ultraviolet (UV) radiation and keep the surface temperature of Earth constant. The layers of most importance to us and other life on Earth are the troposphere and the stratosphere.

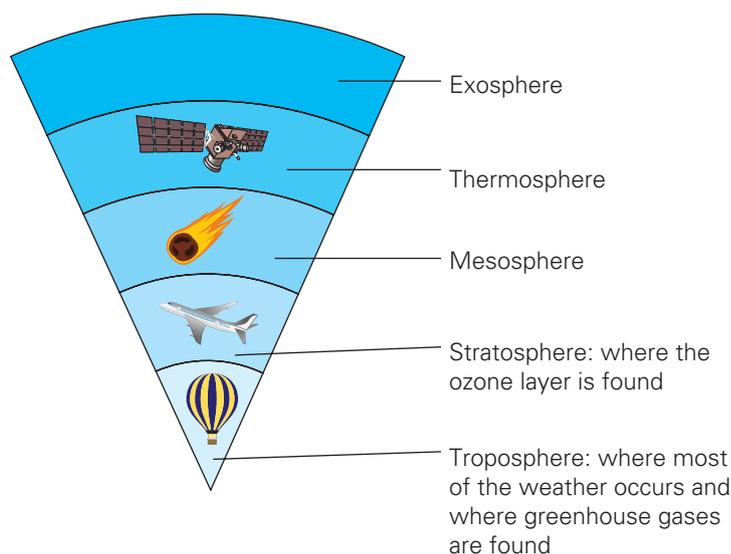


Figure 8.1 The five layers of Earth's atmosphere

### Quick check 8.1

- 1 Name the gas which is the most abundant in Earth's atmosphere.
- 2 Recall the functions of Earth's atmosphere.

Atmospheric gas	Percentage composition (%)
Nitrogen	78
Oxygen	21
Argon	1
Trace gases (e.g. carbon dioxide, neon, methane, water vapour)	<1

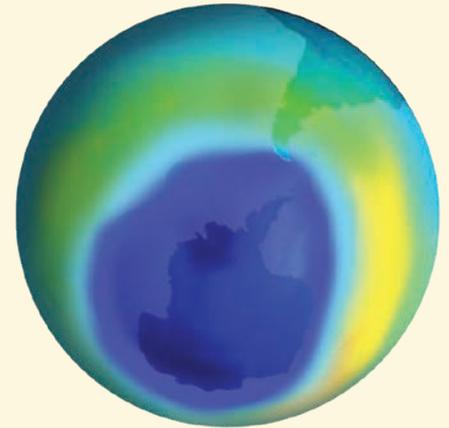
Table 8.1 The composition of gases in Earth's atmosphere

## Explore! 8.1

**The Antarctic hole in the ozone layer**

In 1985 scientists found that parts of the ozone layer above the continent of Antarctica had broken down. They also noticed that similar thinning of the ozone layer was happening over parts of Australia, and that this correlated with an increase in cases of skin cancer. They needed to find out why this had happened and if it could be reversed. Do some research and answer the following:

- 1 Compare the atomic structures of oxygen gas ( $O_2$ ) and ozone gas ( $O_3$ ).
- 2 Identify the main function of the ozone layer in more detail to explain the impact of ozone thinning.
- 3 Research the causes of ozone thinning.
- 4 Describe the purpose of the Montreal Protocol.
- 5 Discuss whether the process of ozone thinning can be reversed. Provide evidence to support your discussion.



**Figure 8.2** The hole in the ozone layer above Antarctica. The bluish purple areas show the least amount of ozone.

## Advances in science 8.1

**Felix Baumgartner: the fastest skydiver on Earth**

On 14 October 2012, Austria's Felix Baumgartner climbed nearly 39 km to the stratosphere in a helium-filled balloon. He then jumped into thin air, freefalling for 4 minutes and 22 seconds before opening his parachute. The entire journey back to the ground lasted just over 4 minutes. Baumgartner reached an estimated speed of 1342 km/h which makes him the first man to break the speed of sound in freefall. In addition, he broke the record for the world's highest ever freefall.

The jump nearly did not happen because a fault in the heater of Baumgartner's visor was making it fog up when he breathed out. During the dive, there was concern early on as he could not get in to the correct position for freefall (head down, arms swept back). Instead, he found himself tumbling over and over. However, due to his extensive freefalling experience, Baumgartner was able to correct his fall and get into a stable position.



**Figure 8.3** Felix Baumgartner

**The biosphere**

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

**biosphere**

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

(including humans), fungi and microscopic organisms such as bacteria.

**Quick check 8.2**

- 1 What is the biosphere?
- 2 Flying birds are part of the atmosphere, true or false? Justify your choice.

## The hydrosphere

The **hydrosphere** is made up of all the water on Earth. This includes the oceans, rivers, lakes, glaciers, rain,

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

water vapour, underground basins and even puddles.

### Quick check 8.3

- 1 What is the hydrosphere?
- 2 Give an example of something that is part of the hydrosphere.



**Figure 8.4** Elephants, as living organisms, are part of the biosphere. Fox Glacier in New Zealand is part of the hydrosphere.

## The lithosphere

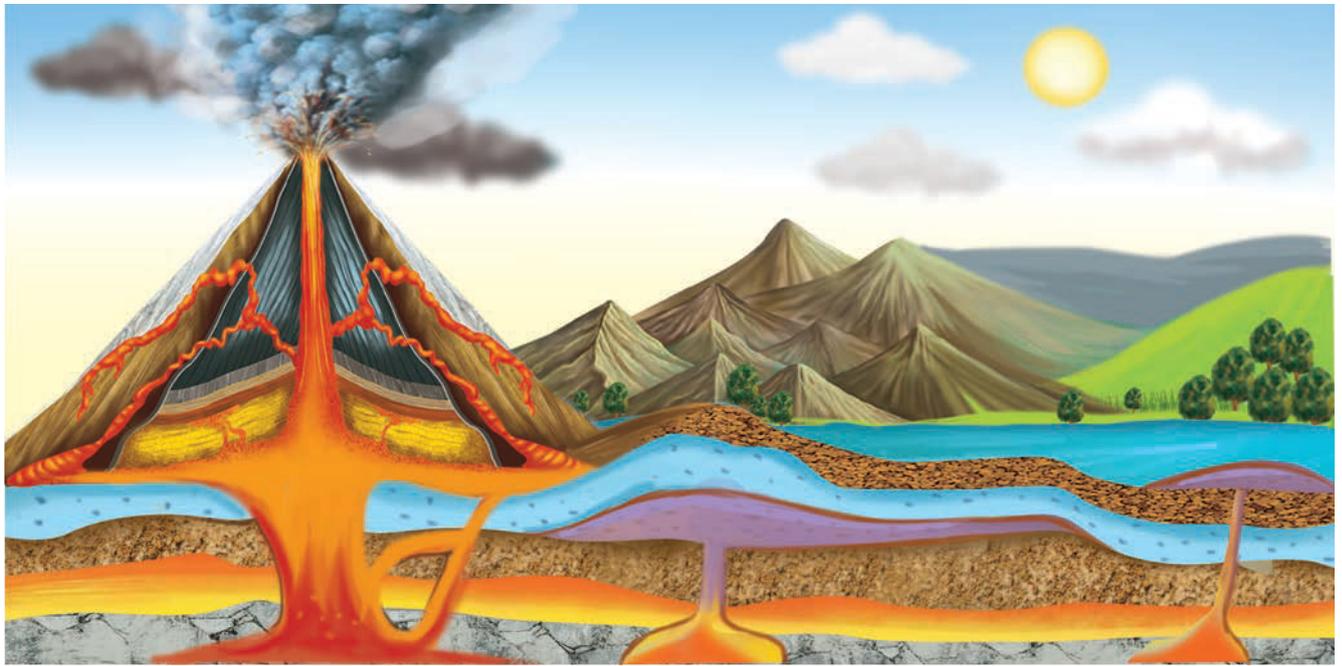
The **lithosphere** consists of the Earth's geological material, such as magma, lava, rocks and minerals located in the Earth's crust and upper part of the mantle.

The lithosphere is in a constant cycle, with matter constantly moving in the processes involved in the rock cycle. Magma erupts from volcanoes as lava, which solidifies, forming rocks. This rock is eroded into sediment, which builds up over time and sinks further into the crust until it is spewed out onto Earth's surface again as lava.

**lithosphere**  
the geological parts of Earth's crust and rigid layer of the upper part of the mantle



**Figure 8.5** Uluru is part of the lithosphere.



**Figure 8.6** The lithosphere is constantly in motion due to the many processes involved in the rock cycle.

The lithosphere is broken up into tectonic plates which float on top of the mantle – most earthquakes and volcanoes occur at boundaries between tectonic plates.

#### Quick check 8.4

- 1 What is the lithosphere?
- 2 Give an example of something that is part of the lithosphere.
- 3 Name the cycle that results in constant movement of the lithosphere.

### Overlapping spheres

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

### Sphere interactions

The chemical spheres on Earth interact and affect each other, maintaining a natural balance. Matter constantly

moves between spheres in cycles. The energy driving the movement of matter comes from the Sun and from the Earth's core. It is the flow of this energy and the cycling of matter that produces chemical and physical changes in Earth's materials. Earth gains and loses matter and energy in different ways, as summarised in Table 8.2.

**Figure 8.7** Productive soil belongs to all four chemical spheres.



	Gain	Loss
Energy	Radiation from the Sun (mostly infrared, visible and UV wavelengths)	Heat loss into space
Matter	Meteorites and comets	Escape of gases into space

**Table 8.2** A summary of Earth's gains and losses of matter and energy

The lithosphere interacts with the other spheres through the cycles of matter. Let's take Figure 8.8 as an example to describe some of the sphere interactions that can take place. Plants in the biosphere obtain water from the hydrosphere and nutrients from the lithosphere via soil. Water vapour is released by plants into the atmosphere.



Figure 8.8 Farmland is one place where multiple spheres interact.



Figure 8.9 Plants interact with multiple chemical spheres.

### Quick check 8.5

- 1 Earth can be described as a closed system, meaning that its total mass does not change. Decide whether this statement is true or false.
- 2 List one way that Earth can gain and lose mass, and one way it can gain and lose energy.
- 3 The rate that matter moves around Earth varies, from very slow to incredibly fast. Decide whether this statement is true or false.
- 4 Give an example of a transfer of matter from the biosphere to the atmosphere.

## Natural events affecting chemical spheres

Natural events such as earthquakes and volcanoes influence the interactions between the chemical spheres. Table 8.3 summarises how natural events cause sphere interactions.

Natural event	Effect on the lithosphere	Effect on the biosphere	Effect on the atmosphere	Effect on the hydrosphere
Earthquake	Fault lines move apart or together Land rises or subducts (sinks) Landslides Mudslides 	Damages lithosphere Destroys ecosystems 	Gas emissions from the ground release toxic gases 	Tsunamis Changes the course of rivers Destroys dams 

Table 8.3 How natural events influence the interaction between spheres

*continued...*

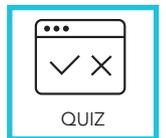
Natural event	Effect on the lithosphere	Effect on the biosphere	Effect on the atmosphere	Effect on the hydrosphere
Volcano	Volcanic lava can create islands Volcanic explosions can destroy mountains and islands that were created by the volcanoes. 	Lava burns plants and animals New islands become habitats for ecosystems 	Large ash clouds release many gases, including greenhouse gases and toxic gases 	Toxic gases dissolve in water and fall as acid rain, which can dissolve building materials 
Cyclone	Intense rainfall causes erosion of the land 	Uproots trees and plants destroying ecosystems 	High wind speeds 	Produces very heavy rain causing floods Storm surges 

Table 8.3 (Continued)

## Section 8.1 questions

## Remembering

- 1 **Define** the following terms in your own words: atmosphere, biosphere, lithosphere, hydrosphere.
- 2 **Choose** the correct sphere for the following examples:
  - a glacier
  - tectonic plates
  - earthworms
  - ozone.
- 3 **Recall** the layer of the atmosphere where most of the weather occurs.
- 4 **Give** the name of the second most abundant gas in Earth's atmosphere.



## Understanding

- 5 **Explain** why you cannot describe Earth as a closed system (one where the total mass does not change).
- 6 **Show** examples of the chemical spheres present in Figure 8.10.
- 7 **Explain** the problems associated with a hole in the ozone layer.



Figure 8.10 Irrigation channels flowing through farmland

## Applying

- 8 **Identify** which of Earth's spheres would contain matter that has arrived from space.
- 9 **Identify** the role of Earth's atmosphere as it relates to sustaining life on Earth.

**10 Identify** the sphere interactions taking place in Figure 8.11.

### Analysing

**11 Analyse** why a healthy river containing dissolved nitrogen, oxygen and carbon dioxide, algae and other organisms, and mineral and rock fragments, contains components from all the chemical spheres.

### Evaluating

**12 Decide** which sphere clouds belong to, and justify your choice.

**13 Discuss** how a natural disaster, such as an earthquake, can affect chemical spheres. Try to include all the spheres in your answer.



Figure 8.11 A seaside landscape

## 8.2 Nutrient cycles

### Learning goals

- To recall the stages in the carbon and nitrogen cycle
- To explain how nutrient cycles show how global systems rely on sphere interactions



WORKSHEET

The cycling and recycling of nutrients such as nitrogen, carbon and water in the chemical spheres is important for sustaining life and ecosystems.



VIDEO  
Why is carbon important?

A **sustainable ecosystem** is a biological environment that is able to support itself without outside assistance.

all four spheres. Carbon is one of the most important chemicals for life on Earth as it is an essential building block for cells. The carbon cycle occurs in many stages, but it is important to note that carbon can stay at one particular stage for thousands of years before moving on to the next stage.

Table 8.4 summarises the forms of carbon in each of the chemical spheres.

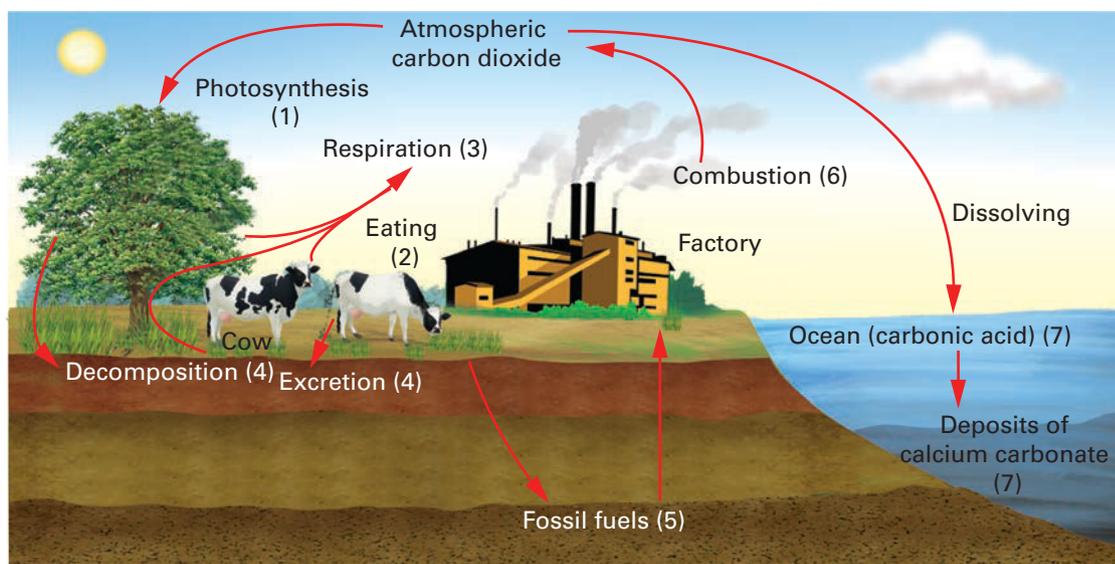
### The carbon cycle

The carbon cycle describes the movement of carbon through

**sustainable ecosystem**  
a biological environment that is able to support itself without outside assistance

Chemical sphere	Carbon content
Atmosphere	Carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ )
Biosphere	Carbohydrates (such as glucose $\text{C}_6\text{H}_{12}\text{O}_6$ ), fats, proteins, vitamins and the DNA of all living things
Hydrosphere	$\text{CO}_2$ dissolved in rivers, lakes and the ocean, forming carbonic acid ( $\text{H}_2\text{CO}_3$ )
Lithosphere	Decomposed organic matter in soils Fossil fuels (coal, oil and gas) Limestone (calcium carbonate, $\text{CaCO}_3$ )

Table 8.4 A summary of the carbon content in each chemical sphere



**Figure 8.12** The main stages and processes in the carbon cycle. The numbers in this figure relate to the text that follows.

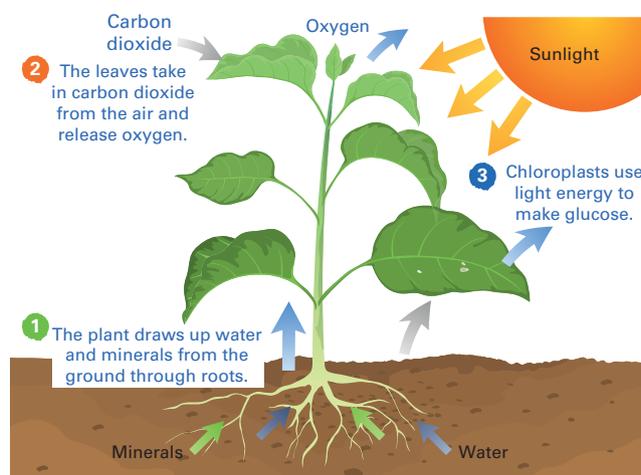
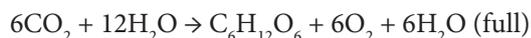
The carbon cycle can be summarised in seven processes, which either increase or decrease carbon dioxide in the atmosphere.

### 1. Photosynthesis

Carbon dioxide in Earth's atmosphere is absorbed by plants during photosynthesis. The carbon dioxide reacts with water taken in from the soil to make glucose, a carbon-containing compound.

The following equations summarise the process of photosynthesis for plants:

carbon dioxide + water  $\rightarrow$  glucose + oxygen



**Figure 8.13** Plants remove carbon dioxide from the atmosphere during photosynthesis.

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### Quick check 8.6

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

### 2. Transfer of carbon through the food chain

Animals obtain their carbon by eating plants and other animals. When animals and plants are eaten, their carbon content is transferred through the food chain.

**Figure 8.14** The carbon content of the cricket is now being consumed by the leopard gecko.



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### 3. Respiration

Plants and animals break down glucose using oxygen to form carbon dioxide, water and ATP (a form of energy that the body uses). This process is called respiration. The carbon dioxide is added to the atmosphere when organisms breathe out.

**Figure 8.15** During respiration, organisms release carbon dioxide gas into the atmosphere.



The following equation summarises respiration:

glucose + oxygen → carbon dioxide + water + ATP



### 4. Excretion, egestion, death and decomposition

Some of the carbon content of animals and plants enters the soil as waste such as urine, faeces and leaf litter.

**Figure 8.16** Excretion of waste materials, such as these wombat faeces, increases the carbon content of the soil.



Dead animals and plants (organic matter) also contribute to the carbon content of the soil. Waste material and dead organic matter is broken down by **decomposers**, which respire, releasing carbon dioxide back into the atmosphere.

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

#### Quick check 8.7

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

### 5. Formation of fossil fuels

Fossil fuels like coal, oil and gas are composed of the carbon from plants and animals that died millions of years ago. Carbon is stored as fossil fuels for millions of years before re-entering the carbon cycle.



**Figure 8.17** Coal is a fossil fuel formed from the carbon content of dead plants that have been buried and compressed for millions of years.

### 6. Combustion

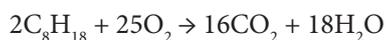
When fuel is burned in oxygen (combustion), carbon dioxide and water are formed. Carbon dioxide is therefore released back into the atmosphere. Later in this chapter, we will look in more detail at how humans are affecting the balance of carbon in the carbon cycle by releasing carbon that has been buried for millions of years.



**Figure 8.18** The combustion of coal in furnace produces large amounts of carbon dioxide gas.

The following equation shows the combustion of octane, a component of oil:

octane + oxygen  $\rightarrow$  carbon dioxide + water



## 7. Formation of limestone

Carbon dioxide gas in the atmosphere can dissolve in the oceans, forming carbonic acid. The carbon dioxide also provides the carbon that combines with calcium in mineral deposits to make calcium carbonate ( $\text{CaCO}_3$ ), which is the major component of shells and the exoskeletons of marine microorganisms. These dead organisms sink to the bottom of the ocean. Over and over millions of years, become compacted forming limestone. Limestone is a sedimentary rock and an important building material.

### Quick check 8.8

- 1 Give an example of a fossil fuel.
- 2 Give the name of the processes where fuels are burned releasing carbon dioxide back into the atmosphere.
- 3 What is the scientific name and formula for the main compound in limestone?

Table 8.5 summarises the gains and losses of atmospheric carbon in the carbon cycle.

Atmospheric carbon gains	Atmospheric carbon losses
Respiration	Photosynthesis
Combustion	
	Dissolving in the oceans

**Table 8.5** A summary of the gains and losses of atmospheric carbon within the carbon cycle



**Figure 8.19** Fossilised shells in limestone

## Practical 8.1

### Limestone and carbon dioxide

#### Aim

To determine whether limestone is a store of carbon dioxide.

#### Materials

- calcium carbonate chips (Limestone is essentially made of calcium carbonate; we use marble chips to represent this.)
- hydrochloric acid (1 M)
- limewater
- 2 × 10 mL measuring cylinders
- 2 test tubes
- delivery tube
- test-tube rack

#### Procedure

- 1 Using a 10 mL measuring cylinder, measure 5 mL of hydrochloric acid and pour it into one of the test tubes.
- 2 Using another 10 mL measuring cylinder, measure 5 mL of limewater and pour it into the other test tube.
- 3 Add three calcium carbonate chips to the acid, and at the same time attach the bung of the delivery tube to this test tube with the other end of the tube in the limewater solution.
- 4 Observe what happens to the limewater.

#### Results

Record your observations from the experiment in your science journal.

#### Discussion

- 1 Describe what happened to the limewater solution.
- 2 In this reaction, calcium carbonate was reacted with hydrochloric acid. Three products were formed. Two of those products were calcium chloride and water. Write a word equation for the reaction which includes the third product.
- 3 Identify the part of the carbon cycle represented by this investigation.

#### Be careful

Ensure appropriate personal protective equipment is worn.  
Wear safety glasses.

## The nitrogen cycle

Nitrogen in its elemental form has the formula  $N_2$ . Nitrogen is important for all living things as it is the basis of DNA and amino acids, the subunits of proteins. The majority of gas found in the atmosphere is  $N_2$  (78%). However, a large proportion of organisms cannot access this form of nitrogen.

The nitrogen cycle can be summarised in six processes, each of which can result in either a gain or loss of nitrogen in the form of nitrates from the soil. Table 8.6 shows the forms of nitrogen in each of the chemical spheres. These processes are illustrated in Figure 8.20.

Chemical sphere	Nitrogen content
Atmosphere	Nitrogen ( $N_2$ ) gas
Biosphere	Amino acids (the building blocks of proteins) and the DNA and RNA of all living things
Hydrosphere	Nitrates ( $NO_3$ ) leached into the water from the soil
Lithosphere	Nitrates ( $NO_3$ ) from the decomposition of organic matter and nitrification

**Table 8.6** A summary of the nitrogen content in each chemical sphere

Stage	Details
1. Nitrogen fixation	Nitrogen from the atmosphere is made accessible to organisms by lightning and nitrogen-fixing bacteria.
2. Uptake by plants	Plants absorb nitrate in the soil to build up proteins.
3. Transfer through the food chain	Animals obtain their nitrogen by eating plants and other animals.
4. Ammonification	Excreted material is broken down by decomposers. Nitrogen is returned to the soil as ammonia.
5. Nitrification	Ammonia is converted back to nitrates by nitrifying bacteria.
6. Denitrification	Nitrates in the soil are converted back into nitrogen gas by denitrifying bacteria.

Table 8.7 A nitrogen cycle: the numbers in the table relate to those in Figure 8.20.

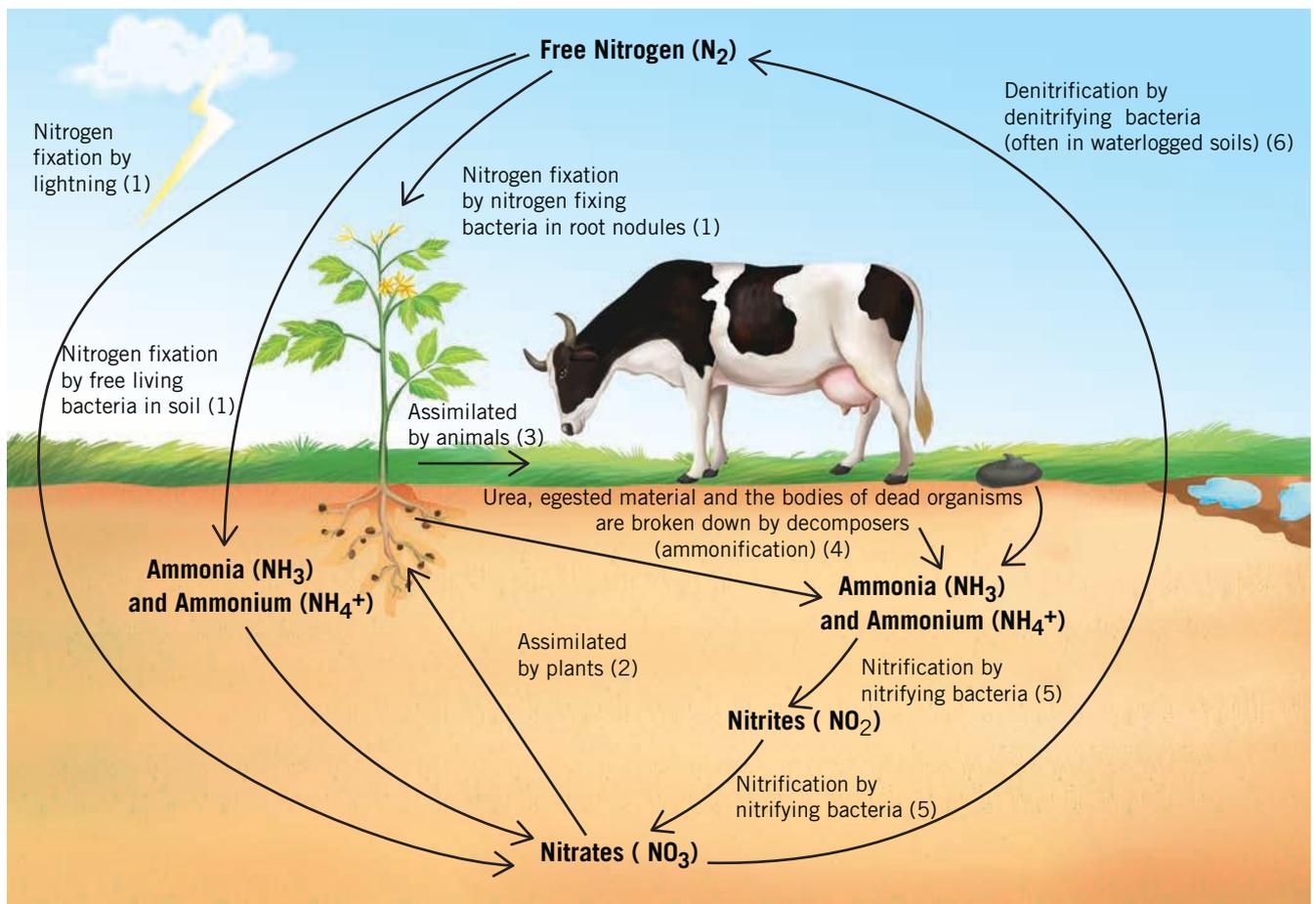


Figure 8.20 The main stages and processes in the nitrogen cycle

Nitrate gains	Nitrate losses
Excretion, death and decomposition	Denitrification
Nitrogen fixation	Uptake by plants
Nitrification	

Table 8.8 A summary of the gains and losses of nitrates in the soil in the nitrogen cycle

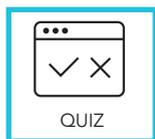
## Quick check 8.9

- 1 Identify where the majority of nitrogen is found in the nitrogen cycle.
- 2 Name the process and type of organisms involved in converting nitrogen gas into useful nitrogen-containing compounds.
- 3 Name the process and types of organism involved in converting nitrates back into nitrogen gas.
- 4 State the importance of nitrogen for living organisms.



Figure 8.21 Nitrogen-fixing bacteria can be trapped in root nodules of certain plants.

## Section 8.2 questions



## Remembering

- 1 **Identify** the cycle (carbon or nitrogen) which includes the following processes:
 

a denitrification	c decomposition
b respiration	d combustion.
- 2 **State** the name and formula of the compound in which carbon is found in the atmosphere.
- 3 **Recall** the name of the process that takes nitrogen gas out of the atmosphere and adds it into the soil as ammonia.
- 4 **Give** the reason why animals and plants require nitrogen.
- 5 Bacteria can take nitrogen from the atmosphere and convert it into nitrogen compounds in the soil. **State** another component of the nitrogen cycle that is able to do this.

## Understanding

- 6 **Describe** the process of photosynthesis to show how carbon dioxide from the atmosphere is transferred into plants and animals.
- 7 **Demonstrate**, with the use of a word equation, why respiration is part of the carbon cycle.
- 8 **Outline** the role of decomposers in both the carbon and nitrogen cycles.
- 9 **Explain** where the carbon in coal, oil and gas originally came from.

## Applying

- 10 **Identify** which of the following processes involves bacteria:
 

• nitrification	• denitrification
• decomposition	• combustion
• photosynthesis.	
- 11 **Select** the best definition for a sustainable ecosystem, and justify your choice.
 

A An environment that requires intervention to continue.
B A biological environment which is self-sustaining; that is, does not require any outside assistance.
C A system that is a mixture of biotic and abiotic factors.

## Analysing

- 12 **Compare** and **contrast** the processes of nitrogen fixation and denitrification in the nitrogen cycle.
- 13 **Examine** both the carbon and nitrogen cycles. What processes are similar?

**Evaluating**

- 14 Evan says that humans are affecting both the carbon and the nitrogen cycles in a negative way. Trent however, disagrees with this statement and thinks that humans do not affect these cycles at all. **Discuss** who you think is correct.
- 15 **Explain** why carbon stored in fossil fuels remains in this form for a long period of time.
- 16 **Explain** why plants can suffer from a lack of nitrogen when they are surrounded by a plentiful supply of nitrogen in the atmosphere.
- 17 **Deduce** what would happen if the nitrogen cycle stopped.

## 8.3

## The greenhouse effect in the atmosphere

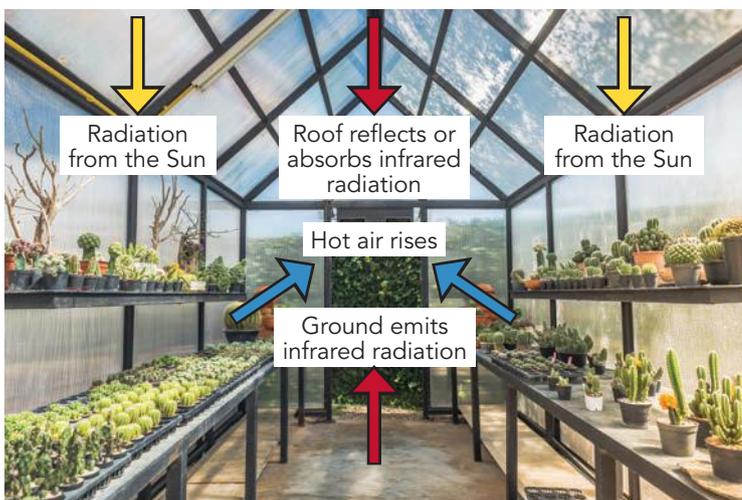
**Learning goals**

- 1 To describe the differences between the natural and enhanced greenhouse effects
- 2 To explain how the greenhouse effect warms Earth
- 3 To explain how humans have contributed to the enhanced greenhouse effects

Greenhouses are made from glass and plastic. When the Sun's radiation passes through these materials, it heats the ground and air inside the greenhouse. As the air heats up, it starts to rise, but it cannot exit the greenhouse as it is stopped by the roof and walls. Some infrared radiation emitted by the ground is also reflected back by the roof. All of this results in the greenhouse heating up, keeping the plants at an optimum temperature for growth.

**The natural greenhouse effect**

Earth has its own way of keeping the heat in, similar to a greenhouse but on a much larger scale. Most of the Sun's radiation passes through Earth's atmosphere where the majority heats the ground and the oceans. The remainder is reflected back into space by ice, clouds and water. The ground and oceans emit radiant energy back towards the atmosphere as infrared radiation. However, instead of leaving Earth's atmosphere, some of this radiation is absorbed and reflected back towards the surface by a layer of gases called **greenhouse gases**. Water vapour ( $\text{H}_2\text{O}$ ) is the most abundant (95%) greenhouse gas. Methane ( $\text{CH}_4$ ), carbon dioxide ( $\text{CO}_2$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ) are three of the other most common greenhouse gases.



**Figure 8.22** Greenhouses protect plants from cold and adverse weather conditions by keeping in the thermal energy.

**Quick check 8.10**

- 1 Name a type of radiation emitted by matter due to its heat.
- 2 Explain why greenhouses are made of glass or plastic.

Table 8.9 compares the effectiveness in retaining heat of the three most common greenhouse gases after water vapour.

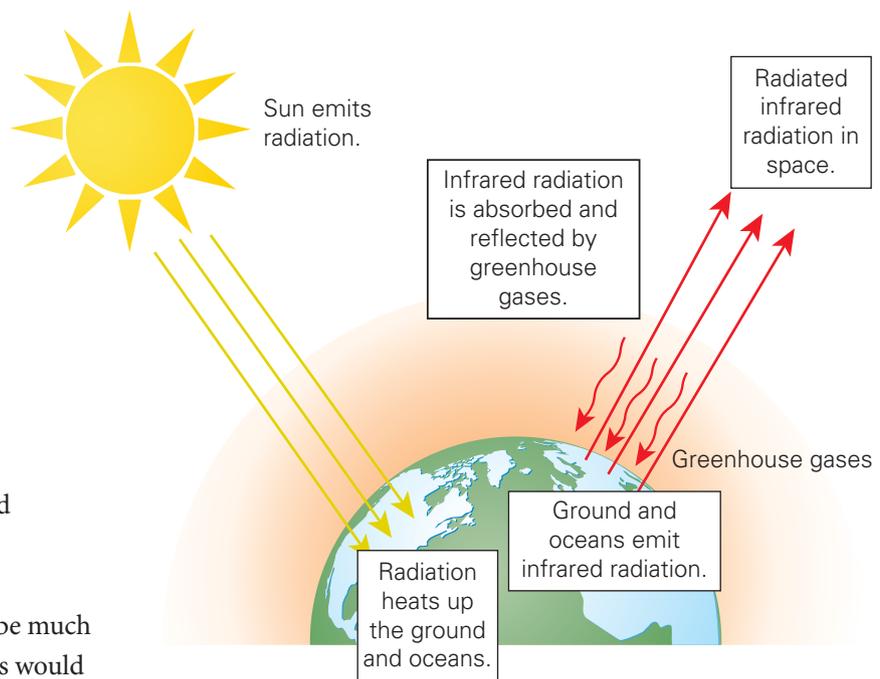
	Carbon dioxide (CO <sub>2</sub> )	Methane (CH <sub>4</sub> )	Nitrous oxide (N <sub>2</sub> O)
% of the total amount of greenhouse gases	84	9	5
Persistence in the atmosphere	100 years	10 years	100 years
Effectiveness of trapping heat compared to carbon dioxide		30 times more effective	300 times more effective

**Table 8.9** A summary of the three most common greenhouse gases, excluding water vapour

The process of trapping the Sun's solar energy in Earth's atmosphere is called the **greenhouse effect**. The radiation from the Sun is described as short-wave radiation. This type of radiation is able to pass directly through the atmosphere. The infrared radiation emitted from the ground and the oceans is described as long-wave radiation. This type of radiation is absorbed by the greenhouse gases, keeping Earth warm. If most of the Sun's radiation was not converted by the ground and the ocean into longer wavelength infrared, we would lose all of the thermal energy back into space, and Earth would be much less habitable. Plants, animals and humans would struggle to survive on Earth without the greenhouse

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

effect's role in maintaining a comfortable consistent average temperature.



**Figure 8.23** A summary of the greenhouse effect

### Quick check 8.11

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

### Did you know? 8.1

#### We need the natural greenhouse effect

Earth's average temperature is 14°C. Without the natural greenhouse effect, this temperature would decrease to -18°C.



**Figure 8.24** Earth would freeze without the greenhouse effect.

Table 8.10 summarises the features of visible light, UV and infrared radiation.

Visible and UV light radiation	Infrared radiation
Emitted by the Sun	Emitted by the Sun, the ground and oceans
Short-wave	Long-wave
Not trapped by the atmosphere	Trapped by greenhouse gases in the atmosphere

**Table 8.10** Features of visible light, UV and infrared radiation

### Quick check 8.12

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

## The enhanced greenhouse effect

The natural greenhouse effect keeps our planet at a comfortable temperature; however, human activity has caused this natural process to intensify. This is called the **enhanced greenhouse effect**.

### Causes

The major cause of the enhanced greenhouse effect is an increase in the concentration of greenhouse gases, carbon dioxide, methane, nitrous oxide and water vapour, in the atmosphere. Table 8.11 summarises how humans have contributed to the increased levels of these greenhouse gases.

**enhanced greenhouse effect**  
the intensifying of the natural greenhouse effect due to human activity

Greenhouse gas	How humans have increased its concentration in the atmosphere
Carbon dioxide	<p>Burning fossil fuels such as coal, oil and gas. Currently, 70% of Australia's electricity is produced by burning coal.</p> 
Methane	<p>Farming cattle (which produce methane when they digest grass) and growing rice in paddies. Increased temperatures lead to the melting of permafrost in the Arctic. Permafrost is frozen soil which contains trapped methane produced from the decomposition of plants and animals.</p> 

**Table 8.11** How humans have increased the concentration of greenhouse gases in the atmosphere

Greenhouse gas	How humans have increased its concentration in the atmosphere
Nitrous oxide	Using fertilisers increases the amount of nitrogen in the nitrogen cycle, which increases the production of nitrous oxide. 
Water vapour	Water vapour is already the most abundant greenhouse gas naturally, but as the concentrations of carbon dioxide, methane and nitrous oxide in the atmosphere increase due to human activity, more heat is trapped, which contributes to increasing water vapour concentrations (increased humidity). This has a positive feedback effect on increasing temperatures, enhancing the greenhouse effect.

Table 8.11 (Continued)

## Explore! 8.2

### Your environmental footprint

An environmental footprint is the effect that an individual has on the environment. It can include greenhouse gas contributions and pollution with non-biodegradable materials. Use your preferred search engine to research how you can calculate your own environmental footprint. Make a list of the things that make up your environmental footprint.

## Quick check 8.13

- 1 State one way in which we have increased the concentration of carbon dioxide in the atmosphere.
- 2 Give one way we have increased the concentration of nitrous oxide in the atmosphere.
- 3 State the composition of permafrost.

## Practical 8.2

### Comparing the natural and enhanced greenhouse effects

#### Aim

To compare the impacts of the natural and enhanced greenhouse effects.

#### Materials

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

#### Procedure

##### Part 1: Prepare the results table

- 1 Read the rest of the steps in the method and make a prediction on what will happen.
- 2 Create an appropriate results table for this experiment.

*continued...*

...continued

### Part 2: Prepare the equipment

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

### Be careful

Care should be taken when handling the lamp as it can become hot with prolonged use. Ensure heat-resistant gloves are worn.

### Part 3: Collect the data

- 1 Using the balance, weigh out 35 g of baking soda into each weighing boat and pour into each beaker.
- 2 Using the 100 mL measuring cylinder, measure 65 mL of water and pour into the control beaker. Immediately cover it with the cling wrap and seal with the elastic band.
- 3 Using the same 100 mL measuring cylinder, measure 65 mL of vinegar and pour into the CO<sub>2</sub> beaker. Immediately cover it with the cling wrap and seal with the elastic band.
- 4 Swirl the contents of each beaker to make sure that the baking soda has fully dissolved.
- 5 Place both beakers underneath the lamp.
- 6 Record the starting temperature of each atmosphere before the lamp is turned on.
- 7 Turn on the lamp and start the stopwatch.
- 8 Measure the temperature in each beaker every 2 minutes for 8 minutes, recording the temperature in your results table.
- 9 At 8 minutes, measure the temperature and then turn off the light.
- 10 Record the final temperature 2 minutes later.

### Results

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

### Discussion

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

### Conclusion

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



**VIDEO**  
Name some effects of climate change

## Out of balance

Carbon dioxide emissions from human activity are our most significant contributor to the enhanced greenhouse effect. Since the Industrial Revolution in the 1800s, we have been burning large amounts of fossil fuels for energy. This means we have been moving stored carbon from the lithosphere into the atmosphere, directly affecting the balance of the carbon cycle.



**WIDGET**  
Greenhouse effect

**carbon sources**  
processes or areas that release carbon

**carbon sinks**  
areas where carbon is stored (e.g. fossil fuels)

As part of the carbon cycle, Earth has **carbon sources**, processes or areas that release carbon (such as when carbon moves from the atmosphere to

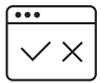
the hydrosphere during rainfall) and **carbon sinks**, areas where carbon is stored (such as the oceans or fossil fuels).

The problem with burning fossil fuels and releasing the carbon stored in them is that the carbon cycle does not have enough carbon sinks to remove the excess carbon from the atmosphere. Fossil fuels take millions of years to form, and Earth's carbon sinks cannot remove enough carbon dioxide to prevent it from building up in the atmosphere. The accumulation of carbon dioxide in the atmosphere is increasing Earth's greenhouse effect.

### Quick check 8.14

- 1 State the definition of carbon sources and give an example.
- 2 State the definition of carbon sinks and give an example.

## Section 8.3 questions



QUIZ

### Remembering

- 1 **Name** three gases in the atmosphere that are responsible for the greenhouse effect.
- 2 **Define** the term 'enhanced greenhouse effect' in your own words.
- 3 **State** what types of radiation is emitted from:
  - a the Sun
  - b the ground and oceans.

### Understanding

- 4 **Explain** the differences between the natural and enhanced greenhouse effects.
- 5 **Compare** and **contrast** short-wave and long-wave radiation.
- 6 **Explain** why the following statement is incorrect: 'The greenhouse effect is caused by humans.'
- 7 **Explain** how a greenhouse mimics the greenhouse effect.

### Applying

- 8 **Identify** why your feet burn on the sand on the beach on a sunny day, but are freezing cold in the water.
- 9 **Draw** a diagram to show how the greenhouse effect keeps Earth warm.
- 10 **Predict** what the conditions on Earth would be like without greenhouse gases and the greenhouse effect.

### Analysing

- 11 **Distinguish** between greenhouse gases and other gases in the atmosphere, such as nitrogen and oxygen.
- 12 **Compare** and **contrast** carbon sinks and carbon sources by giving examples.

### Evaluating

- 13 **Evaluate** why our focus related to the enhanced greenhouse effect is on carbon dioxide and not on other greenhouse gases.
- 14 **Propose** reasons why, even though we have known about the damaging effects of carbon emissions for a long time, Australia still produces 70% of its electricity from coal.
- 15 **Assess** the reasons why the carbon cycle is altered by the release of carbon emissions from burning fossil fuels.

## 8.4 Changing climates

### Learning goals

- 1 To describe the causes and effects of climate change
- 2 To evaluate the scientific evidence associated with the effect of climate change
- 3 To explain how computer modelling can be used to make predictions about climates

The climate of an area is how it behaves over a long period of time, usually over a period of 30 years or more. Areas of the world have differing climates due their position on Earth's surface.



**Figure 8.25** Frozen ships and shipwrecks on Lake Baikal in Siberia, Russia. The climate there is described as sub-Arctic with annual average temperatures of about  $-5^{\circ}\text{C}$ .

### Did you know? 8.2

#### How China used rockets to control the weather

China used rockets before and during the 2008 Beijing Olympics opening ceremony to control the weather. They fired 1100 rockets at a rain belt that could have disrupted the ceremony. The rockets contained silver iodide which caused the rain clouds to disperse. As a result, a city south-west of Beijing recorded 100 mm of rainfall on the evening of the opening ceremony, whereas the capital stayed dry. However, this practice, known as cloud-seeding, is controversial, as not all attempts to use it to control the weather are successful.



**Figure 8.26** The opening ceremony of the Beijing Olympics in 2008

## Climate change

Climate change has occurred when there has been a significant change to normal weather patterns that have been sustained for a long time – between thousands and millions of years.

**glacial period**  
a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

**interglacial period**  
a period in Earth's history when a warming in global temperatures is sustained for a long period of time

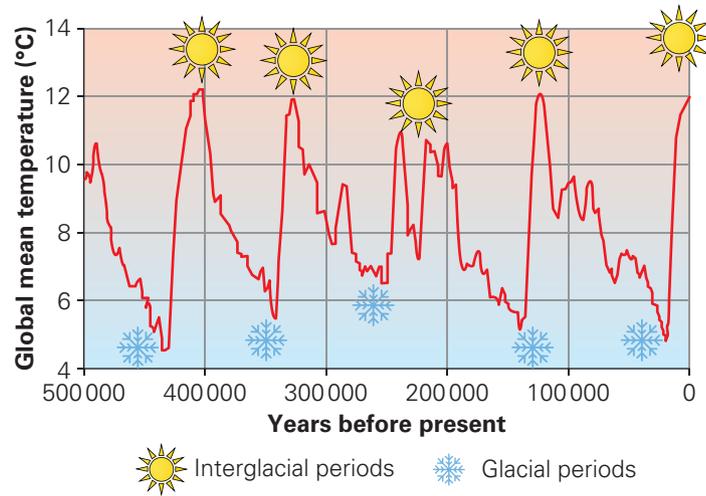


Figure 8.27 Earth has undergone natural cycles of warming and cooling.

Earth has undergone natural cycles of warming and cooling throughout its history.

A **glacial period** is when a reduction in global temperatures is sustained for a long period of time. The last glacial period started around 115 000 years ago and ended around 11 700 years ago. During the latter part of this period, Kangaroo Island off the South Australian coast was connected to the mainland and parts of Tasmania were covered by glaciers.

An interglacial period is when an increase in global temperatures is sustained for a long period of time. We are currently experiencing an **interglacial period**. However, scientists are concerned about the current unusually rapid rises in temperature, and the evidence suggests that human activities have something to do with it.



Figure 8.28 Kangaroo Island is located south-west of Adelaide, about 14.5 km off the coast. The star on the picture shows the location of mainland Australia. The island was connected to the mainland at the end of the last glacial period.

### Quick check 8.15

- 1 Define the term 'climate change' in your own words.
- 2 State the name of the term for when Earth is undergoing a period of cooling.
- 3 State the name of the term for when Earth is undergoing a period of warming.

## Human influences on climate change

It is clear that humans are influencing climate change. The concentration of carbon dioxide in the atmosphere has increased from 280 parts per million (ppm) before 1800 to well over 400 ppm in 2018. Table 8.12 summarises the influences that humans are having on the climate and how climate change is affecting global systems.

Human influence	Global system affected	How the climate is affected	
Deforestation	Carbon cycle and water cycle	<p>Fewer trees results in less carbon dioxide being taken in from the atmosphere through photosynthesis. If the wood is burned, this contributes further to the greenhouse effect.</p> <p>Trees release large amounts of water vapour during transpiration. Fewer trees means less water vapour in the atmosphere and less rain. In 2017–19, parts of New South Wales experienced the lowest ever rainfall on record.</p>	 
Agriculture	Carbon cycle	Cows and sheep produce carbon-containing methane when digesting grass. More cattle mean more emissions. Agriculture accounts for 11% of Australia's greenhouse gas emissions, and 70% of that comes directly from livestock.	
Burning fossil fuels	Carbon and nitrogen cycle	Burning fossil fuels produces carbon emissions, which alters the carbon cycle. Nitrogen oxides (NO <sub>x</sub> ) are also produced when fossil fuels burn, causing smog and acid rain.	
Fertilisers	Nitrogen cycle	Adding fertilisers containing nitrates to the soil speeds up their conversion into nitrous oxide, another greenhouse gas.	

**Table 8.12** A summary of some human influences on climate change

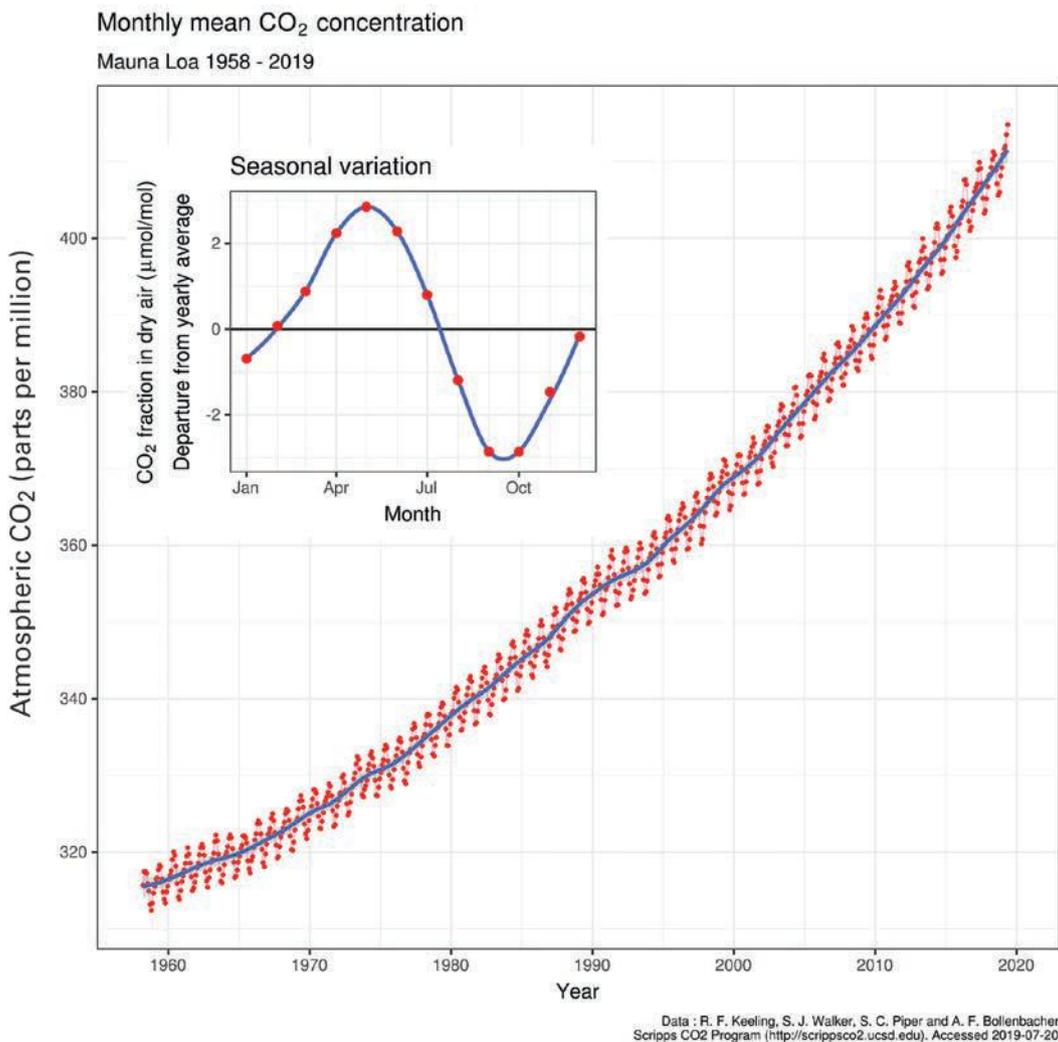
## Quick check 8.16

- 1 State one way humans have affected the nitrogen cycle.
- 2 Explain how burning fossil fuels affects the carbon cycle.

## Effects of climate change

As carbon dioxide concentrations rise, Earth continues to warm.

Over the past 100 years, Earth's average temperature has risen between 0.4 and 0.8°C; 2016 was the hottest year and 2019 was the second hottest since records began. While people have varying opinions on the possible consequences of climate change, the effects of rising temperatures could have dramatic repercussions.



**Figure 8.29** The Keeling curve shows the concentration of carbon dioxide in parts per million from 1959 to 2019 using measurements taken from an observatory in Hawaii. This positive gradient shows that carbon dioxide levels are continuing to increase.

## Polar ice

### Melting polar ice caps

As temperatures on Earth rise, polar ice caps melt, which raises sea levels. Low-lying areas of land, such as Osaka in Japan, which is already being battered by coastal typhoons, are most at risk. Ice also acts as a barrier that prevents sunlight from reaching the oceans. With less ice cover, more of the ocean is able to absorb sunlight, increasing its temperature. This is an ongoing cycle, ultimately leading to increased ice melting and sea level rise.

### Reflecting ice

Meltwater contributing to a greater volume of seawater is not the only risk caused by melting polar ice. Ice reflects the Sun's radiation back into space, which has a cooling effect on the planet. Less ice means less radiation is reflected, which results in an increase in global temperatures.

### Ocean density driving currents

When seawater freezes in winter, only the water freezes – the salt is left behind in the unfrozen seawater below. Waters with higher concentrations of salt are denser and are the main cause of ocean currents, circulating seawater from the sea floor to the surface and all around the globe, along with thermal energy, organic matter and nutrients.

With rising temperatures, less seawater is freezing, which is reducing the density of the oceans. These global ocean currents could eventually cease all together. As seawater becomes stagnant, organic matter and nutrients are not circulated and would impact on the survival of marine life.

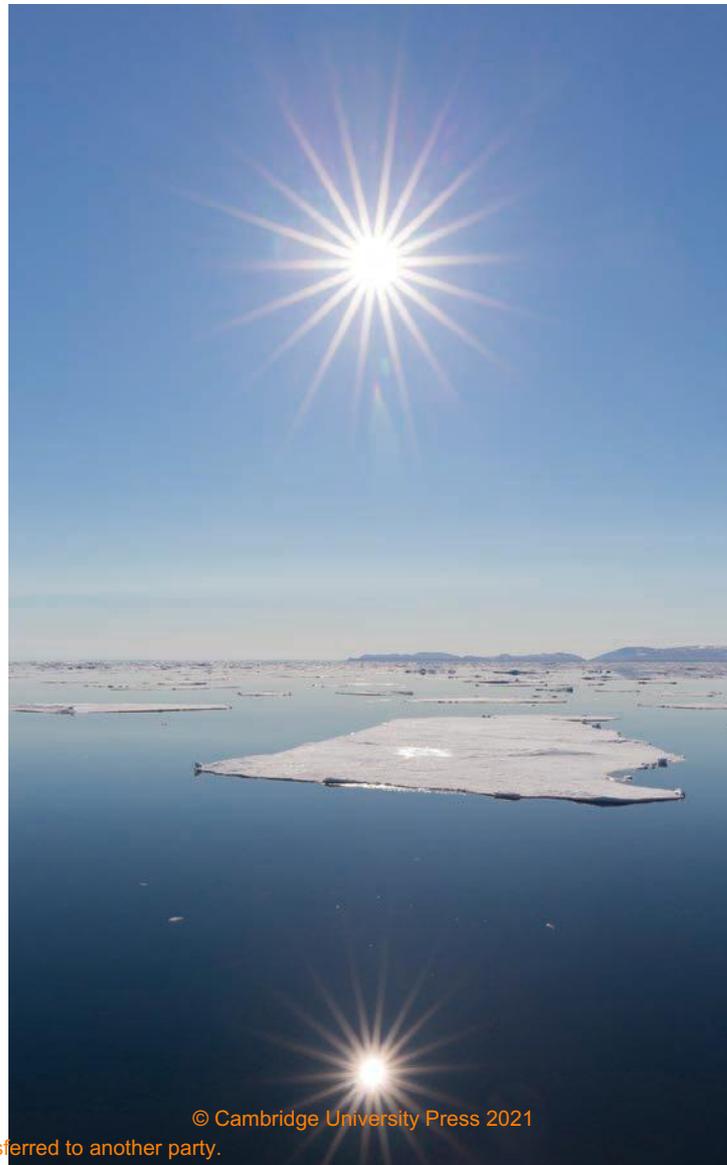
#### Quick check 8.17

- 1 Identify the main problem of melting polar ice caps.
- 2 Identify the problem with a decreased ocean density resulting from reduced freezing of water in winter.



Figure 8.30 Melting ice in Eqi Glacier, Greenland

Figure 8.31 Ice reflecting the midnight sun in the Arctic Ocean



### Practical 8.3

#### Salinity and density

##### Aim

To determine how the concentration of salt in water (salinity) affects its density.

##### Materials

- 10 mL measuring cylinder
- 100 mL measuring cylinder
- 5 × 100 mL beakers
- 5 pipettes
- food colouring (blue, green, yellow and red)
- salt
- water
- weighing boats
- balance

##### Procedure

- 1 Draw the table shown in the results section into your science journal.
- 2 Using a 100 mL measuring cylinder, measure 60 mL of water and pour it into one of the 100 mL beakers. Repeat four more times.

Solution	Mass of salt (g)	Volume of water (mL)	Amount of food colouring (drops)
1	5	60	2 of blue
2	10	60	2 of green
3	15	60	2 of yellow
4	20	60	1 of yellow, one of red
5	25	60	2 of red

- 3 Using the weighing boats and balance, measure the five different masses of salt. Pour the salt into the correct coloured beaker.
- 4 Add the required drops of food colouring from the table above to each beaker.
- 5 Stir the solutions to make sure all the salt has dissolved.
- 6 Using a pipette, draw up 2 mL of solution 5 and add to the 10 mL measuring cylinder.
- 7 Using a pipette, draw up 2 mL of solution 4. Place the pipette along the inside of the measuring cylinder, near the solution added previously. Drop solution 4 drop by drop, allowing it to roll down the side of the measuring cylinder.
- 8 Repeat step 7 for solutions 3, 2 and 1, adding each in turn to the 10 mL measuring cylinder.

##### Results

- 1 Complete the results table.

Solution	Mass of salt (g)	Mass of water (g)	Mass of the solution (g) (mass of salt + mass of water)	Volume of solution (mL)	Density of the solution (g/mL) (mass of solution ÷ volume)
1	5	60		60	
2	10	60		60	
3	15	60		60	
4	20	60		60	
5	25	60		60	

*continued...*

...continued

- 2 Sketch a coloured diagram of the measuring cylinder you created.
- 3 Plot a graph of mass of salt on the x-axis and density on the y-axis.

#### Discussion

- 1 Use your graph to describe the link between amount of salt and the density of a solution.
- 2 Discuss how rising global temperatures affects the concentration of salt in the oceans and how this relates to climate change.

#### Conclusion

State a conclusion about how water salinity affects water density. Support your statement by using your experimental data.

## Biodiversity

**Biodiversity** is a measure of the variety of environments, species and genes in an area.

The more biodiverse an environment, the more resistant that environment is to change (it is more stable). An environment which is not biodiverse may be at risk of complete collapse. Any changes to an environment, like

**biodiversity**  
the variety of species, ecosystems and genes that exist in a particular area

the ones previously discussed can affect the balance within an ecosystem.



**Figure 8.32** The Amazon rainforest is one of the most biodiverse ecosystems in the world.

### Explore! 8.3

#### Climate change effects on Earth

Climate change is a cause of changing global temperatures and, in particular, melting of polar sea ice. Investigate and summarise the long-term effects of melting sea ice on:

- a ocean water levels
- b deep ocean currents
- c marine biodiversity.

## Computer modelling and its applications

Computer modelling is the use of computer simulations to make accurate predictions about Earth's climate thousands and millions of years into the future. With their high processing power, computers are able to run numerous simulations over and over again in a short period of time, something that could take a human over a lifetime to complete. By running numerous simulations, predictions made by computer modelling are much more accurate than those made manually by humans.

**Figure 8.33** A supercomputer at the German Climate Computing Centre crunches data about Earth's climate to predict the future effects of climate change.



Table 8.13 summarises the applications of computer modelling.

Application of computer modelling	Description
Predicting the weather 	You will see this use every day if you watch the news. Multiple simulations are run by computers. Meteorologists (scientists who study the weather) use these simulations to predict the weather conditions for that week.
Predicting climate change 	Models predicting climate change are based on observational data and fundamental numerical laws such as Newton's laws. Perhaps the most complex climate models are the general circulation models (GCMs). Data on climate change reported in the media is generated from numerous simulations of the GCMs.
Monitoring pollution levels 	Atmospheric dispersion modelling predicts the behaviour of pollutants in the air over a specific period of time. It is used by governments to monitor air quality as well as to make predictions of the effects of chemical spills.

Table 8.13 A summary of some of the applications of computer modelling

### Quick check 8.18

- 1 Why do scientists use computer modelling to predict phenomena?
- 2 Give one application of computer modelling.

Computer models rely on accurate data being fed into the simulation. An example of high-quality data is that obtained at the International Space Station by the cloud-aerosol transport system, which can accurately measure atmospheric clouds and aerosols (extremely small particles in the air) all over the world. This data is used in computer modelling to predict what Earth will be like in years to come.

Figure 8.34 The ice on Lake Baikal in Siberia, Russia



## Explore! 8.4

**Reducing the impact of climate change**

Human influences on climate change are not always negative, and there are many technologies being used in Australia and internationally to reduce the impacts of climate change. Examples of alternatives to fossil fuels that are used throughout Australia include solar cells and wind turbines, which reduce greenhouse gas emission. Many new technologies require government financial support for implementation on a large scale.

Write a paragraph summarising each of these technologies.

- Solar cells
- Wind turbines
- Traditional Aboriginal firestick farming
- Carbon capture

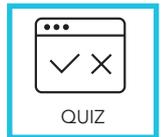
For each technology, complete the following.

- 1 Describe what they are.
- 2 Explain how the technology works.
- 3 Reflect on how they contribute to the effects of climate change.

## Section 8.4 questions

**Remembering**

- 1 **Name** the models used to make predictions about climate change.
- 2 **Define** the term 'climate' in your own words.
- 3 **Complete** the sentence: Earth is currently experiencing *an interglacial/a glacial* period.
- 4 **State** one way that humans have influenced the climate on Earth.
- 5 **Give** a property of ice that allows it to have a cooling effect on Earth.

**Understanding**

- 6 **Classify** the following as either an effect or a cause of climate change:
 

a melting polar ice	c increased use of fertilisers
b reduced ocean currents	d reduced biodiversity.
- 7 **Explain** why computer models are useful in predicting future events.
- 8 **Describe** some differences in climate between Central Australia and Siberia.
- 9 **Explain** why it is important to maintain the biodiversity of an environment.

**Applying**

- 10 **Identify** the uses of atmospheric dispersion modelling.

**Analysing**

- 11 **Compare** global warming and climate change.
- 12 **Describe** the relationship between global temperatures and the terms glacial and interglacial periods.

**Evaluating**

- 13 **Explain** how global warming could cause sea levels to rise.
- 14 **Evaluate** the effect of an unexpected volcanic eruption on climate change predictions.
- 15 There is debate as to whether climate change is a significant risk to life on Earth. **Decide** whether you agree, based on what you have learned in this chapter. Justify your opinion with facts and evidence.
- 16 **Discuss** the different measurements or criteria used by different groups of people when analysing the interactions of Earth's spheres.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>8.1 I can identify and describe the different spheres of Earth and its atmosphere.</b> e.g. Discuss how the biosphere, hydrosphere and lithosphere are all connected.	
<b>8.2 I can describe the carbon cycle.</b> e.g. Identify the part of the carbon cycle that removes carbon dioxide from the atmosphere.	
<b>8.2 I can describe the nitrogen cycle.</b> e.g. Summarise the role of bacteria in the nitrogen cycle.	
<b>8.3 I can explain the greenhouse effect.</b> e.g. State some causes of the enhanced greenhouse effect.	
<b>8.4 I can describe the causes and effects of climate change.</b> e.g. Discuss some of the outcomes of a global climate change.	



## Reflections

- 1 What **connections** come to mind when you think about global systems and your everyday life?
- 2 What new concepts have **extended** your thinking about the interactions between Earth's spheres?
- 3 What information did you find **challenging** or confusing?



### Data questions

The Keeling curve in Figure 8.35 illustrates the change in atmospheric carbon dioxide concentration from 1960 to 2005, as measured from the atmosphere above Hawaii, USA. A media outlet is using this data as evidence to suggest that 'climate is changing because there is increasing atmospheric carbon dioxide'.

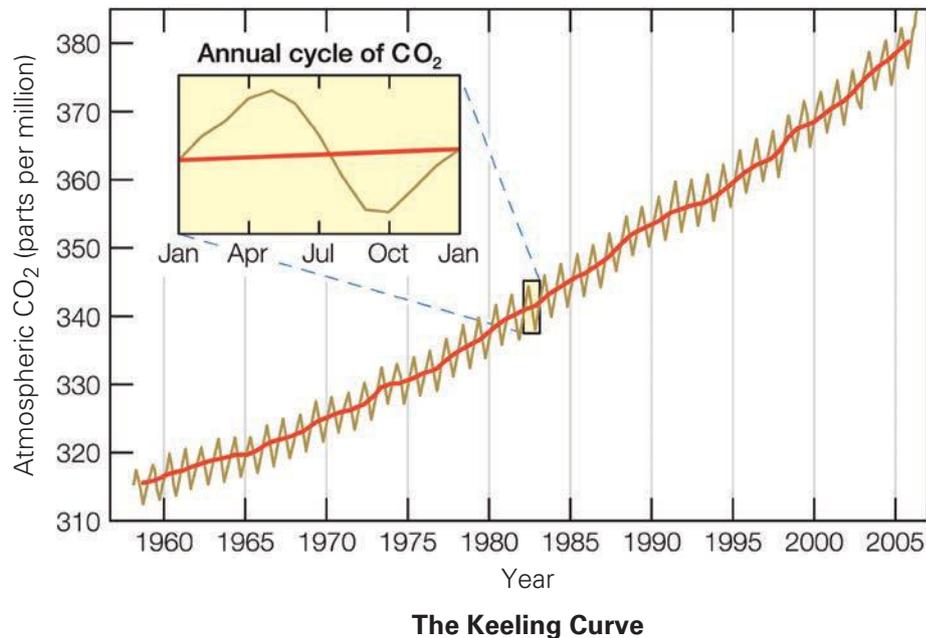


Figure 8.35 Keeling curve showing the atmospheric carbon dioxide concentration over time

- 1 **Identify** the year which had the lowest average atmospheric CO<sub>2</sub> in the atmosphere.
- 2 Use the red line to **determine** the average concentration of atmospheric CO<sub>2</sub> in 1965.
- 3 **Determine** the annual cycles observed for the brown line.
- 4 **Distinguish** the difference between the brown line and the red line.
- 5 **Identify** the general trend of carbon dioxide concentration as time increases.
- 6 **Identify** the pattern(s) occurring in the brown line.
- 7 Can the data in Figure 8.35 be used to **justify** the statement: 'there is increasing atmospheric carbon dioxide'?
- 8 Can the data in Figure 8.35 be used to **justify** the statement: 'climate is changing'?
- 9 **Infer** the atmospheric concentration of CO<sub>2</sub> in 2030, using the trend you have observed in Question 5.
- 10 **Determine** how each of the following people would interpret this data. If you think their opinions would differ, **explain** your reasoning.
  - a climatologist (scientists who study the climate)
  - b a member of the Kuring-gai people (Aboriginal tribe in Sydney)
  - c owner of a petrol company

## STEM activity: Using aerial imagery to track environmental change

### Background information

Today, we use high-tech satellites to gather high-quality data from our ever-changing world. We can now use this technology to help us monitor our impact in our environment.

This was shown on 5 November 2015, the day the world heard about the municipality of Mariana, in the state of Minas Gerais, Brazil. This once paradisiacal location was the location of Brazil's biggest environmental disaster – the collapse of a dam wall on the Gualaxo do Norte river. The resulting flow killed 18 people and covered an entire sub-district with toxic mud from an upstream mine. Studies that will assist with recovering the area and the affected rivers are underway. Satellite imagery will play a pivotal role in the recovery of the area for years to come.

**Design brief:** Design a method to use aerial imagery to track environmental change and make environmental impact predictions.

### Activity instructions

You are an environmental researcher working for your local council along with a team of other professionals, including engineers, policymakers and designers. The Land Management Team asked you to design an interactive tool capable of tracking environmental change over time in specific areas within the council boundaries. They want to demolish a number of buildings in the area for development, and have requested your opinion about possible implications for nearby rivers and creeks. You understand the potential for satellite imagery use (available free on Google Earth) in this situation, and you decide to give your advice after creating a time-lapse video (or series of images) that shows changes in landscape use over time. (Teachers, please check the Online Teaching Suite for a detailed guide and example for this activity.)

### Suggested materials

- Google Earth Pro (free to download)
- web browser (any)
- iMovie, Movie Maker or GIFMaker.org (recommended)

### Research and feasibility

- 1 Outline the advantages and disadvantages of using satellite imagery to assess environmental change within your region. Describe the expertise (skills) needed to gather and decode these images and the potential benefits to the local economy (for example, possible jobs created or improvement to traffic conditions) of using them.

Advantages	Disadvantages
e.g. Economy – predict areas for growth	e.g. Environmental – incorrect use of images without considerations

- 2 Research and decide on a local area that has a river/creek, and a combination of natural/built environment or natural environment that could have development proposed.

### Design and sustainability

- 3 List all the environmental issues currently faced by the chosen area, and future predicted issues based on current and future infrastructure.
- 4 Discuss as a group future development that could be completed in the chosen area. Make a sketch of the future development and annotate the changes, make a list of environmental impacts of the development.
- 5 Decide on the best possible technology to use to create a time-lapse sequence.

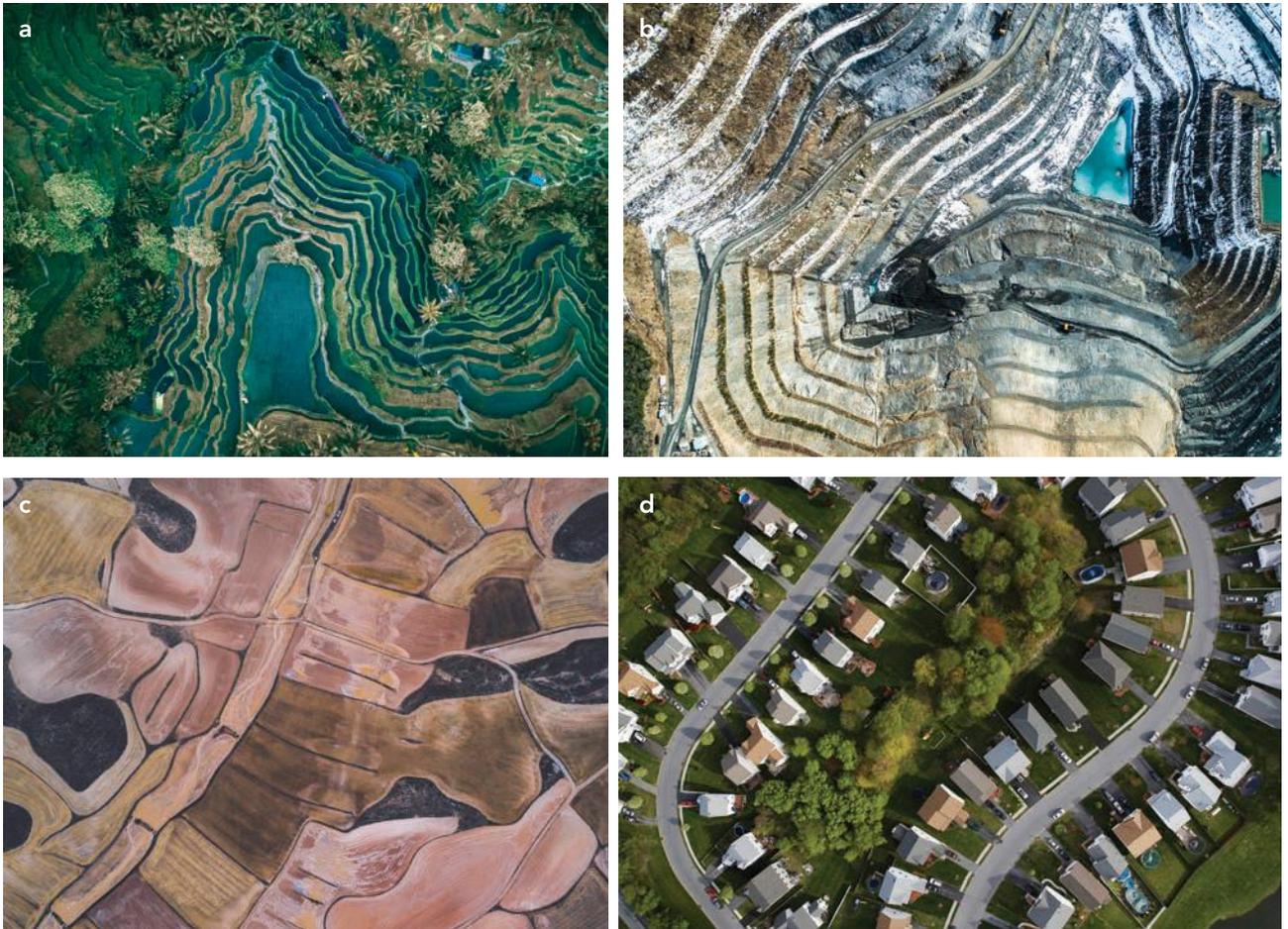


Figure 8.36 Viewed from above: (a) rice terraces in Bali, (b) a quarry, (c) farmland, (d) suburban houses

### Create

- 6 Create a time-lapse sequence of the area and list at least 10 noticeable changes to the landscape within your chosen area. What benefits or disadvantages have these changes brought to the local community?
- 7 Add your future development diagram to your time-lapse and show the environmental impact of your development ideas.

### Evaluate and modify

- 8 In your own words, explain how you could use the skills gained in this activity to enhance environmental conservation in your region.

# Chapter 9

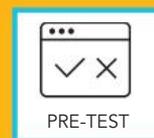
## Homeostasis

### Inquiry questions

How do our bodies respond to internal and external changes?

Which systems are involved with the response?

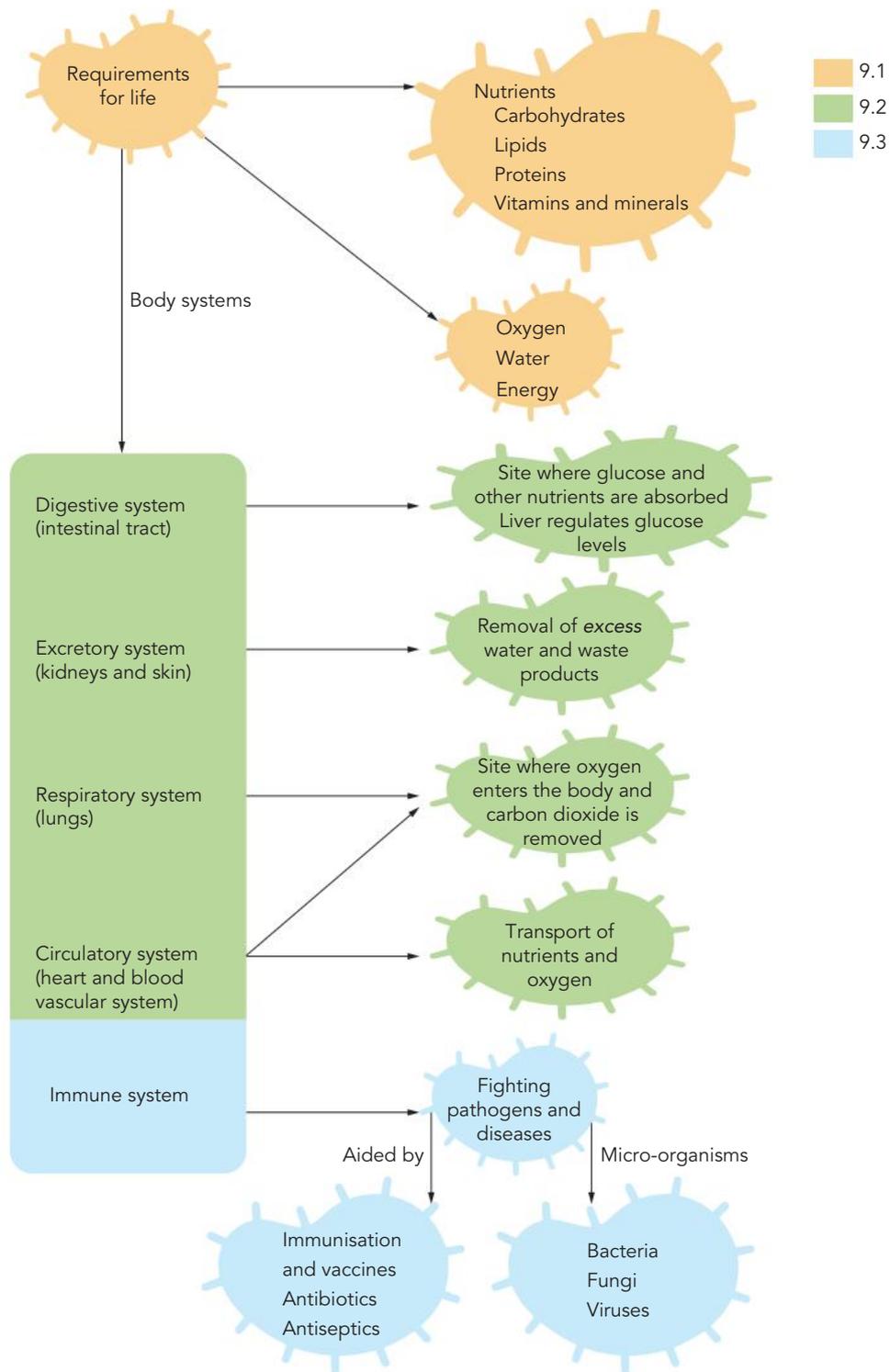
How does the immune system respond to subsequent exposures to the same pathogen?



### Chapter introduction

The human body is a fascinating, yet complex, biological machine. All body systems work in an inter-related way to contribute to the health of the entire organism. The word *homeostasis* originates from the Greek words for 'same' and 'steady'. It refers to the processes living things use to maintain a relatively stable internal environment, in spite of external changes. All cells within the body depend upon the internal body environment to survive and function, and some are very fussy about the conditions they are prepared to tolerate! This chapter will focus on the role of feedback systems in the human body that detect and respond to change, including the damage made by invading pathogens and the body's ability to defend itself against that damage.

# Chapter map



# 9.1 The requirements for life

## Learning goals

- 1 To recall the difference between multicellular and unicellular organisms
- 2 To identify the requirements of life and outline their role within the human body
- 3 To describe cellular respiration and its role in all living organisms



## Multicellular versus unicellular organisms

Recall that all living organisms consist of cells. Complex organisms, such as fish, humans and other mammals, consist of many cells and are called multicellular organisms. For example, the human body is made up of trillions of cells.

**Multicellular** organisms are complex and require specialised systems to carry out specific functions. They contain various levels of organisation where individual cells perform specific functions, yet also work together for the good of the whole organism. Simple

organisms like bacteria, amoebas and paramecium consist of just one cell and are called 'unicellular' or 'single-celled' organisms. In **unicellular** organisms, the single cell functions on its own and performs all required life functions. This chapter, however, will focus on multicellular organisms that rely on highly organised and interdependent internal body systems to respond to changes in their environment.

## Essential requirements for life

Animals, such as humans, can live for several weeks without the nutrients obtained from food and survive a few days without water, yet can only live a few minutes without oxygen. Humans clearly need water, oxygen and nutrients to produce the energy required for purposes like breathing, digestion, movement and growth.

During a process called **cellular respiration**, the energy stored in the chemical bonds of glucose (which is obtained in one's diet) is released as useable chemical energy in the form of ATP. This process occurs in organelles called mitochondria, and it provides cells with the energy required for their specialised functions. The other reactant needed for cellular respiration is oxygen, and you obtain this by breathing in the oxygen from the air. The word equation for cellular respiration is shown in Figure 9.2. The reactants are on the left of the arrow and the products are on the right.

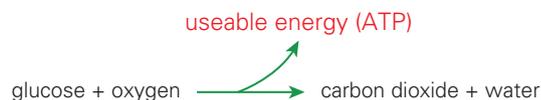


Figure 9.2 Word equation for cellular respiration

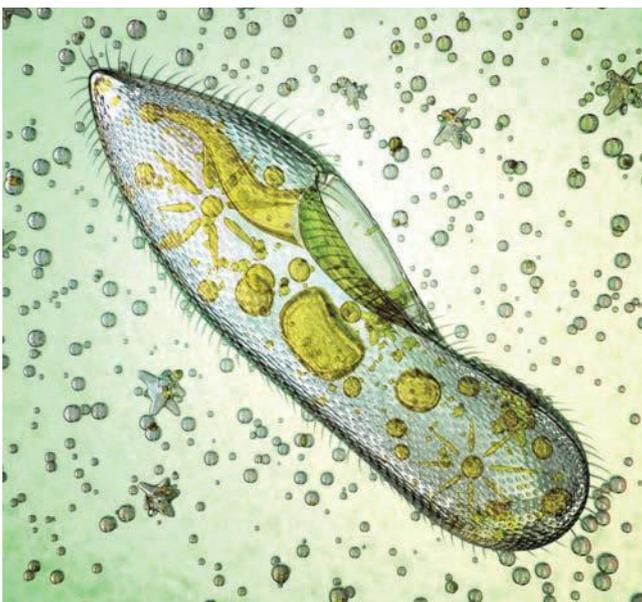


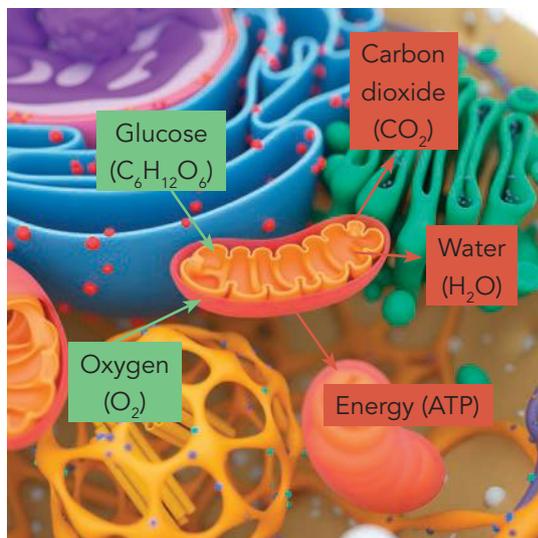
Figure 9.1 A unicellular organism known as *Paramecium caudatum*

**multicellular**  
composed of more than one cell

**unicellular**  
composed of a single cell

**cellular respiration**  
an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy

Carbon dioxide and water are waste products in this process, and although the water can be used in other processes, carbon dioxide must be excreted, as high concentrations in the body can lead to serious complications.



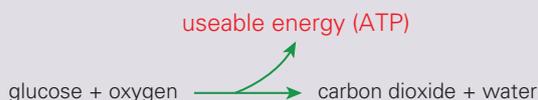
**Figure 9.3** Cellular respiration occurs in the mitochondria of animal and plant cells to provide energy for cellular work. The reactants of the chemical reaction are shown in green and the products are shown in red.

### Try this 9.1

#### Make a revision poster!

Orient your paper in landscape mode and draw the word equation for cellular respiration across the page. Underneath each word, draw a diagram of the substance. Also annotate the equation to show where the reactants come from and how the products are removed from the body.

#### CELLULAR RESPIRATION REVISION POSTER



### Quick check 9.1

- 1 State the main difference between a unicellular and a multicellular organism.
- 2 Recall the essential requirements for life.
- 3 State the reactants and products from the process of cellular respiration.
- 4 Recall why cellular respiration is an essential requirement for life.

## Nutrients

Nutrients are the chemicals obtained from a healthy diet that provide you with the energy and building blocks your body needs to grow and repair.

The five main groups of nutrients that your body needs for optimum functioning are:

- carbohydrates
- lipids (fats and oils)
- proteins
- vitamins
- minerals.

#### carbohydrate

biological molecule made of carbon, hydrogen and oxygen, which can be broken down in the body with the release of energy

#### lipid

a chemical substance such as a fat or oil that can be used as an energy source

## Carbohydrates

**Carbohydrates** provide the main fuel source for many vital organs, including the brain and kidneys. The digestive system breaks down complex carbohydrates into glucose which cells then use in cellular respiration to make energy available.

## Lipids

Fats and oils, also called **lipids**, are greasy substances that also provide the body with energy. A gram of fat provides at least twice as much energy as a gram (g) of carbohydrate, but the energy stored in fats and oils cannot be obtained as quickly as the energy in carbohydrates. The body uses fat for long-term energy storage.



**Figure 9.4** Fats tend to be solid at room temperature (like butter). Oils tend to be liquid at room temperature (like olive oil). Their chemical properties determine their melting points.

Fat deposits under the skin also provide thermal insulation to control the loss of heat from the body, while some vital organs are surrounded by layers of fat that help to protect them from shock.

**protein**

a chemical substance composed of amino acids which has structural and regulatory functions; can also be used as an energy source

**enzyme**

a biological catalyst that increases the rate of a chemical reaction without itself being changed by the reaction

**antibody**

also called immunoglobulin; a protective protein produced by the immune system in response to the presence of a foreign substance (called an antigen)

**amino acid**

an organic molecule that forms the basic building block of a protein

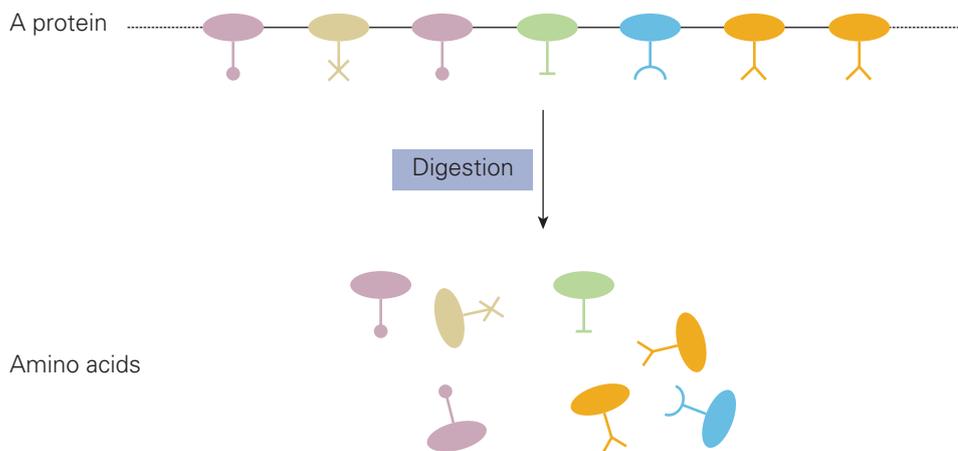
**Proteins**

**Proteins** are found in all living things and perform many functions, especially structural and regulatory ones. The following describes some of the main functions of proteins.

- Structural proteins, for example, muscle, skin and hair, are composed mainly of protein.

- Proteins called **enzymes** are responsible for controlling the chemical reactions that take place in your body.
- Some proteins have specific functions – for example, haemoglobin carries oxygen around in the bloodstream.
- **Antibodies** are a type of protein which enable your body to resist infectious diseases.

Humans consume protein in their diet, and the digestive system breaks these large molecules down into their building blocks, called **amino acids**, that can be reassembled to make structural and functional proteins. Major dietary sources of protein include meat, fish, dairy, legumes, nuts and seeds.

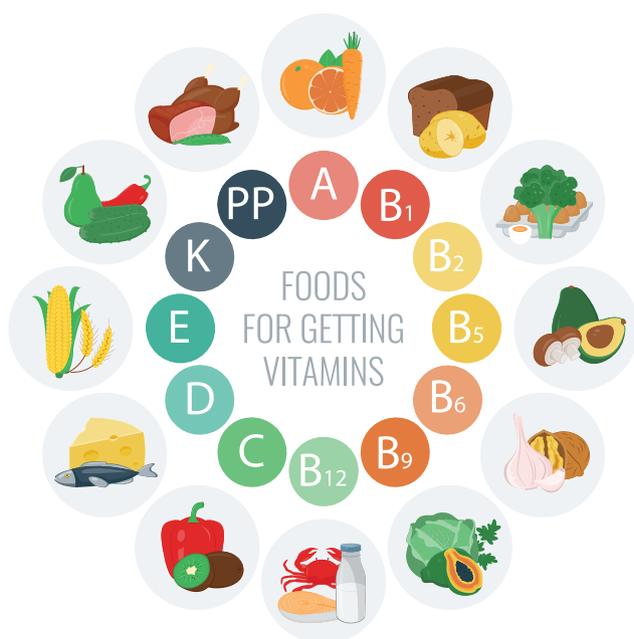


**Figure 9.5** During digestion, proteins are broken down into individual amino acids. Your body cannot absorb protein molecules, but amino acids can be absorbed and reassembled within the body to build new proteins.

**Vitamins and minerals**

Your body needs tiny amounts of essential micronutrients known as vitamins and minerals. These chemical compounds assist in thousands of chemical reactions in the body: some work with enzymes as catalysts; others play a role in strengthening your bones, healing wounds and helping nerve cells conduct electrical impulses; and others assist in the breakdown of

carbohydrates and proteins. A deficiency of vitamins can lead to disease, such as scurvy or rickets. Most people can get all of the necessary vitamins and minerals by eating a healthy, varied diet and do not need to routinely take supplements in tablet form. Some vitamins and minerals are toxic when taken in excess of the body's requirements.



**Figure 9.6** This vitamin wheel shows some of the different vitamins your body needs and the foods they are found in.

### Explore! 9.1

#### Scurvy

Throughout the thirteenth to sixteenth centuries, thousands of sailors and explorers on long journeys died from what is now known to be a preventable disease: scurvy. Research some of the gruesome symptoms that were observed aboard the sailing ships, and how this disease was combatted at the time.

### Quick check 9.2

- 1 State the five main groups of nutrients that your body needs.
- 2 Draw up a table to describe the function or purpose of each of the five nutrient groups in the body.

## Practical 9.1

### Measuring the energy content in food

#### Aim

To investigate the amount of chemical energy stored in various foods.

#### Materials

- large test tube
- test-tube rack
- test-tube holder (wooden peg)
- heatproof mat
- bottle cork with a needle inserted into the top
- thermometer
- tin can open at both ends (to act as a chimney)
- 25 millilitres (mL) measuring cylinder
- assorted food samples, e.g. Twisties (do not use nuts)
- measuring scale

#### Planning

- 1 Write a paragraph about the chemical energy stored in food and the different components of food that provide energy.
- 2 Develop a hypothesis to predict which food sample/s will transfer the most energy.
- 3 Identify as many controlled variables as possible and describe how these will be managed to prevent them from affecting the measurements.
- 4 Complete a risk assessment for this investigation, describing how any risks will be controlled.

#### Be careful

No food items are to be consumed.

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### Procedure

- 1 Draw the results table below.
- 2 Place the tin can, Bunsen burner and cork on the heatproof mat. Ensure the room is well ventilated to avoid a build-up of smoke.
- 3 Use the measuring cylinder to pour 10 mL of water into the test tube.
- 4 Measure the starting temperature of the water and record it in the results table.
- 5 Measure the mass of the food sample and record it in the results table.
- 6 Place the food sample on the needle.
- 7 Have the test tube in its holder, ready to be placed over the flame.
- 8 Use the Bunsen burner to light the food sample. Immediately place the tin can over the top and hold the bottom of the test tube in the flame.
- 9 Measure the final temperature of the water as soon as the food sample is completely burned out and record it in the results table. (If it doesn't burn completely, relight it from the Bunsen burner and continue immediately.)
- 10 Repeat with other food samples.
- 11 It takes 42 joules to raise the temperature of 10 mL of water by 1°C. Multiply the temperature change for each sample by 42 to find the energy content of the sample.

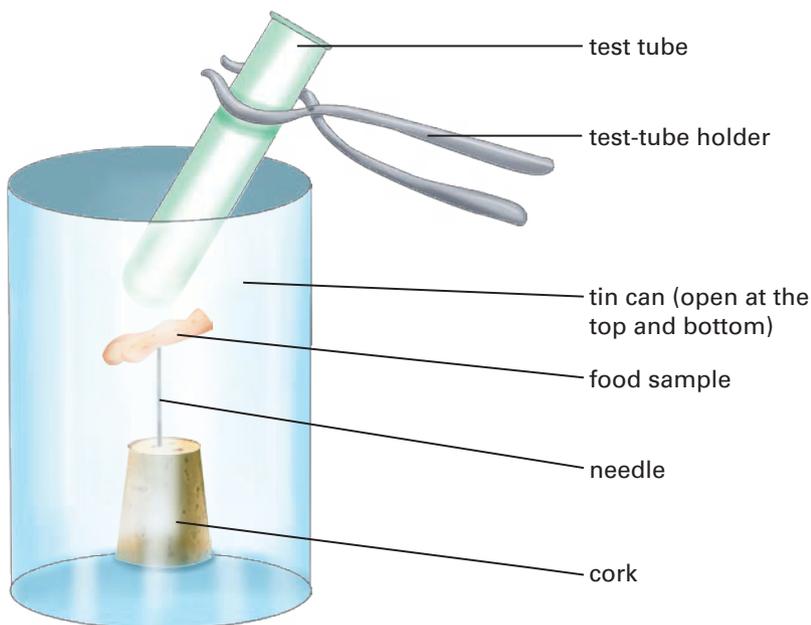


Figure 9.7 Experimental set-up

### Results

Type of food	Energy content per 100 g (J)	Mass (g)	Starting temperature (°C)	Final temperature (°C)	Temperature change (final – starting temperature) (°C)	Energy content (temperature change × 42 joules) (J)

### Discussion

- 1 Describe any trends, patterns or relationships in your results.
- 2 When the food was burned, the chemical energy was released as heat energy which was measured by how much it heated up the water. Deduce whether any energy was lost, and if so, how.
- 3 Identify the foods that contained the most and least energy per gram. Was your hypothesis supported?
- 4 Identify any unusual results that you found.

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- 5 Compare the actual energy content per 100 g of food (found on the nutritional label) with the energy content that you calculated.
- 6 Identify any potential sources of error in this experiment.
- 7 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 foods and energy content. Justify your answer with data.

## Advances in science 9.1

### Hydration

More than half of your body by mass is water: it is found in your blood, inside your cells and between your cells. You use water to maintain your blood pressure and your body temperature and for many other day-to-day functions. It is recommended that you drink 2 L of water per day, as fluids are readily lost through sweating, passing urine and even breathing! This fluid loss is heightened when you are exposed to high temperatures and during high-intensity exercise, so you need to increase your

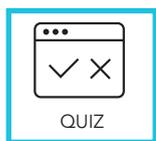


**Figure 9.8** Even very small amounts of dehydration will reduce an athlete's performance in individual or team sports, including football.

fluid intake to prevent your body from becoming dehydrated. Dehydration leads to decreased blood pressure, increased heart rate and temperature, and a loss of physical coordination, meaning you are not performing at your best. A lot of energy is expended trying to regulate the internal conditions. As dehydration progresses, you can experience muscle cramping, nausea, vomiting and diarrhoea, as well as accompanying psychological symptoms such as a decrease in concentration and mental functioning.

Most elite athletes playing Australian Rules football can expect to lose, on average, approximately 1 L of fluid per hour, and in hot, humid weather, 2–3 L per hour. One way they combat this is by drinking sports drinks, which contain water, carbohydrates and salts that are claimed to result in improved hydration. However, these sports drinks often contain high levels of sugar, and scientific studies have shown they contribute to childhood obesity (as teenagers drink them when not engaging in sports) and tooth decay in elite footballers.

## Section 9.1 questions

**Remembering**

- 1 **Identify** one major difference between a unicellular and a multicellular organism.
- 2 **Provide** two examples of a unicellular organism and two examples of a multicellular organism.
- 3 **List** three requirements for healthy human life.

**Understanding**

- 4 In your own words, **explain** what occurs during the process of cellular respiration.
- 5 **Suggest** two ways that water is lost through the body.
- 6 **Explain** three different functions of proteins in the human body.

**Applying**

- 7 **List** three essential nutrients that you think a healthy diet should include.
- 8 **Suggest** a reason why pasta is often eaten by footballers the night before they play their match.

**Analysing**

- 9 An athlete is contemplating going on a diet to lose some weight and decides to minimise their carbohydrate intake. **Propose** some potential consequences or considerations for the athlete.
- 10 On average, females tend to need less energy overall in their daily recommended energy intake (kJ) compared to men. If men have on average more muscle mass and less body fat, **propose** possible reasons for this difference.
- 11 Dietary fats are essential for cell growth and energy. Fats provide more energy than carbohydrates. **Suggest** why athletes don't eat lots of fatty food just before they compete.

**Evaluating**

- 12 **Predict** if any health issues would arise if a person was drinking sports drinks when they were not physically required to do so.
- 13 According to the Australian Institute of Health and Welfare, 1 in 4 Australian children were overweight or obese in 2014–2015. Decide whether or not childhood obesity is a problem in Australia. **Recommend** several strategies on how childhood obesity rates might be reduced.
- 14 If the New South Wales Government banned all sugary foods and drinks in all schools, would this solve obesity in children? **Discuss** the pros and cons of this rule.



## 9.2 Body systems working together

### Learning goals

- 1 To recall the organs involved in the respiratory, circulatory, digestive and excretory systems of the body
- 2 To define homeostasis using the stimulus–response model
- 3 To describe, using examples, how body systems maintain homeostasis

### Coordination: It's a team effort!

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

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

All multicellular organisms depend upon their body systems working together to maintain homeostasis. The body does an amazing job to maintain a stable internal environment, despite considerable changes within the external environment.

This process is known as

**homeostasis.** When a change occurs in an animal's external environment, such as an increase in temperature, an adjustment must be made so that the internal environment of the body and cells remains stable.

The nervous system plays the primary role in controlling and coordinating most actions of the human body. It works



**homeostasis**  
the maintenance of a relatively stable internal body environment, despite changes in the external environment

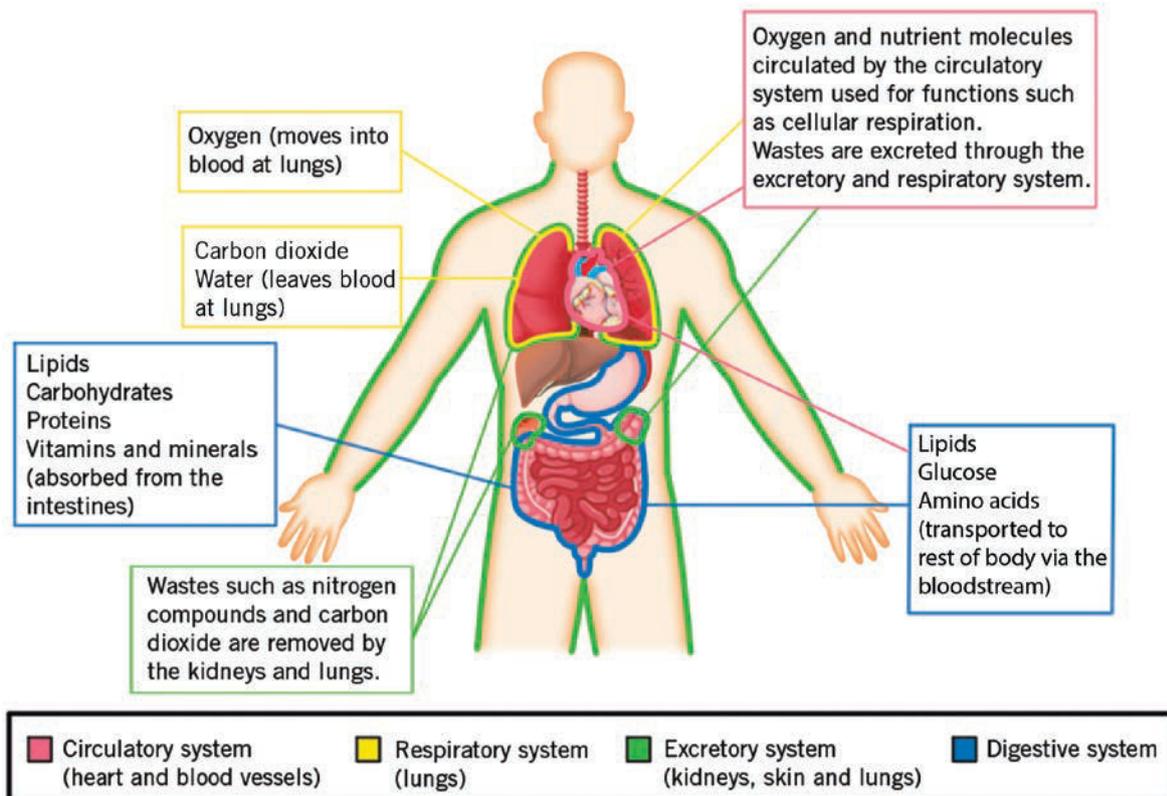


Figure 9.9 An example of how 4 of the 11 body systems work together with other systems



VIDEO  
Describe  
how negative  
feedback  
works

in partnership with the endocrine system, which produces particular hormones that are released into the blood stream in response to external or internal changes. Together they form a team: the nervous system provides fast-acting, short-lasting effects, and the endocrine system triggers slow-acting, long-lasting effects.

detected by **receptor** sites within the body, and if a response is required, then certain actions are brought about by **effectors** within the body to bring the body back to its 'normal' or optimum level. This can be described using the five-step stimulus–response model, shown in Figure 9.10 and Table 9.1.

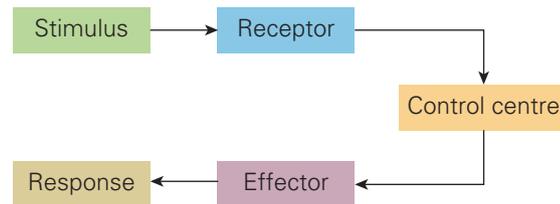


Figure 9.10 A flow chart outlining the stimulus–response model

## Stimulus–response model

To achieve homeostasis, the body needs to respond to changes within the body's internal and external environment as the result of **stimuli**. Changes are

### stimulus

(plural: stimuli) any object or event that elicits a sensory or behavioural response in an organism

### receptor

a sense organ (or cell or group of cells) that detects a stimulus

### effector

a muscle, gland or organ capable of responding to a response signal from the control centre

Stage	Description	Example
Stimulus	The thing that has changed in the external or internal environment	External temperature drops drastically
Receptor	Specialised cells that detect the change and send a stimulus signal to the control centre	Temperature receptors (thermoreceptors) in the skin
Control centre	Receives the signal from the receptors and coordinates the response, sending a response signal to the effector	Hypothalamus in the brain receives the information regarding the drop in temperature and sends an electrochemical signal to the effector
Effector	The muscles or organs that are signalled to cause the response	Muscles begin to contract and relax quickly (shivering) to generate heat
Response	The body returns to a state of balance so the receptors are no longer active	Body core temperature is raised back to within normal range

Table 9.1 A summary of the stages of the stimulus–response model

## Explore! 9.2

### X-ray art

X-ray art is an artistic style used by the Aboriginal peoples of Arnhem Land to draw native animals. This style of painting using the cross-hatch design is known as 'rrark'. Animals are painted showing some internal anatomical features. Use the internet to find some more examples of paintings, sculptures or headdresses produced by Aboriginal and Torres Strait Islander peoples that show internal features of animals.

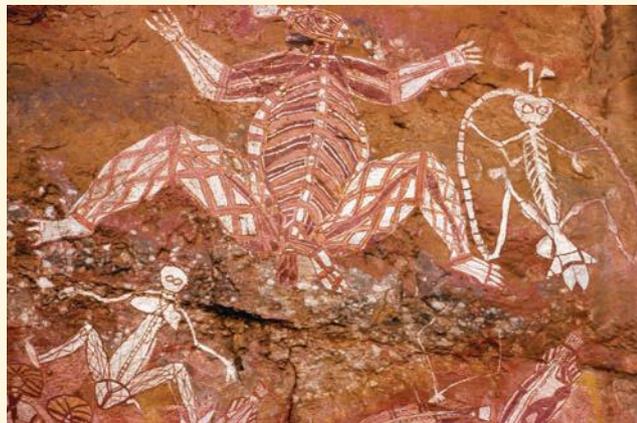
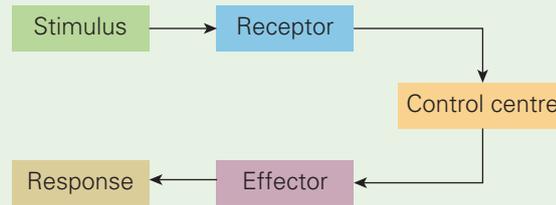


Figure 9.11 Aboriginal paintings depicting X-ray figures stand on Nourlangie rock in Arnhem Land, Northern Territory.

**Quick check 9.3**

- 1 Define the term 'homeostasis'.
- 2 Explain why homeostasis is so important to your survival.
- 3 State the part/s of the body that are involved in maintaining homeostasis.
- 4 Create a stimulus–response model in your notes or on A4 paper, and using an example such as body temperature, annotate it with information about each of the five parts, similar to Figure 9.12.



**Figure 9.12** A flow chart outlining the stimulus–response model

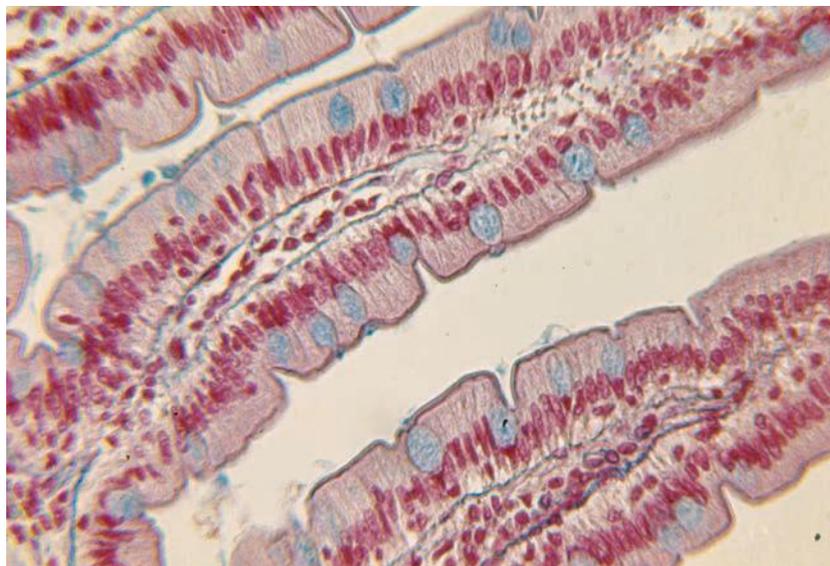
## Body systems maintain homeostasis

### The digestive system

The food you eat contains a variety of nutrients that are necessary for building new body tissue, repairing damaged tissues and providing energy to power your cellular processes. The digestive system enables you to break down the food you eat and absorb the nutrients along with all their stored energy. It also enables you to absorb water, vitamins and minerals, and to eliminate wastes from the body.

For example, recall that your body needs glucose for cellular respiration. When you consume

carbohydrates, enzymes begin to break them down from the moment they enter your mouth: even a savoury cracker begins to taste sweet when left on the tongue for a few minutes as enzymes in saliva begin to break the complex carbohydrates down into sugars. This partially digested food is then broken down physically (by the teeth), before it progresses through the digestive system and continues to be broken down chemically (by enzymes). The smaller molecules, such as glucose, will diffuse across the cell membranes in your intestines and be absorbed into the bloodstream, ready to be circulated around the body to where they are needed.



**Figure 9.13** Villi are the finger-like projections found in the small intestine which have a high surface area to aid the absorption of nutrients into the bloodstream.

Diffusion is the movement of a substance from an area of high concentration to an area of low concentration. If a drop of dye is added to a glass of water, without stirring, the dye will gradually spread and colour the entire contents – this is an example of diffusion.

It is an important process for moving substances within cells as well as into and out of them. When glucose-rich blood flows near actively respiring cells (which are using glucose), glucose will diffuse from the blood into those cells.

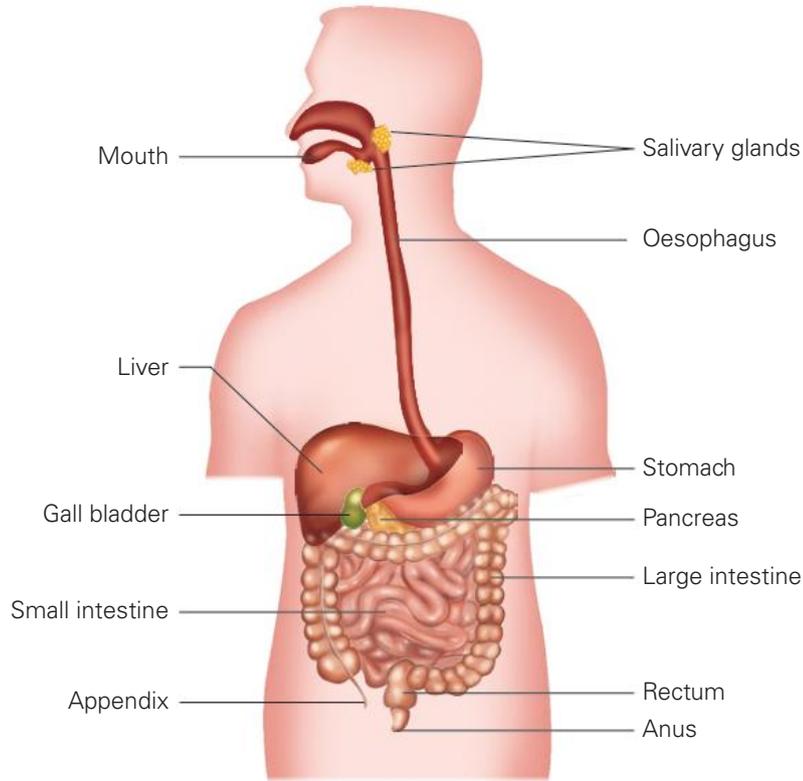


Figure 9.14 The human digestive system

### Did you know? 9.1

#### No stomach

The platypus and echidna, both egg-laying mammals (monotremes), do not have stomachs. With the use of DNA sequencing, scientists discovered that the genes responsible for making important digestive enzymes are missing and that the platypus and echidna evolved without a stomach. Research how the platypus and echidna digest their food without a stomach.



Figure 9.15 Both the platypus and echidna do not have a stomach.

### Regulating blood glucose levels

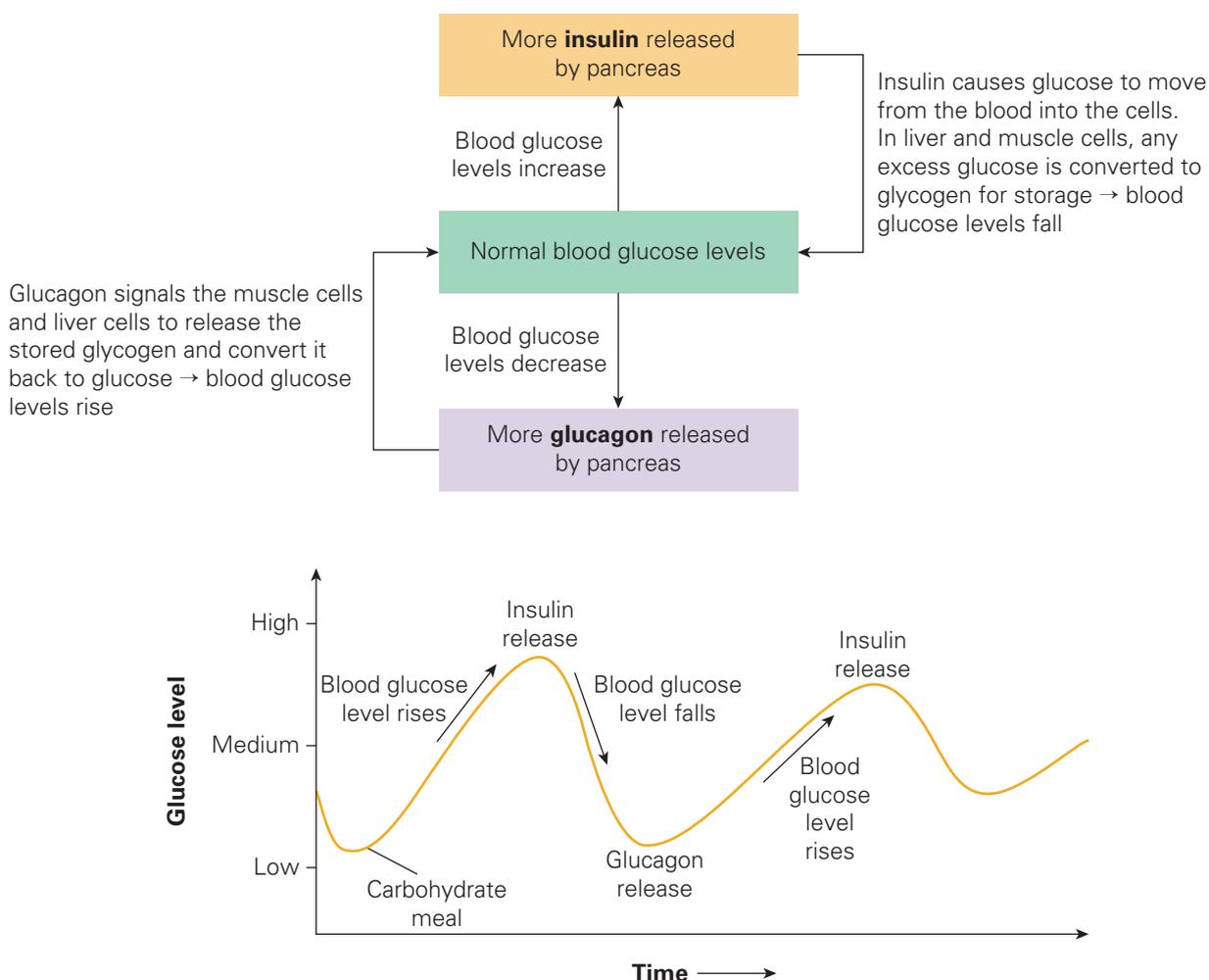
Body cells function best when conditions are stable within narrow physical and chemical ranges. One of the substances that needs to be closely regulated is the concentration of glucose in your blood. Your brain requires a constant glucose supply and is highly sensitive to changes in blood glucose levels. When you over-indulge and eat three doughnuts in a row, your body is swamped with glucose, and your blood sugar levels surge. Similarly, your body must also cope with prolonged periods of time when you do not ingest any glucose – like when you are asleep! Such drastic swings must be ironed out and the glucose level must be kept constant.

Homeostasis of blood glucose levels is controlled by two hormones that are secreted by the pancreas: **insulin** and **glucagon**. Both hormones are slow-acting products of your endocrine system, and they act upon effectors (which are usually glands or organs) to bring about changes to regulate the blood sugar level. They are released in different amounts according to your blood glucose levels (see Figure 9.16).



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

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



**Figure 9.16** After a carbohydrate-rich meal, insulin levels in the bloodstream increase as the body needs to decrease the blood glucose levels.

**Try this 9.2**

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

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

**Explore! 9.3****Diabetes**

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

- 1 What is the difference between type 1 and type 2 diabetes?
- 2 Who is normally affected by each type of diabetes and at what age is it typically diagnosed?
- 3 How is each type of diabetes treated?
- 4 What are some of the factors that predispose people to developing diabetes?



**Figure 9.17** Insulin is injected into the body by a person with diabetes.

**Quick check 9.4**

- 1 Recall the primary role of the human digestive system.
- 2 Describe the role that digestive enzymes play in providing energy to your cells.
- 3 After a meal rich in simple carbohydrates, your blood glucose levels rise sharply. Recall the hormone that is released by the pancreas to decrease the levels.

## The excretory system

The digestive system works very closely with the excretory system, whose main responsibility is the removal (excretion) of wastes and excess water from the body. The excretory system includes the liver, kidneys, and associated organs such as the ureters and bladder. However, other organs such as the large intestine, skin and lungs also play a role in the excretion of certain substances. The major excretory organs are summarised in Table 9.2.

The kidneys control and regulate the amount of water, ions, and other substances in the blood and play a vital role in maintaining homeostasis.

Each kidney contains approximately 1 million **nephrons** – tiny microscopic structures that are known as the functional unit of the kidney. The nephrons filter the blood, keeping the things your body needs (water and ions) and getting rid of the things it does not (metabolic wastes such as urea, poisons, and excess water and ions [salts] taken in through your diet). The waste fluid then leaves the nephrons, moves along tubes called ureters and enters the bladder where it will eventually be passed out as urine (see Figure 9.18). The nephrons of the kidney filter 100 mL of fluid every minute, but only 1 mL of this finds its way into the bladder.

**nephron**  
the functional unit of the kidney, involved in filtering the blood to produce urine

Organ	Role in excretion
Kidneys	Filter the blood and form urine which allows removal of urea, excess salts and water
Large intestine	Stores waste material not absorbed after digestion, forming faeces which are passed from the body
Liver	Breaks down toxins and excess amino acids (from proteins) that are in the bloodstream
Lungs	Exhale water vapour and carbon dioxide
Skin	Secretes sweat (which contains some waste materials) for temperature control

Table 9.2 Organs that assist with excreting wastes

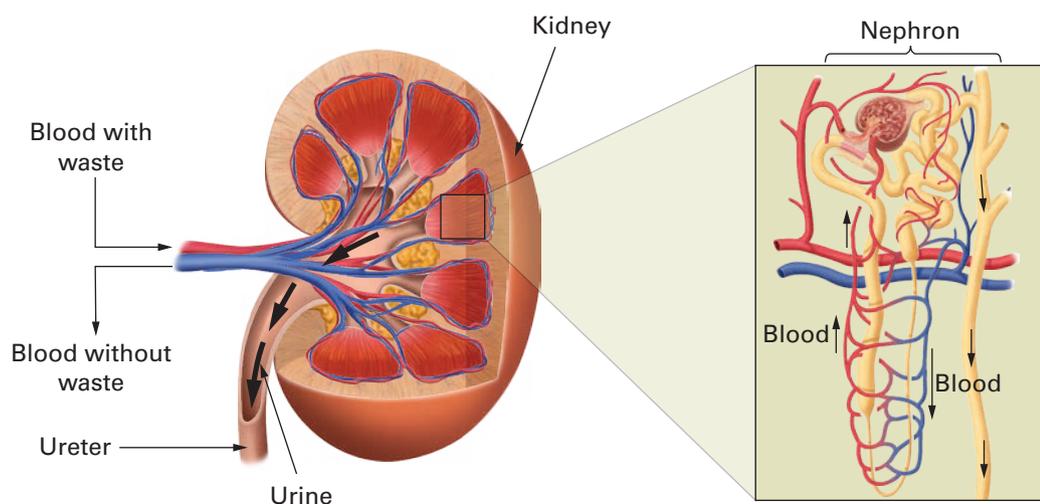
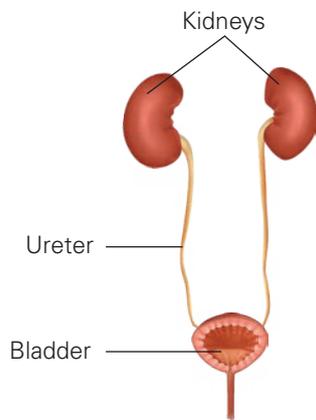


Figure 9.18 The structure of the kidney and one nephron: the functional unit of the kidney



**Figure 9.19** A simple overview of the organs involved in urine production, storage and excretion

## Regulating water levels

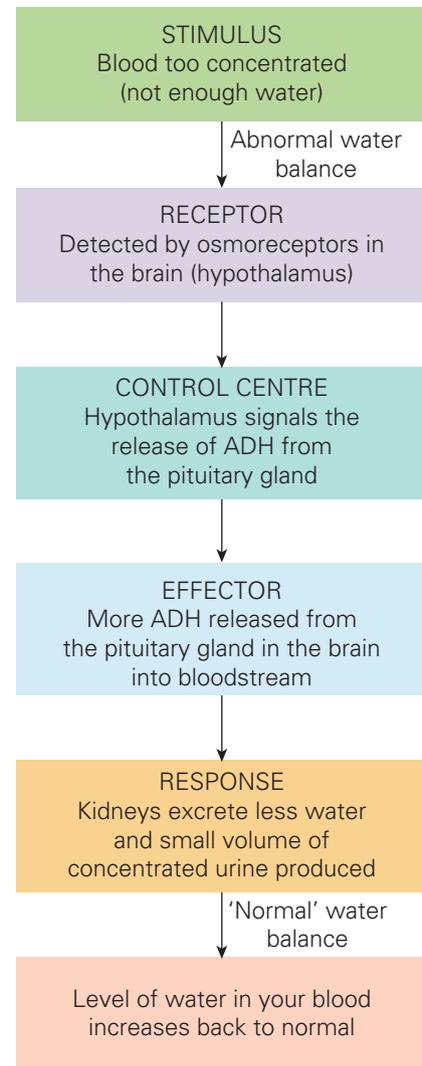
Regulation of the amount of water in the blood is a very important example of homeostasis. It is often referred to as **osmoregulation**. The amount of water in the blood is measured continuously by a group of osmoreceptors in the hypothalamus of the brain. (This will be explored in more detail in Chapter 10.) They can detect if there

**osmoregulation**  
the regulation of water levels  
in the blood/body

are low levels of water in the blood (the blood is very concentrated) or high levels of water in the blood (the blood is very dilute).

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

- 1 Osmoreceptors in the hypothalamus (central nervous system) detect low blood water levels.
- 2 The hypothalamus triggers the pituitary gland (central nervous system) to release antidiuretic hormone (ADH).
- 3 ADH is carried by the blood (circulatory system) to the kidneys.
- 4 ADH increases the ability of the kidney tubules (excretory system) to reabsorb water and return it to the blood.
- 5 Water levels in the blood increase to their normal level.



**Figure 9.20** The stimulus–response flow chart for when water levels are low

### Try this 9.3

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

### Quick check 9.5

- 1 Recall the organs that are involved in excretion of wastes.
- 2 State two functions of the excretory system.
- 3 Identify the part of the kidney that is responsible for filtering blood. Describe its role.
- 4 Recall what ADH stands for and its role in osmoregulation.
- 5 State the part of the brain that monitors blood water concentration.

## The respiratory and circulatory systems

The respiratory system and the circulatory (also called cardiovascular) system work together to keep up a constant supply of oxygen to the cells of the body. The systems work together to ensure that the cells obtain the required amount of oxygen to perform cellular respiration to release energy, and that they can also get rid of the waste product – carbon dioxide. The respiratory system (lungs and diaphragm) is responsible for breathing which drives the exchange of gases. The circulatory system, as the name suggests, is

responsible for circulating the respiratory gases, but also transporting nutrients, water and hormones.

### The respiratory system

The respiratory system facilitates the exchange of gas inside the lungs. To breathe in, a large muscle called the diaphragm contracts, moves downwards and draws air into your lungs. The air (which is approximately 21% oxygen) travels into the nose and mouth, down the trachea (windpipe) and to branching tubes called bronchi (singular: bronchus) and smaller bronchioles into the left and right lungs.

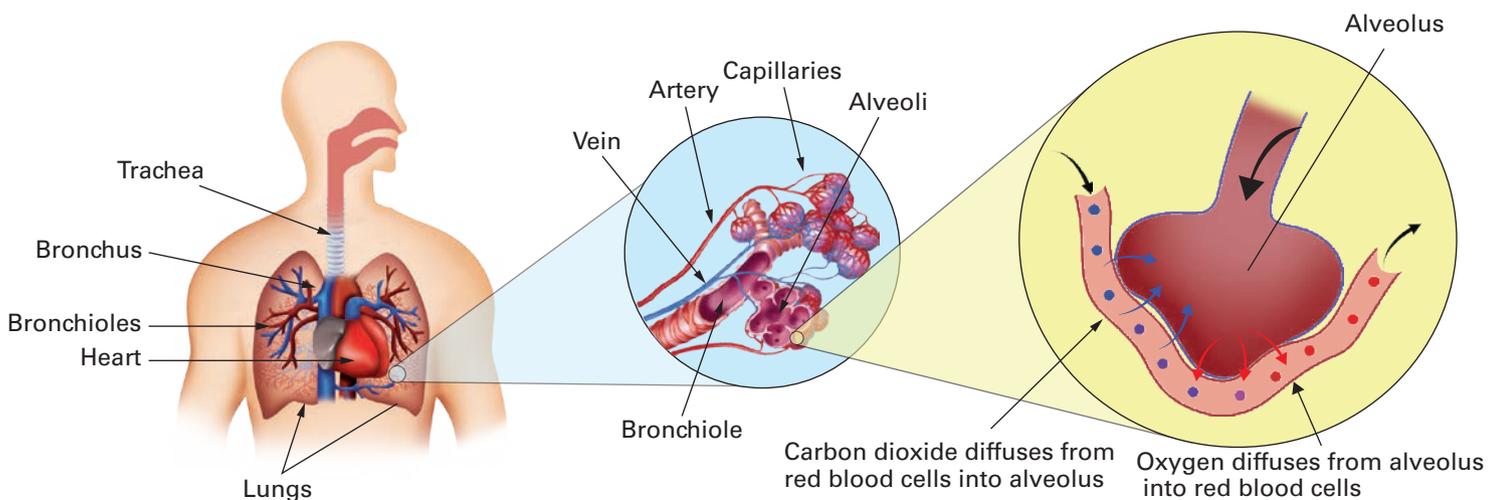


Figure 9.21 Zooming in on the respiratory system

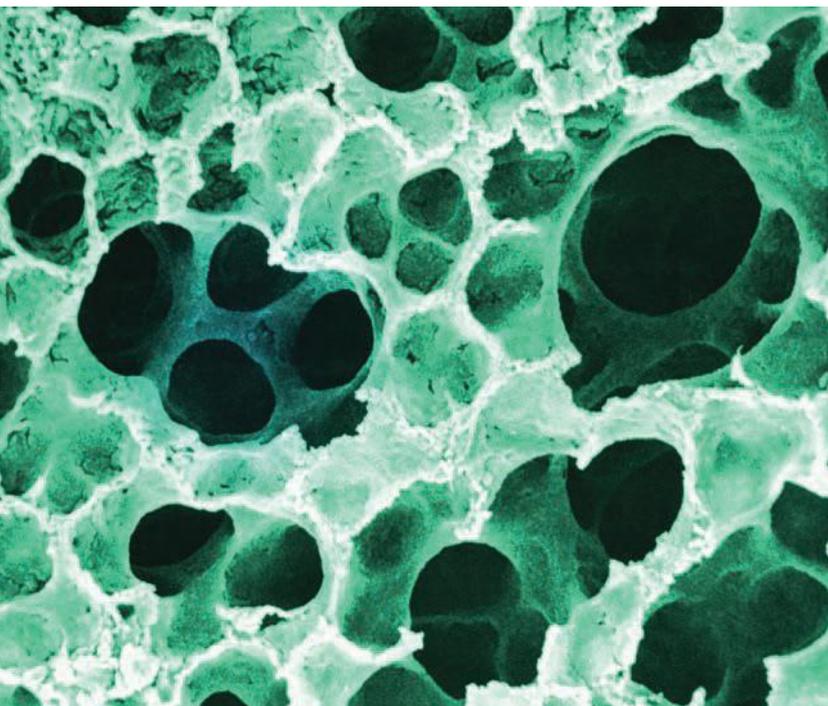


Figure 9.22 Alveoli in the lungs

These tubes terminate in microscopic air sacs called **alveoli** (singular: alveolus). The alveoli are surrounded by tiny **capillaries** (the smallest vessels in the circulatory system) whose walls are only one cell thick. It is between the alveoli and the capillaries that gas exchange occurs, by the process of diffusion. Oxygen diffuses into the capillaries, and once in the blood, it binds to **haemoglobin** molecules in the red blood cells, which carry the oxygen to all the cells in the body. When your cells carry out cellular respiration, they use the oxygen and produce carbon dioxide, which needs to be disposed of. Carbon dioxide diffuses out of the body cells and moves into the bloodstream, and if allowed to accumulate, can increase the acidity of your blood.

**alveoli**  
(singular: alveolus) tiny air sacs found within the lungs, which are the site of gaseous exchange

**capillaries**  
(singular: capillary) the smallest vessels that contain oxygenated blood and enable red blood cells to deliver oxygen to the tissues on a cellular level

**haemoglobin**  
an iron-containing protein which is responsible for oxygen transport within red blood cells

It then travels to the lungs where it diffuses from the capillaries into the alveoli of the lungs and is breathed out (exhalation).

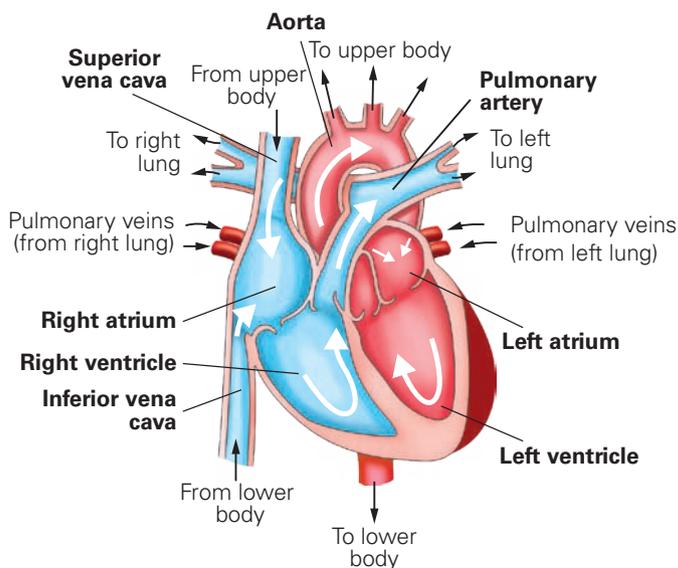
## The circulatory system

The circulatory system is the transport system of the body. It has four main functions, which are to:

- transport nutrients, gases, hormones and waste products around the body
- protect the body from infection by transporting antibodies
- help maintain body temperature
- help maintain fluid balance within the body.

The human heart functions like a double-sided pump. The right side of the heart pumps blood that is low in oxygen and high in carbon dioxide – also known as deoxygenated blood – to the lungs. The left side receives oxygenated blood from the lungs and pumps it to the rest of the body.

Each time the heart beats, it pushes the blood through your arteries and you can feel this wave of pressure as a pulse. You can feel your pulse at specific parts of the body where the arteries are close to the skin. The



**Figure 9.23** Human heart anatomy diagram showing blood flow with main parts

## Try this 9.4

Construct a flow chart showing the movement of oxygen and carbon dioxide through the lungs, heart, body and returning to the lungs. Include the anatomical features of the heart and label the vessels entering and exiting the heart and lungs.

locations commonly used by a medical professional are at the radial artery (inside the wrist) or at the carotid artery (on the side of your neck under your jaw).

## Maintaining blood pressure

Homeostatic control of blood pressure is critical to your survival. If your blood pressure is too high, it can result in damage to internal organs, and if your blood pressure is too low, you can lose consciousness. The heart and blood vessels contain special pressure receptors (baroreceptors) that can detect the change in blood pressure. If the blood pressure decreases, signals are sent from the brain stem to the heart to allow for the blood vessels to constrict (get smaller) and the heart rate to increase, also increasing blood pressure.

As discussed above, the kidneys regulate the amount of water in the blood. In doing so, they also play a role in regulating blood pressure. Too much water and the blood pressure is high, too little water (as in dehydration) and the blood pressure is low. If blood pressure is too high, the brain stem sends signals to the heart to slow down and to the blood vessels to dilate, thus lowering blood pressure.

## Quick check 9.6

- 1 Compare the functions of the respiratory system with the functions of the circulatory system.
- 2 Explain why you need oxygen and why you need to get rid of carbon dioxide.
- 3 Recall the location of the receptor sites that detect changes in blood pressure.
- 4 Other than the heart, recall an organ that is involved in maintaining blood pressure.

**Practical 9.2****Exercise, heart rate and breathing rate**

The body's energy needs vary according to how active you are. When you are resting, less energy is required, so you consume less oxygen. However, your respiratory and circulatory systems must work together to meet your increased energy needs during exercise.

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

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

**Aim**

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

**Planning**

Construct a specific and relevant research question and develop a hypothesis for this activity.

**Materials**

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

**Procedure**

- 1 Draw the results table below.
- 2 Measure your partner's resting heart rate by placing your index and middle fingers on the inside of their wrist. Using the stopwatch, count the number of beats in a 15-second period. (Optional: wear a heart rate monitor.)
- 3 Get your partner to count how many times they exhaled in this 15-second period.
- 4 Multiply both numbers by 4 to get beats per minute and breathing rate per minute. Record these in the table.
- 5 Instruct your partner to walk at their usual pace outside for a 2-minute period (low intensity). When the 2 minutes is up, immediately measure their heart rate and get them to count how many times they take a breath in a 15-second period.
- 6 Multiply both values by 4 and record in the table.
- 7 Measure the heart rate and breathing rate twice more: once 1 minute after they stopped walking and once 2 minutes after.
- 8 Instruct your partner to run around outside and use the stopwatch to time them for a 2-minute period (high intensity). When the 2 minutes is up, immediately measure their heart rate and get them to count how many times they take a breath in a 15-second period.
- 9 Multiply both values by 4 and record these in the table.
- 10 Measure the heart rate and breathing rate twice more: once 1 minute after they stopped walking and once 2 minutes after.

*continued...*

...continued

**Results**

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

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

**Discussion**

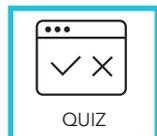
- 1 Describe any trends, patterns or relationships in your results.
- 2 Explain your results (both heart rate and breathing rate) with reference to the homeostatic mechanisms occurring in the body.
- 3 Compare how long it took for the heart rate and breathing rate to return to rest following low-intensity and high-intensity exercise.
- 4 Discuss any potential sources of error from this experiment.
- 5 Propose at least two suggestions on how this experiment could be improved.

**Conclusion**

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

**Extension**

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

**Section 9.2 questions****Remembering**

- 1 Homeostasis is the maintenance of a relatively stable internal environment. **Name** four things that are tightly regulated within the human body.
- 2 **Identify** the functioning or functional unit of the kidney.
- 3 **Identify** between which two structures gas exchange occurs in the lung.
- 4 **Outline** which hormones are secreted by the pancreas and what effect they have.

**Understanding**

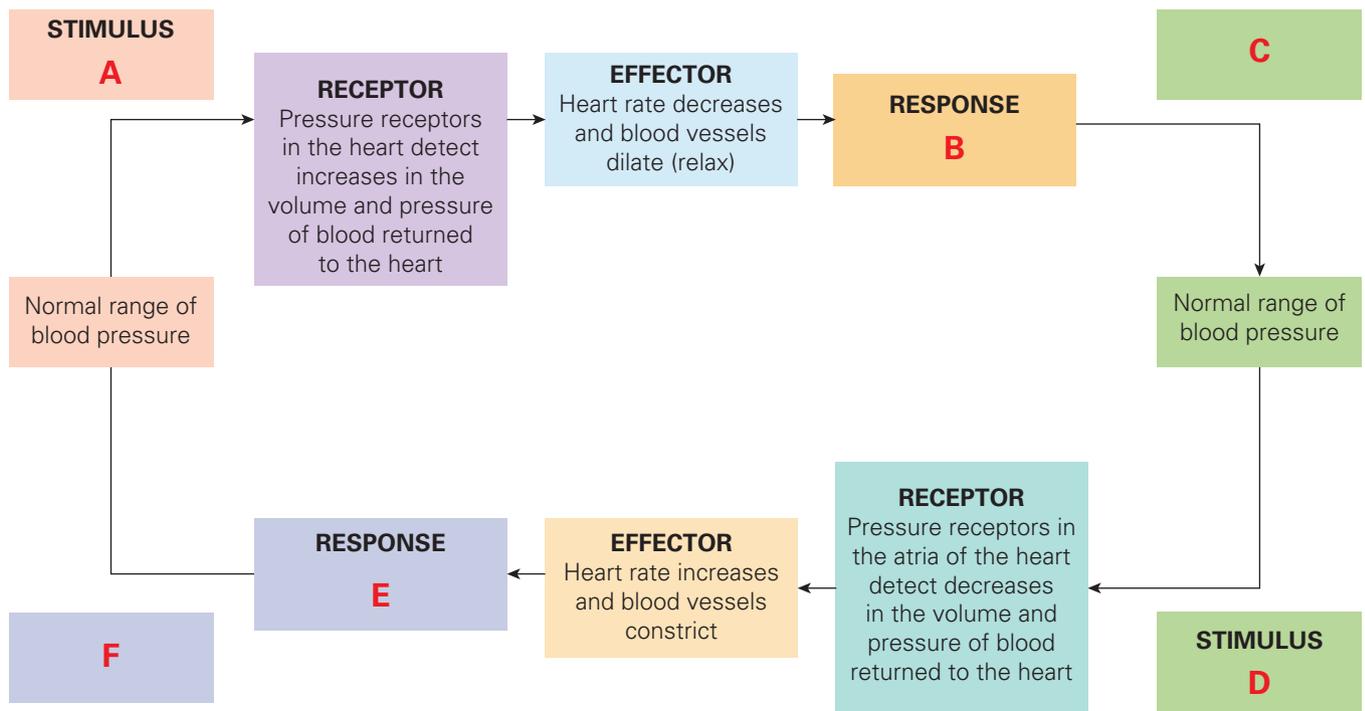
- 5 **Explain** how the body responds to the increased energy demands of exercise.
- 6 **Construct** a labelled diagram showing the stages of the stimulus–response model.

**Applying**

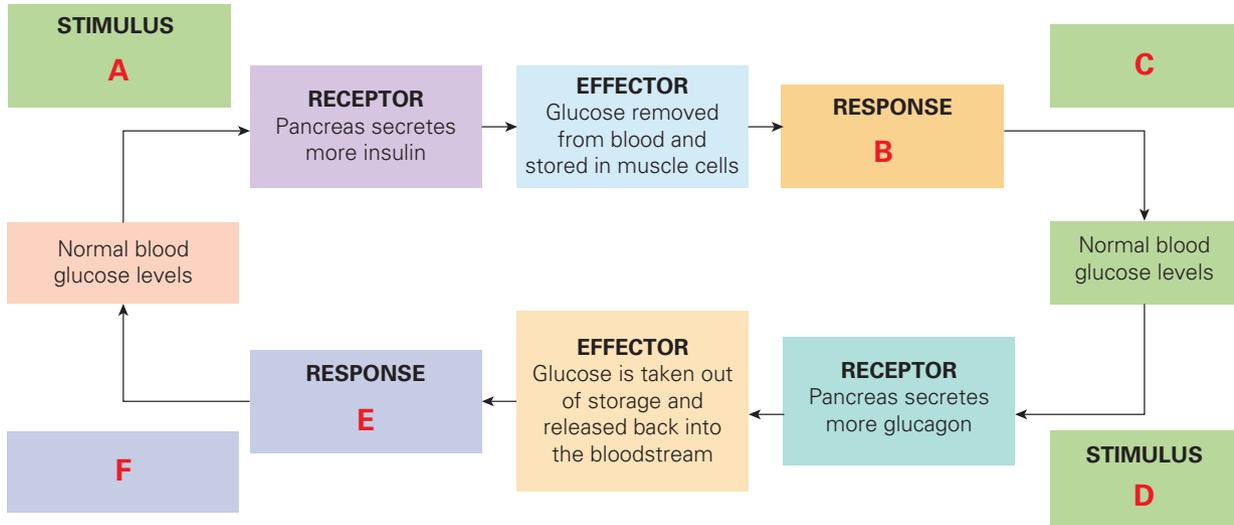
- 7 A person who has undergone a serious and lengthy surgical operation stands up for the first time after the surgery. They lost a significant amount of blood during the procedure and their blood pressure is low, making them feel dizzy. **Draw** a stimulus–response model showing the steps the body would take to address this deviation from normal blood pressure.

**Analysing**

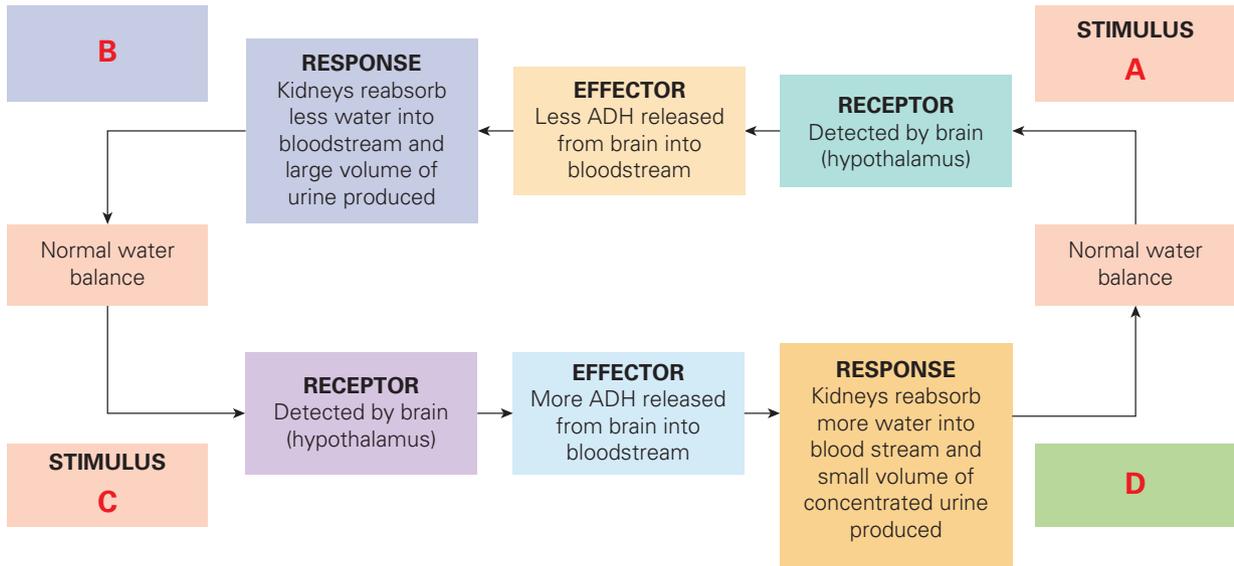
- 8 **Discuss** why both the lungs and kidneys are considered to be organs involved in excretion.
- 9 **Construct** a Venn diagram showing the digestive, circulatory and respiratory systems. In their overlapping zones, summarise in dot points the way the systems interact.
- 10 **Categorise** the following organs as receptors or effectors:
- hypothalamus
  - baroreceptors
  - liver
  - kidney tubules
  - pancreas
  - skeletal muscles
- 11 **Complete** this flow chart to compare the ways in which the body responds to each of the following scenarios. You can do this by identifying what the letters represent.
- High blood pressure versus low blood pressure



**b** High blood glucose levels versus low blood glucose levels

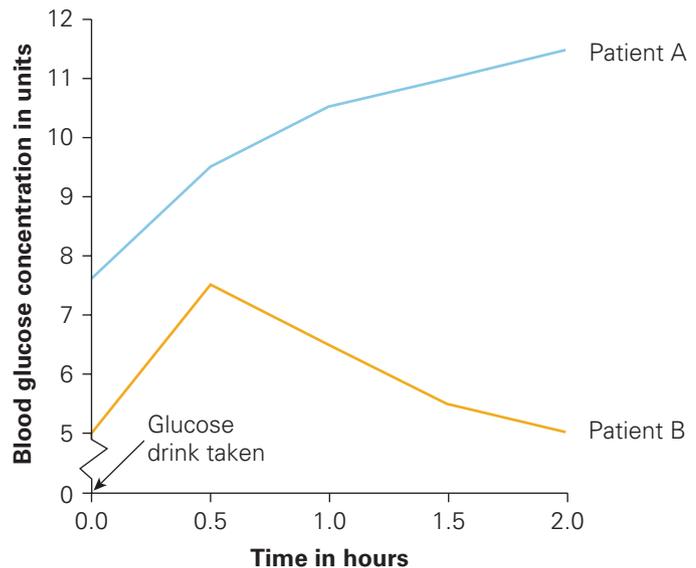


**c** High levels of water in the blood versus low levels of water (dehydration)



**Evaluating**

**12** The graph on the right shows the results of a glucose tolerance test for two patients, A and B. **Justify** which patient has diabetes using data from the graph.



## 9.3 Response to micro-organisms

### Learning goals

- 1 To describe the different types of microbes and explain the differences between them
- 2 To outline the function of the immune system
- 3 To describe how white blood cells protect us from infection
- 4 To explain how the immune system protects us from subsequent infections from the same micro-organisms
- 5 To describe how vaccinations work
- 6 To describe how antibiotics and antibiotic resistance works



WORKSHEET

VIDEO  
Three main pathogens

### Pathogens

Disease results when an infectious agent, called a **pathogen**, invades living tissue.

Some pathogens are cellular; that is, they are made of cells. Examples are bacteria, fungi and parasites. Some pathogens are non-cellular, for example, viruses, viroids and prions. Individual pathogens within an infected individual reproduce very

quickly under their optimum conditions and need to be destroyed as quickly as possible to avoid illness. They can cause illness by either interfering with the normal functioning of the body tissues or producing toxins that damage the host tissue. Table 9.3 lists common diseases caused by bacteria, fungi and viruses.

Bacterial diseases	Fungal diseases	Viral diseases
Typhoid	Ringworm	Warts
Gonorrhoea	Thrush	Poliomyelitis
Syphilis	Tinea	Rubella
Tetanus		Influenza
'Strep throat'		Common cold
Gastroenteritis		COVID-19
Anthrax		AIDS
		Mumps

Table 9.3 Some common diseases caused by different pathogens

### Bacteria

**Bacteria** are simple unicellular organisms called **prokaryotes**, which have a cell wall but no membrane-bound organelles (such as a nucleus or mitochondria) inside (see Figure 9.24). Individual bacteria cannot be seen with the naked eye, but a bacterial colony (group of many bacteria) will be visible if it contains a

sufficient number of bacteria. Scientists, therefore, need a microscope to study individual bacteria.

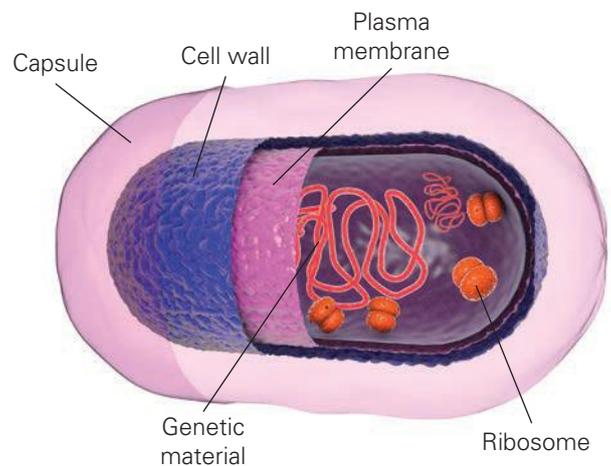


Figure 9.24 General structure of a bacterial cell

Most bacteria reproduce by a process called **binary fission** whereby the genetic information of the bacterium replicates and the cell divides into two. Each cell produced during binary fission is a genetic clone of the parent cell. Some bacteria, like *Escherichia coli*, can divide every 20 minutes under optimum conditions. After just 3 hours, you have had 9 cell divisions, equating to a growth from 1 bacterium to 512 bacteria. After 20 divisions, under suitable conditions, there would be over 1 million bacteria. That is why you can quickly become ill when harmful bacteria invade your body.

#### pathogen

an infectious agent, such as a bacterium, virus, prion or parasite, that can cause disease

#### bacteria

(singular: bacterium) microscopic, unicellular (single-celled) organisms

#### prokaryote

a single-celled organism with no membrane-bound organelles (such as a nucleus), e.g. a bacterial cell

#### binary fission

a form of asexual reproduction; the most common form of reproduction in prokaryotes, and occurs when the cell divides, giving rise to two identical cells



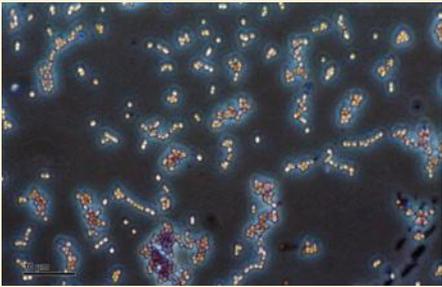
**Figure 9.25** Coloured scanning electron micrograph (SEM) of *Escherichia coli* bacteria (pink) on a gecko's tongue. The magnification is  $\times 8000$ .

### Types of bacteria

One way of classifying bacteria is by the shape of their individual cells. The main shapes are rods, spheres and spirals. Examples of these can be seen in the magnified images in Table 9.4.

#### Quick check 9.7

- 1 Define the term 'pathogen'.
- 2 Recall why bacteria are considered prokaryotes.
- 3 Describe how bacteria reproduce, and why this is a problem if a pathogenic strain infects a person.
- 4 State the different names and shapes of bacteria.

Shape	Biological name	Diseases	Magnified image
Rod	bacillus (plural: bacilli)	Typhoid Tuberculosis	
Spiral	spirillum (plural: spirilli)	Syphilis	
Spherical	coccus (plural: cocci)	Streptococcus (causes tonsillitis)	

**Table 9.4** Common types of disease-causing bacteria.

**Did you know? 9.2**

One of the first investigators of bacteria grew them on the jelly of the eye of an ox! Nowadays, biologists use nutrient agar plates. Agar is a jelly derived from red algae, which some bacteria can use as food on its own. However, if a food like meat extract has been added, bacteria can readily grow on it and will divide to form colonies very quickly.



**Figure 9.26** Scientists used to use jelly from the eye of an ox for growing bacteria. Nowadays, a nutrient agar dish is used. This one contains bacterial colonies.

**Practical 9.3****Using antibacterial agents to prevent the growth of bacteria****Aim**

To determine the most effective antibacterial agent.

**Planning**

- 1 Write a paragraph about antibacterial agents and their impact on bacteria.
- 2 Develop a hypothesis to predict which antibacterial agents will be the most effective.
- 3 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
- 4 Complete a risk assessment for this investigation, describing how any risks will be controlled.

**Materials**

- Petri dish containing sterile nutrient agar
- cotton buds
- marker pen
- masking tape
- tweezers
- filter paper

**Be careful**

Ensure gloves are worn when handling nutrient agar plates. Do not sample from the body or expose the agar to any pathogenic organisms. Hands are to be washed with soap immediately after handling nutrient agar plates. All working surfaces are to be wiped down with disinfectant after all nutrient agar plates are collected. Once the plate is sealed, it is not to be reopened. Once the plate has been observed, it should be sterilised via autoclave.

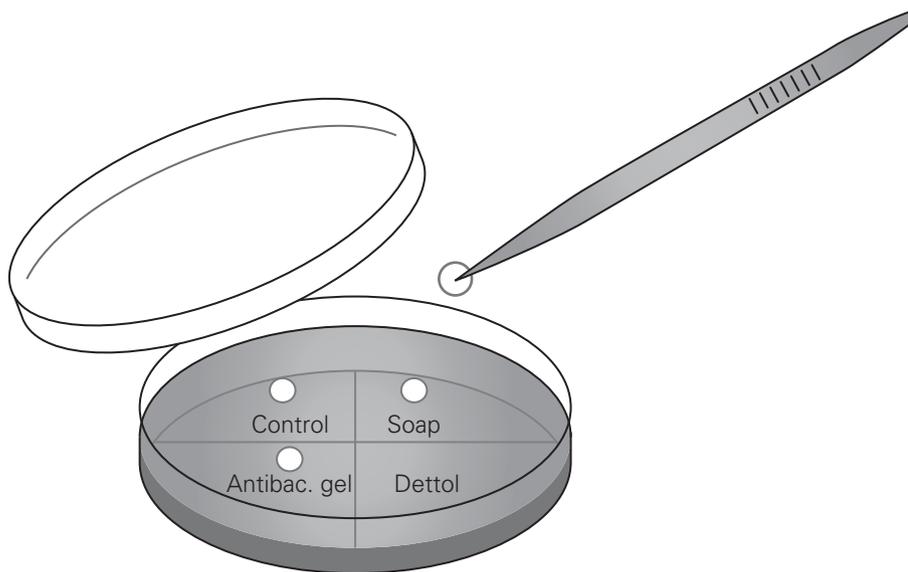
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- hole punch
- different antibacterial products (e.g. cleaning products, manuka honey, hand sanitiser)
- disposable gloves
- disinfectant
- hand wash (soap)

### Procedure

- 1 Using a marker, split the Petri dish into quarters by drawing on the outside of the plastic base of the dish. Label three of the quarters with three of the antibacterial products you will be testing. The fourth will be your control.
- 2 Using a cotton bud, wipe over an object of choice, such as a phone screen, computer keyboard, computer mouse or door handle.
- 3 Open the Petri dish and swab the cotton bud gently over the nutrient agar.
- 4 Create some filter paper discs by using a hole punch.
- 5 Using the tweezers, dip one of the filter discs in one of the antibacterial products.
- 6 Place this disc in the centre of the appropriately labelled agar quarter.
- 7 Repeat steps 5–6 with two other antibacterial products.
- 8 Place a clean filter paper disc in the control quarter.



**Figure 9.27** Make sure you label the outside base of the dish, not the actual agar!

- 9 Secure the lid with three pieces of tape.
- 10 Wipe down all work surfaces with disinfectant after all the nutrient agar plates have been collected.
- 11 The plates will be stored upside down (with the agar at the top) in an incubator at 37.6°C for 1–2 days.
- 12 Remove the plates from the incubator and observe the colonies of bacteria that have grown.

**Warning:** Microbes can produce harmful toxins, so it is very important to seal them securely. Taking careful precautions and minimising exposure to the microbes can protect us from dangerous infections. It is essential that the plates produced are sealed, collected and destroyed (incinerated or autoclaved). Ensure hands are washed after handling any plates.

### Results

- 1 Calculate the zone of inhibition (ZOI) for each filter paper disc. The ZOI is the clear area around each disc where there is no bacterial growth. Measure the diameter of the ZOI by placing a ruler across the centre of the filter paper disc and measuring from one side of the ZOI to the other. Repeat this measurement at an angle of 90 degrees to the first to calculate the mean diameter.

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- 2 Sketch the colonies and ZOI that you can see on your agar plate.

### Discussion

- 1 Compare the ZOI of each antibacterial product and the control.
- 2 Sequence the products in order of the most to least effective at killing bacteria.
- 3 Compare your results with other products that your classmates have tested. Identify the most effective product at killing bacteria.
- 4 Discuss why certain products may be better than others at killing bacteria.
- 5 Discuss the purpose of the control quarter of your agar plate.
- 6 Identify any potential sources of error in this experiment.
- 7 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 bacterial growth and antibacterial products. Justify your answer with data.

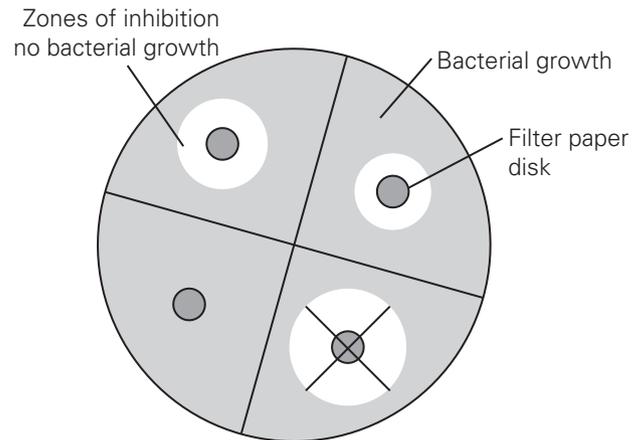


Figure 9.28 Take two measurements of each clear zone.

## Fungi

**Fungi** can be single-celled or multicellular organisms that contain a nucleus and have a cell wall made of chitin. They also have membrane-bound organelles, including mitochondria, which means they are **eukaryotic** organisms like plants and all animals, including you! Familiar fungi include yeasts, moulds, and mushrooms. Unlike plants, fungi cannot photosynthesise their own food. Instead they use their long, fibrous cells to penetrate plants and animals, breaking them down and extracting their nutrients. You may have seen furry growth on



Figure 9.29 The pink area between this person's toes is a localised tinea infection (commonly known as 'athlete's foot').

decaying food – this is a type of fungus. For example, the furry growth on a rotten orange is the mass of fruiting bodies produced by the fungus that has infected the orange. Mushrooms and toadstools are the fruiting bodies of fungi that feed on things in the soil. Several species of fungi, mostly yeasts, live harmlessly on the human body, but others can cause skin diseases like tinea, thrush and ringworm.

**fungus**  
(plural: fungi) single-celled or multicellular organisms which contain a nucleus and a cell wall made of chitin

**eukaryote**  
an organism with a nucleus and membrane-bound organelles



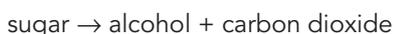
Figure 9.30 The green-black areas are mould growing on pieces of bread.

## Practical 9.4

### Fermentation

Yeast is a type of fungus, one that is very useful in the production of many foods. You might have some baker's yeast in the cupboard at home – it is used when baking bread. Yeast exists as single cells and reproduces by a process called **budding**, where a yeast cell develops a small 'bud', which grows and eventually separates to form a new yeast cell.

Yeast feeds on sugar. This specialised process, known as **fermentation**, allows for sugar to be broken down by yeasts (in the absence of oxygen) to form alcohol and carbon dioxide.



Some alcoholic beverages (like champagne) are fizzy because the carbon dioxide is contained and not allowed to escape. A similar reaction causes bubbles in baked goods, which causes breads and cakes to rise.

### Aim

To investigate the process of fermentation using yeast.

### Materials

- 5 test tubes
- test-tube rack
- 200 mL beakers
- balloon
- limewater
- sugar
- yeast
- delivery tube with stopper
- teaspoon
- marker pen
- measuring cup for 10 mL

### Procedure

- 1 Collect five test tubes. Place the first four in a rack and label them A, B, C and D (as shown in Figure 9.31).
- 2 Fill each test tube A–D according to the table below.

A	B	C	D
2 teaspoons sugar 10 mL warm water	1 small heaped teaspoon yeast 10 mL warm water	2 teaspoons sugar 1 small heaped teaspoon yeast 10 mL warm water	2 teaspoons sugar 1 small heaped teaspoon yeast 10 mL warm water

- 3 Place a balloon over the end of test tube C.
- 4 Attach a delivery tube to test tube D and place the outlet into some limewater in a fifth test tube as shown in the diagram.
- 5 Leave all test tubes for approximately 30 minutes. Observe the results after this time.

### Results

Tabulate the results of the experiment by recording your observations, including smell.

### Discussion

- 1 Describe any trends, patterns or relationships in your results.
- 2 Suggest some reasons for the different results obtained in test tubes A, B and C, making reference to the contents of the test tubes.
- 3 Explain why it is important to use warm water and not to use water that is too hot.

#### budding

an asexual reproduction process where the new individual is a clone of the parent organism

#### fermentation

a chemical process by which energy is produced in the absence of oxygen

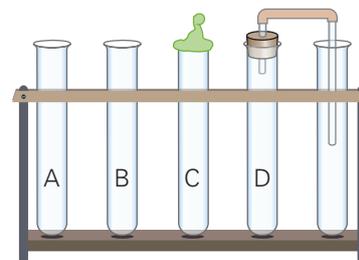


Figure 9.31 Experimental set-up

## Viruses

**Viruses** are tiny pathogens. They cannot be seen with a light microscope but can be seen with an electron microscope. Viruses are made up of a core of genetic material surrounded by a protein coat. However, when they penetrate a suitable host cell, they take it over and turn it into a virus factory (see Figure 9.32).

As you have learned, one of the key requirements for life is the ability to reproduce. Since viruses depend upon invading other cells and using the invaded cell to replicate and survive, viruses are in a grey area between living and non-living. Regardless, viruses are an important part of all ecosystems, including the human

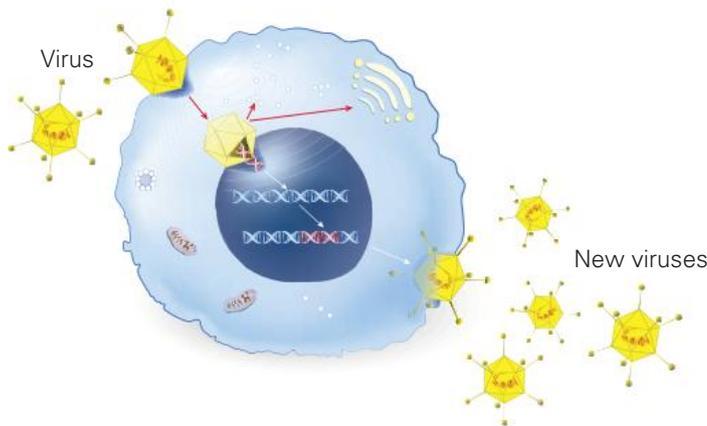


Figure 9.32 The replication of a virus via a host cell

body. In your body, viruses are known to infect not only your own cells, but also other pathogens that live inside you.



## Disease transmission

From the Black Death in the fourteenth century to the COVID-19 pandemic, epidemics of infectious diseases (diseases caused by pathogens) have afflicted societies throughout history. In the modern world, the modes of transmission of infectious diseases are well understood. Table 9.5 outlines the main modes of transmission.

**virus**  
an extremely small non-cellular pathogen composed of infectious particles that are inactive outside a living host cell

### Quick check 9.8

- 1 State three common types of fungi.
- 2 Describe how fungi are able to obtain the nutrients they need to survive.
- 3 Explain how yeast cells reproduce.
- 4 Describe the structure of viruses and how they reproduce.
- 5 Scientists argue that viruses are in fact non-living. Discuss why this may be the case.

Mode of transmission	Description	Examples
Direct contact	Spread is by skin-to-skin contact between people or via surfaces they have touched.	A student has tinea (fungal infection) and showers on a school camp without wearing thongs. Another student uses the same shower and develops the same fungal infection.
Airborne	Pathogens can be spread via droplets of saliva produced when you cough and sneeze, or by spores spread in the air.	A person infected with the common cold (rhinovirus) sneezes on the train, and the person next to them wakes up infected the next day.
Vectors	Disease-carrying organisms spread pathogens.	A tourist is bitten by a mosquito in Papua New Guinea and contracts malaria.
Waterborne	Pathogenic organisms live in water and can be passed on by drinking the water.	A person becomes infected with typhoid after drinking water that has not been chemically treated in a developing country.
Blood	Pathogens are spread by contaminated blood or other body fluids.	Human immunodeficiency virus (HIV) can be transmitted through shared needles from tattooing, piercings or medical procedures.

Table 9.5 Modes of infectious disease transmission

## Explore! 9.4

Governments and people around the world were taken by surprise when a flu-like infection was identified in Wuhan, China, in late 2019. The virus causing the disease was identified and classified on 7 January, just days before the first death from the virus was recorded. By 20 January, cases were being reported outside China, and the virus then spread exponentially around the world. By 7 March, 100 000 cases were recorded worldwide, and on 11 March the World Health Organization announced that COVID-19 was a global pandemic. By 3 April, 1 million cases had been recorded, and by the start of May only a handful of countries had not recorded any cases and over a 220 000 people had died.

Like in many countries, Australia's national, state and territory governments instituted wide-ranging measures to minimise the spread of the virus through the community. This included restricting travel, closing businesses, banning gatherings and requiring people to work, study and remain at home except for essential tasks.

We will all remember the 'lockdown' periods and physical distancing measures for a long time – you have been living through history in the making. Use the internet to research the current status of, and knowledge about, COVID-19 to answer the following questions.

- 1 Differentiate between the terms 'coronavirus', 'SARS-CoV-2' and 'COVID-19'.
- 2 In what ways is COVID-19 similar to and different from the seasonal flu?
- 3 People who get seriously ill with COVID-19 often decline after a week of mild illness. Predict what is happening to their immune system.
- 4 Compare how effective different public health measures were in different countries.
- 5 Why was physical distancing an important public health measure for COVID-19?
- 6 Why is a vaccine considered a vital part of managing SARS-CoV-2?

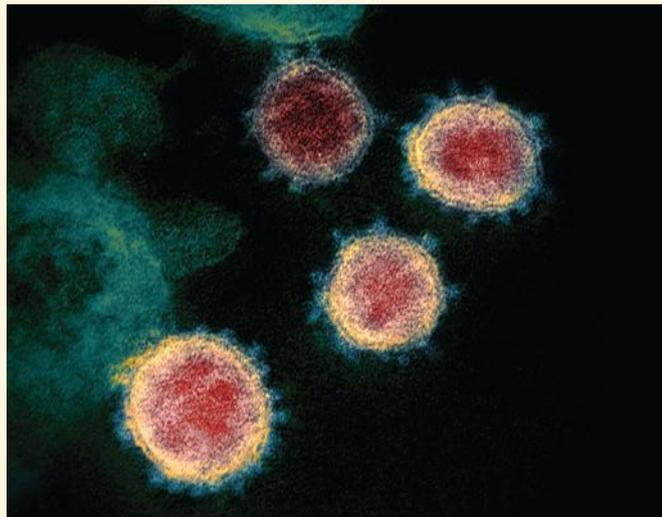


Figure 9.33 The virus that causes COVID-19

#### immune system

the system (cells and tissues) that enables the body to protect itself against disease

#### non-specific immunity

immunity provided by the branch of the immune system that does not depend on recognition of the pathogen; includes the first and second lines of defence such as physical barriers, inflammation and fever

#### specific immunity

immunity provided by the branch of the immune system that is specific to each particular pathogen; the third line of defence

## The immune system

The body's **immune system** is its defence against infectious diseases. To function properly, the immune system must be able to detect, distinguish and respond to a variety of pathogens and damaged or foreign cells. The immune system has three lines of defence, which can be divided into two categories. The first

and second lines of defence respond in the same way to all infections: they provide **non-specific immunity**. The

third line of defence provides **specific immunity** against a particular pathogen (see Table 9.6).

Non-specific immune system	Specific immune system
First and second lines of defence	Third line of defence
General defence that responds the same way for every infection	Targeted defence that produces antibodies to combat a specific pathogen
No 'memory' of prior infections; same intensity of response every time	Remembers a pathogen and responds harder and faster if it encounters it again (adaptive)

Table 9.6 Immune system lines of defence

## First line of defence

The first line of defence aims to prevent infection: it is the first point of the human body that the pathogen comes into contact with. For example, it includes surface barriers like intact skin (protecting external boundaries) and mucous membranes (protecting internal boundaries, such as in the gut, mouth and nose). This

line of defence is very useful, because if the pathogens cannot enter the host's body, they cannot disrupt normal physiological functions and cause disease. These barriers release chemical secretions, such as sweat, tears, ear wax, mucus and stomach acid, which restrict the growth of pathogens on their surfaces and prevent the entry of pathogens into the body.

### Advances in science 9.2

#### Spray-on skin

Patients who sustain burn injuries are at high risk for developing infections as they have 'lost' their first line of defence. If patients survive the first 72 hours after their burn injury, infections are the most common cause of death. In 1993, Professor Fiona Wood and Marie Stoner developed a spray-on skin for burns patients that allows skin grafts to be applied much earlier, reducing both the risk of infection and the risk of scarring. This technique is now used worldwide.



**Figure 9.34** Professor Fiona Wood was the recipient of the Australian of the Year Award in 2005.

## Second line of defence

If pathogens manage to cross the first line of defence, then internal defences are activated. An immediate response begins when special proteins come together to mark pathogens so they will be targeted for destruction. After a few hours, white blood cells of a type called phagocytes will start to engulf the pathogens in a process called **phagocytosis**. This triggers inflammation, which helps the immune response by increasing blood flow and the permeability of capillaries in the infected area, actively bringing more immune cells to the site of an infection.

## Third line of defence

The third line of defence in the body's immune response provides immunity that is specific to each particular pathogen. This specific immune system is adaptive, which means that it can 'learn' from an infection

and respond more quickly if it encounters the same pathogen again. This immune response takes a few days to become protective.

All immune cells need to differentiate between infected or foreign ('non-self') cells and non-infected 'self' cells.

To do this, they identify a special molecule on the cell membrane called an **antigen**. Healthy cells have self-antigens that do not trigger a response. However, a pathogen will have foreign antigens on its surface – these are a sign to the immune system that the cell should be destroyed. The presence of foreign antigens activates two special types of white blood cells known as **lymphocytes**: B cells and T cells.

#### phagocytosis

a cellular process where a white blood cell engulfs and ingests a cell or large particle to break it down using enzymes

#### antigen

a substance that induces an immune response in the body; can be foreign (non-self) or a self-antigen

#### lymphocyte

white blood cell that is involved with fighting disease; some produce antibodies

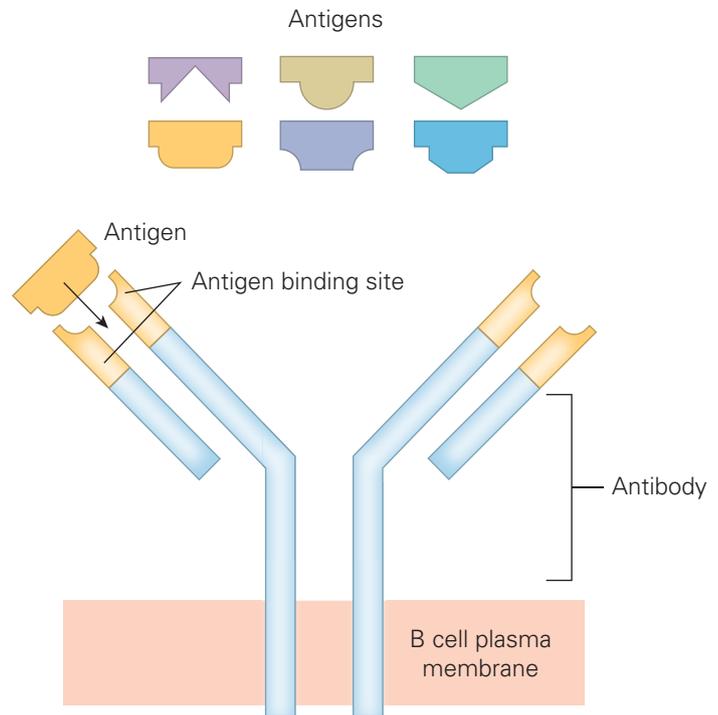
**memory cell**

a type of white blood cell that is formed after exposure to a pathogen and remembers that pathogen in the future

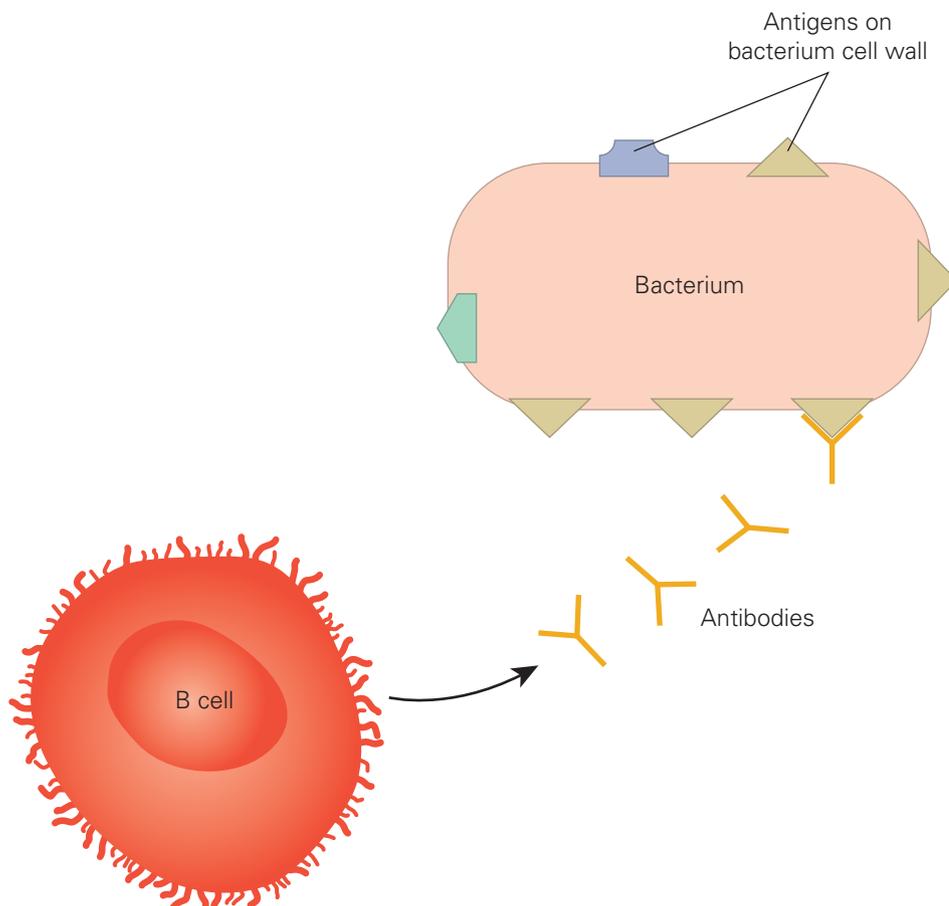
The B cells are the part of the immune system that produces antibodies. Antibodies are Y-shaped proteins that

recognise and bind to an antigen. Just like a lock and key that must match in size and shape. A specific antibody can only bind with one kind of antigen (see Figure 9.35). An antibody bound to an antigen is a signal for T cells to come and destroy the pathogen (see Figure 9.36). The type of T cell that takes this role is known as a killer T cell. Another type of T cell is the helper T cell. Helper T cells act like team leaders and provide chemical instructions to other T cells and B cells to replicate themselves and fight infection.

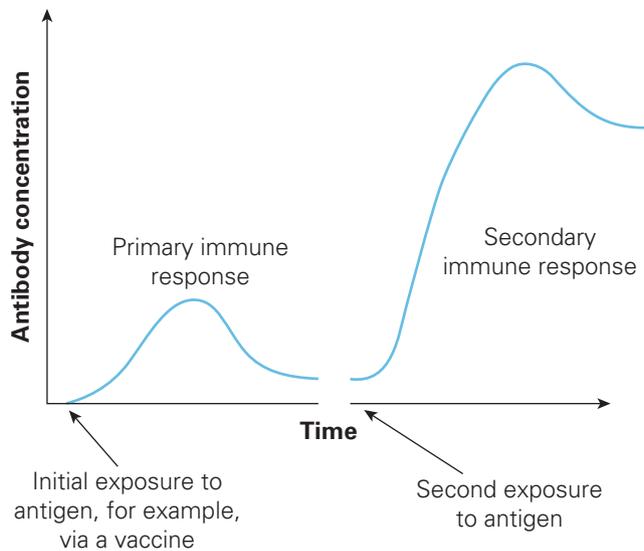
Both T cells and B cells can also form **memory cells**, which retain a 'memory' of a specific pathogen or antibody. Memory cells make the immune response much faster and stronger if the body encounters that specific pathogen again (see Figure 9.37). Sometimes, the second and subsequent responses are so effective you might not even feel unwell or know you have been infected! Being able to resist a pathogen in this way is called immunity.



**Figure 9.35** Like a lock and key, antibodies are designed with specific binding sites that can only attach to certain antigens with the right shape and size to match the binding site on the antibody. In this figure, only the yellow antigen would attach to the antibody as it matches the shape and size of the antibody's binding site. The other colours (antigens) are different shapes.



**Figure 9.36** Antibodies bind to the antigens on a pathogenic bacterium. This bacterium does not have long to live!



**Figure 9.37** The second immune response to an antigen on the surface of a pathogen is faster and larger than the first response.

**Quick check 9.9**

- 1 Contrast non-specific and specific immunity.
- 2 Copy and complete the following table, then recall what is involved in each line of defence.

Non-specific immune response		Specific immune response
First line of defence	Second line of defence	Third line of defence

**Immunisation and vaccines**

**vaccine**  
a chemical substance composed of a dead or weakened version of a pathogen that is injected or ingested to make a person immune against that pathogen

**immunise**  
the injection of a weakened or dead version of a pathogen to trigger the production of antibodies; provides protection against that pathogen in the future

**Vaccines** enable you to produce antibodies specific to a particular pathogen without ever having to be actually infected by it! Vaccination involves the injection of a dead (or inactivated) pathogen or a weakened form of a living

pathogen (complete with all its identifying antigen flags) into your body. The antigenic material in a vaccine cannot cause an infection, but the immune system still recognises it as a threat (because of the antigens) and responds by producing antibodies. This **immunises** you against the disease caused by that pathogen. After the threat has passed, many of the antibodies will break down, but the memory cells remain in the body ready to act if you encounter that pathogen again. Immunisation acts like a first exposure to a pathogen, but without the risk of actually getting sick!

**Did you know? 9.3**

**Human papillomavirus**

Infection with certain types of the human papillomavirus (HPV) can lead to changes in the cells of a woman’s cervix and has been shown to be a precursor for developing cervical cancer. Cervical cancer is the growth of these abnormal cells in the lining of the cervix. Globally, it is responsible for the death of one woman every 2 minutes. Research published by the International Papillomavirus Society has shown the rates of HPV infection in Australia have declined from 24% of Australian women aged 18 to 24 to 1% in the last decade. Researchers attribute this decline to the roll-out of the national immunisation program for HPV, which began in 2007. You probably received this vaccine at school!

**Figure 9.38** It is hoped that over the next four decades cervical cancer will be totally eradicated because only 1% of young women in Australia today are infected with HPV.



**Quick check 9.10**

- 1 Define the term 'vaccine'.
- 2 Compare vaccination with an infection from an actual pathogen.

**What are antibiotics?**

**Antibiotics** are chemical substances produced by a living organism (usually a mould) that can stop the growth of bacteria. Antibiotics can be effective against

**antibiotic**

a substance that inhibits the growth of bacteria inside the body

certain types of bacteria but may have little effect against other types.

**Antibiotic resistance**

Antibiotics have been used in medicine since the 1930s as the primary method of fighting bacterial infections in the human body. However, scientists are becoming increasingly concerned about drug-resistant bacteria ('superbugs'), because infections due to these bacteria often last longer, cause more severe illnesses, require more doctor visits or longer hospital stays, and may even cause death. Antibiotic resistance occurs as a result of people not completing a required course of antibiotic medication. This might happen when the sensitive

and weaker bacteria are killed quickly, so the person feels better and stops taking their medication. But that can leave alive some bacteria that, because of genetic mutations, are less susceptible (more resistant) to the antibiotic. As these bacteria reproduce, they produce a colony of antibiotic-resistant bacteria that can be passed on to other people!



**Figure 9.39** An agar plate that has been covered in bacteria. Each of the dots shows where an antibiotic disc was placed. The size of the surrounding clear section shows the effectiveness of the antibiotic at killing that type of bacteria.

**Did you know? 9.4****Unnecessary antibiotics**

At least 30% of antibiotic courses prescribed are unnecessary, meaning that no antibiotic is needed at all. For example, people often seek antibiotics when they are suffering from the common cold, but a cold is actually a viral infection and antibiotics will be useless.

**antiseptic**

a substance that stops or slows down the growth of micro-organisms, used externally on skin

**septic**

describes a wound infected with a harmful pathogen

**Antibiotics versus antiseptics**

While antibiotics can kill and stop the growth of bacteria, **antiseptics** can prevent the growth and development

of other pathogens, without necessarily killing them.

They tend to work on a large variety of microbes and are most often used externally, for example, antiseptic hand washes. When harmful pathogens grow in living animal tissue, the tissue is said to be **septic**. Many of the antiseptics used in the past killed the bacteria in wounds but also damaged or killed the tissue around the wound. Modern antiseptics seldom injure the tissues.

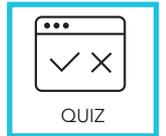
## Quick check 9.11

- 1 Contrast antibiotics and antiseptics.
- 2 A patient in a hospital ward is isolated due to infection with a 'superbug'. Describe superbugs and propose why the patient needed to be isolated.

## Section 9.3 questions

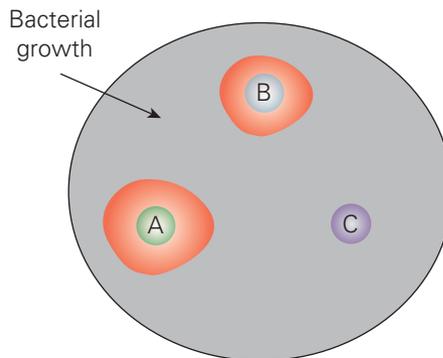
## Remembering

- 1 What is a pathogen? **Provide** two examples.
- 2 **Determine** whether bacteria are classified as prokaryotes or eukaryotes. Why?
- 3 A lymphocyte is a special type of white blood cell. **Identify** the two different types of lymphocyte.
- 4 **Name** three diseases caused by viruses.



## Understanding

- 5 **Describe** one difference between bacterial cells and eukaryotic cells (for example, plant or animal cells).
- 6 **Compare** and **contrast** bacteria and viruses.
- 7 Antimicrobial substances A, B and C were tested for their effectiveness against a strain of bacteria growing on agar as illustrated in the figure below. Interpret the results shown by answering the following questions.

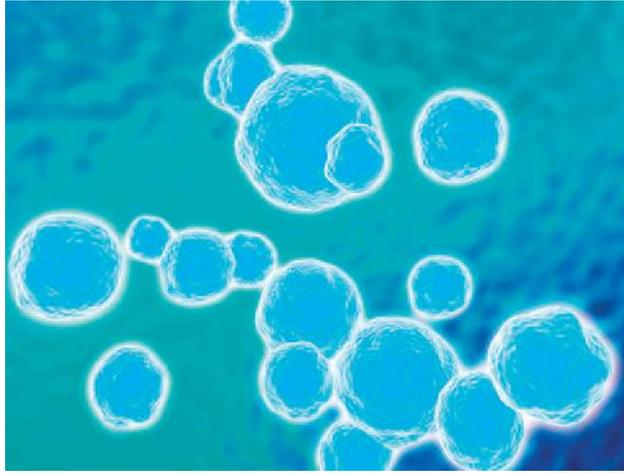


- a Of the antimicrobial substances tested, which was the most effective? **Explain** your reasoning.
  - b Of the antimicrobial substances tested, which was the least effective? **Explain** your reasoning.
- 8 **Outline** how immunisations can help fight disease.
  - 9 **Explain** why a virus is considered to be non-living.
  - 10 **Compare** and **contrast** the role of antibiotics and antiseptics.
  - 11 **Outline** the difference between non-specific immunity and specific immunity.

## Applying

- 12 **Identify** reasons why viruses cannot be treated with antibiotics.
- 13 The body's immune system may sometimes start to recognise 'self' antigens as foreign and 'non-self'. **Propose** what might happen in this case.

- 14 The image below shows MRSA bacteria that have developed resistance towards antibiotics. When they reproduce, the resistance is passed on to the resulting organisms.



- Bacteria come in a variety of shapes, each with a specific name. **Suggest** the scientific name for this type of bacteria.
- State** the name given to the process of bacterial reproduction.
- The MRSA bacteria can survive on a healthy person's skin or lungs without causing any symptoms or ill effects, while in an immune-compromised person it can be life-threatening. **Suggest** two ways it can spread from one individual to the next, along with possible ways spread can be prevented.

#### Analysing

- 'Superbugs' are strains of bacteria that have adapted and become resistant after coming into contact with an antibiotic. **Describe** why superbugs are a huge problem in society.
- Briefly **describe** how vaccines work.

#### Evaluating

- Contrast** the first, second and third lines of defence. You may **create** a Venn diagram to present the information.
- Herd immunity describes a population's resistance to a particular disease if a high proportion of individuals within the population are immune to the disease, usually through vaccination. Based on this information and what you have learned about how vaccination works, formulate and **evaluate** positive and negative viewpoints towards compulsory vaccination of children.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>9.1 I can recall the essential requirements for life.</b> e.g. Describe the essential requirements for every living organism.	
<b>9.2 I can recall the definition of homeostasis.</b> e.g. Define the term homeostasis.	
<b>9.2 I can describe the stimulus–response model.</b> e.g. Construct a flow diagram to show the stimulus–response model.	
<b>9.2 I can describe how blood glucose levels are controlled in the body.</b> e.g. Using the stimulus–response model, describe what will happen if a person without diabetes eats a bag of lollies.	
<b>9.2 I can describe how water levels are controlled in the body.</b> e.g. Using the stimulus–response model, describe what will happen if a person does not drink enough water.	
<b>9.2 I can recognise how the circulatory and respiratory systems work together.</b> e.g. Discuss the effect of increased exercise on the circulatory system and the respiratory system.	
<b>9.3 I can recall different types of pathogen.</b> e.g. Define the term pathogen.	
<b>9.3 I can discuss the different lines of defence in the body.</b> e.g. Contrast the first and second lines of defence with regard to the body's immune system.	
<b>9.3 I can discuss the problems surrounding antibiotic resistance.</b> e.g. Explain why not finishing a course of antibiotics is problematic.	



## Reflections

- 1 What **connections** come to mind when you think about homeostasis and your everyday life?
- 2 What new concepts have **extended** your thinking about:
  - how the body maintains homeostasis, and
  - the body's defence systems?
- 3 What information did you find **challenging** or confusing?

## Data questions

A student with diabetes measures their blood sugar level hourly and the data is plotted in blue in Figure 9.40. Another student, who does not have diabetes, also measures their blood sugar as a comparison, and this is plotted in orange. The students are careful to eat the same three meals on this day – breakfast, lunch and dinner at the same time – and the student with diabetes injects insulin straight after each meal.

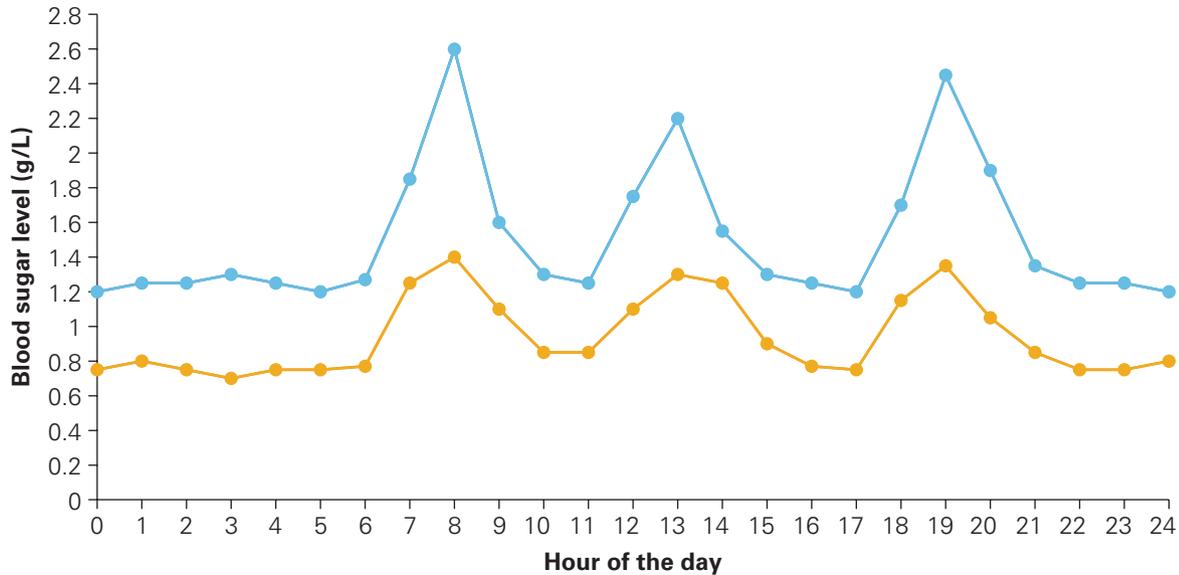


Figure 9.40 Relative blood sugar level over a 24-hour period. Orange line – student without diabetes, Blue line – student with diabetes.

- 1 **Identify** the homeostatic (steady state) blood sugar level for each student.
- 2 **Determine** the times that the students ate breakfast, lunch and dinner.
- 3 **Identify** the peak blood sugar level for both students on this day.
- 4 **Identify** any patterns or trends that appear in the data.
- 5 **Contrast** the change in blood sugar level after each meal and provide a reason for the difference between the two students.
- 6 **Infer** a reason for the lower peak in blood sugar for the student with diabetes after eating lunch than after the other meals.
- 7 **Justify** whether the comparison of data would be valid if the students ate different meals on this day.
- 8 After the student with diabetes ate dinner, **deduce** the time that insulin was injected into the bloodstream. Assume that insulin starts to act immediately upon injection.
- 9 **Predict** what would happen to the plotted data if the student with diabetes did not use insulin directly after the breakfast meal.

## STEM activity: Simulating the transmission of disease

### Activity instructions

You will use a model to determine the origin of an infection with a direct contact disease, and, taking on the role of biomedical engineers, you will analyse the data and predict future infection levels. You will then evaluate the role of simulations in modelling the transmission of disease and suggest improvements to this activity.

**Design brief:** Design a simulation that demonstrates the transmission of a direct-contact disease.

### Suggested materials

- 0.1 M NaOH
- phenolphthalein solution in a dropper bottle
- distilled water
- droppers
- plastic cups or test tubes

### Be careful

Do not spill the contents of the cups. Use water to wash if you come into contact with the liquid.  
Do not drink the contents.

### Research and feasibility

- 1 Research how direct-contact diseases spread through populations.
- 2 Research how models are currently used to simulate the spread of disease.
- 3 List the key features of the simulation models and how they represent the real-world contamination of infectious diseases.

### Design and sustainability

- 4 Design Option 1: A simulation that uses a cup filled with distilled water as a healthy person and a contaminated cup (with traces of sodium hydroxide which can be detected through a pH monitor) as a contaminated person. You will use droppers as a method of contamination. The chemical phenolphthalein can be used as an indicator to test if the cups' contents test positive or negative for contamination.  
Design Option 2: A simulation that uses any method that has been checked by your teacher

for safety measures. Remember any chemicals you plan to use must be checked by referring to their material safety data sheet (MSDS).

- 5 Check that your chemicals/materials are safe to use and dispose of. Minimise waste wherever possible.

### Create

- 6 Perform your group activity with at least 15 class members and record your results in any way. The following table can be used as a guide.  
HINT: Ask the teacher to contaminate the first cup without students watching so it is a surprise for the whole class.

Class member	Contact 1	Contact 2	Contact 3	Test positive/negative

- 7 Tracing the source of infection. Take on the role of epidemiologists and try to determine the source of the infection in your community – who was the original carrier?

### Evaluate and modify

- 8 Evaluate the model through a group discussion, and list your findings. Remember that engineers must assume certain things when creating models. For example, this activity assumes that each person who exchanges fluid with an infected person gets infected. Another assumption was that there was no incubation time. Most infectious agents will need time to multiply before they can be transmitted to another person.
- 9 Write a short report evaluating the model you used. How could you change the simulation to make it more realistic? Consider the following questions before you write your answer: How would the results differ if everyone could choose how many exchanges to have? How would the results differ if you have only a 20% or 50% chance of contracting the disease after being exposed? How would the results differ if infected people were sometimes quarantined? How would the results differ if a vaccine becomes available that prevents infection? How would the results differ if the infected person dies very quickly or very slowly after contracting the disease?



# Chapter 10

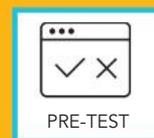
## Response and coordination

### Inquiry questions

Why can we control the speed with which we eat food but not the speed with which it is metabolised?

How does your body respond to changes?

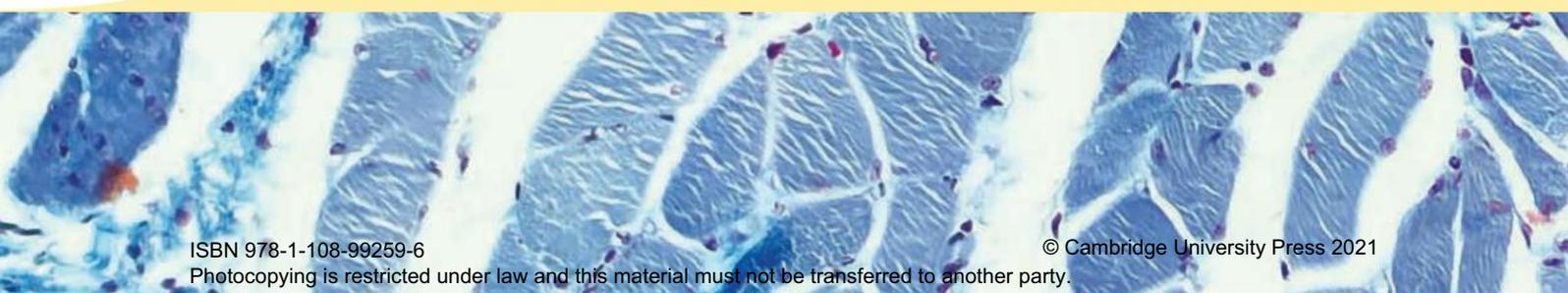
How does your brain communicate with the rest of your body?



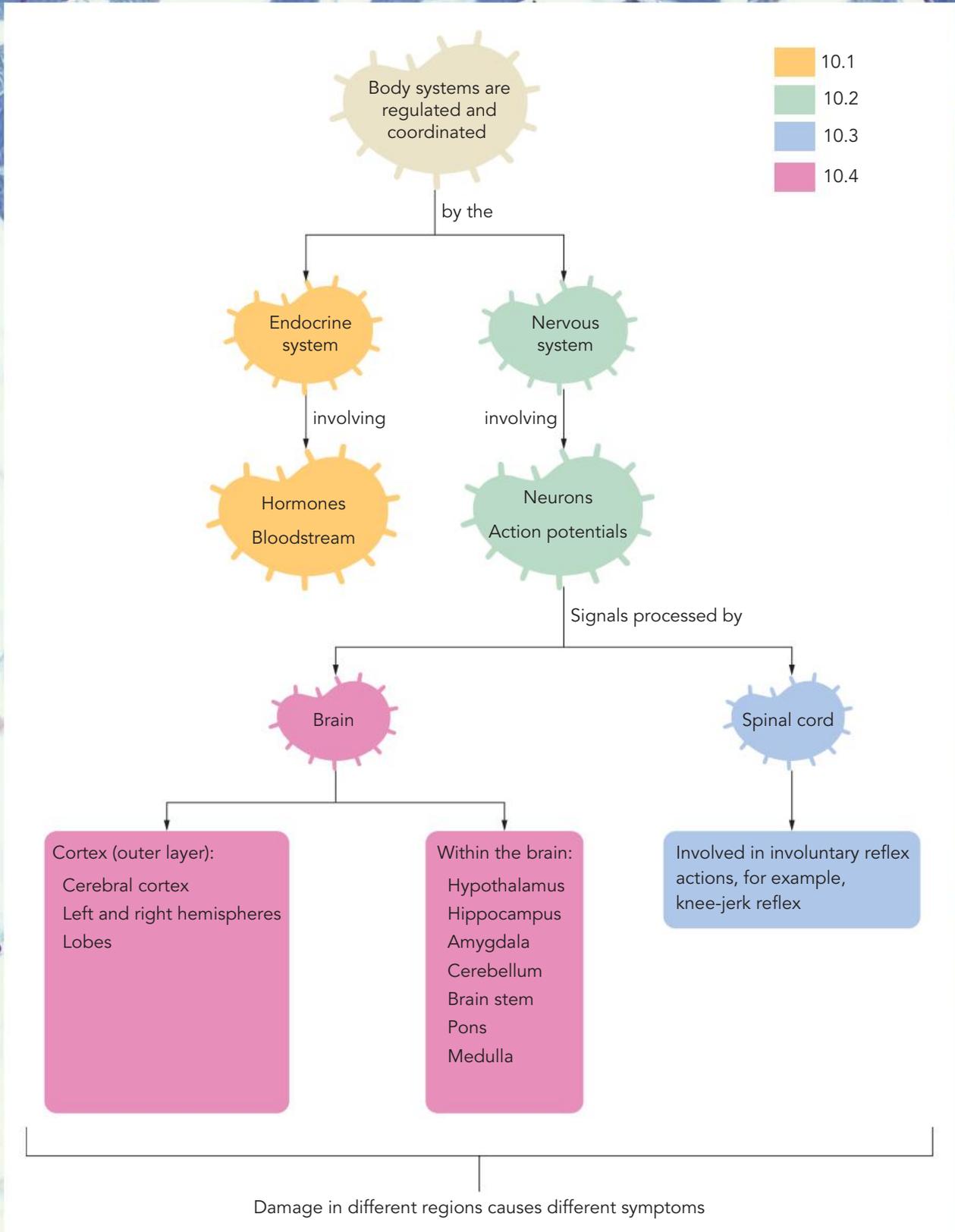
PRE-TEST

### Chapter introduction

The brain is the master organ that controls the actions of nerves within the nervous system. It is also involved in the regulation of hormones within the endocrine system. Any thought, feeling or behaviour that you experience or undertake on a daily basis is ultimately controlled by the brain. You will begin by looking at how the brain provides a critical link between the nervous and endocrine systems. Then you will look in depth at the structure and function of the human nervous system.



# Chapter map



# 10.1 Keeping control

## Learning goals

- 1 To describe the structure of the nervous system
- 2 To describe the structure of the endocrine system
- 3 To distinguish between messages sent electrically vs chemically

The brain controls most bodily functions by communicating with different parts of the body every

second of every day. It does this in two ways: by sending electrical signals and neurotransmitters via the nervous system and by sending and receiving chemical messengers (hormones) via the endocrine system.

spelled 'neurones'). A **neuron** is essentially an individual nerve cell. Networks of these neurons allow signals to move between the brain and other parts of the body, and make up what is known as the **nervous system**.

The human nervous system is composed of two main parts: the central nervous system (CNS), which includes the brain and spinal cord, and the peripheral nervous system (PNS), which is all of the neurons and nerve networks throughout the body that lie outside the CNS. The PNS is further divided into two functional parts: the **somatic nervous system**, which controls the voluntary movement of muscles and the **autonomic nervous system**, which controls involuntary body functions, such as digestion, lacrimation (making tears) and salivation.

**neuron**  
an individual nerve cell

**nervous system**  
consists of the brain, spinal cord and peripheral nerves and receptors that communicate fast messages within the body

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

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

## The nervous system

The basic building blocks of the nervous system are our neurons (less commonly

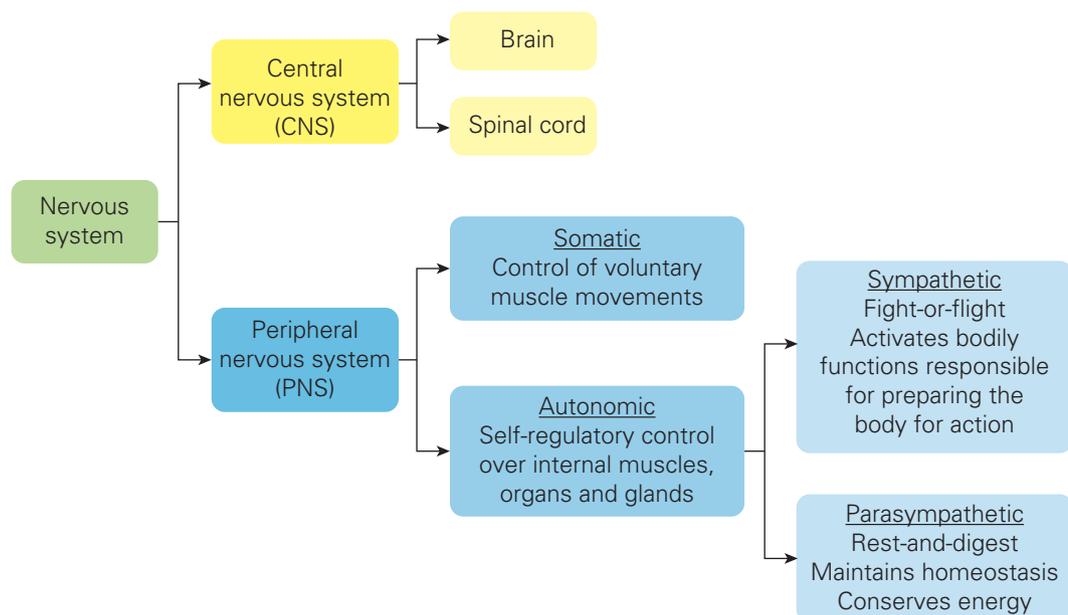


Figure 10.1 The components of the human nervous system

## Quick check 10.1

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



## The endocrine system

The **endocrine system** uses glands located throughout the body which secrete **hormones** that regulate a variety of bodily processes, such as metabolism, digestion, blood pressure and growth.

While the endocrine system is not directly linked to the nervous system, the two interact in many ways. Some of the most important endocrine glands are found within the brain; these include the pineal gland, the hypothalamus and the pituitary gland.

Located at the base of the forebrain is a tiny collection of neurons known as the hypothalamus. The hypothalamus

links the nervous and endocrine systems. It is responsible for regulating an astonishing number of behaviours, such as sleep, hunger, thirst, sexual behaviour, and emotional and stress responses.

The hypothalamus also controls the pituitary gland and the release of several different hormones.

Other important glands found throughout the body include the thyroid, thymus and adrenal glands, and the pancreas, ovaries and testes. These glands are involved in regulating our metabolism, fight-or-flight responses and reproductive processes.

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

**hormone**  
a chemical messenger that is secreted by endocrine glands and circulated in the bloodstream to act on a target cell

**target cell**  
a cell affected by a specific hormone

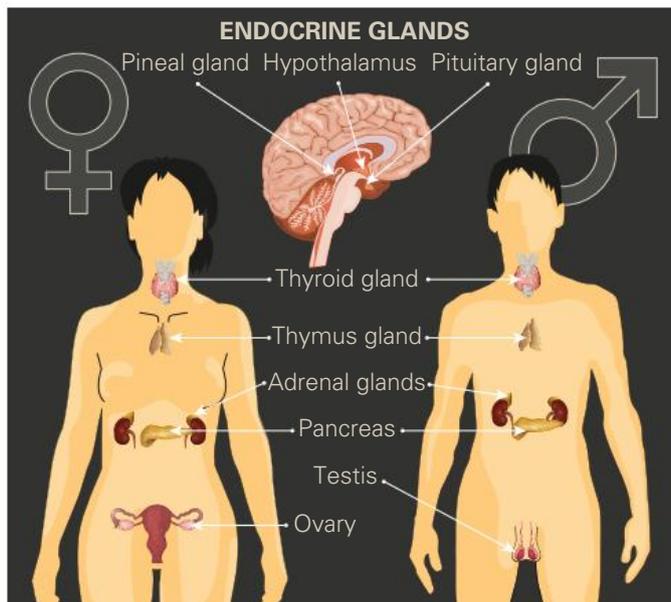


Figure 10.2 Endocrine glands in the female and male body

## Hormones

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

Organisms are coordinated by many hormones and small amounts of these chemicals can have major effects. Table 10.1 shows where hormones are produced and what effect they have on the human body.

Organ	Hormone	Action of hormone
Pancreas	Insulin	Decreases blood glucose levels by increasing the uptake of glucose by cells and causing the conversion of excess glucose to glycogen in liver and muscle cells
	Glucagon	Increases blood glucose levels by stimulating processes to convert the stored glycogen back into glucose which is released into the bloodstream
Adrenal gland	Adrenaline	Secreted at moments of fear, stress or excitement, and has the effect of increasing the heart rate, constricting blood vessels close to skin, dilating blood vessels to some muscles, raising blood pressure and causing a rise in blood sugar. All these factors make the person ready for physical action during the fight-or-flight process.
Kidneys	Erythropoietin	Promotes the production of red blood cells by the bone marrow
Pituitary gland	Growth hormone (GH), antidiuretic hormone (ADH) and others	GH stimulates cell division, growth and repair of the body, and ADH regulates the amount of water in the blood.
Pineal gland	Melatonin	Responsible for regulating sleep patterns as it induces sleep. Melatonin is secreted in dark conditions and ceases to be released under light.
Hypothalamus	Various hormones	Sometimes referred to as the 'master switchboard', the hypothalamus is part of the brain and is the main control for the endocrine system. It operates with the pituitary gland (the 'master gland') as well as via neurons to other glands.
Testes	Testosterone	Promotes growth of bone, development of muscle, growth of facial hair and deepening of the voice in males during puberty
Ovaries	Oestrogen	Promotes development of breasts and hair and changes the shape of the hip bones in females during puberty
Thyroid	Various thyroid hormones, including thyroxine	Controls the body's rate of energy production and metabolism, and controls how sensitive the body is to other hormones
Parathyroid gland	Parathyroid hormone	Controls the amount of calcium in the blood and bones
Thymus	Thymosin	Stimulates the development of T cells that play an important role in the maintenance of a healthy immune system

**Table 10.1** Endocrine glands, their hormones and actions

### Explore! 10.1

#### Endocrine-disrupting chemicals in plastics

How can the rising rates of cancer and metabolic conditions such as diabetes be explained? What about declining fertility rates? Well, one hypothesis is that exposure to endocrine-disrupting chemicals are affecting our body functions. The scientific research behind this hypothesis has mainly come from rat and mice studies, but some scientists believe it holds true for humans too. Endocrine-disrupting chemicals are commonly found in plastics and many other everyday household products, so what are the safe levels of exposure? Research the following questions.

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

### Quick check 10.2

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

## Two systems working together

As discussed in Chapter 9, the body maintains a relatively constant internal environment through a process called **homeostasis**. Homeostasis is maintained by the endocrine and nervous systems working together. They use chemical messengers and electrical impulses to communicate with cells and glands, but the speed of message transmission and the length of the effects differ between the

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

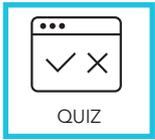
**homeostasis**  
the maintenance of a relatively stable internal body environment, despite changes in the external environment

The key differences between the features of the endocrine and nervous systems are shown in Table 10.2.

Feature	Nervous system	Endocrine system
Signals	Electrical and chemical messengers (via electrical impulses and neurotransmitters)	Chemical messengers (hormones)
Pathway	Transmission by neurons in the nervous system	Transported in the bloodstream (circulatory system) and lymph (lymphatic system)
Speed of information transfer	Fast	Comparatively slow
Duration of effect	Short-lived	Typically longer-lasting
Type of action and response	Voluntary or involuntary	Involuntary
Target cells	Adjacent cells	Often distant (many cells may be affected)
Example of action	Your friend throws a ball at you. Your sense organs detect the visual stimulus and the message is transmitted via neurons to your brain. Further messages are then sent down the spinal cord and via motor neurons and your skeletal muscles are stimulated to contract. As a result, you reach out and catch the ball.	When a male reaches puberty, the pituitary gland secretes a hormone called luteinising hormone. This acts on the testes and stimulates them to release testosterone. As the amount of testosterone builds up in his system, it triggers sperm production, muscle development, hair growth and changes to his voice.

**Table 10.2** A comparison of the nervous and endocrine systems

## Section 10.1 questions

**Remembering**

- 1 **Identify** the basic building block of the human nervous system.
- 2 **Name** two endocrine glands found within the brain.

**Understanding**

- 3 **Outline** how hormones reach their target cells.
- 4 **Explain** the difference in speed of the transmission within the nervous and endocrine systems.

**Applying**

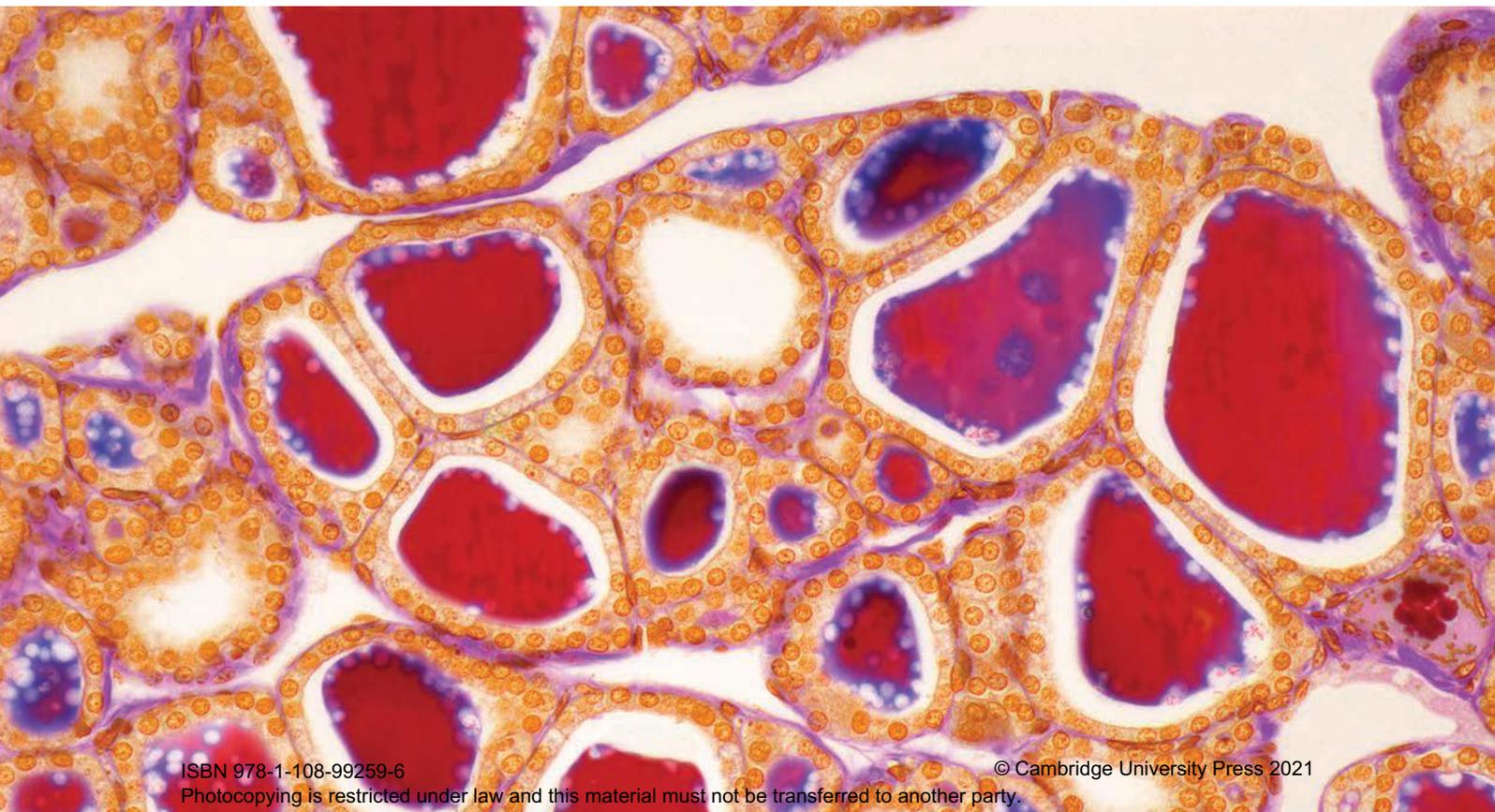
- 5 **Identify** the similarities and differences between the nervous and endocrine system. You may choose to **construct** a Venn diagram to display the information.

**Analysing**

- 6 **Compare** the somatic and autonomic divisions of the nervous system. How are they similar and how are they different?
- 7 **Classify** the following events as being under somatic or autonomic control:
  - a sweating
  - b walking
  - c pulling your hand away from a flame
  - d contractions of intestine to move food along.

**Evaluating**

- 8 The contraceptive pill contains a chemical which acts like the hormone oestrogen. It attempts to stop sperm reaching an egg in several ways, including:
  - suppressing ovulation so an egg is not released from the ovaries
  - making the cervical mucus thicker and hence more difficult for sperm to reach an egg
  - decreasing the thickness of the lining of the womb so it is not thick enough to allow an egg to attach to it.**Deduce** some reasons why the pill is *not* guaranteed to work 100% of the time.



# 10.2 Neurons and the nervous system

## Learning goals

- 1 To understand the roles of different kinds of neurons
- 2 To describe the stages of electrical signal transmission in neurons

## Types of neurons

The brain and nervous system are made of approximately 100 billion specialised nerve cells, known as neurons. Neurons transmit signals (neural information) within the nervous system. There are three types of neurons.

- **Sensory neurons** transmit neural information from receptors to the CNS. The sensory information being transmitted could be from any of your five senses.
- **Interneurons** (also called relay neurons) transmit neural information within the spinal cord and brain. Interneurons connect the sensory and motor

neurons and can only be found in the CNS.

- **Motor neurons** transmit neural information from the CNS to the PNS. This information is designed to initiate a response in the effector, which could be a muscle or gland.

To help remember the three types of neurons, think of a SIM (Sensory, Inter, Motor) card from a mobile phone.



### sensory neuron

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

### interneuron

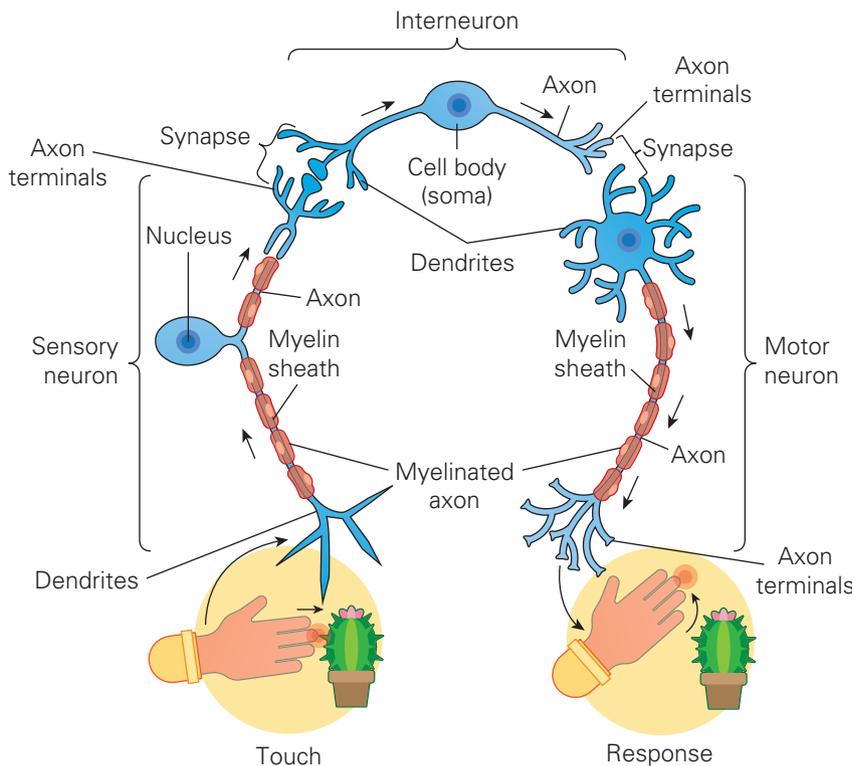
a nerve cell that transmits information within the brain and spinal cord (central nervous system)

### motor neuron

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

### synapse

the junction between two neurons



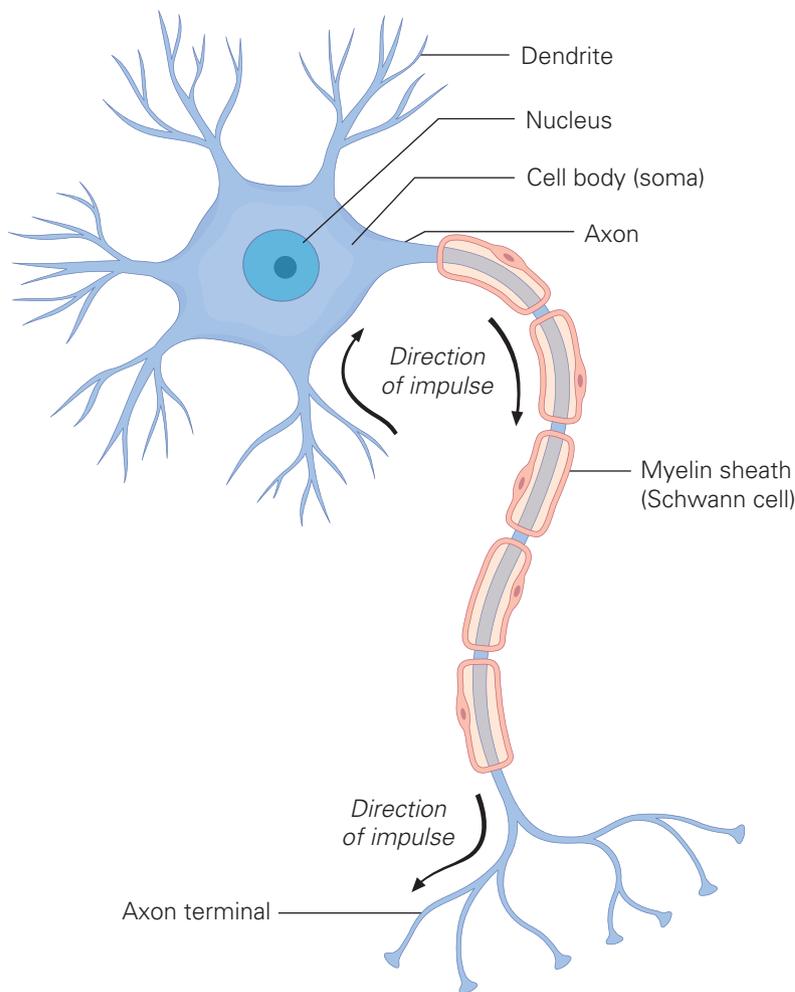
**Figure 10.3** The three types of neuron (sensory, inter and motor) form an arc. Note how the sensory neuron has receptors to detect a stimulus and the motor neuron causes your response.

## Structures of a neuron

The key structures of the neuron include the dendrites, cell body (soma), axon, myelin sheath, axon terminals and the **synapse**. The synapse is not a true structure – it is the junction between neurons. The synapse includes the axon terminal (of the sending neuron), the gap between the neurons (synaptic cleft) and the dendrite (of the receiving neuron).

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

Table 10.3 Structures of the neuron



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

**Figure 10.4** The key structures of a motor neuron showing the neural impulse travelling in one direction only along the neuron, from the dendrites to the axon terminals

### Quick check 10.3

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

### Practical 10.1

#### Making model neurons

##### Aim

To create and evaluate a model of a neuron.

##### Planning

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

##### Materials

- A piece of A3 paper
- A selection of materials to make the model neurons (suggestions include pipe cleaners, aluminium foil, pom-poms, straws, modelling clay/plasticine or similar).

##### Suggested procedure

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

##### Discussion

- 1 Identify three structures of a neuron in your model and relate their biological structure to the material that you chose to represent them in your model.
- 2 Suggest any changes or improvements that could be made to your model. Justify your suggestions by explaining how each change will improve the quality of the model.
- 3 List three benefits and three limitations of your model.
- 4 Evaluate the usefulness of your model in helping you understand the structure and function of a nerve cell.

##### Conclusion

Draw a conclusion about the effectiveness of using models in science. Include previously mentioned benefits and limitations in your response.

## Communication within and between neurons

### Communication within: action potential

An **action potential** is another name for the electrical impulse (neural impulse) that moves along a neuron. It travels only the length of the neuron, and once the action potential reaches the axon terminal, it relies on a chemical messenger (neurotransmitter) to pass the action potential on to the next neuron.

The speed of an action potential moving along an axon varies between neurons.

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

The fastest travel over 100 metres per second, with the slowest travelling at about 1 metre per second. The speed depends upon two factors: the diameter (width) of the axon (the larger the diameter, the faster the impulse) and whether the axon has a myelin sheath (an action potential travels faster down an axon with a myelin sheath).

### Explore! 10.2

#### Multiple sclerosis (MS)

Multiple sclerosis is a degenerative neurological condition characterised by the development of *scleroses* (Greek for 'scars') on neurons of the central nervous system. These scars result in damage to the myelin sheaths, which insulate the neurons, so the neurons do not transmit messages effectively. This can lead to a variety of symptoms, such as problems with motor (muscle) control, visual problems if the damage occurs in the optic nerves, problems with coordination and balance, and memory loss. Research multiple sclerosis and answer the following questions.

- 1 Identify which of the following neurons can be affected: interneurons in the brain, motor neurons, interneurons in the spinal cord, or sensory neurons. Describe how each identified neuron is affected.
- 2 Outline treatments that exist for multiple sclerosis.

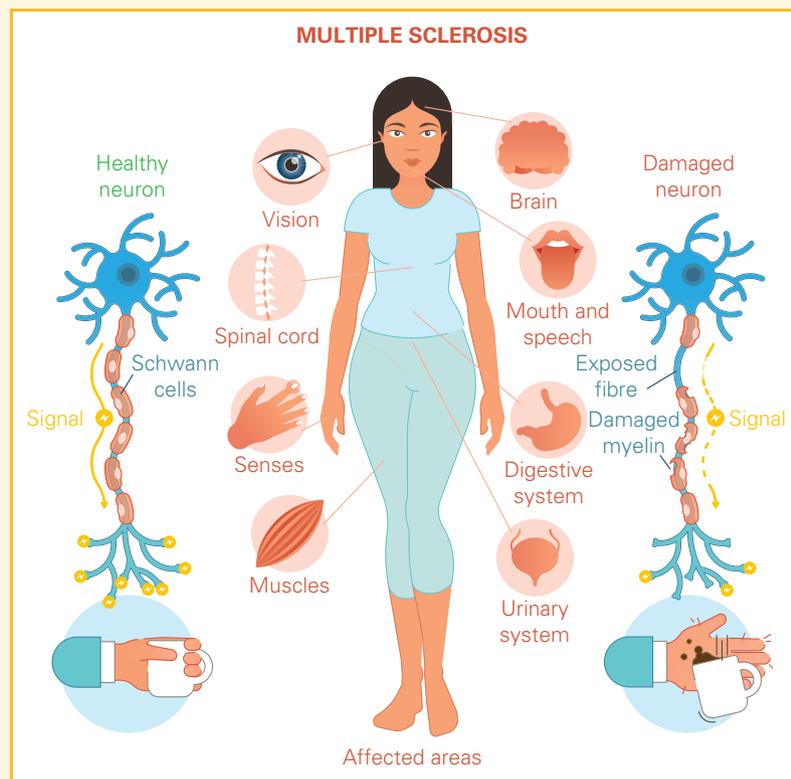
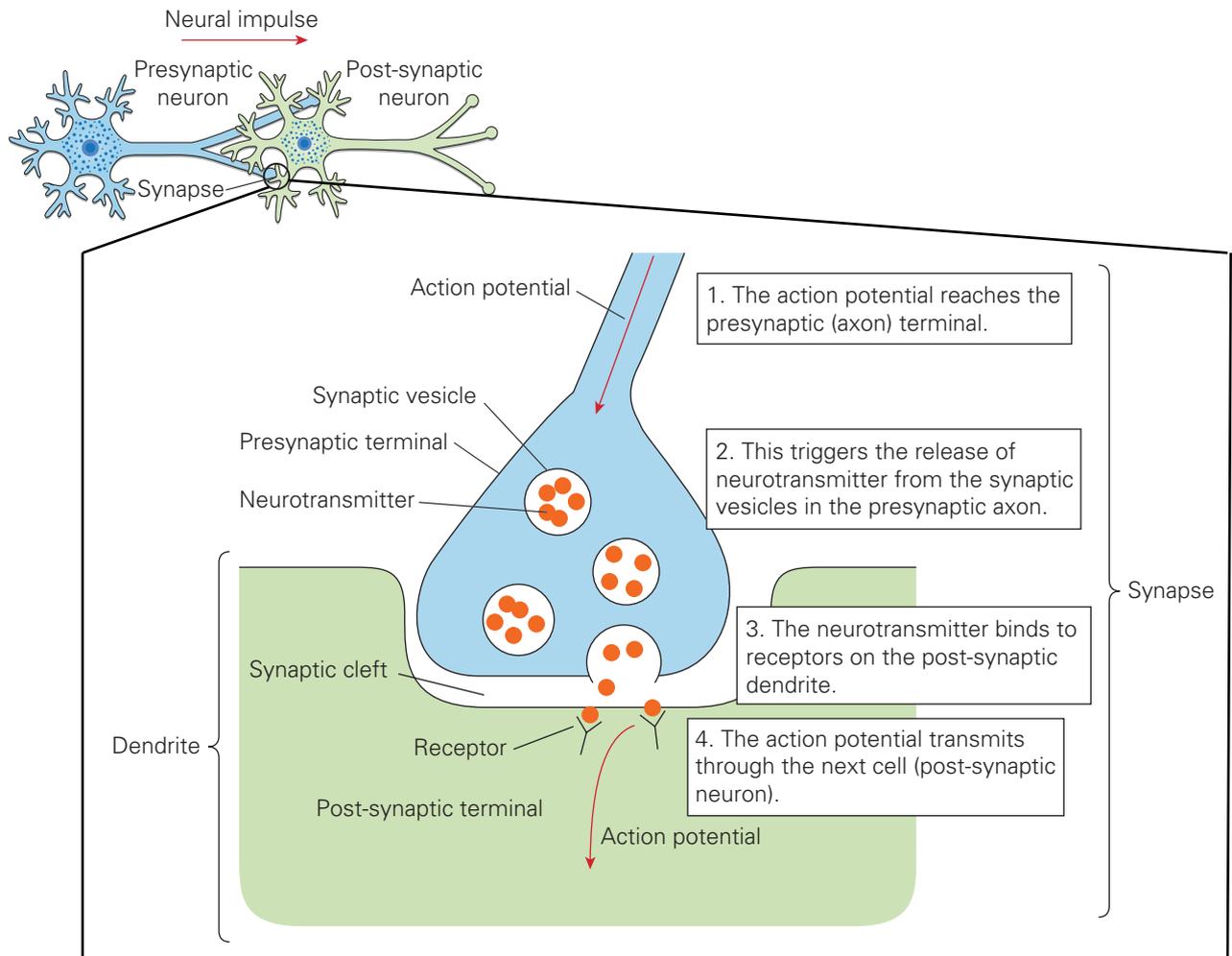


Figure 10.5 Multiple sclerosis affects many areas of the body.

### Communication between neurons: the synapse

When neurons communicate with each other, the action potential travelling down the axon causes neurotransmitters to be released from synaptic vesicles within the axon terminal. This part of the synapse is known as the presynaptic terminal. The specialised chemical messengers then move across the gap between neurons (the synaptic cleft).

Once the neurotransmitters cross the synaptic cleft, they bind to special receptor sites on the dendrite of the next neuron – called the post-synaptic terminal. The receptor sites convert the information back into electrical signals which are then transmitted to the cell body of the post-synaptic neuron and along the axon. This process continues until the last neuron in the pathway connects to a muscle or gland, causing a response. This process is shown in Figure 10.6.



**Figure 10.6** Communication between neurons involves the action potential triggering the release of neurotransmitters from their synaptic vesicles in the presynaptic neuron, which then cross the gap and bind to receptors on the post-synaptic neuron.

**Quick check 10.4**

- 1 State if an action potential is a signal between two neurons, along a neuron or along an axon.
- 2 Define the term 'neurotransmitter' in your own words.
- 3 Describe the role of the post-synaptic neuron.
- 4 Organise these stages of the flow chart in the correct order, showing how an action potential passes from one neuron to another.

Action potential stimulates synaptic vesicles to release neurotransmitters	Action potential initiated	Neurotransmitters released into synaptic cleft	Action potential travels along the presynaptic neuron's axon	Neurotransmitters bind to receptor sites on post-synaptic neuron's dendrites
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The human body produces many different types of neurotransmitters and each neurotransmitter has a specific role to play in the functioning of the brain.

The way they can do this is by only binding to specific receptor sites. A neurotransmitter binds to a receptor in much the same way that a key fits into a lock.

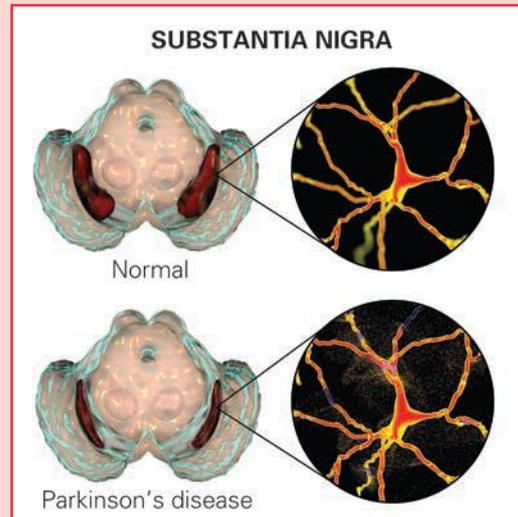
### Advances in science 10.1

#### Parkinson's disease

Neurodegenerative disease is an umbrella term for a range of conditions that primarily affect the neurons in the human brain. Examples of neurodegenerative diseases include Parkinson's disease, Alzheimer's disease and multiple sclerosis.

Parkinson's disease is a progressive, degenerative neurological condition that affects a person's control of their body movements, resulting in motor and non-motor symptoms. Parkinson's disease results from the loss of cells in various parts of the brain, including a region called the substantia nigra. This is a part of the brain where the production of the neurotransmitter dopamine is very common. When dopamine production is depleted, the motor system nerves are unable to control movement and coordination. The dopamine-producing cells are lost over a period of years resulting in the appearance of motor symptoms, such as tremors and rigidity.

Currently, there is no known cure for Parkinson's disease, but motor symptoms may be relieved by medications that increase the level of dopamine or mimic dopamine in the brain. The future of diagnosis and treatment of neurodegenerative disease depends upon technological advances in brain imaging and diagnostic tools. For example, a British company has recently produced a special pen, called a NeuroMotor Pen, that can help diagnose nerve disorders such as Parkinson's disease. The pen is connected to a tablet on which patients complete several handwriting and drawing tasks. Any abnormalities are quickly detected and can be used as 'digital biomarkers' to monitor patient progress. A number of low-cost wearable sensors and mobile phone applications have been developed that allow the symptoms of the patient to be continuously detected and quantified. The information can then be sent to a hospital to generate a daily report that will alert the doctor if there is any unusual data.



**Figure 10.7** Computer illustration showing a healthy substantia nigra (top) and degenerated substantia nigra (bottom) of human brains.

### Explore! 10.3

#### Parkinson's disease

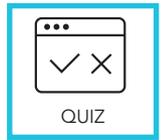
Research one of the following topics. Summarise your findings by explaining how technologies have improved knowledge and understanding of Parkinson's disease, or have helped people with Parkinson's live better lives.

- An imaging technique that allows us to identify and learn about Parkinson's disease (for example, PET scans or DaT/SPECT imaging)  
OR
- A technology developed to aid people with Parkinson's disease to have a better quality of life (for example, the wearable sensor networks mentioned above; MagnaReady's line of men's and women's shirts with magnetic buttons; MouseCage's Steady Mouse)

## Section 10.2 questions

## Remembering

- 1 List the three different types of neurons found within the human nervous system.
- 2 Draw a motor neuron and label all the key structures.
- 3 Identify the function of dendrites.



## Understanding

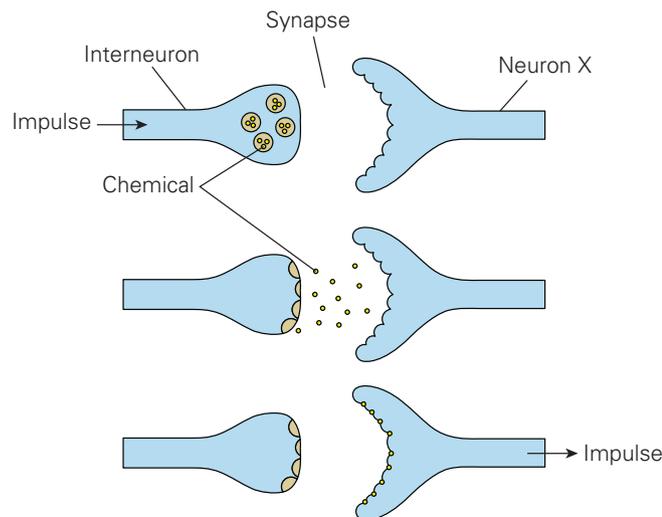
- 4 Describe how the function of the motor neuron and sensory neuron differ.
- 5 Describe the synapse.
- 6 List the steps involved in neurotransmission across a synapse.

## Applying

- 7 Using the 'lock-and-key' analogy, explain how neurotransmitters work across the synapse.
- 8 If a drug blocks the receptor sites, explain the effect it could have on neurotransmission across the synapse.

## Analysing

- 9 Caffeine is known to increase alertness levels. You usually feel tired when the neurotransmitter adenosine is released. Discuss how caffeine may affect the neurotransmitter adenosine.
- 10 Dopamine is a neurotransmitter that is involved in making us feel good. Caffeine works by slowing down the rate of dopamine leaving the brain to your body, while at the same time not affecting the rate at which it is released into your brain. This leads to an increased level of dopamine in the brain for a short time. Deduce how this might affect your feelings and behaviour.
- 11 The figure below shows how an impulse moving along an interneuron causes an impulse to be sent along another type of neuron, neuron X.



- a Identify what type of neuron is neuron X.
- b Describe how information passes from the interneuron to neuron X. Use the diagram to help you.

## Evaluating

- 12 Compare and contrast the structure of a neuron with the structure and function of a goblet cell (secretes protective mucous and can be found in the intestinal wall). What can you conclude about how a cell's structure relates to its function?

## 10.3 The spinal cord

### Learning goals

- 1 To explain why reflexes are important for animal survival
- 2 To define a reflex arc
- 3 To describe the sequence of events in the stimulus–response model as a result of a stimulus
- 4 To relate the location of damage to the spinal cord to the severity of the resulting injury



### Reflex actions

A **reflex action**, or spinal reflex, is a quick, automatic and involuntary action that protects the body from danger. Sometimes

#### reflex action

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

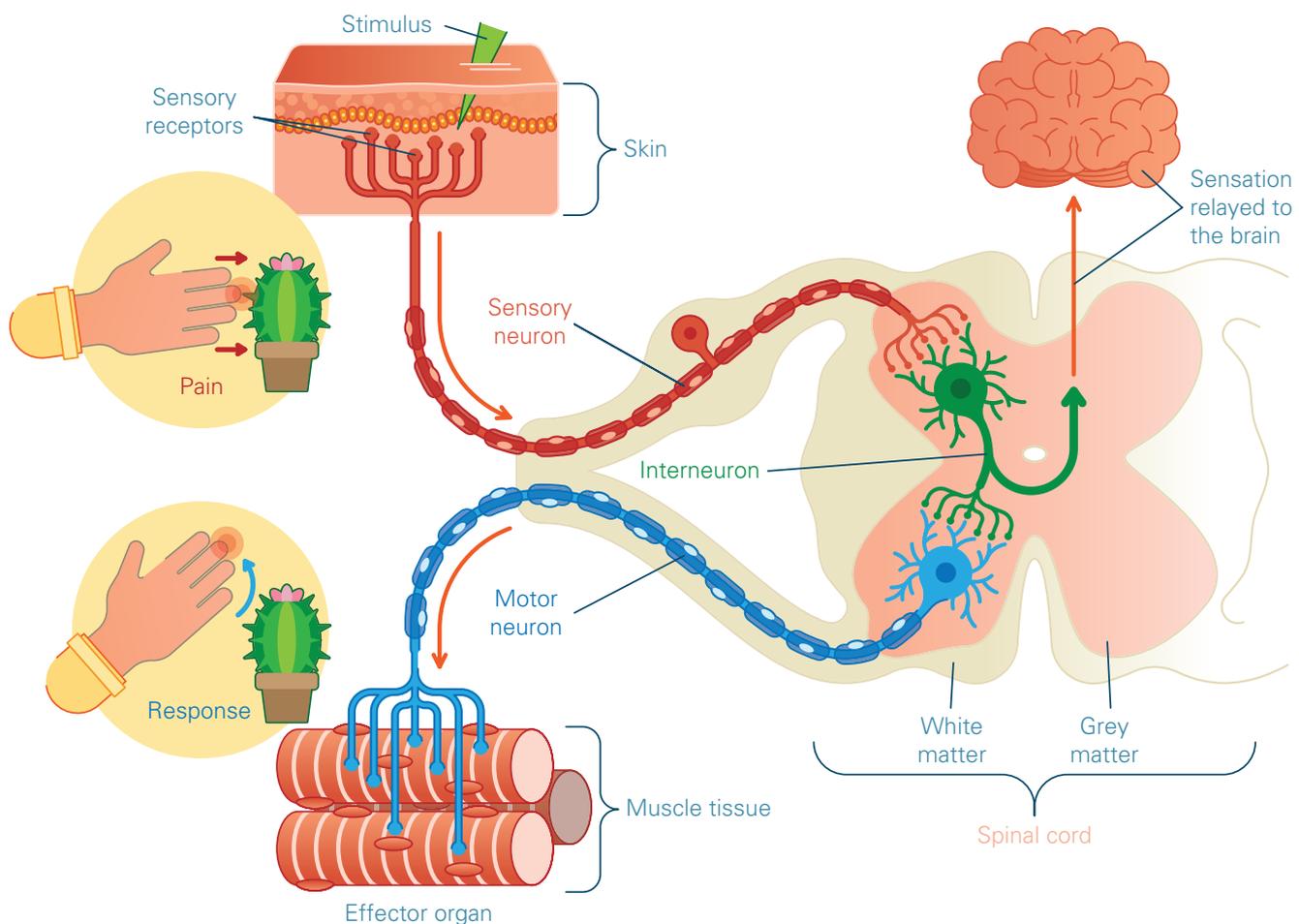
#### reflex arc

the pathway that the signal travels during a reflex action

it is necessary for the body to react very fast, without waiting for instructions from the brain. In these cases, the spinal cord is primarily responsible for

responding to the stimulus and initiating a response. A message will be sent to the brain, but not until shortly afterwards – the brain actually registers the stimulus and the response *after* the response has occurred.

A reflex action therefore involves no more than three neurons. The signal travels to the spinal cord and back to the muscle, which contracts quickly. This can also be called a **reflex arc**. Figure 10.8 shows an example of a reflex arc.



**Figure 10.8** An example of a reflex arc. You touch a pointy cactus with your finger, and a receptor in a sensory neuron detects the pain and initiates an action potential. The impulse is carried to the spinal cord where the sensory neuron connects to an interneuron. The interneuron then connects to a motor neuron that sends an action potential through to the muscle tissue. Your muscles contract and you move your hand away from the sharp cactus.

**stimulus–response model**  
the process of detecting and responding to a stimulus

When a receptor detects a stimulus which results in an effector eliciting a response, the process is called the **stimulus–response model**.

### The knee-jerk reflex

A common reflex action is known as the ‘knee-jerk’ reflex. To test your knee-jerk reflex, a medical professional taps a reflex hammer on the quadriceps tendon below your kneecap. This tendon connects to the quadriceps muscle on top of your thigh. The tap of the hammer causes a slight stretch within the quadriceps muscle.

This stretch is detected by receptors in the muscle, which send a message to the muscle. Interestingly, the knee-jerk reflex is monosynaptic, meaning no interneurons are involved. Instead, the sensory neuron communicates directly across a synapse to a motor neuron in the spinal cord. The motor neurons conduct the impulse right back to the quadriceps, triggering a muscle contraction that makes you kick. The kick tells the medical professional that a particular section of the spinal cord and the associated nerves are working properly.



## Practical 10.2

### Testing your reflexes and response times

#### Background information

Reaction time is a measure of how quickly a person responds to a stimulus. Many factors can affect reaction time, including age, gender, practice, blood sugar, alcohol, caffeine and general fitness. You will design your own investigation to explore the effect of how long you practise on reaction time.

#### Aim

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

#### Planning

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

#### Materials

- stopwatch
- ruler
- well-lit room

#### Procedure

Do not practise the experiment before starting to collect the results. You should start measuring immediately to ensure that the effect of practice time can be determined.

- 1 Have your partner lean their forearm on a bench with their weakest hand extending over the edge. If they are left-handed, they should use their right hand and vice versa. Ask them to make a **pincer grip** with a gap of 2 cm between their thumb and index finger.
- 2 Dangle the ruler above their hand so that the end marked 0 cm is hanging between their thumb and index finger.
- 3 Instruct them to catch the ruler with their thumb and index finger when they notice you have released it.
- 4 Release the ruler without warning.
- 5 Take note of the measurement on the ruler where they have caught it. This is the number of centimetres that the ruler fell before the person responded. Use the conversion table to determine the reaction time.

**pincer grip**  
a grasp that uses the pads then tips of the index finger and thumb to pick up and grasp objects

*continued...*

...continued

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

- 6 Each person should complete the drop test 15 times. Record the ruler reading and reaction time for each test.

### Results

Create a results table for this experiment.

### Data processing

Draw a graph of drop test number against reaction time.

### Discussion

- 1 Identify any patterns, trends or relationships in your results.
- 2 The ruler drop experiment is not really testing a reflex. Draw a stimulus–response flow chart, highlighting the part that proves this is not a simple reflex. Explain why this is the case.
- 3 Compare your results with other people in your class. Do students who play particular sports or musical instruments have faster reaction times?
- 4 Identify any potential sources of error in this experiment.
- 5 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

### Conclusion

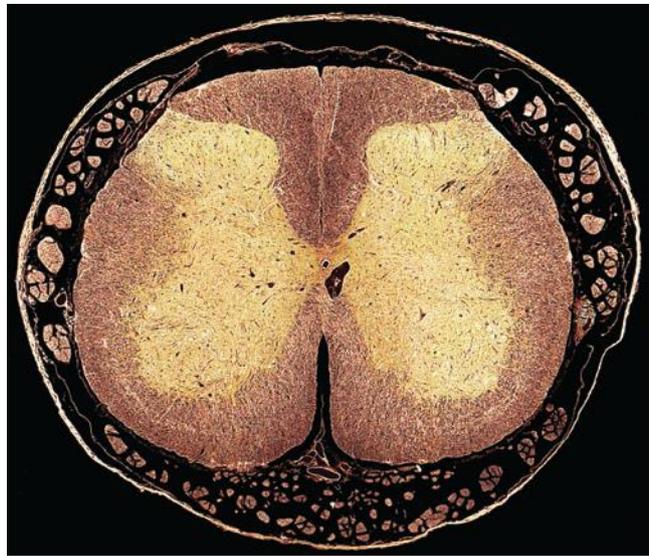
Draw a conclusion from this experiment regarding practice time and reaction time. Justify your answer with data.

**Quick check 10.5**

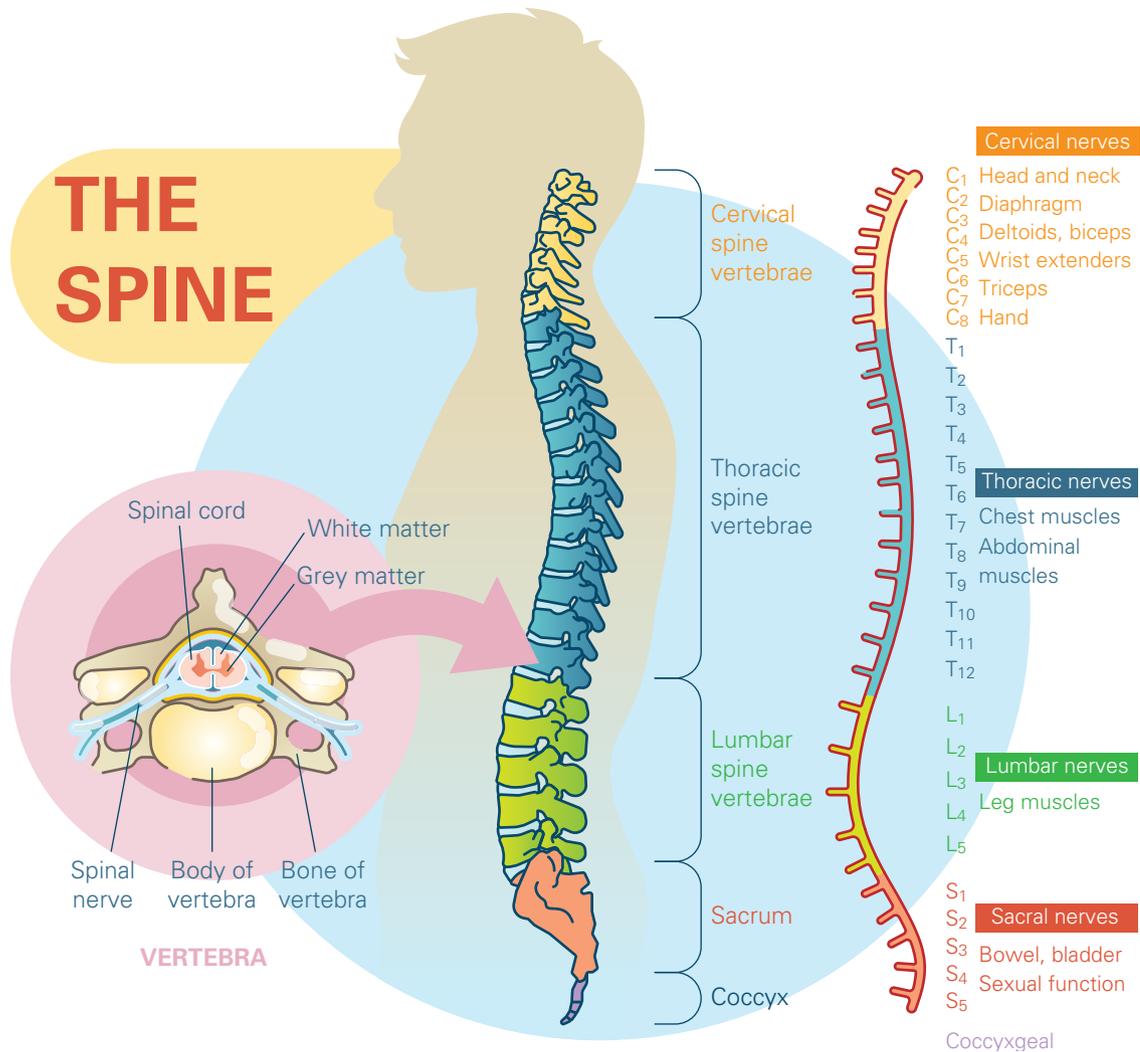
- 1 State if the following sentence is true or false: 'The brain is not immediately involved in a reflex arc.'
- 2 Illustrate, using a diagram, a reflex arc for a person touching a flame.
- 3 Compare the reflex arc and stimulus-response models of the nervous system.

**Causes and effects of spinal cord damage**

The spinal cord is a bundle of nerves that carries messages between the brain and the rest of the body. It contains both white matter and grey matter, as shown in Figure 10.9.



**Figure 10.9** Light micrograph (LM) of a cross-section through the human spinal cord in the lumbar region. The spinal cord consists of a butterfly-shaped core (yellow) known as grey matter, which consists of soma, dendrites and axon terminals, so it's where the synapses are also found. Surrounding the grey matter is a larger region of white matter, made up of myelinated axons that connect different parts of the grey matter.



**Figure 10.10** The spine is divided into sections – cervical spine, thoracic spine, lumbar spine, sacrum and coccyx – and the spinal cord is protected and supported by the vertebra.

Classification	Description
Quadriplegia ('quad' means four)	Four limbs affected by impaired sensation and movement. If spinal injury is high up the spine, then chest muscles, such as the diaphragm, can also be affected
Paraplegia	Lower limbs affected by impaired sensation and movement
Triplegia ('tri' means three)	Rare incomplete spinal cord injury leads to three limbs affected by impaired sensation and movement

**Table 10.4** Classification of spinal cord injuries

The spine consists of 33 vertebrae:

- 7 cervical (neck, C1 to C7)
- 12 thoracic (upper back, T1 to T12)
- 5 lumbar (lower back, L1 to L5)
- 5 sacral (sacrum – located within the pelvis, S1 to S5)
- 4 coccygeal (coccyx – located within the pelvis).

By adulthood, the five sacral vertebrae fuse to form one bone (the sacrum), and the four coccygeal vertebrae fuse to form one bone (the coccyx).

Damage to the spine may result in spinal cord injuries. These may be caused by traumatic injuries including those from car crashes, sports or falls. Non-traumatic injuries, such as arthritis or degeneration of parts of the spine, may also cause spinal cord injuries.

If the spine is injured, the location of the damage determines the effects that the person suffers. Spinal cord damage is classified according to the person's type of loss of motor and sensory function. Table 10.4 describes the main categories of spinal cord injuries.

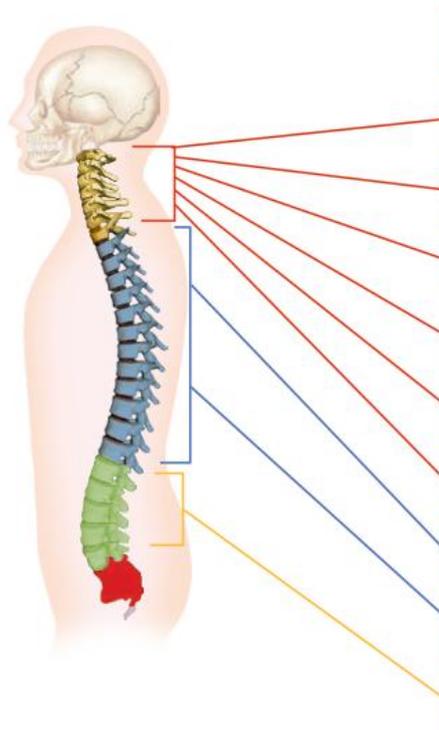
The types of symptoms experienced by a person with spinal cord injury depend upon the location and severity of the injury. They may include:

- muscle weakness or paralysis (including difficulty breathing if the diaphragm muscle is affected)
- sensory dysfunction such as loss of sensation or pins and needles
- sexual dysfunction
- digestive problems
- problems regulating heart rate and blood pressure
- loss of control over bowel and bladder function.

### Impairment and rehabilitation of spinal cord injuries

The position of the spinal cord injury will determine the extent of impairment symptoms and the potential for rehabilitation. Figure 10.11 shows the levels of spinal cord injury down the spine and the associated rehabilitation potential.





Level of injury	Possible impairment	Rehabilitation potential
C1 - C3	Unable to breathe, potentially fatal	Dependent on care
C4	Quadriplegia and breathing difficulty	Dependent on care, may need ventilator
C5	Quadriplegia with little shoulder and elbow function	May need some respiratory support. May be able to self-feed with assistive devices or technology
C6	Quadriplegia with shoulder, elbow, and some wrist function	May be able to use wheelchair, feed and dress self. Usually needs help with bowel and bladder
C7	Quadriplegia with shoulder, elbow, wrist, and some hand function	May be able to assist with bowel and bladder management
C8	Quadriplegia with normal arm function; hand weakness	May be able to drive a car with modifications and assist with bowel and bladder management
T1 - T6	Paraplegia with loss of function below mid-chest; full control of arms	Quite independent with wheelchair
T6 - T12	Paraplegia with loss of function below the waist; good control of torso	May be able to participate in athletic activities with wheelchair
L1 - L5	Paraplegia with varying degrees of muscle involvement in the legs	May be able to walk short distances with braces or other assistive devices

Figure 10.11 Spinal cord injury and the potential for rehabilitation

### Quick check 10.6

- 1 Name the different regions of the spine.
- 2 Define the terms 'quadriplegia' and 'paraplegia' in your own words.
- 3 State three ways a spinal cord injury might occur, including symptoms that might result from that injury.

### Practical 10.3

#### Garfish dissection – investigating the spinal cord

##### Aim

To observe the spinal cord of a garfish and how it is protected by the spine.

##### Materials

- garfish
- Petri dish
- forceps
- scalpel
- probe
- newspaper
- dissection microscope
- dissection board
- disposable gloves



Figure 10.12 A catch of silver garfish

*continued...*

...continued

### Procedure

- 1 Working in pairs, place a garfish on a clean board.
- 2 Using forceps and scalpel, carefully make an incision down the underbelly from pectoral fins to anus.
- 3 Remove guts if necessary.
- 4 Remove as much flesh surrounding the backbone as possible so it is 'clean'.
- 5 Place spine (backbone) onto a Petri dish.
- 6 Discard flesh (wrap in newspaper before placing in bin).
- 7 View the spine using the microscope, and make a sketch showing the individual vertebrae. Include a title, labels and magnification.
- 8 Once this first sketch is completed, remove the dish from under the microscope for the next part of the activity.

### Be careful

Scalpels are extremely sharp. Proper cutting technique should be demonstrated before student use. Never use the scalpel to cut towards any part of your body. Extreme care is required when handling the scalpel. User discretion is advised.

### Separating the spinal cord from the spine

- 9 Carefully try to separate the vertebrae from one another to try to locate and examine the spinal cord. If you are careful, you will be able to feel the resistance of the spinal cord. Do not rush this, as the spinal cord is very fine and will break easily.
- 10 Once you have a section of the spinal cord, place it (with the vertebrae, if still attached) under the microscope. Draw a sketch of the spinal cord. Include a title, labels and magnification.

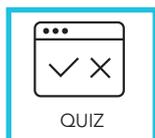
### Results

Record your observations and include your two sketches.

### Discussion

- 1 Comment on the appearance of the garfish's spine. Decide whether the spine provided sufficient protection for the spinal cord.
- 2 Differentiate between the appearance of the garfish's spinal cord and spine.
- 3 Discuss whether you expect fish to require a backbone as strong as a land creatures' backbone.

## Section 10.3 questions



### Remembering

- 1 A person suffers a spinal cord injury while surfing and loses motor control and sensation in their legs. **Identify** how this spinal cord injury would be classified.
- 2 **Define** the term 'reflex action' in your own words. Include its role in defending the body against damage.
- 3 **Name** an example of a reflex action.

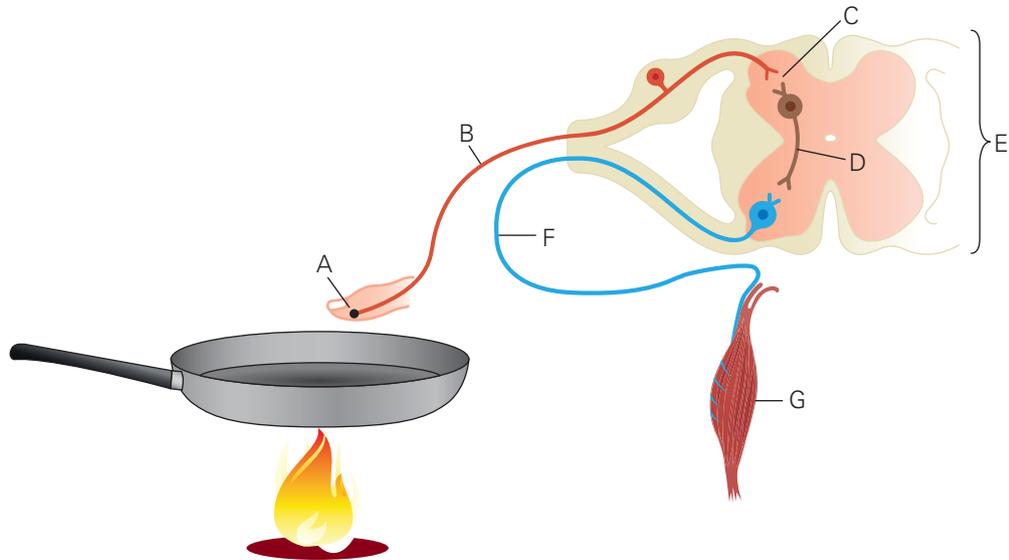
### Understanding

- 4 Extend your understanding of causes of spinal cord damage, by **listing** four different activities (perhaps activities you take part in) that could pose a potential risk.
- 5 **Discuss** how paraplegics differ from quadriplegics.
- 6 **Distinguish** between the stimulus and the response in the knee-jerk reflex.

### Applying

- 7 Using the stimulus–response model, **construct** a flow chart showing the steps involved in the following scenario. Be sure to include these terms on your flow chart: stimulus, motor neuron, muscle, interneuron, sensory neuron, receptor. A person is standing in a crowd and hears someone call their name. They turn their head to look for who it might have been.

- 8 Sophia accidentally touches a hot pan and automatically snatches her hand away from it. The diagram shows the structures involved in this action.
- Label the diagram below.
  - Illustrate the stimulus–response model referring to the diagram below. You may choose to draw it as a flow chart.



- 9 **Construct** a hypothesis for this experiment: Ask a friend to stand on the other side of a glass window and look straight ahead. Throw a cotton wool ball at their eyes from a close distance (about 20 cm away). Did they blink? Describe the type of action you predict.
- 10 Imagine this: if you sneak up behind someone and make a sudden loud noise, they may respond by blinking, twitching, moving their head suddenly, screaming or throwing their hands up. Using your knowledge of reflexes, **discuss** whether their response is voluntary or not, and give some reasons why this reflex might be a helpful mechanism to have.

### Analysing

- 11 Joshua has been diagnosed with quadriplegia. **Infer** which part of his spinal cord is likely to have been damaged and suggest possible symptoms he might show.
- 12 Luke has damage to his spinal cord at L3. **Classify** his injury as paraplegia or quadriplegia.

### Evaluating

- 13 **Assess** the following sentences and change one word to make them true.
- A sensory neuron carries information from the central nervous system to the peripheral nervous system.
  - Involuntary responses to stimuli are often the most complex actions.
  - A spinal cord injury in the cervical region is likely to result in paraplegia.
- 14 A person picks up a very hot cup of coffee and immediately drops it, breaking the mug. **Draw** a flow chart, beginning at stimulus and ending in response. Highlight the section of the flow chart that demonstrates whether this is a reflex or a response that is coordinated by the brain.

## 10.4 The brain

### Learning goals

- 1 To state the function of the brain
- 2 To identify the parts of a brain and describe their functions
- 3 To predict how different brain injuries will affect a person
- 4 To understand the role of neuroplasticity in learning



### Cerebral cortex

The cerebrum is the largest part of the human brain. Its outer layer is called the **cerebral cortex**. It is only 2–3 millimetres (mm) thick, yet it contains three-quarters of the brain's neurons. The cerebrum is folded to increase cortical surface area, and amazingly, if you were able to unfold it, it would be the size of a pillow case!

The cerebral cortex is divided into two hemispheres (left and right) which each contains four lobes. The left and right hemispheres are connected by a thick band of nerve fibres called the **corpus callosum**.

### The hemispheres

Each of the left and right hemispheres is responsible for movement and sensation in the opposite side of the body. This is known as **contralateral organisation**.

Each hemisphere is also involved in specific functions; for example, the left side specialises in the ability to

formulate and understand language. Each hemisphere can specialise or exert greater control than the other in various functions. This is known as **hemispheric specialisation**. Yet it is a simplistic view of the two hemispheres, as with any activity both hemispheres are always active.

### The lobes

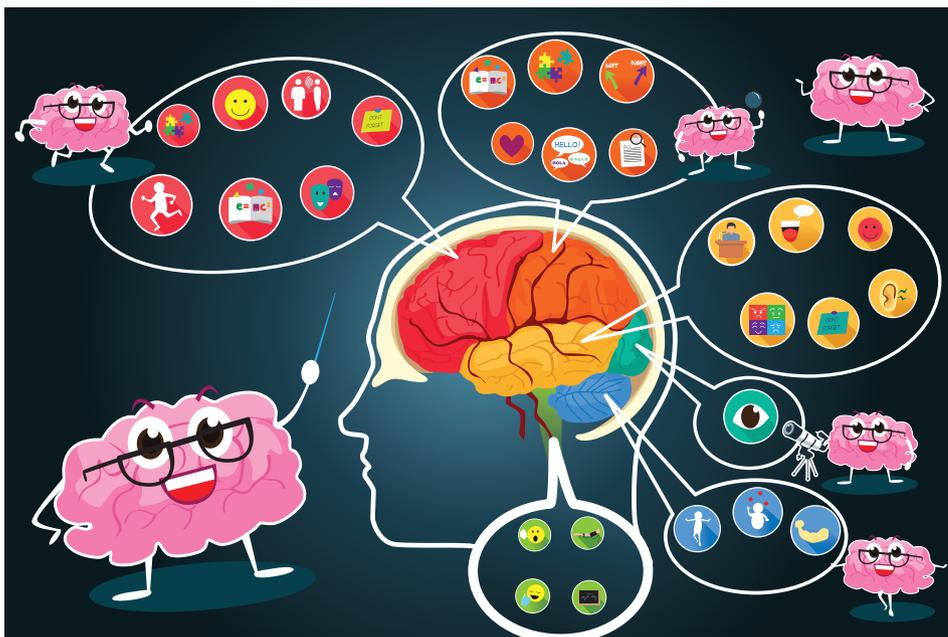
The cerebral cortex is responsible for many processes such as language, memory, learning, thinking, problem solving and personality traits. There are four lobes of the cerebral cortex on each side of the brain: the frontal lobe, the parietal lobe, the occipital lobe and the temporal lobe. They each have their own specialised functions as illustrated in Figure 10.13.

**cerebral cortex**  
outer layer of the brain

**corpus callosum**  
a bundle of nerve fibres connecting the left and right hemispheres of the brain

**contralateral organisation**  
each hemisphere of the brain is responsible for the motor function and sensation in the opposite side of the body

**hemispheric specialisation**  
each hemisphere of the brain can exert greater control over specific functions



**Figure 10.13** Specialised functions of the frontal (red), parietal (orange), occipital (green) and temporal (yellow) lobes of the brain, as well as the cerebellum (blue) and brain stem (light green), which are located below the cerebral cortex

### Quick check 10.7

- 1 Recall the names of the four lobes of the cerebral cortex.
- 2 Define the roles of the following areas:
  - a corpus callosum
  - b left and right hemispheres
  - c brain stem
  - d cerebellum
- 3 Propose the role of the primary visual cortex.

### Structures within the brain

There are other important brain structures involved with behaviour that are not found on the cortex (outer layer) of the brain, but within the brain, as shown in Figure 10.14.

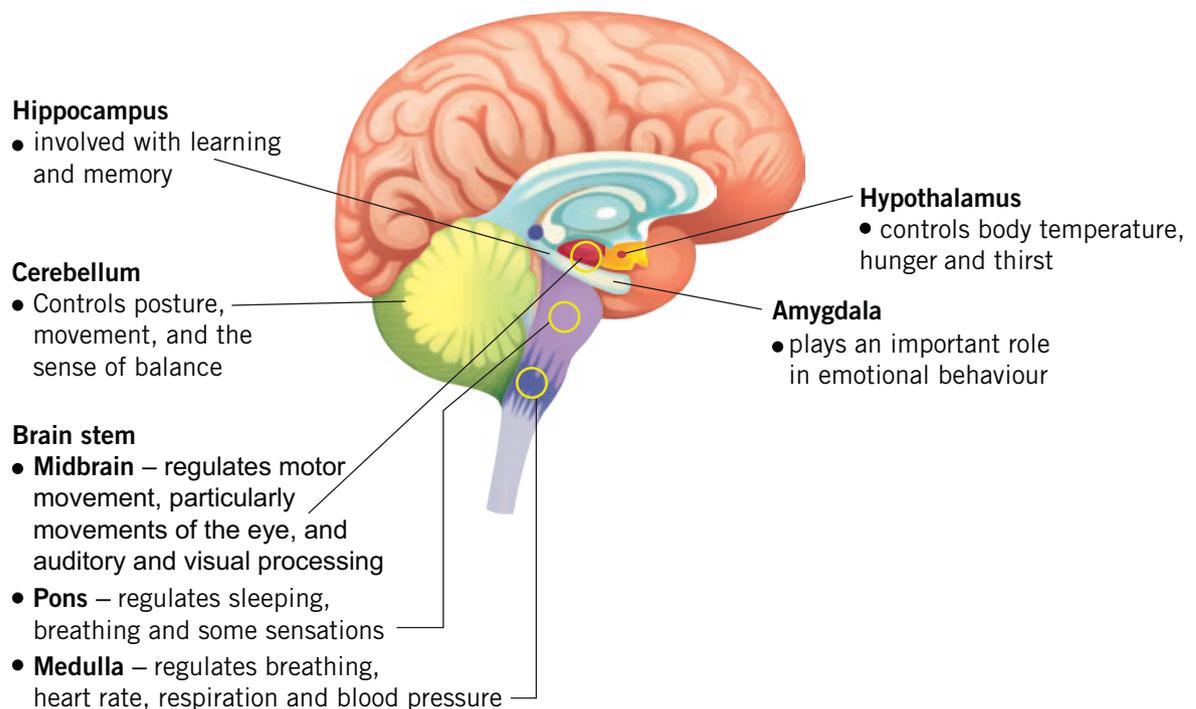


Figure 10.14 A diagram of the structure of the brain

### Practical 10.4

#### Does talking interfere with right-hand motor tasks?

Humans are the only animals that are predominantly right-handed. You don't believe me that right-handedness is more common. Do a quick survey in your class! The part of the brain responsible for speech and language is in the left hemisphere of the cerebral cortex. It is also known that the left and right hemispheres control the movement in the opposite sides of the body.

#### Aim

To investigate whether talking will interfere with a balancing (motor) task.

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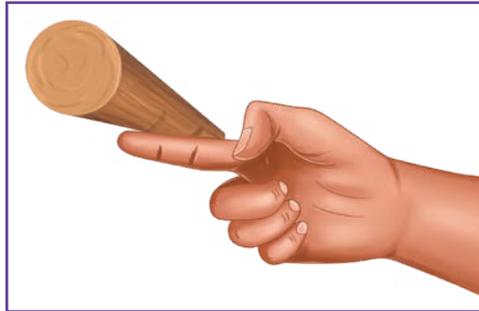
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### Materials

- 30 cm wooden rod or similar
- stopwatch

### Procedure

- 1 Construct a hypothesis about whether people will be better at balancing the rod when they are talking or silent, and whether there will be a difference between balancing on the side of their dominant or non-dominant hand.
- 2 Draw the results table below.



- 3 Form groups of three and record whether each person is left- or right-handed – their favoured hand is their dominant hand.
- 4 Each person should practise balancing the rod on both their dominant and non-dominant index fingers. Ensure that the person balancing is standing, and that the rod is in the same position between the middle knuckles (as shown above).
- 5 Take it in turns. To begin with, the person being tested should balance the rod on the index finger of their dominant hand and remove the steadying hand when instructed. Time how long they can balance it on that finger. Repeat with the rod on their the index finger of their non-dominant hand. Record these results in the table.
- 6 Now repeat this experiment, but as the person removes the steadying hand and the clock starts, the third person should start saying words the person must spell. Use the words suggested below. Record these results in the table.

Words to spell:

brain, conclusion, cerebral cortex, hemisphere, frontal, neuron, receptor, vision, sensory, spinal cord, vertebrae, parietal, occipital, experiment, reflex, hypothesis, cerebellum

- 7 Repeat the experiment with the other two group members.

### Results

	Time balanced (s)				
	Dominant hand	Dominant hand, silent	non-Dominant hand, silent	Dominant hand, speaking	non-Dominant hand, speaking
Person 1					
Person 2					
Person 3					
Average	N/A				

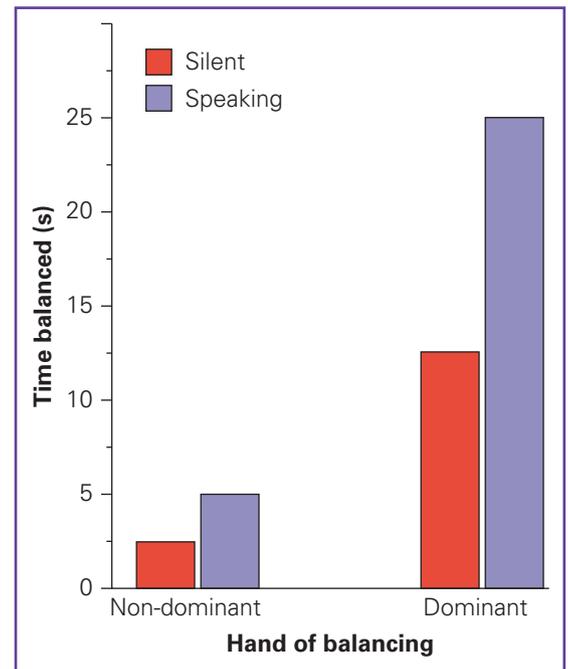
Create a graph of your results similar to that shown below, showing each individual and their four times.

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### Discussion

- 1 Identify any patterns, trends or relationships in your results.
- 2 Do the results confirm your hypothesis?
- 3 Explain the average results obtained using the facts stated prior to the Aim.



## Practical 10.5

### Determining the sensitivity of body parts

#### Aim

To determine whether the fingertip, upper arm or back is the most sensitive body area.

#### Materials

- ruler with millimetres or centimetres
- paperclip
- paper and pencil

#### Procedure

- 1 Draw the results table below.
- 2 Construct a hypothesis for this experiment: predict which part of the body (fingertip, upper arm or back) will be the most sensitive and why.
- 3 Decide who will be the experimenter and who will be the participant.

#### Be careful

Take care not to scrape the skin with the paperclip (i.e. be gentle)



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- 4 Open your paperclip.
- 5 Spread the ends and use the ruler to measure the distance between them.
- 6 Adjust them until they are exactly 4 cm apart.
- 7 The experimenter alternates touching the participant's fingertip with either both ends of the paperclip or one end of the paperclip. (A gentle touch is all that is required. Make sure the participant can't see the paperclip touching them.)
- 8 If the participant correctly feels whether one or both ends were used, tick the relevant column (✓); place a cross (X) if they do not feel the number of ends correctly.
- 9 Repeat steps 7–8 on the participant's upper arm and back and record your results in your table.
- 10 Repeat steps 5–9, bringing the paperclip ends closer each time until they are touching. Use the distances 3 cm, 2 cm, 1 cm, 0.5 cm and 0.0 cm (touching).
- 11 Complete the results table.

### Results

Distance between paperclip ends (cm)	Fingertip one point (✓ or X)	Fingertip two points (✓ or X)	Upper arm one point (✓ or X)	Upper arm two points (✓ or X)	Back one point (✓ or X)	Back two points (✓ or X)
4.0						
3.0						
2.0						
1.0						
0.5						
0.0						

### Discussion

- 1 Which body part proved to be the most sensitive? Did this support your hypothesis?
- 2 Why do you think different parts of the body have different levels of sensitivity? What function does this serve?

### Quick check 10.8

- 1 State the main role of the hippocampus.
- 2 A person suffers a brain stem stroke. Identify which vital body functions might be affected.
- 3 State the main role of the cerebellum of the brain.

### Advances in science 10.2

#### Alzheimer's disease

Alzheimer's disease is an example of a neurodegenerative disease. It occurs when neurons in the brain shrink and eventually 'die' at a greater rate than normal. This causes the brain to shrink, which is especially seen in the ventricles of the brain. Over time, amyloid plaques (deposits of protein around other neurons) and neurofibrillary tangles (twisted fibres built up inside the neuron) form, preventing the neurons of the brain from communicating properly.

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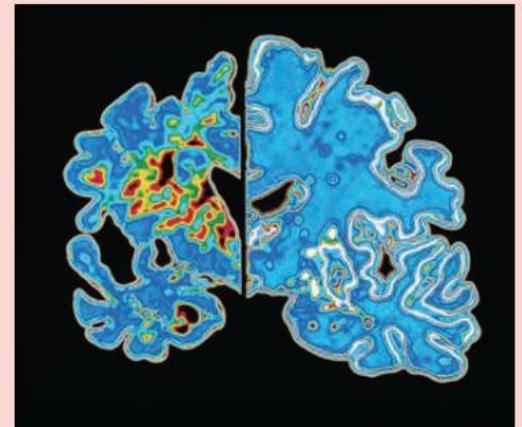


**Figure 10.15** On the left is half of a healthy brain with normal neurons, while on the right the Alzheimer's brain shows amyloid plaques and brain shrinkage.

Early symptoms of Alzheimer's disease include the inability to form new memories, impaired recent personal memories, impaired memory for names, difficulty finding the right word when speaking, confusion, unusual irritation and impaired decision-making. Progressive symptoms include frequent repetition of stories or questions and the failure to recognise family members. There is no cure for Alzheimer's disease, but medications can slow the progression of symptoms.

In 2016, scientists found a new way to use brain-imaging technology called positron emission tomography (PET) scans. These scans were able to look at changes in the brain at a cellular level, while other scans only looked for a decrease in brain cells. PET scans involve the injection of a radioactive solution into the patient's brain. The amount of radiation measured in particular regions of the brain indicates how active those regions are at a particular time.

This new way of using technology was tested on 86 adults without any neurodegeneration and 15 with suspected Alzheimer's disease. The scientists were able to prove definitively which people were clear, which were at risk and which people had the condition. The findings have also helped scientists understand more about how the neurofibrillary tangles and amyloid plaques build up as the brain ages.



**Figure 10.16** Computer graphic of a vertical slice through the brain of an Alzheimer's patient (left half) compared with a normal brain (right half).

#### neuroplasticity

the ability of the brain to change its neuron structure and function over time, in response to experiences; also known as neural plasticity

### The brain's plasticity

**Neuroplasticity** is the term used to describe the ability of the brain's neural structure

or function to be changed through experience at any time during your life. This refers to the brain's ability to be modified (it is flexible, pliable and malleable). Neuroplasticity is necessary for learning.

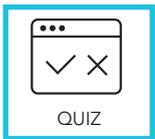
The development of the brain is an amazing process. A child's environment and experiences determine the connections each neuron makes, and the number of connections each neuron has ranges from thousands of connections to just a few. Some studies on infants use an electroencephalogram (EEG) to study their brain activity while the infants complete different tasks. The scientists use various experiments, often based on simple games, and test the babies' physical or cognitive (mental) responses with sensors including eye-tracking, brain activation and body movements. Despite the lack of verbal communication, the EEG detects, amplifies and records the electrical activity of the infant's brain, allowing scientists to make assumptions based on the readings.

As a child's brain has greater plasticity than an adult's, children can use other parts of the brain to form alternative neural connections to compensate for any missing or damaged part of the brain. This is also why it is easier to learn new skills and languages at a younger age.

### Quick check 10.9

- 1 Define the term 'brain plasticity' in your own words.
- 2 Explain why brain plasticity is useful.
- 3 Explain what 'EEG' stands for and what it is used for.

### Section 10.4 questions



#### Remembering

- 1 **Name** the outer layer of the brain and state how thick it is.
- 2 **Identify** the part of the brain that is involved in learning and memory.

#### Understanding

- 3 **Explain** what you might see if you were to remove the cerebral cortex.
- 4 **Explain** how the right side of the brain controls the movement of the left side of the body.

#### Applying

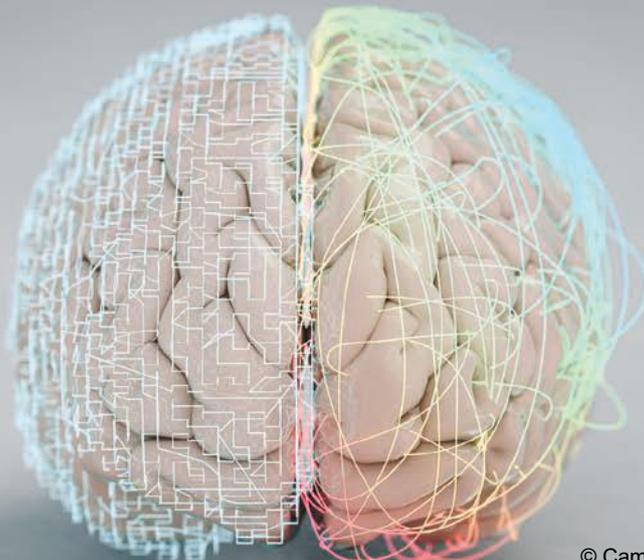
- 5 **Discuss** why it is incorrect to say that someone is 'right-brained' or 'left-brained'.

#### Analysing

- 6 Mariam has suffered brain damage to her frontal lobe. **List** three symptoms she may display.
- 7 **Discuss** how a neurodegenerative disease differs from brain damage due to an accident.

#### Evaluating

- 8 **Evaluate** whether you think it is easier for a child to learn a new language or skill compared to an adult. Justify your response.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>10.1 I can describe the structure of the nervous system.</b> e.g. Contrast the somatic and autonomic nervous systems.	
<b>10.1 I can describe the role of the endocrine system.</b> e.g. Define the term 'hormone' in your own words.	
<b>10.1 I can discuss how the endocrine and nervous systems work together.</b> e.g. Compare the endocrine and nervous systems.	
<b>10.2 I can distinguish between a sensory neuron, interneuron and motor neuron.</b> e.g. Draw a labelled diagram of a sensory neuron.	
<b>10.2 I can explain how nervous impulses pass between neurons.</b> e.g. Describe how a nervous impulse can cross a synaptic cleft.	
<b>10.3 I can explain the importance of reflex actions.</b> e.g. Construct a labelled flow diagram of the reflex action that would occur if someone burned their finger touching a hot pan.	
<b>10.4 I can describe the structure and function of the brain.</b> e.g. Recall the role of the cerebellum.	



## Reflections

- 1 What **connections** come to mind when you think about the endocrine and nervous system in your everyday life?
- 2 What new concepts have **extended** your thinking about how our nervous system responds to the environment?
- 3 What information did you find **challenging** or confusing?



### Data questions

Melatonin is secreted from the pineal gland in the hours of darkness and is a hormone that coordinates the body to go to sleep. The amount of melatonin produced in the average 14-year-old and 70-year-old across the hours of a day is presented in Figure 10.17. Note: this data assumes a bedtime (lights out) of 9 p.m.

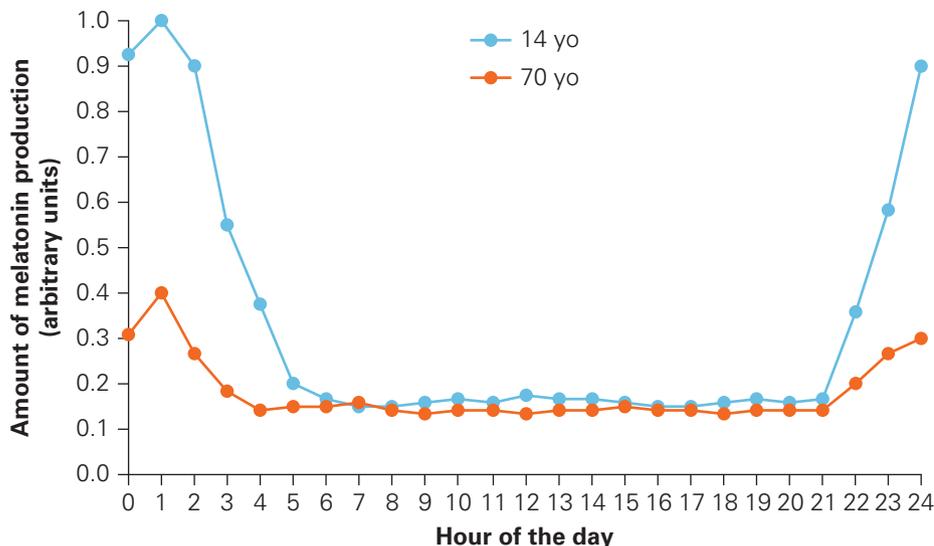
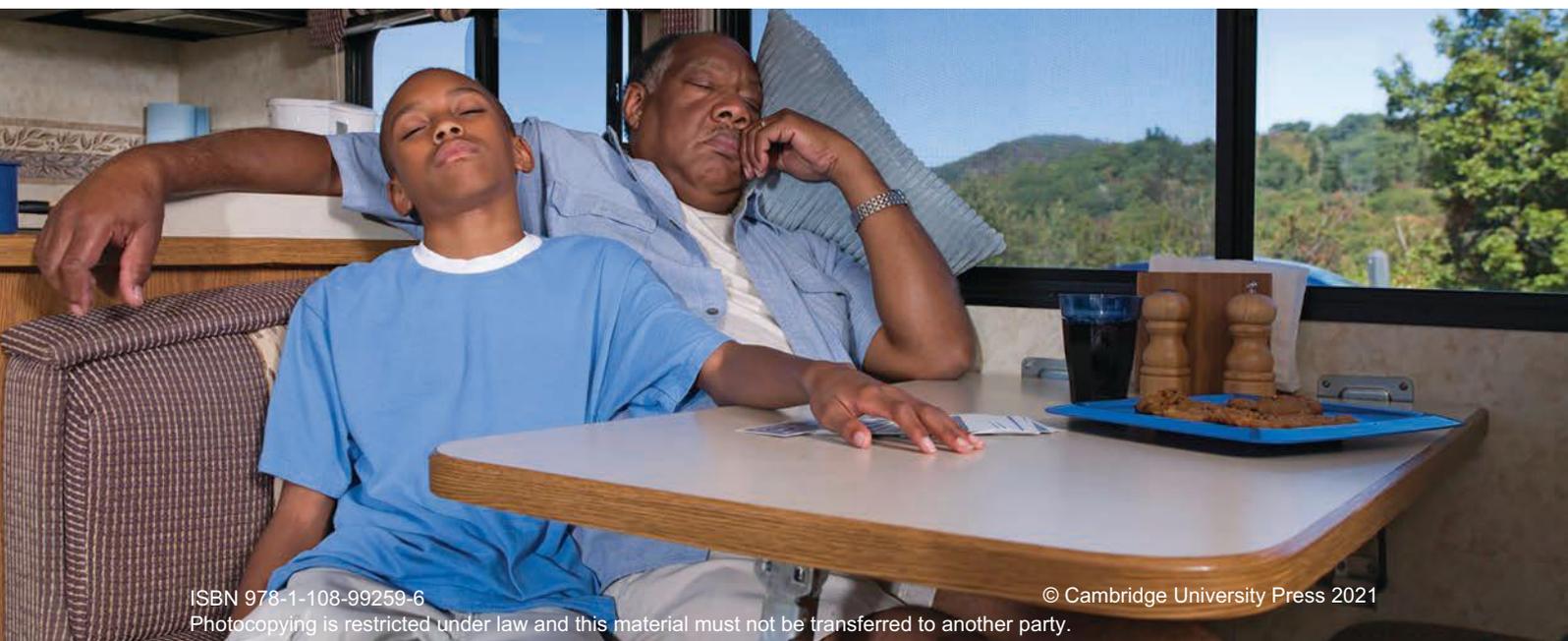


Figure 10.17 Amount of melatonin produced by the average 14-year-old and 70-year-old

- 1 **Identify** the time of day when most melatonin is produced for both the 14-year-old and 70-year-old.
- 2 If the 14-year-old produces 100 mg of melatonin at 1 a.m., **calculate** what mass of melatonin the 70-year-old produces at this time.
- 3 Over the course of 24 hours, **determine** which of the 14-year-old or 70-year-old will produce more melatonin.
- 4 The melatonin production of a 30-year-old at 1 a.m. was determined to be 0.7. **Identify** a trend between the age of a person and their daily melatonin production.
- 5 **Identify** any patterns in the data collected.
- 6 **Contrast** their respective melatonin values and comment on whether the 14-year-old or the 70-year-old will feel sleepier at 10 p.m.
- 7 Use the data in Figure 10.17 to **justify** that melatonin production is triggered by darkness.
- 8 **Deduce** the melatonin production of a 30-year-old at midday.
- 9 **Predict** what would happen to the daily melatonin production of a 14-year-old or 70-year-old if at 9 p.m., instead of lights out, they watched videos on the internet for another 2 hours.



## STEM activity: Texting and reaction times



**Figure 10.18** In NSW there are penalties for using a mobile device while driving. It will cost the driver 5 demerit points and a fine of about \$400.

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

### Activity instructions

In this activity, you will use materials and your imagination to create an experiment that produces:

- at least three sets of data
- at least three bar graphs
- a conclusion that clearly responds to the following scenario.

Transport for NSW is so worried about young people's attitudes towards texting while driving that it hired your young start-up company to conduct a sequence of experiments in the community to determine whether texting can slow down a person's reaction times.

### Suggested materials

- 30 cm ruler
- scissors
- cardboard
- paper
- pen
- mobile phone to record slow-motion videos
- Microsoft PowerPoint, Google slides or Mac Keynote for presentations
- video-editing software for making short documentaries

### Research and feasibility

- 1 Research and make a list of the factors that influence a person's reaction time.
- 2 Create a table and make predictions of how these factors will decrease or increase a person's reaction time.

Factor	Reaction time effect	Reason
e.g. Being tired	Decrease reaction time moderately	Tiredness decreases ability to absorb information

- 3 Discuss in your group, then list important information you will need to record about your participants whose reaction times will be tested. Hint: make sure you have thought about all the factors that might affect a person's reaction times, such as sleep, exercise or video game playing.

### Design and sustainability

- 4 Using the materials on the material list, design a way to test the effect of mobile phone texting on a teenager's reaction time.
- 5 Design a table that includes information about each participant's recorded information.

### Create

- 6 Perform your experiment, making sure you collect multiple sets of data for each participant and their important information.

### Evaluate and modify

- 7 Reflection is an integral and vital aspect of any project out there in the real world. How could you use ICT tools (for example, apps, video, slow-motion camera) to enhance this experiment?
- 8 The results may change when a different type of ruler is used, such as metal, plastic or timber. Predict how the size or length of the ruler, and whether the dominant or non-dominant hand was used, might have affected the results.
- 9 Consider adding other distracting sounds and sights during the activity, such as turning on a TV set or flicking a flashlight on and off. Do your responses slow with so many sensory signals?
- 10 Create a graphical representation of your results and present your results to the class.

# Chapter 11

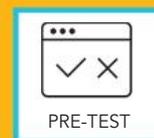
# Ecosystems

## Inquiry questions

Where does energy come from and how does it move through an ecosystem?

What must happen for an ecosystem to survive?

Are human impacts on the ecosystem only detrimental or can humans provide benefits to an ecosystem?

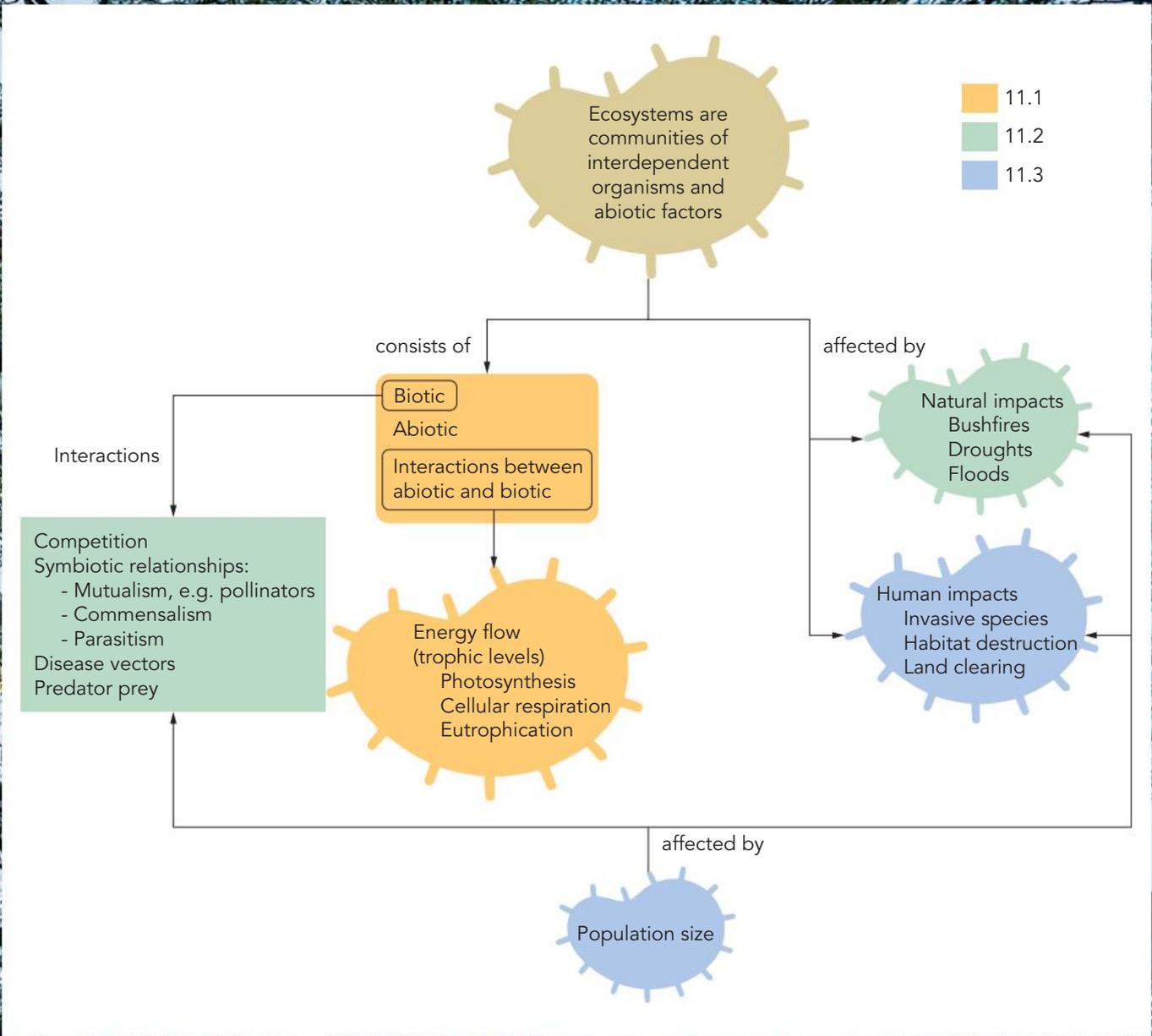


## Chapter introduction

The many varied ecosystems on Earth are composed of living organisms, non-living components and the interactions that occur between them. Humans can have a dynamic impact on the stability and health of ecosystems, but humans are just one species of consumer. Thousands of other consumers hunt for prey, compete for resources and rely on specific characteristics of their habitats, such as temperature, oxygen levels and water, for survival.

This chapter examines the relationships between the biotic and abiotic components within ecosystems and the many different forms of interactions between organisms. You will also explore how populations change in size and about the effects of environmental changes within ecosystems.

# Chapter map



# 11.1 What is an ecosystem?

## Learning goals

- 1 To identify the components of an ecosystem
- 2 To outline how matter is cycled through ecosystems
- 3 To describe the flow of energy through an ecosystem
- 4 To describe the process of photosynthesis and relate it to the source of energy in an ecosystem
- 5 To outline the process of cellular respiration and relate it to the energy needs of consumers
- 6 To describe, using examples, how environmental changes affect ecosystems



**Ecosystems** consist of all the living things in an area, all of the non-living components (such as air, rocks, temperature, humidity, salinity) and all of

the interactions taking place between the living things and their surroundings.

Ecosystems consist of many different habitats and are often connected in a larger biome. A **biome** is a specific geographical area of the planet, classified according to the main climatic features, vegetation and specific adaptations of the organisms

within that environment. A biome can be made up of many ecosystems. Australia contains many of the world's biomes, each of which have their own organisms and climate.

### ecosystem

an ecological unit made up of living components, non-living components and the interactions between them

### biome

a region of Earth's surface classified by the particular combination of climate, plants and animals that are found within it

### biotic

living factors, such as plants, animals and bacteria

### abiotic

non-living factors, such as temperature, pH, salinity, rocks and water



VIDEO  
Features of an ecosystem

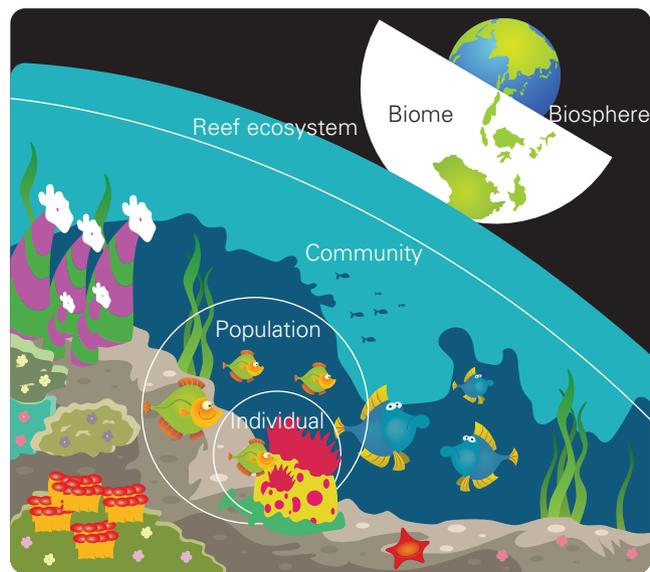


Figure 11.2 Levels of organisation in a reef ecosystem

## Components of an ecosystem

An ecosystem consists of three essential components:

- a living component (**biotic** factors) consisting of populations of different organisms (for example, humans, plants, animals, fungi, bacteria), some of which are microscopic, as well as the organic matter produced by these organisms, such as faeces or decaying organic matter
- a non-living component (**abiotic** factors) that includes things such as rocks and sand, but also all the things that can be measured – such as temperature, light intensity, wind speed, rainfall, humidity, pH and salinity. Abiotic factors play an important role in the overall distribution and abundance of organisms within an ecosystem
- the interaction between the biotic factors and the abiotic surroundings.

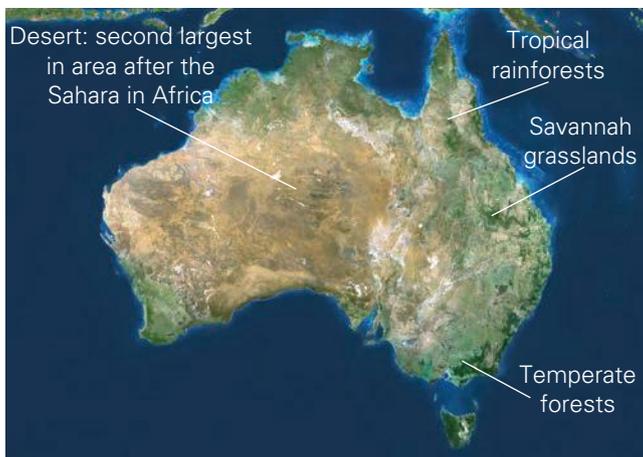


Figure 11.1 Location of some Australian biomes

An ecosystem can also be classified as a community and its **habitat**.

$$\text{habitat} + \text{community} = \text{ecosystem}$$

Within an ecosystem, the habitat is the place in which an organism lives. You can think of it as the organism's physical surroundings, which may be a pond, grassland or treetop canopy. A habitat can have biotic and abiotic components.

A **population** is a group of individuals of one species living in a certain habitat at a given time, for example, a herd of water buffaloes who live near a certain river.

A **community** is a group of all the populations of different organisms that live within a habitat at a particular time, and is therefore always considered biotic. A river community might include water buffalo, birds, grasses, bacteria, fish and crocodiles. All species

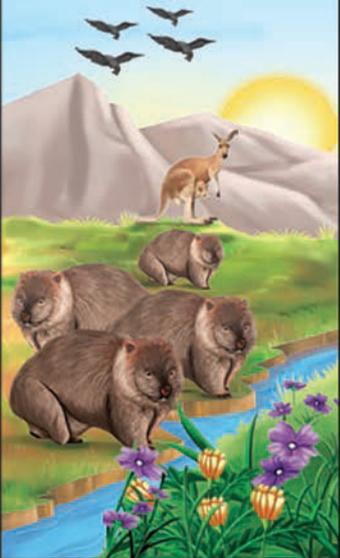
in the community interact with one another, and also with their habitat.

The **productivity** of an ecosystem depends on both biotic and abiotic factors. Living organisms interact with both the biotic and abiotic components of their ecosystem, forming different types of relationships that increase the complexity of the community.

- habitat**  
the environment an organism lives in
- population**  
members of one species living in a particular area at a given time
- community**  
all the populations of different species living in a particular area at a given time
- productivity**  
the rate of generation of biomass in an ecosystem

**Quick check 11.1**

- 1 Define the terms 'population', 'community' and 'ecosystem'.
- 2 State the three essential components that are present within an ecosystem.
- 3 Distinguish between a biotic component and an abiotic component of an ecosystem, including examples of each.

<b>Individual</b> A single living organism	<b>Population</b> A group of individuals living in a particular place and time	<b>Community</b> Populations of various species in a particular region (biotic)	<b>Ecosystem</b> The interactions between the community and the habitat (biotic + abiotic)
			

**Figure 11.3** The various levels of complexity, beginning from an individual organism right through to a complete ecosystem

## Try this 11.1

Abiotic factors can be classified into chemical or physical components. Chemical components relate to the chemical nature of matter. Physical components can be observed without changes in the chemical nature of matter.

For the factors below, select whether they belong to the chemical or physical domain. Copy the table and place a tick in the appropriate column.

Abiotic factor	Physical component	Chemical component
Humidity		
pH of soil		
Day length		
Temperature range		
Dissolved oxygen concentration of water		
Wind speed		
Rainfall		
Concentration of mineral ions in soil		

**food chain**

the flow of energy from organism to organism in an ecosystem

**producer**

also known as an autotroph; an organism capable of making its own food

**consumer**

also known as a heterotroph; an organism that must eat or consume other plants or animals as a source of energy

**primary consumer**

the consumer who eats the producer in a food chain

**secondary consumer**

the consumer who eats the primary consumer

**tertiary consumer**

the consumer who eats the secondary consumer

**quaternary consumer**

the consumer who eats the tertiary consumer

**food web**

a series of interconnected food chains

## Energy flow through ecosystems

A **food chain** shows the flow of energy from organism to organism through an ecosystem. Energy flow is illustrated using arrows which point in the direction of energy transfer. The Sun is the original source of the energy in most organisms but is rarely included in the food chain. A simple example of a food chain:

plant → mouse → snake →  
kookaburra

within ecosystems, and these can all be interlinked in a complex pattern called a **food web**.



**Figure 11.4** A Laughing Kookaburra, *Dacelo novaeguineae*, eating a yellow-naped snake, *Furina barnardi*.

## Try this 11.2

Redraw the food chain you have been looking at and add the following labels: producer, primary consumer, secondary consumer, tertiary consumer. Also add labels to show which of the consumers are herbivores (feeds on plants) and which are carnivores (feeds on animals).

**Reflect:** Must a primary consumer always be a herbivore?

As in this example, food chains typically start with a **producer**, in this case, the plant. The **consumer** that eats the producer is called a **primary consumer** (the mouse), and the consumer that eats the primary consumer is called a secondary consumer (the snake). Organisms that feed on **secondary consumers** are called tertiary consumers (the kookaburra) and organisms feeding on **tertiary consumers** within an ecosystem are called **quaternary consumers**. Numerous food chains exist

The term **trophic level** refers to the position an organism occupies in a food chain. Numerous organisms may occupy the same trophic level. Also, one particular organism may occupy different trophic levels within a single food web due to being a consumer in multiple food chains. Trophic levels are easily represented in a pyramid shape. Producers make up the first trophic level and herbivores, which are the first consumers in the food chain, are in the second trophic level. Add trophic levels to your food chain diagram from the activity in Try this 11.2. Food chains do not have an infinite number of trophic levels. Typically, land-based food chains have fewer than six levels. The highest ranked consumer is sometimes referred to as the **apex predator**.

The Sun is the key abiotic factor that provides plants with the energy required producers to make their own food. Plants and algae can turn the radiant energy they absorb from the Sun into glucose, a form of sugar, which they then use to grow. Because plants produce their own food, they are called producers or **autotrophs** (meaning self-feeding).

Consumers are organisms that must eat or consume other plants or animals (producers or other consumers) to obtain their energy as they cannot produce their own food. They are known as **heterotrophs**. If an ecosystem had no producers, herbivorous consumers would not have

a source of energy, and it would be impossible for all other organisms to exist. Producers capture the Sun's energy and bring it into the ecosystem in a useable form through the process of photosynthesis.

Any organism may be classified as either an autotroph or a heterotroph according to their energy requirements and pathways.

**trophic level**  
the position an organism occupies in a food chain

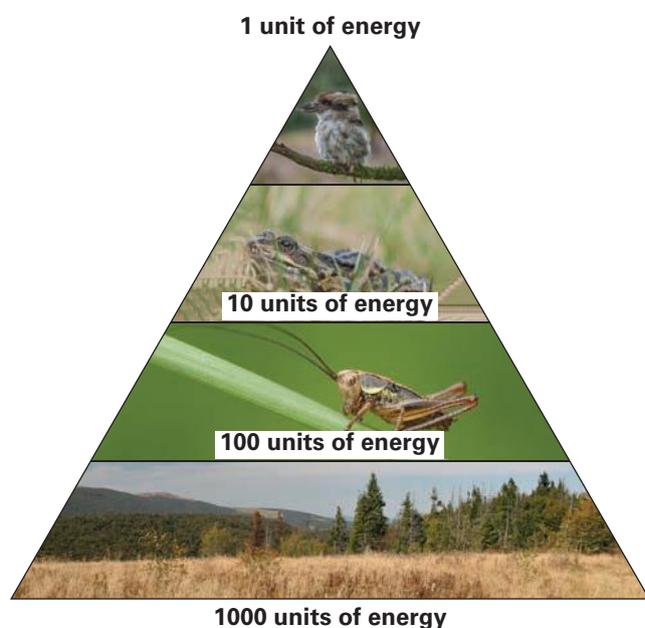
**apex predator**  
the highest level consumer in a food chain

**autotroph**  
also known as a producer; an organism capable of making its own food

**heterotroph**  
also known as a consumer; an organism that must consume plants or animals as a source of energy

Energy transfer between trophic levels is not very efficient: only approximately 10% of the energy an organism consumes is passed on to the next organism in the food chain (that is, up to the next trophic level). The remaining 90% is lost as heat or in wastes, such as faeces. Therefore, the amount of energy available to organisms decreases substantially at each subsequent trophic level. This produces a pattern called an 'energy pyramid'.

The energy pyramid in Figure 11.5 shows how much energy is present in each stage of an Australian woodland ecosystem.



**Figure 11.5** A trophic pyramid or 'energy pyramid' showing the energy flow from the grass through to the kookaburra

### Try this 11.3

- 1 Only 10% of the energy from one trophic level is transferred to the next level, so what happens to the 90% energy that is lost?
- 2 Do you think a pyramid is a good shape to represent how matter and energy transfer in an ecosystem? Why or why not?

### Quick check 11.2

- 1 State the organism in Figure 11.5 that would fulfil each of the following roles: producer, primary consumer, apex predator.
- 2 Construct a food chain for Figure 11.5.
- 3 Distinguish between an autotroph and a heterotroph, providing an example of each.
- 4 Explain why energy is an essential component within an ecosystem.

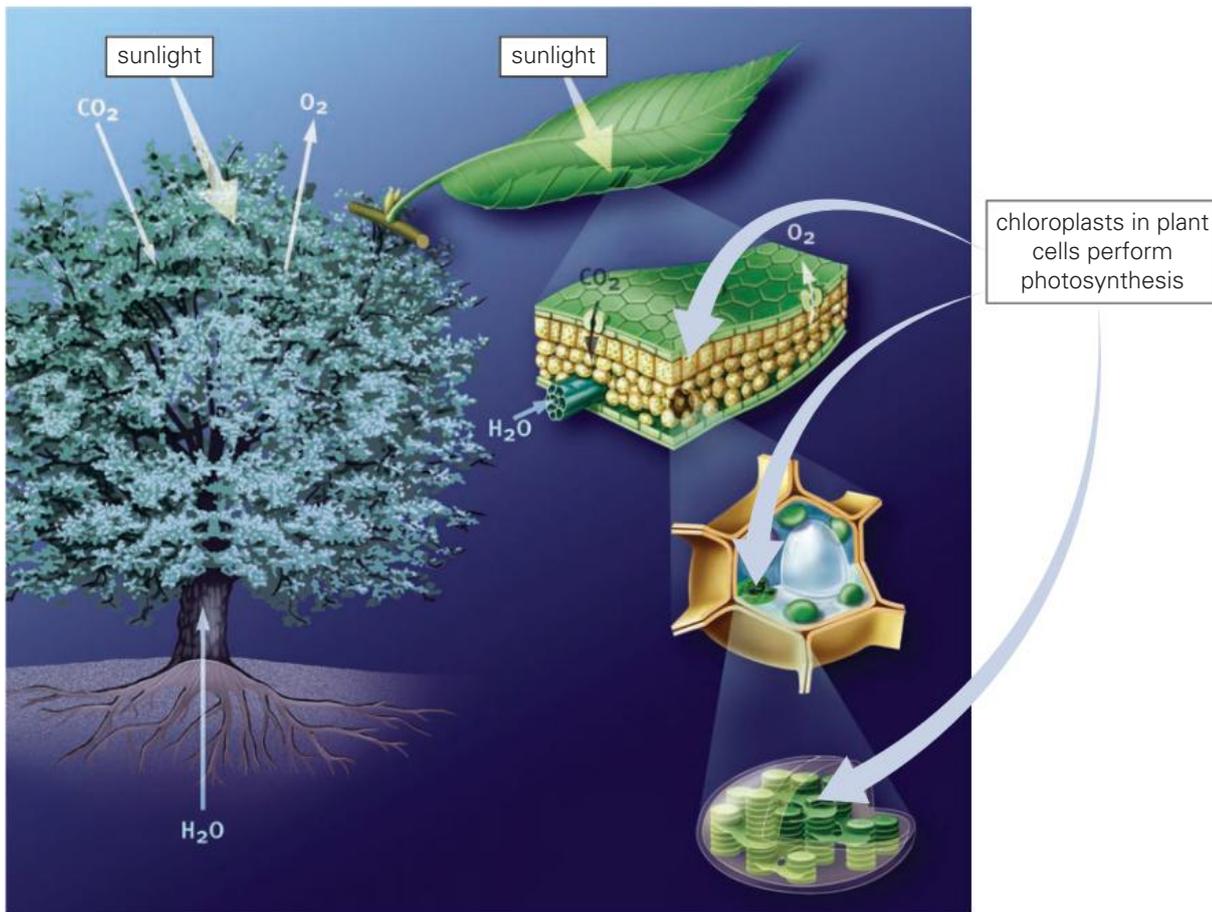
## Energy within ecosystems: photosynthesis, respiration and eutrophication

### Photosynthesis

**photosynthesis**  
the chemical reaction by which some organisms make their own food

An ecosystem derives its energy from the Sun, and this energy is cycled through the plants, animals and

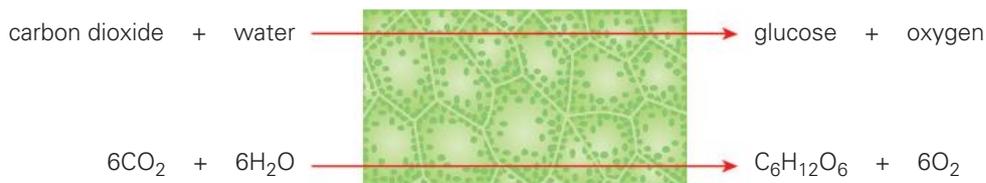
micro-organisms living within it. The process called **photosynthesis** allows plants to capture the Sun's radiant energy and use it to produce glucose. This then forms the energy source for all the consumers along the remainder of the food chain, including you! Plants also use the glucose as their own energy source. Even the waste product of photosynthesis is incredibly useful for us humans – plants release oxygen as a product of the chemical reaction.



**Figure 11.6** Plants trap sunlight in tiny organelles called chloroplasts and use it to produce glucose and oxygen from the reactants of carbon dioxide and water.

The chemical reaction named photosynthesis uses carbon dioxide and water, and in the presence of sunlight converts these into glucose and oxygen.

This reaction can be described with the simple equations shown below.



**Figure 11.7** Chemical and word equations of the photosynthesis reaction that occurs in plant cells containing chloroplasts.

Photosynthesis occurs in **chloroplasts**, organelles in plant cells that contain the substance **chlorophyll**, which is responsible for absorbing the Sun's energy.

Plants can either immediately use the glucose they produce, store it as starch or build it into cellulose to make their cell walls or other cellular components.

Photosynthesis can be affected by the plant's environment, with factors such as the availability and intensity of sunlight and the availability of water determining the effectiveness of the process.

**chloroplasts**  
organelles found in plant cells (and some protists e.g. algae) that contain chlorophyll and as such, conduct photosynthesis

**chlorophyll**  
a group of green pigments found in the chloroplasts of plants and algae (as well as in the mesosomes of cyanobacteria) that are responsible for the absorption of light and subsequent production of glucose during photosynthesis

### Try this 11.4

#### Looking at chloroplasts under a light microscope

##### Materials

- moss or spirogyra plant
- dilute iodine solution
- water
- light microscope
- slides
- coverslips
- tweezers

##### Procedure

- 1 Using tweezers, carefully remove a leaf from the plant and place it on a microscope slide.
- 2 Put a drop of water on the leaf and cover with a coverslip.
- 3 Starting at the lowest magnification, observe the leaf through the light microscope. Can you see any chloroplasts?
- 4 Remove the slide and gently lift the coverslip. Stain your sample by putting a drop of the dilute iodine solution on the leaf. Iodine stains starch a dark blue-black colour.
- 5 Repeat step 3. Can you see any chloroplasts?
- 6 Discuss with a partner the observed characteristics of the chloroplasts.

### Practical 11.1

#### The effect of light on plants

##### Aim

To investigate the effect of light on plant growth.

##### Materials

- 3 Petri dishes
- cotton wool
- fast-growing seeds such as mustard or cress

##### Planning

- 1 Write a summary of the background information about the factors that affect plant growth.
- 2 Identify the independent, dependent and control variables for this experiment.

##### Procedure

- 1 Draw a results table that will allow the collection of sufficient relevant data.
- 2 Cover the base of each Petri dish with cotton wool and dampen it by adding the same volume of water to each.
- 3 Add twenty seeds to each Petri dish and place them on a brightly lit, warm windowsill.
- 4 Wait a few days to allow the seeds to germinate, ensuring that the cotton wool does not dry out. Remember to always add the same amount of water to each Petri dish.
- 5 Once the seeds have been given enough time to germinate, ensure each Petri dish contains ten seeds, removing any extra seeds where necessary (not all of the seeds will have germinated, which is why twenty were added at the start).

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- 6 Place one Petri dish in full light on a windowsill, the second in a darkroom or dark cupboard, and the third in partially lit conditions.
- 7 For a week, measure the height of each seedling in each Petri dish and record the measurements in your results table. You must record the height of each individual seedling on each day. You may want to sketch a diagram that will remind you which seedling is which.
- 8 Calculate the mean growth (change in height) of the seedlings in each Petri dish each day.

### Results

Record your data in your results table.

### Discussion

- 1 Draw a graph that plots the day number against the mean growth. Plot all three sets of data on the one graph.
- 2 Identify any trends, patterns or relationships in your results.
- 3 Extrapolate your data to predict what the mean plant growth would be after 10 days.

## Cellular respiration

Plants do not perform photosynthesis simply to produce glucose for consumers to eat! Producers, just like all living organisms, need to break down that glucose to

### cellular respiration

an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy in the form of ATP

### ATP

a molecule that provides useable energy in cells

### eutrophication

when a body of water becomes too enriched with nutrients, causing an excessive growth of algae that may result in oxygen depletion of the water

release energy in a useable form. This process is called **cellular respiration**.

During cellular respiration, glucose is broken down with oxygen, producing carbon dioxide and water as waste products. Small packets of energy are also released and stored in molecules of **ATP**.

Bacteria, plants and animals (including humans) all need that energy to power the functions of their cells.

The word and chemical equations for cellular respiration are shown in Figure 11.8.

The overall process of respiration is carried out in cell organelles called mitochondria (singular: mitochondrion) in plant and animal cells.

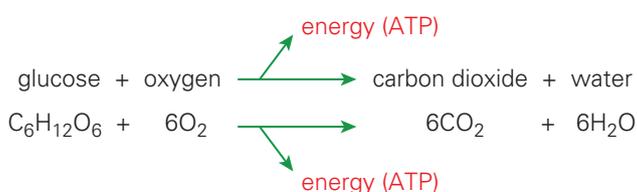


Figure 11.8 The process of cellular respiration

## Eutrophication

**Eutrophication** is the term given when a body of water becomes too enriched with nutrients, causing an excessive growth of algae that may result in oxygen depletion of the water. This can kill other life within the water body. These nutrients include nitrates and phosphates, which are often found in fertilisers, and in detergents used regularly in our homes and in industry.

### Quick check 11.3

- 1 Insert the correct words to complete these sentences:
  - a Photosynthesis \_\_\_\_\_ glucose by capturing radiant \_\_\_\_\_ from the Sun.
  - b Cellular respiration breaks down \_\_\_\_\_ to release useable energy.
  - c Plants perform \_\_\_\_\_ and cellular respiration.
  - d Humans can only perform \_\_\_\_\_ and must \_\_\_\_\_ other organisms for a source of glucose.
- 2 State the word equations for photosynthesis and cellular respiration.
- 3 Describe what happens when an excess supply of nutrients is introduced to a healthy body of water.

## Explore! 11.1

**Eutrophication**

- 1 Research how eutrophication occurs, then draw a flow chart summarising the key steps in the process of eutrophication.
- 2 Find some locations in Australia where eutrophication has occurred or is occurring. Make a list of five waterways affected and the state or territory they are in.
- 3 How can governments help prevent eutrophication and how can they fix the problem after it has already started? Summarise in dot points what you find out.

## Practical 11.2

**Phosphates in fertilisers and detergents****Aim**

To investigate the effect of detergent on the health of plants.

**Materials**

- water plant
- detergent (to make 1%, 5% and 10% dilutions as instructed below)
- tap water
- 4 × 250 millilitres (mL) beakers
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- glass stirring rod
- weighing balance
- ruler

**Planning**

- 1 Summarise the background information about the ingredients of detergents and write a paragraph regarding the effect of detergents on plant growth.
- 2 Create a relevant and specific research question for this experiment.
- 3 Construct a hypothesis for this experiment relating to the effect that the detergent has on the overall health of the plant.

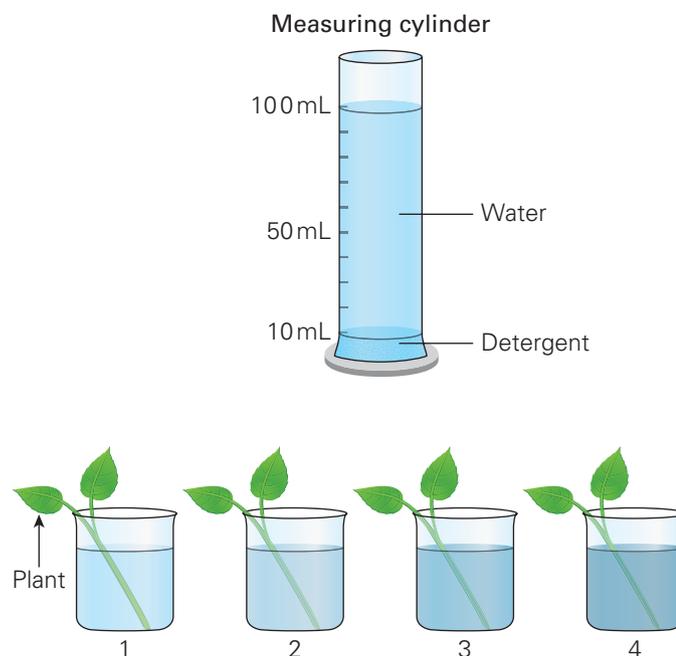
**Procedure**

Figure 11.9 Experimental set-up

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- 1 Draw the following results table.
- 2 Cut four 20 centimetre (cm) lengths of a water plant, then weigh and record the mass of each piece.
- 3 Label the beakers 1–4, and place one length of the water plant in each beaker.
- 4 Fill the first beaker with 100 mL of tap water using a 100 mL measuring cylinder.
- 5 Measure 1 mL of detergent in the 10 mL measuring cylinder and then transfer to the 100 mL measuring cylinder.
- 6 Dilute with water by adding tap water up to the 100 mL mark. Use a glass stirring rod to ensure the solution is mixed consistently.
- 7 Transfer the 1% detergent solution to beaker 2.
- 8 Repeat steps 5–6 with 5 mL of detergent to create a 5% solution. Add to beaker 3.
- 9 Repeat steps 5–6 with 10 mL of detergent to create a 10% solution. Add to beaker 4.
- 10 Place the four beakers, uncovered, on a windowsill to stand for 7 days.
- 11 After 7 days have passed, weigh and make observations of the plants. You can use the ruler for appropriate measurements.

### Results

Complete the following results table below and graph these results.

Detergent solution (%)	Original plant mass (g)	Final plant mass (g)	Change in mass (g)	Observational change
0				
1				
5				
10				

### Discussion

- 1 In a scientific experiment, it is often important to include a 'control' as it provides a benchmark to measure the other results against. No interventions are done to the control. State which beaker in this experiment represented the control and give a reason for your answer.
- 2 Explain whether the observational changes are related to the change in the plant's mass after 7 days.
- 3 Can you explain the effect detergent had, with reference to eutrophication?
- 4 Compare the results from the graph with your predictions about which percentage detergent solution would have the greatest effect on the plant.

### Conclusion

- 1 Make a claim from this experiment regarding detergent and the health of plants.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.



## Environmental changes affecting ecosystems

Many biotic and abiotic factors affect population size. These factors are known as secondary ecological events as they affect one or more of the four primary ecological factors (birth, death, immigration and emigration rates). For example, seasonal changes, such as drought or flood,

may increase the death rates within a population. Within Australia, fires, drought and flood all affect population sizes of organisms living within ecosystems.

### Seasonal effects on ecosystems: fire

Bushfires have a major influence on Australian ecosystems. They have both positive effects, such as encouraging plant development, and negative effects, such as killing wildlife.

Bushfires can stem from natural causes such as lightning strikes, but can also be deliberately lit. Aboriginal and Torres Strait Islander peoples learned to harness bushfires as an important tool for purposes such as:

- creating easier access through thorny and thick vegetation
- attracting animals for hunting by encouraging new vegetation growth
- encouraging the growth of plants used for food and spiritual purposes.

The fires lit by Aboriginal and Torres Strait Islander peoples were regular in frequency and low in intensity, and contained within manageable areas. This regular use of fire resulted in vegetation of varying ages across the landscape.

The primary fuel for bushfires is dead, fine vegetation on the forest floor. Bushfire risk has a lot to do with how moist the fuel is. If the vegetation is green and contains

more than 30% moisture, it will not ignite; however, when the moisture is lower, fires can ignite and spread easily.

Fire does not just destroy homes; it also destroys the landscape. Many animals die in the fire; others escape to a safer area but are then unable to return to their natural habitat because there is no food available or their home is gone. In the fires of 2019–20, an estimated 1 billion animals were killed. It may take years for the food sources to recover, leading to the potential loss of more animals. This results in an increase in the death rate and a decrease in the birth rate.

However, fire has some positive outcomes.

- Burning releases nutrients locked in plant and rotting organic materials, enriching the soil for germinating seeds.
- The bushy undergrowth burns away, allowing more sunlight to reach seeds and young plants.
- Some seed pods are triggered to open, either by the heat of the fire or by a chemical in the smoke.

## Explore! 11.2

### Bushfire policies and programs

In light of the bushfires in December 2019 and January 2020, when an area of about 18 million hectares was burned, there is a heightened urgency to improve fire prevention measures. These were the largest bushfires since 1974 when 117 million hectares was burned.

In the Kimberley, a region in northern Western Australia, the First Nations peoples and traditional owners of the land conduct traditional burns by lighting 'cool' fires during the early dry season (March–July).

- 1 Investigate the Kimberley Land Council's Indigenous fire management program on the KLC website. Explain how the program works.
- 2 What have been the findings of fire research on the effects of traditional Aboriginal and Torres Strait Islander peoples' fire regimes?
- 3 How have these findings influenced fire management policy throughout Australia?
- 4 What is the evidence regarding the effectiveness of traditional fire practices?



**Figure 11.10** Rangers and traditional owners conduct burns in the Katiti-Petermann Indigenous Protected Area, in the remote desert country near the Western Australia and Northern Territory border.

## Seasonal effects on ecosystems: droughts and floods

Droughts can significantly affect ecosystem processes. They can have major impacts on the rural economy and can lead to other environmental problems such as severe fires, dust storms and the degradation of land.

It is common in parts of Australia to experience droughts that are ended by floods. Flash floods tend to be localised, short-lived and generally the result of an extreme storm. Conversely, longer lasting flooding can result from heavy rain over the catchments of extensive river systems. Flooding can have negative impacts, including loss of human life, livestock and wildlife; damage to homes and infrastructure; land degradation (such as erosion and loss of mineral nutrients); and spread of disease.

The environmental benefits of flooding result from recharging the underground water systems and flushing excess salts from the soil. Floods can also deposit sediments on the flood plains, resulting in a nutrient-rich soil, and they allow fish and other animals that need the water to breed or disperse to other areas. This can increase birth and emigration rates.

### Quick check 11.4

- 1 State two negative and two positive outcomes of bushfire.
- 2 Name the main fuel for bushfires.
- 3 Define a flash flood.
- 4 State two environmental benefits of flooding.

## Section 11.1 questions

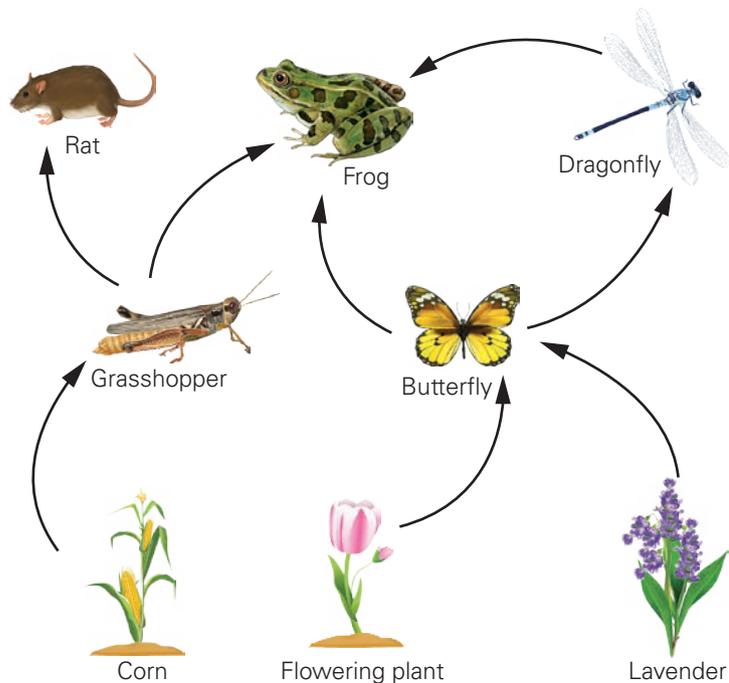


### Remembering

- 1 **Identify** the three components of an ecosystem.
- 2 **Recall** the word and chemical equations for cellular respiration.
- 3 **Recall** the word and chemical equations for photosynthesis.
- 4 When energy is transferred along a food chain from organism to organism (or up the trophic pyramid) **state** what percentage of energy is efficiently transferred.
- 5 **Provide** two specific examples of biotic factors found within the biome of an Australian desert.

### Understanding

- 6 **Compare** which organisms perform photosynthesis and which organisms perform cellular respiration.
- 7 **Explain** why humans are not considered to be autotrophs.
- 8 **Classify** the organisms in the food web (right) as producers, primary consumers, secondary consumers and tertiary consumers.
- 9 A rabbit eats some grass to gain its energy. **Explain** where this energy originated from, and what processes it went through to be in a useable form for the rabbit to carry out cellular functions.
- 10 **Outline** the steps between the Sun (as a source of energy) and a secondary consumer.
- 11 **Outline** two examples of how floods may negatively influence an ecosystem.



### Applying

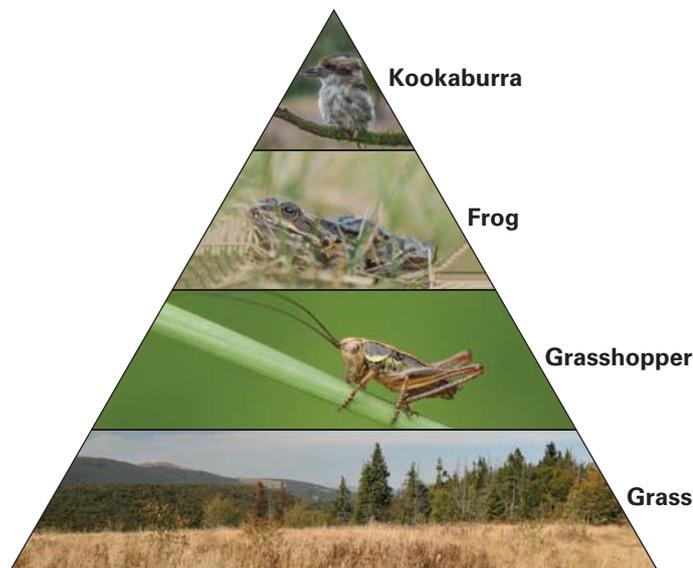
- 12 **Discuss** the biological impacts that the use of detergents could have within ecosystems.

**Analysing**

- 13 Compare** and contrast the role of a heterotroph with an autotroph within an ecosystem.  
**14** The table below shows oxygen levels around plants at different light intensities.

Light intensity (%)	Oxygen ( $\mu\text{L}/\text{min}$ )
9	4
15	9
28	17
48	29
55	34
90	55
100	60

- a Graph** the results.  
**b Analyse** the findings.
- 15** In your own words, **outline** one similarity and one difference between photosynthesis and respiration.  
**16 Explain** the difference between a community and a habitat.  
**17** The pyramid below shows each stage of an Australian woodland ecosystem. Food chains do not have infinite trophic levels. Typically, land-based food chains have fewer than six levels.



- a** A blade of grass weighs 0.5 grams. An average-sized grasshopper (like the one in the food pyramid above) weighs 5 grams and must consume half of its body mass in food per day. **Calculate** how many blades of grass the grasshopper needs to eat per day.  
**b** Assume a frog must eat five grasshoppers per day, while a kookaburra must eat two frogs per day. Use this information along with your answer from part **a** to **calculate** how many blades of grass are needed to keep a kookaburra alive for a day.

**Evaluating**

- 18 Justify** which trophic level is the most important for an ecosystem.  
**19 Construct** a mind map showing the relationship between the different levels of consumer within an ecosystem.  
**20 Evaluate** the following statement: 'Ecosystems would cease to exist, should producers be eliminated.'

# 11.2 Interactions between organisms and their environment

## Learning goals

- 1 To identify the different types of symbiotic relationships
- 2 To describe the complex relationship between organisms in an ecosystem
- 3 To outline and predict changes in predator–prey cycles



The role an organism fulfils within an ecosystem is known as its **ecological niche**. This includes its habitat, diet and relationships or interactions with other organisms within the ecosystem – for example, where it makes a home, what it eats and what time of the day it is active. Interactions occur between organisms of the same species or of different species within the niche. Interactions vary depending on how organisms behave

at different times of the day and in different seasons. Many interactions take the form of competition or predator–prey. Other interactions represent a symbiotic relationship between species, such as mutualism, commensalism or parasitism.

## Competition

Organisms in a similar niche within an ecosystem compete with one another for resources that are in

short supply. This occurs when different organisms require the same resources, such as food, space, shelter and mates, to survive and thrive. Competition within and between species occurs in all communities.

**Interspecific competition** is competition for resources,

**ecological niche**  
the role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment

**interspecific competition**  
competition for food or resources between members of different species

**intraspecific competition**  
competition for food or resources between members of the same species

such as a specific food source, between members of different species. For example, kangaroos and sheep compete for grass as their major food source. In contrast, **intraspecific competition** is competition



**Figure 11.11** Male giant Australian cuttlefish competing for mates is an example of intraspecific competition.

between the members of the same species, such as male cuttlefish competing for a mate. Note that intraspecific competition is usually more intense than interspecific competition because organisms of the same species will have identical needs.

If two species are in competition with each other for the same limited resources, the better suited and more effective species will be able to use the resource more than the other species. This may result in the less efficient competitor leaving the ecosystem to find an environment with less competition.

## Quick check 11.5

- 1 Define the terms 'interspecific competition' and 'intraspecific competition' in your own words.
- 2 Describe what happens when two species are competing for food, and one species is better adapted or stronger.

## Symbiotic relationships

When individuals from two different species share a close and long-term biological relationship, it is known as a **symbiotic relationship**. Examples include mutualism, commensalism and parasitism.

### Mutualism

**Mutualism** is a symbiotic relationship in which both species benefit and neither is harmed. For example, plants have a mutualistic relationship with **pollinators**. Some plants, like grasses, are pollinated by wind, but many flowering plants rely on insects, birds, small mammals or reptiles to transfer pollen from one plant to another. Because the pollinator benefits from feeding on the nectar from the plant and the plant benefits by being pollinated, the relationship is mutualistic.

Another example is clownfish living with sea anemones in the Great Barrier Reef, as seen in *Finding Nemo*. The clownfish hides from predators among the stinging tentacles of the anemone. In turn, the fish cleans the anemone, provides nutrients in the form of waste and scares away predatory fish such as the butterfly fish.



**Figure 11.12** A clownfish living among a sea anemone's tentacles is protected from predators and provides nutrients to the anemone. This is an example of mutualism.

#### symbiotic relationship

any type of close and long-term relationship between two types of living organism

#### mutualism

a symbiotic relationship where both organisms benefit

#### pollinator

an organism, such as an insect, that carries pollen from one plant, or part of a plant, to another



VIDEO  
Relationships  
between  
organisms

## Advances in science 11.1

### A strange relationship between salamanders and algae

In 2017, scientists discovered a new type of symbiotic relationship between salamanders and algae, and a very strange one at that! In a bizarre and intimate arrangement, these two very different species seem to share cells. The photosynthetic algae make their home inside the body cells of the salamander but it is not clear what benefit this has. The algae were already known to grow inside the egg capsule of the salamander, which was a mutualistic relationship. The algae releases oxygen into the egg capsule and feeds off the nitrogen-rich waste the egg produces.

Scientists sequenced the DNA of both organisms, revealing that the salamander does still recognise the algae as 'foreign'. They hypothesise that it might potentially benefit the salamander by teaching its immune system to not let disease-causing agents migrate into their cells in the future.



**Figure 11.13** The spotted salamander, *Ambystoma maculatum*, has an unusual symbiotic relationship with a green alga, *Oophila amblystomatis*.

## Commensalism

**Commensalism** is a symbiotic relationship in which one organism benefits, while the other organism is

**commensalism**  
a symbiotic relationship where one organism benefits and the other neither benefits nor is harmed

**parasitism**  
a symbiotic relationship where a parasite benefits from living on or in a host (which is harmed)

not affected (gains neither harm nor benefit). These types of relationships are much rarer than mutualism or parasitism. One example is that of cattle egrets, which hang around grazing cattle

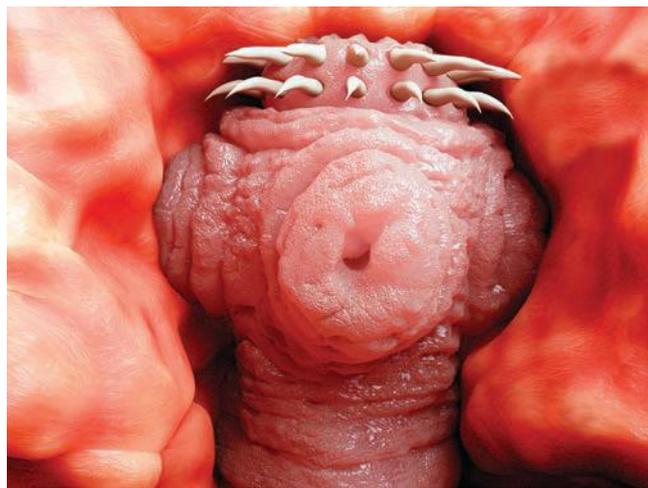
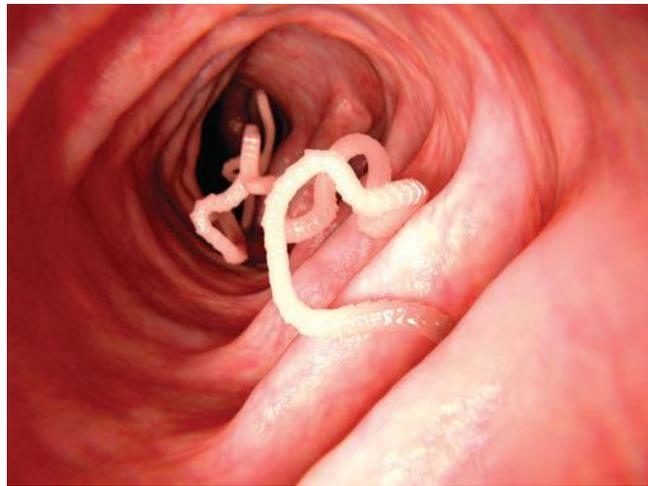
(and other animals) to catch insects that are stirred up. The cattle receive no benefit or harm. Other examples include hermit crabs using the shells from dead snails (seashells) as their homes and mites getting a 'free ride' by attaching to other larger insects.



**Figure 11.14** A cattle egret waiting to catch insects stirred up by a feeding cow

## Parasitism

**Parasitism** is a symbiotic relationship in which one species benefits and the other is harmed. The species that benefits is called the parasite and the one that is harmed is the host. The host is harmed, but not usually killed, as then the parasite would die too! Instead, the parasite survives on or in the host, and causes minor damage such as stealing nutrients.



**Figure 11.15** These tapeworms are endoparasites that inhabit the digestive tracts of animals (including humans). Tapeworms use their specialised hooks to anchor themselves in the intestine and absorb nutrients through their body wall. Disturbingly, they can grow to several metres in length, but they do not necessarily cause symptoms.

There are two main types of parasites: ectoparasites and endoparasites. 'Ecto' means outer or external, so ectoparasites live on the surface of other organisms, for example, lice found on a lizard. 'Endo' means inner or internal, so endoparasites are found living inside other organisms. An example of an endoparasite is a tapeworm living in a sheep's digestive system. Many species of animals are parasites, at least during some stage of their life. Most species are also host to one or more parasites.

## Quick check 11.6

- 1 Complete the following table, describing the types of relationships between organisms. Use a smiley face, sad face or neutral face to represent how each organism is affected.

Relationship	Definition	Organism 1	Organism 2
Competition			
Mutualism			
Commensalism			
Parasitism			

- 2 Contrast an ectoparasite and an endoparasite.

## Predator–prey

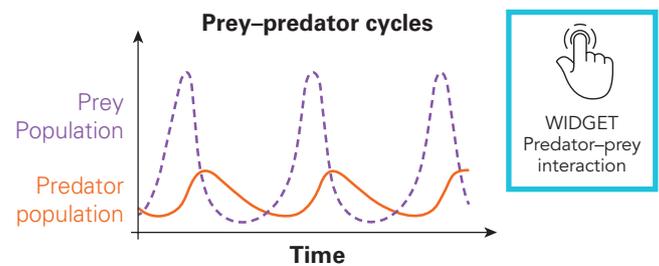
A predator–prey relationship occurs when one organism, known as the **predator**, kills and eats another organism, known as the **prey**. It is unusual for predators to depend upon one species of prey, so if one prey species reduces in supply, the predator can prey upon other species. For example, foxes prey on rabbits, but are also capable of hunting and eating newborn lambs and other small mammals.

The relationship between predator and prey is usually balanced, but occasionally there is a change in balance due to a change in conditions. For example, favourable conditions may lead to an increase in the prey population, which in turn can lead to an increase in the number of predators. If a period of adverse conditions occurs to reduce the prey population, predators will

turn to another prey species and there may be an increase in intraspecific competition among the predators.

**predator**  
an animal that hunts other animals as its source of food

**prey**  
a living animal that is captured and eaten by a predator



**Figure 11.16** Predator and prey populations exhibit fluctuations in size where numbers of each are largely dependent on the other. Other factors, such as winter food shortage or drought, may also be important.

## Try this 11.5

Feral rabbits do have natural predators such as the red fox; however, their ability to reproduce quickly has seen rabbits continue to thrive within Australia. Generally, if there is a shortage of prey, then there will be fewer predators surviving in that environment. Another predator and prey relationship occurring in the deserts of Australia is that of the red kangaroo and the dingo. The dingo is the apex predator in this biome and although they do not usually prey on kangaroos, they will hunt and kill them when food is scarce.

*continued...*

...continued

Using the graph (Figure 11.17), answer the following questions.

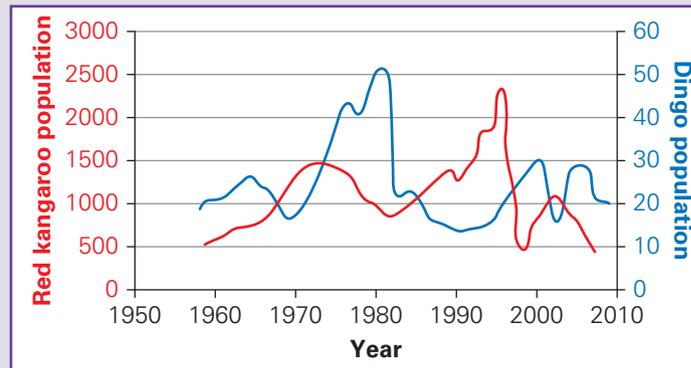
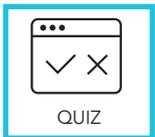


Figure 11.17 Population sizes over time for the dingo (in blue) and the red kangaroo (in red)

- 1 When was the greatest abundance of red kangaroos?
- 2 What happens to the dingo population as red kangaroo numbers increase?
- 3 Examine what happens to the dingo population size when the red kangaroo population size decreases.
- 4 Describe the pattern of the predator–prey relationship shown in the graph.
- 5 Identify and discuss a factor, other than the red kangaroo population, that may influence the size of the dingo population.
- 6 Identify and discuss a factor, other than the dingo population, that may influence the size of the red kangaroo population.

## Section 11.2 questions



### Remembering

- 1 **Identify** the type of symbiotic relationship a pollinator and a plant share.
- 2 When there is a large increase in the population size of an animal that is prey, **identify** what tends to happen to the population size of the predators.

### Understanding

- 3 **Classify** the type of competition between two male bull elephants when they fight for access to females.
- 4 **Explain** what is meant by an organism's 'ecological niche'.
- 5 **Compare** the roles of a bee and a flower in their mutualistic relationship.

### Applying

- 6 If all the predators from an area were removed, **discuss** the positive and negative effects on the overall sustainability of the ecosystem.
- 7 **Define** the following terms in your own words, detailing the types of relationships between organisms. **Name** an example for each relationship that has not appeared in this chapter.
  - Competition – interspecific
  - Competition – intraspecific
  - Mutualism
  - Commensalism
  - Parasitism
  - Predator–prey

- 8 **List** three examples of predators and research what their preferred prey is.
- 9 A 'parasitoid' has characteristics that are halfway between a parasite and a predator. An example of this is a female wasp who lays her eggs just underneath the skin of a caterpillar. When they hatch, they eat the host from the inside out. **Identify** which elements of this interaction are like a parasite and which are like a predator.

### Analysing

- 10 **Compare** and contrast the role of an ectoparasite and an endoparasite, providing examples for each.
- 11 **Examine** the role of mutualistic relationships within ecosystems, using examples not already used in this chapter.

### Evaluating

- 12 The table below shows population numbers of feral rabbits and red fox, by year, in a specific niche. Answer the questions that follow.

Year	Feral rabbits	Red fox
1900	18 000	6 000
1910	65 000	18 000
1920	40 000	61 000
1930	28 000	28 000
1940	25 000	4 000
1950	51 000	10 000
1960	70 000	32 000
1970	30 000	42 000
1980	52 000	11 000
1990	78 000	28 000
2000	18 000	42 000
2010	4 000	5 000

- a Using the above data, **produce** two line graphs on the same graph. Be sure to include all the appropriate labels including title, label of *x*-axis, label of *y*-axis and a legend.
- b These population graphs are said to fluctuate. **Explain** what this means, using data from the graph.
- c **Propose** reasons for the relationship between the two population graphs.
- d It can be stated that a good predator–prey relationship keeps the two populations 'in balance'. **Discuss** what this means.
- 13 **Justify** the importance of both interspecific and intraspecific competition within an ecosystem.
- 14 **Decide** whether the following descriptions are examples of mutualism, commensalism or parasitism.
- a A man notices he has tinea (a fungus) growing between his toes.
- b A woman notices her cat looks very bloated. She takes it to the vet and they suggest deworming the cat, as it likely has tapeworm.
- c Small fish swim around on the back of whalesharks for protection from predators.
- d Birds stand close to wild buffalo and eat the insects that are stirred up as the buffalo graze.

# 11.3 Population dynamics within ecosystems

## Learning goals

- 1 To describe factors that contribute to a change in population size
- 2 To outline methods used to determine the size of a population
- 3 To select a sampling method to estimate the abundance or density of a species, based on the organism and the area being studied
- 4 To discuss, using examples, human impacts on population dynamics of ecosystems as well as strategies used to manage their conservation
- 5 To outline ways that Aboriginal and Torres Strait Islander peoples' cultural practices and knowledge of the environment contribute to the conservation and management of sustainable ecosystems



## How does population size change?

Population sizes may fluctuate within an ecosystem. Demography is the name we

give to the study of vital statistics that affect population size. Four primary ecological factors determine population size.

- Births
- Deaths
- Immigration
- Emigration

It is the combination of these four factors that produce the change in the size of a population over time.

**Immigration** refers to the movement of individuals **into** the population, whereas **emigration** refers to the movement of individuals **out of** a population. The equation below best represents this change in population size.

**immigration**  
the movement of individuals into the population

**emigration**  
the movement of individuals out of the population

**quadrat**  
a tool used to measure species abundance

It makes sense that if the sum of the births and immigration is greater than the deaths and emigration of the population, then the population will increase in size, and vice

versa. The many biotic and abiotic factors that affect population size are known as secondary ecological events because their influence occurs via their effect on one or more of the primary ecological factors.

Other factors that can limit population growth include:

- shelter (for example, owls that rely on hollows in trees will search new locations for nesting spots)
- the number of predators
- the availability of water
- the balance of male and female numbers
- the presence of diseases.

## Methods used to determine the size of a population

### Using a quadrat

In some cases, it may be possible to count the number of individuals of a particular species, for example, the number of echidnas in an area of state forest. However, in most cases counting all the individual organisms is impossible or impractical, so a sampling method may be necessary. A **quadrat** is a tool used to record the abundance or density of a particular species in a study area, so that you don't need to record every organism across the whole study area. It is particularly useful for plants, slow-moving animals and marine algae.

$$\text{change in population size} = (\text{births} + \text{immigration}) - (\text{deaths} + \text{emigration})$$

Using information from your quadrats, you can estimate the population number and density of each species over the whole study area.

A quadrat is placed using random sampling or systematic sampling within the area you are studying. To achieve truly **random sampling**, a grid of numbers and letters should be laid over the sampling area and specific sampling sites should be chosen on the basis of randomly generated combinations of numbers and letters. **Systematic sampling** may involve you placing a quadrat in an ordered way along a transect line, or on a grid arrangement through the area being sampled.

Once you have your sampling strategy, you can measure the species you are studying within the quadrat: either count the number of individuals or estimate the percentage cover. Direct counts are suitable when counting animals or larger plants. However, when a plant is abundant, percentage cover is more appropriate.

**random sampling**  
a sampling technique where each sample has an equal chance of being selected

**systematic sampling**  
a sampling technique where each sample is taken at fixed intervals that have been previously decided upon

When directly counting the number of plants or animals, you can calculate the average number of individuals (total number of individuals counted divided by number of quadrats), and then calculate the total population using the following equation:

$$\text{total population} = \frac{\text{average number per quadrat} \times \text{total area being studied}}{\text{area of quadrat}}$$

For example, four quadrats of one square metre are randomly placed in a bushland area of 1200 square metres (m<sup>2</sup>) and the number of native orchids is directly counted. The results are as follows:

Quadrat	Number of orchids
1	3
2	1
3	2
4	0

The average number of orchids per quadrat is  $\frac{6 \text{ in total}}{4 \text{ quadrats}} = 1.5$  orchids.

The best estimate of the total population of orchids in this bushland area using the formula is:

$$\text{total population} = \frac{\text{average number per quadrat} \times \text{total area being studied}}{\text{area of quadrat}} = \frac{1.5 \times 1200}{1} = 1800 \text{ orchids}$$

total population = 1800 orchids

The native violet (*Viola banksii*) is a small, spreading ground cover that is found in shady areas. Due to its abundance, it is difficult to do a direct count, so percentage cover should be used instead.

Each quadrat can be split into smaller squares. When estimating, you should count the number of squares that the plant fills. For partly filled squares, you should ignore those that are less than half filled.



**Figure 11.18** Setting up quadrats and counting plants. (a) A quadrat for measuring native violet. (b) In this example, the dark green plant covers 25% of the 1 m by 1 m quadrat.

In Figure 11.18 a the quadrat has been divided into 25 squares. This means that each square is 4% of the total quadrat area. The native violet covers approximately five squares, so it covers 20% of the ground.

When sampling an area with four quadrats, you found the following results:

Quadrat	Percentage cover (%)
1	13
2	16
3	20
4	25

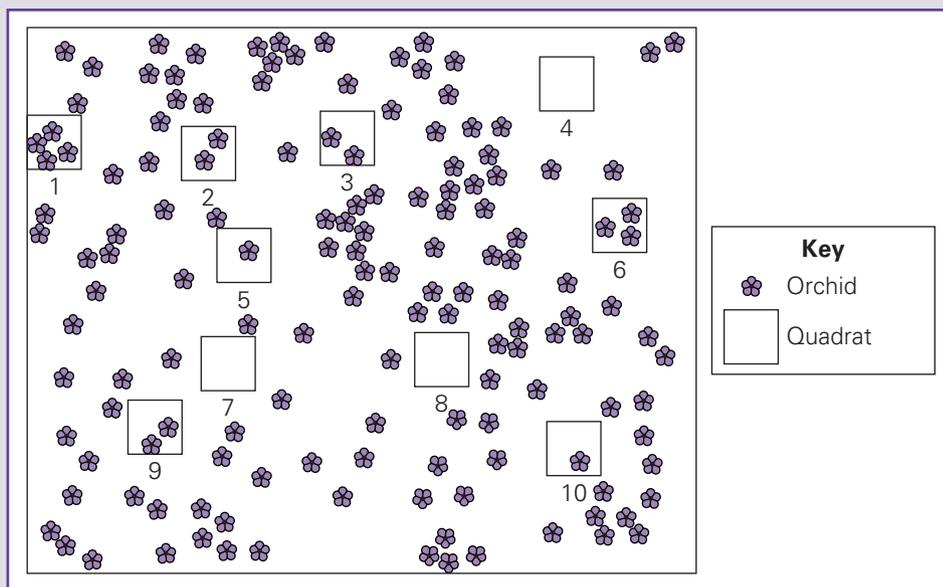
Therefore, the average percentage cover of native violet is  $\frac{74}{4} = 18.5\%$

**Try this 11.6**

**Sampling an ecosystem**

Some Year 9 students wanted to find the number of orchids growing in bushland. The students placed 10 quadrats at different positions on the lawn. Each quadrat measured 1 m × 1 m. The students counted the number of orchids in each quadrat.

- 1 Describe a method that students could use to decide where to place the 10 quadrats.
- 2 The diagram shows the lawn with the positions of the orchids and the quadrats.



Complete the table to show:

- how many orchids were found in each of the quadrats
- the total number of orchids in the quadrats.

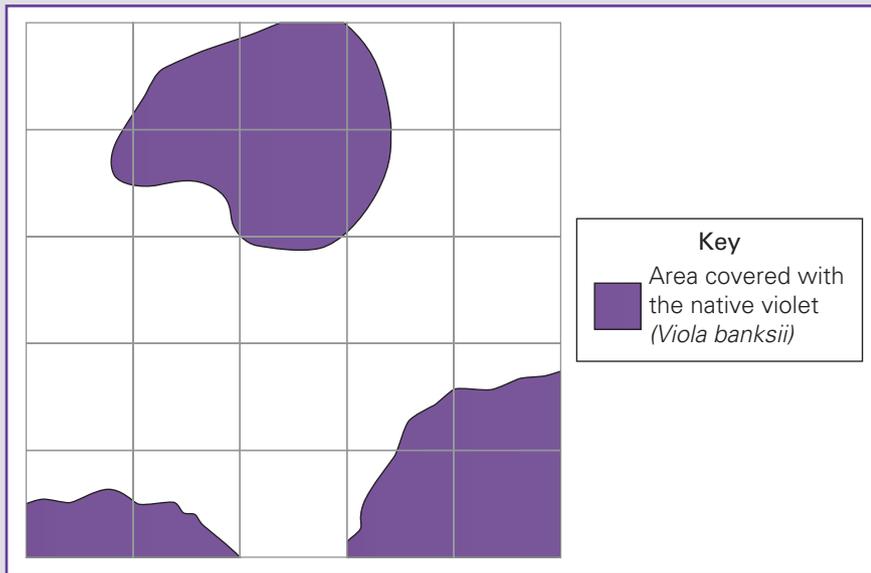
Quadrat number	Number of orchids
1	
2	
3	
4	
5	1
6	3
7	0
8	0
9	2
10	1
Total	

- 3 Calculate the mean number of orchids per quadrat.
- 4 The bushland measured 120 m long and 100 m wide. Estimate the number of orchids in the bushland.

*continued...*

...continued

The students then decided to investigate the percentage cover of native violet inside a quadrat.



- 5 Estimate the number of squares covered with native violet.
- 6 Describe how you worked out your answer to question 5.
- 7 Use your answer from question 5 to calculate the percentage cover of native violet.
- 8 Suggest a strength and a limitation of using a quadrat to determine plant abundance in certain areas.

## Capture–mark–recapture

### capture–mark–recapture method

a method for estimating animal population sizes that involves capturing, tagging, releasing and recapturing a sample of the population

Measuring the population size of fast-moving animal species is sometimes difficult. A suitable way of measuring population size, rather than

setting up quadrats or individually counting all the individuals within the species, is the **capture–mark–recapture method**.

- 1 Ecologists capture a sample of the species.
- 2 These individuals are tagged or marked in an inconspicuous way, ensuring any handling is humane and considerate of the animal's needs, and then released.
- 3 Sometime later, another sample is captured from the population.
- 4 Ecologists count how many marked individuals are in the second sample, and use this information to estimate the population size using the Lincoln Index:

$$N = \frac{M \times n}{m}$$

where

$N$  = Population estimate

$M$  = Number of animals captured and marked in first sample

$n$  = Number of animals captured in second sample

$m$  = Number of  $n$  that were already marked

## Investigating ecosystems in Australia

When planning field investigations, it is important to acknowledge Aboriginal and Torres Strait Islander peoples of the land. This may involve but is not limited to the following recommendations.

- Understand that Aboriginal and Torres Strait Islander peoples may have information that will help formulate hypotheses.

- Collaborate with a local First Nations community. Field investigations might disturb the environment and affect the local community.
- Acknowledge cultural heritage sites, which might be protected under legislation. It is important to follow and honour legal obligations, particularly when planning field investigations.

### Try this 11.7

#### Capture–mark–recapture modelling

- 1 Several chocolates (M&Ms) have been put in a container. Look in the container and estimate how many M&Ms there are. Record your estimate.
- 2 Using a spoon, dig out a sample of M&Ms. This is your first trapping sample,  $M$ . Record how many chocolates there are.
- 3 To 'mark' these M&Ms, simply replace them with Smarties. Place these 'marked individuals' back into the population (container).
- 4 Shake the container and, without looking, remove another spoonful of chocolates. This is your second trapping sample,  $n$ . Record how many chocolates there are.
- 5 How many of the chocolates in your second trapping sample were Smarties? This is  $m$ . Record it.
- 6 Now use the Lincoln Index equation to calculate your population estimate,  $N$ .
- 7 Count the actual total number of chocolates in the container. Record the number.
- 8 Was your estimate using the formula closer than your initial guess?
- 9 Suggest some ways that you could increase the accuracy of your estimate.
- 10 Deduce for which species of animal this technique would work well and for which species would it not work well. Justify your opinions.

#### Be careful

No food items are to be consumed.

### Quick check 11.7

- 1 For each of the following organisms, state if a quadrat would be an appropriate tool for estimating the population.
  - a Hawks
  - b Cacti
  - c Starfish
  - d Beetles
- 2 Organise the following statements in the correct order to show how to estimate the number of organisms in an area.
  - A Count the number of organisms present in the quadrat
  - B Randomly place the quadrats
  - C Multiply by the number of quadrats that would occupy the area you wish to estimate the population within
  - D Calculate the average number of organisms per quadrat
- 3 A biologist captures a sample of wallabies and tags them for later identification. A year later, another sample is captured and the number of tagged wallabies is used to estimate the population size. Recall the name of this method.

## Advances in science 11.2

### Using drones for population sampling

Are ecologists working in the field a thing of the past? A 2018 study suggests that drones are more accurate at counting populations of wildlife than doing it the old-fashioned way! Whereas a ground-counting researcher needs to find a good location and rely on a set of binoculars, a drone can hover above the colony of animals and get a superior vantage point. The digital images taken by the drones can then be re-used later if researchers want to review the data manually.

More research is required into the impact of the drones on the wildlife so that drone protocols can be established to ensure the animals are not unduly stressed.



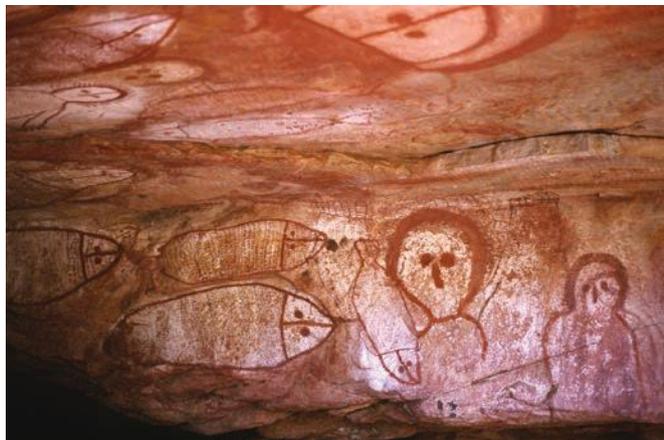
**Figure 11.19** A drone collecting data on elephant numbers in Botswana

### Human impact on population dynamics

Aboriginal and Torres Strait Islander peoples have a ‘Caring for Country’ approach whereby they consider themselves an interdependent part of any environment rather than above or separated from it. They have a deep appreciation and respect of the natural environment and an ingrained responsibility to sustainably maintain the ecosystems they’re part of.

An example of this is the hunting techniques used by Aboriginal and Torres Strait Islander peoples to

catch marine animals. They are based on long-term sustainability, and animals are recognised as being both an important food source and essential to the marine environment. Totemic relationships also underpin what can and can’t be hunted by individuals, reinforcing sustainability. Archaeological evidence shows us that Aboriginal and Torres Strait Islander peoples have been hunting and eating dugongs and turtles for thousands of years – their sustainable hunting approach has ensured the continuity of populations. For example, hunters select young, male dugongs rather than pregnant or nursing females.



**Figure 11.20** Rock art paintings of a turtle (left) from Arnhem Land, Northern Territory, and dugongs (right) in West Kimberley, Western Australia

**invasive species**  
an organism that is outside its natural distribution and causes harm to an environment

Since European settlement in Australia, many different organisms have been moved from one part of the country to another or have been brought to Australia from overseas. This was done either deliberately or accidentally. Introduced species have caused many environmental problems including threatening native species.

An organism that is outside its usual range of distribution and causes harm to the environment is known as an **invasive species**. A range of organisms have become invasive.

- The feral rabbit and feral camel are examples of introduced animals.
- The plant disease myrtle rust was first discovered in April 2010. It has now spread from New South Wales to Queensland, Victoria, Tasmania and the Northern Territory, threatening several plant species.

- The Athel pine is considered a weed in Australia and has economic and environmental impacts. It consumes water more quickly than native plants, reducing water holes. It also excretes concentrated salt through its leaves, making the ground underneath much saltier and preventing native pasture grasses from growing. This alters the flow pattern of rivers, causing flooding and bank erosions.

Unfortunately, some native animals have disappeared or have suffered due to a loss of habitat or competition and predation by a variety of introduced animals. This has resulted in adverse effects on the ecosystems that exist within Australia. Of Australia's threatened and endangered species, 1257 are directly affected by invasive species (207 plants, 57 animals and three pathogens).

### Section 11.3 questions

#### Remembering

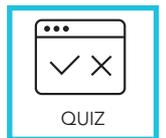
- 1 **State** two events that can increase a population size and two events that can decrease a population size.
- 2 **Identify** what a quadrat is used to estimate.
- 3 **Outline** the equation used to estimate the population size of a species using the capture–mark–recapture process. Define the variables (letters) in your answer.
- 4 **State** the word equation used to represent the change in population size.

#### Understanding

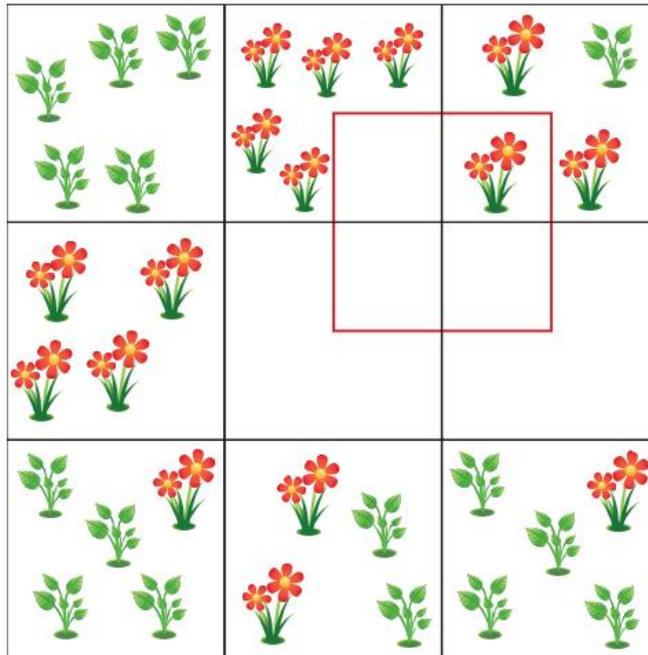
- 5 **Summarise** the key advantages of using quadrats to determine the population size of marine algae within a tidal coast ecosystem.
- 6 An ecologist wants to estimate the number of birds living in a wetland. **Suggest** a reason why a quadrat would not be an appropriate tool.

#### Applying

- 7 Using your understanding of the equation used to represent change in population size, **predict** what would happen to the size of a feral rabbit population, should an increase in predators and decrease in food source occur.
- 8 **Model** this scenario using beads or counters.  
A population of 10 wallabies immigrates into a new area. Eight of the wallabies have a joey, one of whom dies when only a few days old. One of the male wallabies is shot by a farmer, and two new wallabies immigrate into their mob. How many wallabies remain?



- 9 A plant biologist undertook a quadrat technique to estimate the population size of the red-flowered plant. The red square shows the placement of the quadrat. Based on the results, **estimate** the population of the red flowered plant in this ecosystem and compare your result to the actual population size.



- 10 **Estimate** the population size of the northern hairy-nosed wombat given the following information from a capture–mark–recapture study: animals were captured and marked in the first sample, 60 were captured in the second sample, and 30 of this second sample already marked from the first sample.

### Analysing

- 11 **Discuss** how the capture–mark–recapture method is used to estimate population size within ecosystems.
- 12 ‘Carrying capacity’ refers to the number of individuals which current resources can sustain. **Analyse** the following statement: ‘The population size is only as big as its carrying capacity.’ In your analysis, discuss what factors come into play once the population size exceeds carrying capacity.
- 13 **Develop** three possible reasons why a species may immigrate to a new habitat.

### Evaluating

- 14 **Deduce** the impacts of the following introduced species on the Australian ecosystem and copy and complete the following table. You may need to research the consequences and possible solutions to the following introduced species.

Introduced species	Consequence to Australia’s ecosystem	Possible solutions
Feral camels		
Feral rabbits		
Cane toads	Predators were poisoned by the toads, allowing other smaller prey to increase in number.	
Feral cats	They have caused declines in a number of small native mammals and birds and are an obstacle to reintroducing nearly extinct native species.	
Red fox		

- 15 Knowledge of the natural world is key to Aboriginal and Torres Strait Islander peoples. **Deduce** how the introduction of invasive species may have influenced or affected the traditions and culture.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>11.1 I can distinguish between the different components of an ecosystem.</b> e.g. Organise the following from small to large in terms of their ecological scope: population, individual, ecosystem, community, biome.	
<b>11.1 I can describe how energy flows through an ecosystem.</b> e.g. Recall what the arrow means in a food chain.	
<b>11.1 I can describe different trophic levels of an ecosystem.</b> e.g. Compare an autotroph and a heterotroph.	
<b>11.1 I can recall the equations for respiration and photosynthesis.</b> e.g. State the balanced symbol equation for respiration.	
<b>11.2 I can discuss how organisms interact within an ecosystem.</b> e.g. Describe commensalism, giving an appropriate example.	
<b>11.3 I can calculate population size using <math>\text{Change in population size} = (\text{births} + \text{immigration}) - (\text{deaths} + \text{emigration})</math>.</b> e.g. Calculate the population of kangaroos if 16 new joeys were born, 23 moved in from another area, 80 died from natural causes and none left the area.	
<b>11.3 I can describe how to estimate population size of organisms in an area.</b> e.g. Explain the capture–mark–recapture method.	



## Reflections

- 1 What **connections** come to mind when you think about ecosystems and your everyday life?
- 2 What new concepts have **extended** your thinking about ecosystems?
- 3 What information did you find **challenging** or confusing?



### Data questions

Figure 11.21 depicts the changing populations of dingo and red kangaroo in a desert region of Australia over a 50-year period.

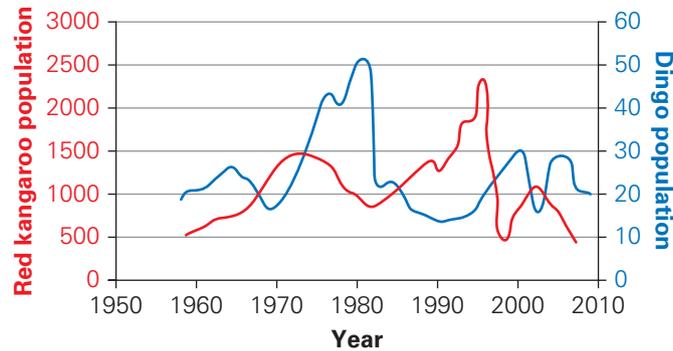


Figure 11.21 Red kangaroo and dingo populations from 1950 to 2010

- 1 **Identify** which line colour represents the population of dingoes over time.
- 2 **Estimate** the population of dingoes in the year 2000.
- 3 **Identify** the year that had the largest dingo population.
- 4 **Identify** the pattern between the two populations with reference to the terms 'predator' and 'prey'.
- 5 **Deduce** the population of red kangaroos when the population of dingoes was at its peak.
- 6 **Infer** why the red kangaroo population was greatest in the mid-1990s.
- 7 In the year 2015 the red kangaroo population fell to a trough of approximately 300 in this region. **Predict** how the dingo population might have changed in this time.
- 8 **Predict** the populations of red kangaroos and dingoes in 2030 given the data in Figure 11.21.



## STEM activity: Saving an endangered species

**Design brief:** Design a product that can help an endangered species survive.

### Activity instructions

Taking on the role of an engineer, you and your team are going to work through the design process. First, you will need to select an endangered species from New South Wales to investigate and research, including the reasons why it is now endangered. You will then design a product that will help prevent your endangered species from becoming extinct. You will not build your product, so this allows you to come up with a greater range of ideas. Your design will be pitched to your fellow engineers in class, so you can all give and receive feedback on your designs as critical friends.

### Suggested materials

- internet access
- pencil
- paper

### Research and feasibility

- 1 Define in your own words the problem you are being asked to solve, and decide which endangered species your group will focus on.
- 2 Research and list all the factors that are currently affecting that endangered species.

Factor	Issues	Impact
e.g. Location	Deforestation	Insufficient homes for animals.

- 3 Discuss in your group the main factor (or combination of factors) that is causing the greatest impact and threatening your species with extinction.
- 4 Include in your research a map of New South Wales showing your species' distribution, and tabulated data showing the population change of your species over time.

### Design and sustainability

- 5 Considering all the factors you have researched, discuss in your group a possible solution to help rebuild the population of the endangered species.
- 6 Reflect on how to increase the sustainability of the area within New South Wales that your group is focusing on and how the environmental conditions can be improved.

### Create

- 7 Create a presentation (in any medium you wish) of your proposed solution. Draw a detailed design (including materials and annotations) for your solution, and describe how your design will work to solve the problem. Keep in mind what your prototype is made of and try to choose renewable resources.

### Evaluate and modify

- 8 Discuss and evaluate with your class the positive, negative and interesting features of each team's design.



**Figure 11.22** The grey nurse shark (*Carcharias taurus*) is considered a critically endangered species in NSW.

# Chapter 12

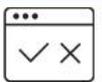
## Genetics

### Inquiry questions

What is the relationship between DNA, genes and chromosomes?

How is genetic information passed from one generation to the next?

What causes an organism's DNA to change and what effect does this have on the organism?

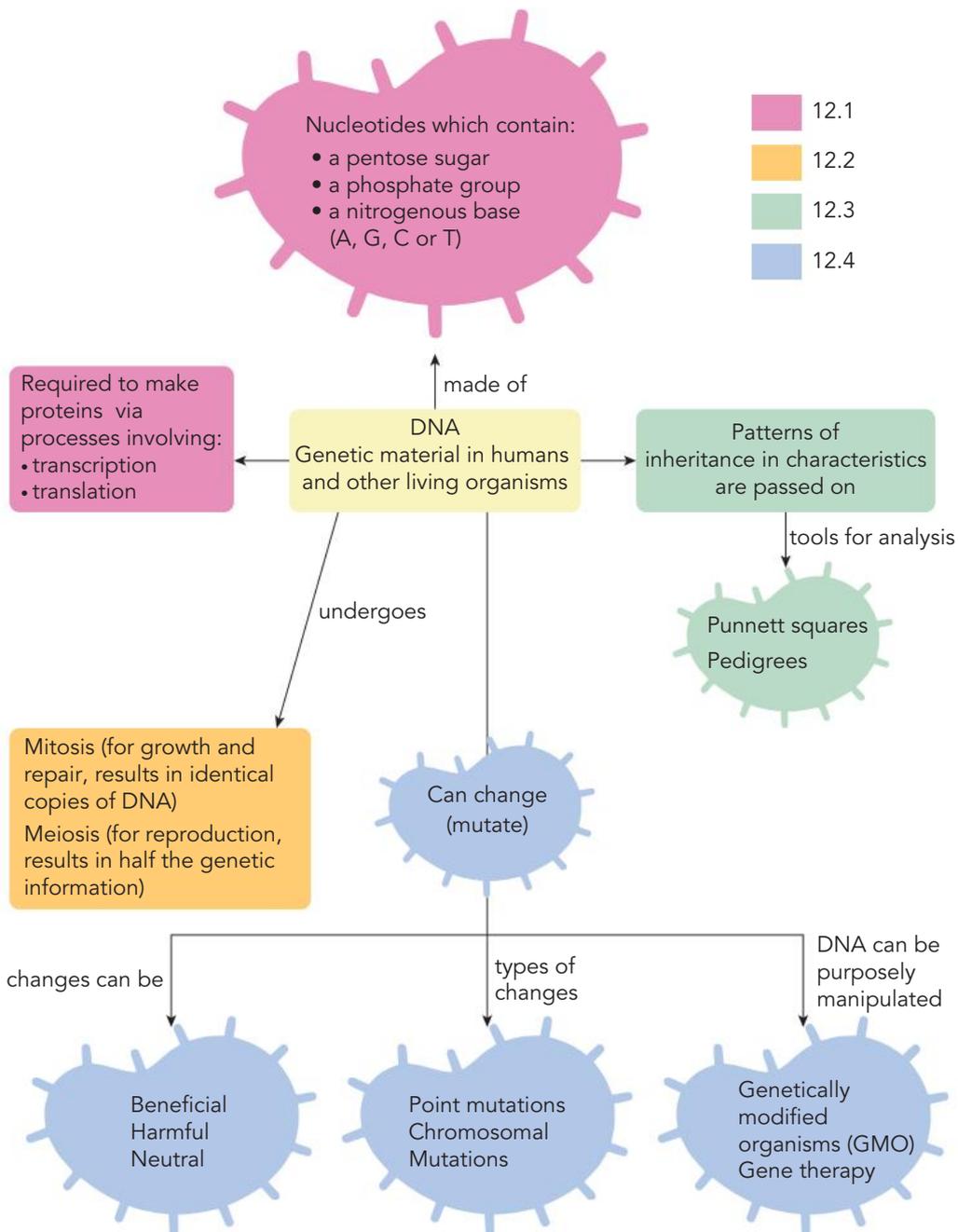


PRE-TEST

### Chapter introduction

Everyone is unique. That is thanks to the genetic make-up we all have within us, known as DNA. DNA carries the important instructions that make us who we are. This chapter delves into the DNA molecule and the important role that genes play in the inheritance of the characteristics that make us who we are. Geneticists rely upon DNA in many different areas; for example, to examine the probability of passing on traits to offspring and to assist with forensic investigations by using DNA profiling. You will also examine the structure of DNA and the effect of mutations.

# Chapter map



# 12.1 Introduction to genetics and DNA

## Learning goals

- 1 To describe the Watson and Crick model of the structure of DNA
- 2 To define the terms chromosome and gene
- 3 To describe the relationship between DNA, genes and chromosomes
- 4 To briefly describe the role of proteins in the body
- 5 To describe the role of genes which code for a specific protein
- 6 To outline gene expression as the grouping of three bases in DNA to determine the type of amino acids that join together to form a protein strand

## Genetics



**Genetics** is the study of inheritance. Genetic information called deoxyribonucleic acid (**DNA**), which is contained in the nucleus of the cell, is passed on from generation

to generation. This results in traits or specific characteristics being passed on from parents to offspring, and occurs in all species – including humans.

**genetics**  
the study of inheritance

**DNA**  
genetic make-up that carries the instructions for life (deoxyribonucleic acid)

## Practical 12.1

### Extracting DNA from cells

#### Time period

30–45 minutes

#### Aim

To investigate and extract DNA from strawberries.

#### Materials

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

#### DNA extraction mixture:

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

#### Procedure

- 1 Wash strawberry with tap water, remove green leaves and add to plastic sandwich bag.
- 2 Add DNA extraction solution (10 mL) and close sandwich bag, removing excess air.
- 3 Squash strawberry into the liquid using hands until strawberry is sufficiently crushed.
- 4 Pour strawberry mixture through a filter funnel lined with gauze into a test tube.
- 5 Discard gauze and strawberry remains into a bin.
- 6 Add an equal volume (10 mL) of cold ethanol to the test tube using a plastic pipette.
- 7 Mix the two layers of liquid slowly with a skewer stick.
- 8 Collect white solid on the skewer stick. This is DNA.

#### Be careful

Wear safety glasses and a lab coat. No food items are to be consumed.

*continued...*

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### Results

Write observations for what occurred during each step of the method.

### Discussion

- 1 Describe whether the white solid could contain all of the DNA of the strawberry.
- 2 Compare the amount of solid collected visually to other groups in the classroom. Were results consistent?
- 3 Describe the variables that were not made consistent between groups in the classroom.
- 4 Suggest any changes that could be made to the method to improve the quality of the recorded data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

### Conclusion

Draw a conclusion regarding the efficiency of this method in extracting all the DNA from a strawberry, based on the observations from this experiment and other groups' observations.

## Structure of DNA

DNA is a double-stranded molecule that forms a 'double helix' shape, like a twisted ladder.

DNA is a **polymer** (*poly* means 'many') as it is made up of numerous subunits called **nucleotides**.

A nucleotide of DNA has three major components:

- a five-carbon deoxyribose sugar
- a nitrogenous base – one of adenine (A), guanine (G), cytosine (C) or thymine (T)
- a negatively charged phosphate group.

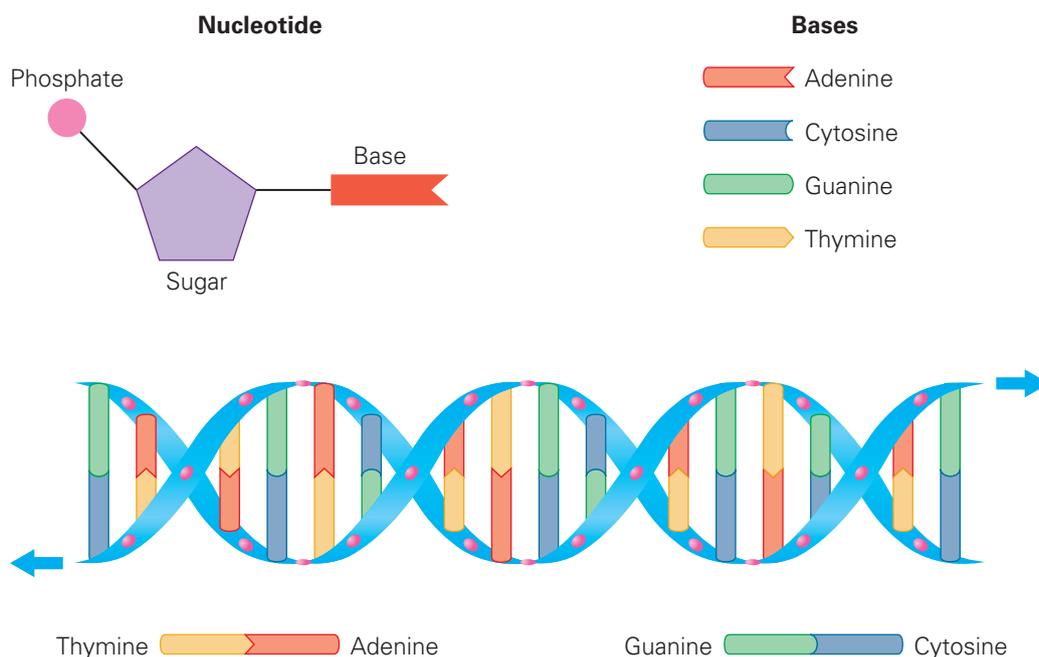
The nucleotides bind together to form two long strands. The two strands then bind together (using

**hydrogen bonds** between the nitrogenous bases) and twist to form the double helix (twisted ladder shape). The sugars and phosphates form what would be the side of the ladder (and are called the sugar–phosphate backbone), while the nitrogenous bases from one strand align towards the centre and bind to complementary bases on the other strand to form the rungs of the ladder.

**polymer**  
a substance composed of large and/or complex molecules (macromolecules) which are made up of multiple smaller and/or simpler subunits (monomers).

**nucleotide**  
a subunit of DNA, consisting of a phosphate group bound to a deoxyribose sugar, which in turn is bound to a nitrogenous base

**hydrogen bonds**  
chemical bonds that hold the two DNA strands together

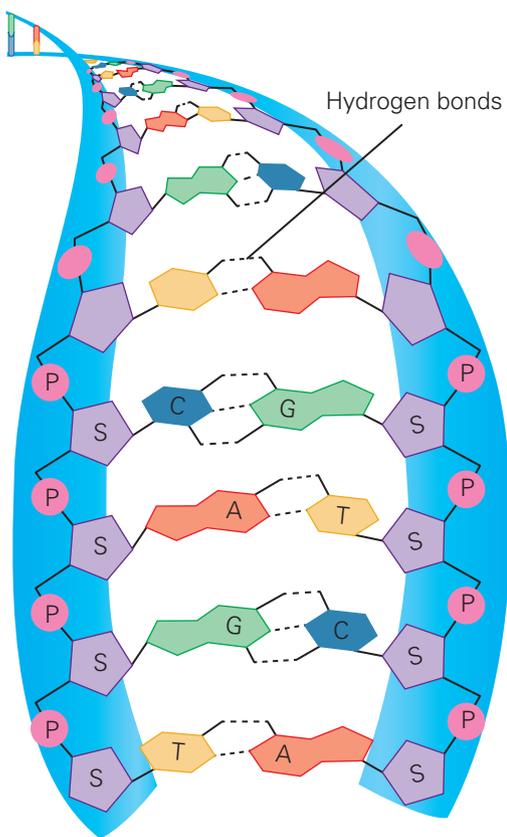


**Figure 12.1** The structure of DNA: the subunits called nucleotides all join up to form the double-stranded DNA. Note the sugar–phosphate backbone on the edge of the DNA molecule and the nitrogenous bases joining in the centre.

**complementary pairing**  
adenine only binds with  
thymine and cytosine only  
binds with guanine

As can be seen in Figure 12.1, the bases on one strand pair with the bases on another

strand: adenine (A) always pairs with thymine (T) and guanine (G) always pairs with cytosine (C). This pairing is called **complementary pairing** and has to do with the shape of the nitrogenous bases and the number of hydrogen bonds they need to form to hold the strands together. For example, you can see in Figure 12.2 that guanine and cytosine both form three hydrogen bonds, while adenine and thymine only form two hydrogen bonds.



**Figure 12.2** A closer look at the structure of DNA. The sugar-phosphate backbone forms the edge and the nitrogenous bases form complementary pairs in the centre. Hydrogen bonds hold the two strands together.

## Try this 12.1

### Modelling DNA using lollies

Remember not to consume the lollies in the classroom and to beware of allergies.

#### Materials

- liquorice ribbons or sour strips
- a handful of jelly babies
- cocktail sticks

#### Procedure

- 1 Sort the jelly babies into four groups of colours.
- 2 Pair up the jelly babies so that one particular colour always goes with another particular colour; for example, red with yellow and orange with green.
- 3 Place a pair of jelly babies onto each cocktail stick as if you were making lolly kebabs. Ensure that the pairs are always of matched colours.
- 4 Attach your lolly kebabs to the long strips of liquorice.
- 5 Keep doing this until you have about 5–7 horizontal cocktail sticks attached and it starts to look a bit like a ladder.
- 6 The paired coloured sweets represent the base pairs, while the liquorice is the sugar-phosphate backbone.
- 7 Pick up your lolly ladder and twist it to represent the double helix shape of DNA.

## Quick check 12.1

- 1 Recall the three key components that make up a nucleotide, the basic building block of DNA.
- 2 Describe the overall shape of DNA.
- 3 If a strand of DNA was to contain the nitrogenous bases seen below, state the bases in its complementary strand. One DNA strand: ATATAGATAGATCAGACA

## Explore! 12.1

### The discovery of DNA

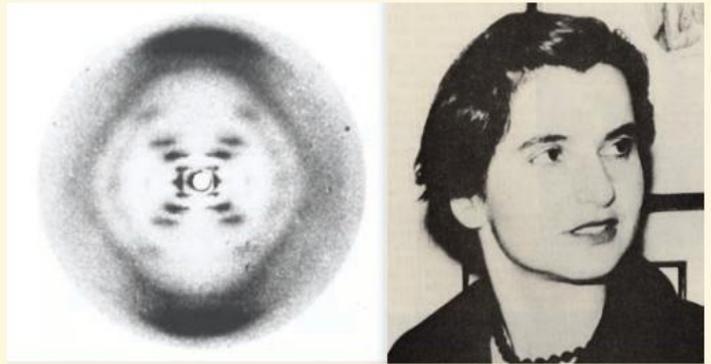
Friedrich Miescher was a German biochemist who first observed DNA in 1869. However, it took almost a century for scientists to understand the structure of DNA, the mechanisms by which it carries genetic information, and what it is made of.

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Research the following scientists who, among many others, contributed to our understanding of DNA. Produce a timeline by researching their contribution, the year this contribution was made and how it differed from/added to the previous scientist's contribution. Also comment on the importance of technology on the development of what we know about DNA now.

- Friedrich Miescher
- Erwin Chargaff
- Francis Crick and James Watson
- Rosalind Franklin
- Maurice Wilkins



**Figure 12.3** 'Photo 51' shown (left) was taken by Dr Rosalind Franklin (right) and Ray Gosling at King's College London in 1952, confirming the helical structure of DNA. This later enabled the first correct model of the DNA structure to be built.

## What is a chromosome?

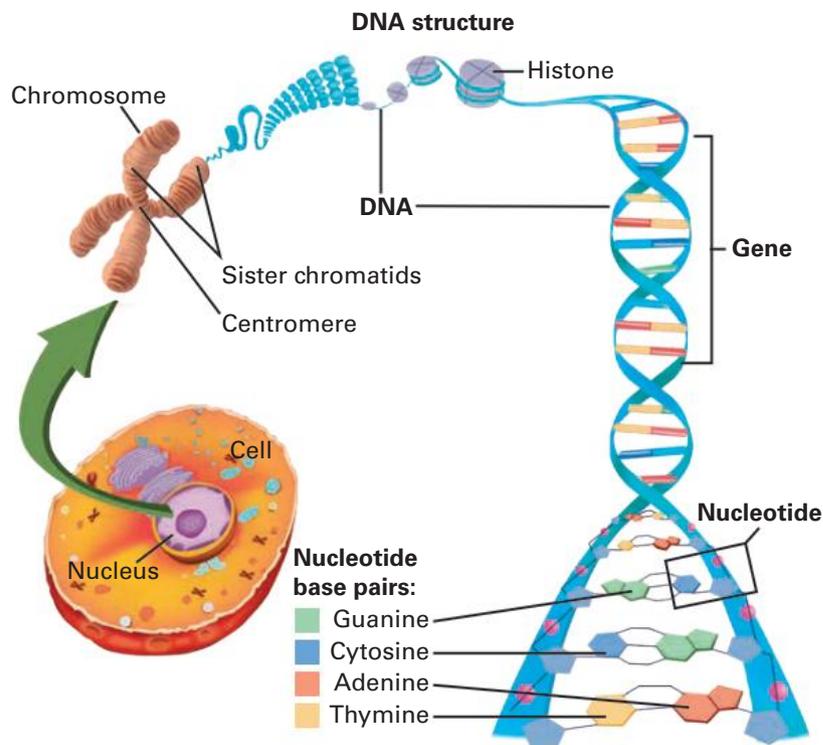
Just prior to cell replication, the DNA winds up tightly around proteins called histones to form structures called **chromosomes**. Each molecule of DNA condenses to form one chromosome. Along the chromosome are **genes**, which are the units of inheritance. Genes are actually just sections of DNA or chromosome that hold the specific instructions required for making each and every one of the proteins

in our bodies! Proteins are fundamental to all of the chemical reactions in an organism, and also form much of the structure of a chromosome due to the histones that DNA wraps around.

**chromosome**  
a structure of tightly wound DNA

**gene**  
a length of chromosome

You may be familiar with the X-shape of a chromosome, but this shape is only seen when DNA



**Figure 12.4** The relationship between DNA and chromosomes

**centromere**

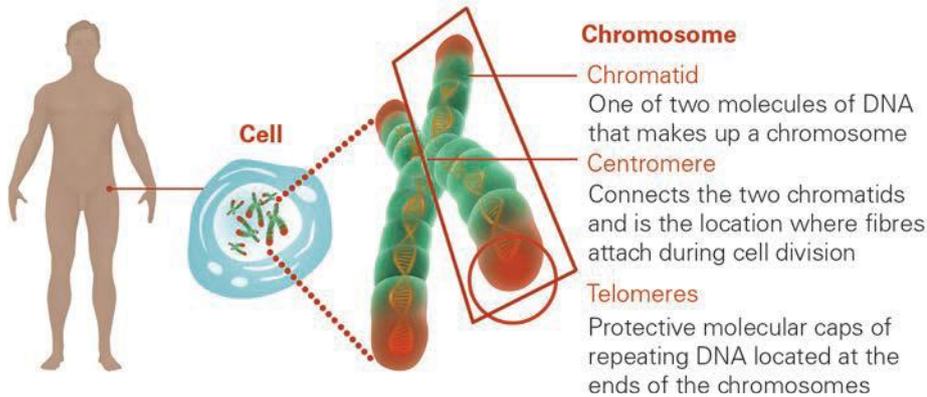
a structure that holds two sister chromatids together

**sister chromatids**

two copies of the same chromosome, connected at a centromere

replication (when DNA is copied) is occurring. Before replication, the chromosome appears as a single condensed DNA molecule. After replication, this produces two identical chromatids that are joined together by **centromeres** to form the distinct

X-shape; these are then known as **sister chromatids**. They belong to the same chromosome. Figure 12.5 shows this.



**Figure 12.5** The distinct X-shaped chromosome showing the two chromatids and the centromere.



**Figure 12.6** A scanning electron micrograph of a human chromosome. Notice the two identical chromatids joined at a centromere.

### Advances in science 12.1

#### Professor Elizabeth Blackburn

Born in Hobart in Tasmania, Australia, Elizabeth Blackburn took an early interest in nature and studied biochemistry at the University of Melbourne. She completed her PhD at Cambridge University, United Kingdom, and then went on to work in the United States. Through her research, she and her colleagues discovered that the ends of DNA, called telomeres, have a particular DNA that prevents chromosomes from breaking down. The enzyme telomerase produces the telomeres' DNA. Professor Elizabeth Blackburn was awarded the 2009 Nobel Prize in Physiology or Medicine together with her colleagues Jack W. Szostak and Carol Greider.



**Figure 12.7** Nobel Prize Laureate Professor Elizabeth Blackburn was integral to the research on telomeres.

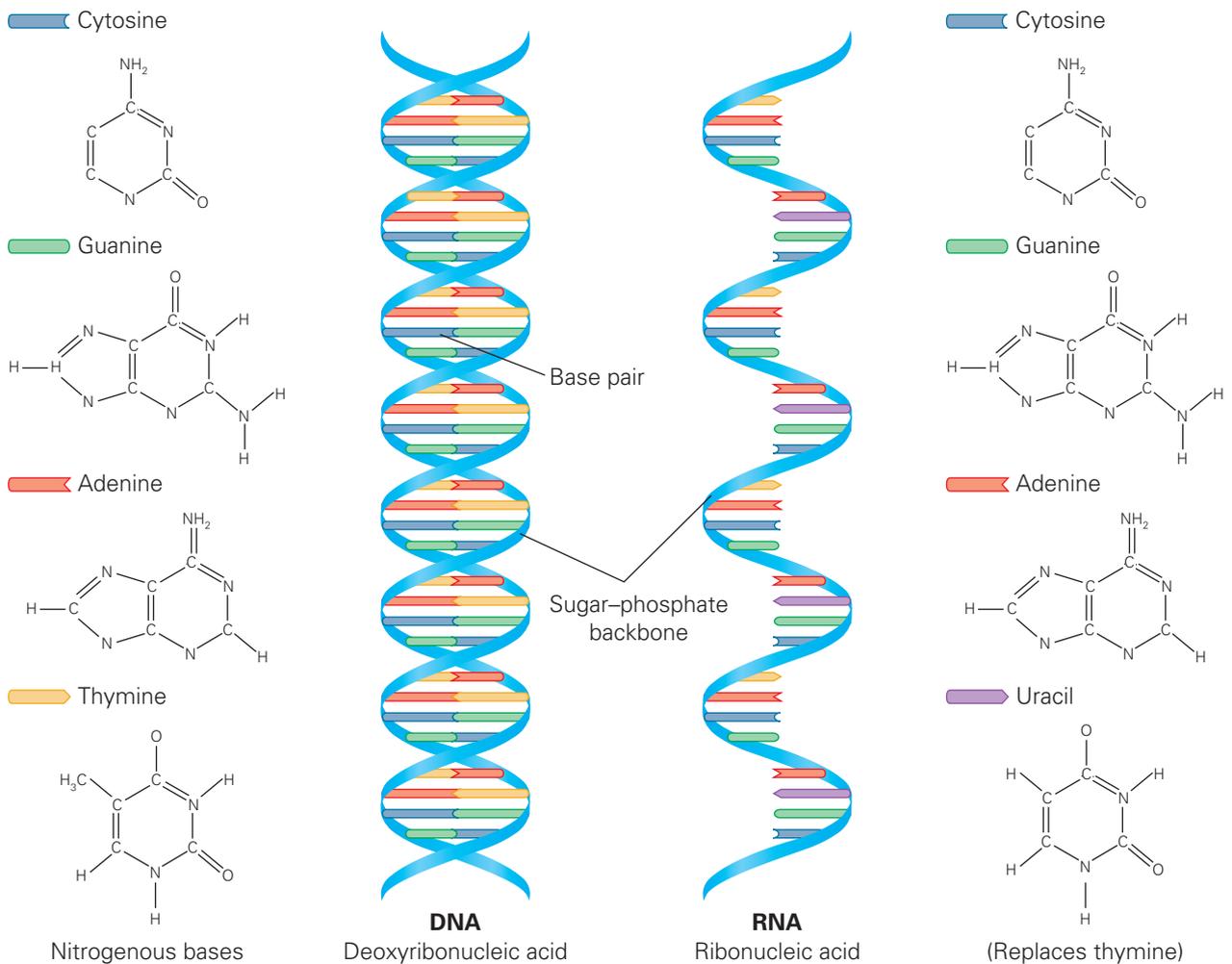
### Different forms of nucleic acids

There are four types of biomacromolecules: proteins, carbohydrates, lipids (fats and oils) and nucleic acids. Nucleic acids are found in two forms: DNA and

**ribonucleic acid (RNA)**. There are key differences between the two types of nucleic acids, which are outlined in Table 12.1.

	DNA	RNA
Number of strands	Two	One
Type of sugar	Deoxyribose	Ribose
Nitrogenous bases	Guanine Cytosine Adenine Thymine	Guanine Cytosine Adenine Uracil
Where is the molecule found?	In eukaryotes, DNA is found in the nucleus, mitochondria and chloroplasts. In prokaryotes, DNA is found within the cytoplasm.	Cytoplasm Nucleus Ribosomes
Different forms	DNA Mitochondrial DNA (mtDNA) Chloroplast DNA (cpDNA)	Messenger RNA (mRNA) Transfer RNA (tRNA) Ribosomal RNA (rRNA)

**Table 12.1** The main differences between the two nucleic acids, DNA and RNA



**Figure 12.8** DNA and RNA

**Quick check 12.2**

- 1 Describe the relationship between chromosomes, genes, DNA and base pairs.
- 2 Contrast the structures of DNA and RNA.

## The purpose of DNA: making proteins

### Why do we need proteins?

Proteins are complex molecules that play a critical role in many body functions. We make use of approximately one

#### base triplet

three DNA bases that code for an amino acid

#### transcription

the first stage of protein synthesis where the base sequence of DNA is copied into mRNA

#### translation

the second stage of protein synthesis where a sequence of mRNA is translated into a sequence of amino acids

billion proteins every day, just to function normally. Proteins play many and varied roles in the body. They are the main structural component of cells, they can build and repair tissue, and may include enzymes to break down substances.

Protein molecules include the

haemoglobin molecules that carry oxygen around our body, and the hormones that regulate our glucose levels and development. Collagen and keratin are structural proteins, making up the structural components of organs. Amylase and lipase are catalytic proteins that help control the rates of reactions. Other proteins help us fight pathogens, transport molecules and move our muscles.

### The link between DNA and proteins

Remember that genes are sections of DNA that hold the specific instructions required for making each of the

proteins in our bodies. The sequence of the nitrogenous bases in the gene provides these instructions (or code) for the production of proteins. Each group of three nitrogenous bases in DNA is called a **base triplet**, and each codes for a particular amino acid to be assembled. Amino acids are the subunits of proteins. The order of the base triplets specifies the sequence of amino acids that forms a particular protein.

### Quick check 12.3

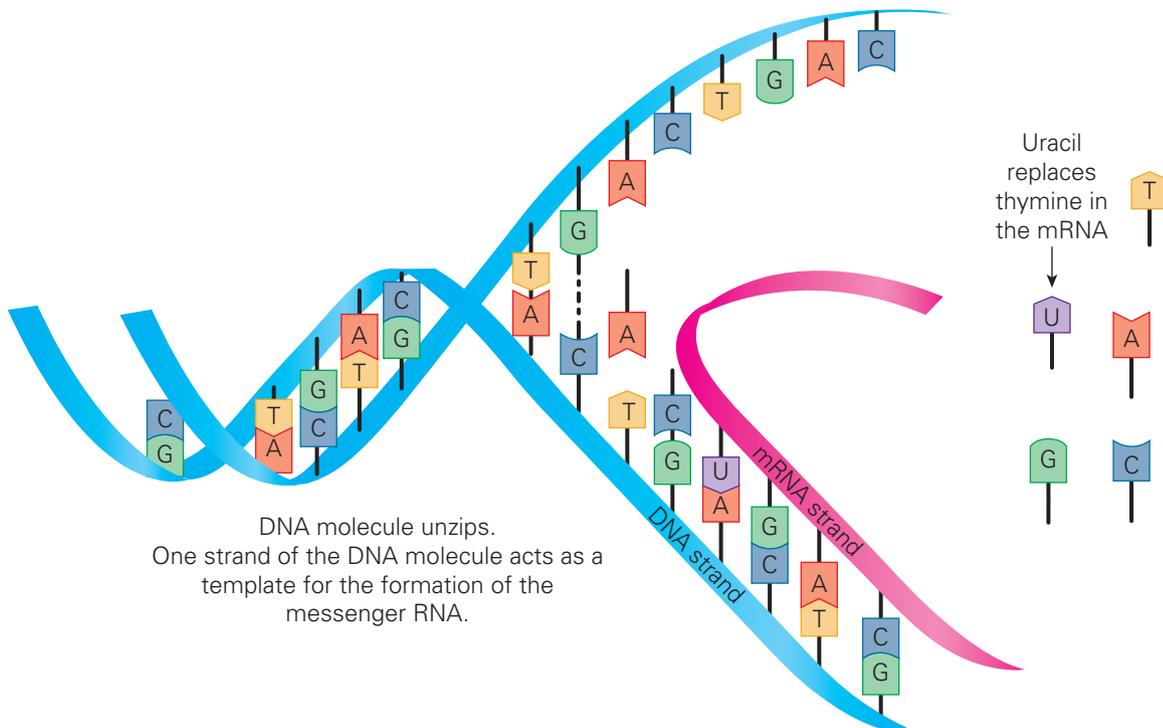
- 1 Recall why proteins are important.
- 2 Describe the relationship between DNA, amino acids and proteins.

## Making proteins using the DNA code

To build proteins using the DNA code in genes, the gene must be expressed; that is, the instruction in the DNA is converted into a protein. This means two processes need to occur: **transcription** and **translation**.

### Transcription

Transcription happens in the nucleus of the cell. The transcription process requires getting access to the



**Figure 12.9** When the DNA double helix unwinds and unzips, one strand of the DNA acts as the template on which the messenger RNA strand is formed.

DNA code in the genes, otherwise the code cannot be copied. This is like you having to open the recipe website before you can copy the brownie recipe. Transcription begins when an enzyme (RNA polymerase) binds to the gene being copied. This signals to the DNA double stranded helix to unwind, which allows the enzyme to read the code on one of the DNA strands (called the DNA template strand). As the enzyme reads the code, it builds a complementary copy of the gene using RNA nucleotides, C, G, A and U. RNA follows the same complementary pairing as DNA, with one exception. Where DNA has the nitrogenous base thymine (T), RNA has uracil (U). The resultant single-stranded RNA formed is called messenger RNA (mRNA). When the mRNA peels away from the DNA template strand, the DNA double strands rejoin and re-form a helix. The mRNA can then leave the nucleus and go to the site of protein production, the ribosomes.

## Translation

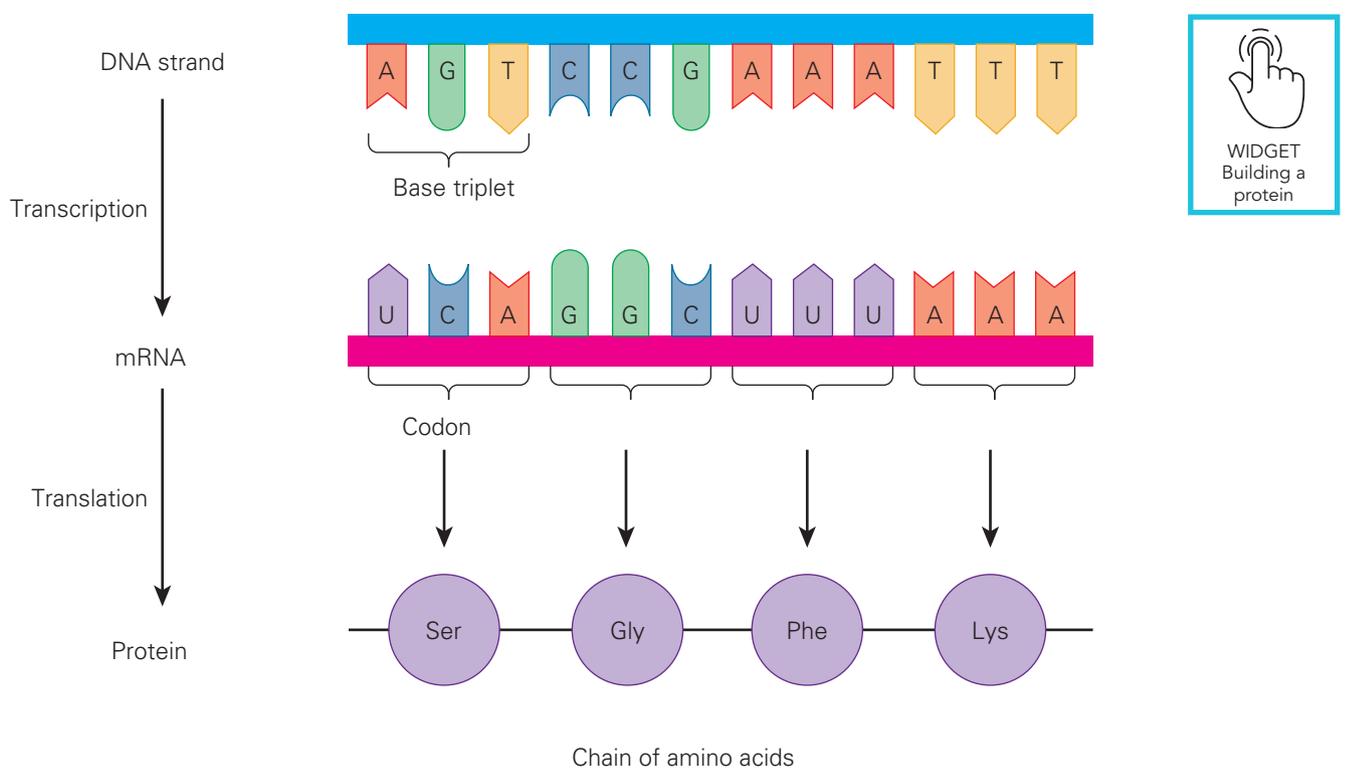
Once mRNA reaches the ribosomes in the cytoplasm, it must be 'decoded' or translated so that the necessary protein can be made. The nitrogenous bases in the

mRNA are decoded in groups of three called **codons** (base triplets in the original DNA template

**codon**  
three nucleotides (base triplet) on mRNA that code for an amino acid

strand). Each codon in the mRNA specifies which amino acid is added to the polypeptide chain – remember, it is a chain of amino acids that we call a protein. The process of translation is simplified in Figure 12.10 and involves several enzymes and another type of RNA called transfer RNA (tRNA). It occurs at the ribosomes, which may be freely floating in the cytoplasm or attached to the endoplasmic reticulum (ER) in the case of rough ER. Each tRNA molecule is responsible for transporting one specific amino acid towards the ribosome for delivery.

Figure 12.11 lists the 20 different amino acids that make up the range of proteins we have in our world. Using this figure you can identify the amino acid that a codon codes for. For example, if the first codon of your mRNA strand is AUG, you look up the A on the left and the U at the top and find where they intersect. At that spot is a box containing four different codons. You then read left across from the G on the right and you will see your codon AUG. Next to the codon it says Met, which means



**Figure 12.10** The process of transcription and translation from the DNA molecule

AUG codes for the amino acid methionine. The codon AUG is unique as it can also be called the START codon. This means that it is the first codon in the transcribed mRNA that undergoes translation. In eukaryotes, AUG codes for methionine (Met) and is also the only START codon.

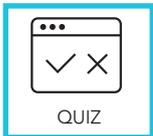
		2nd letter in the codon				
		U	C	A	G	
1st letter in the codon	U	UUU   Phe (F) UUC   UUA   Leu (L) UUG	UCU   UCC   Ser (S) UCA   UCG	UAU   Tyr (Y) UAC   UAA   STOP UAG   STOP	UGU   Cys (C) UGC   UGA   STOP UGG   Trp (W)	U C A G
	C	CUU   CUC   Leu (L) CUA   CUG	CCU   CCC   Pro (P) CCA   CCG	CAU   His (H) CAC   CAA   Gln (Q) CAG	CGU   CGC   Arg (R) CGA   CGG	U C A G
	A	AUU   Ile (I) AUC   AUA   Met (M) AUG   START	ACU   ACC   Thr (T) ACA   ACG	AAU   Asn (N) AAC   AAA   Lys (K) AAG	AGU   Ser (S) AGC   AGA   Arg (R) AGG	U C A G
	G	GUU   GUC   Val (V) GUA   GUG	GCU   GCC   Ala (A) GCA   GCG	GAU   Asp (D) GAC   GAA   Glu (E) GAG	GGU   GGC   Gly (G) GGA   GGG	U C A G

**Figure 12.11** Chart of amino acids showing that the genetic code is degenerate. This means that more than one codon can code for a single amino acid. Due to this redundancy, the 64 codons code for the 20 amino acids.

### Quick check 12.4

- The following codons are found in a strand of DNA: TAC TAA TTA TCG ACT ACT AGC. State the complementary mRNA strand and use the figure above to determine the amino acids produced from the complementary strand.
- Contrast transcription and translation.
- Explain why you do not need to read the code on both strands of DNA when transcribing DNA into mRNA.

### Section 12.1 questions



#### Remembering

- Name** the basic building blocks or subunits of DNA.
- State** where in the cell the proteins are created (synthesised).
- Recall** the name for the shape of DNA.
- Draw** and label a nucleotide.
- Recall** the purpose of DNA.

#### Understanding

- Describe** the key differences between mRNA and DNA.
- Name** the four bases found in DNA and state the complementary base pair rule.
- Explain** the relationship between DNA, genes and chromosomes.
- Explain** why all mRNA strands start with the codon AUG.
- Explain** how the body produces so many different proteins with only four different nitrogenous bases.

**Applying**

- 11 Explain** how the genetic information found in the chromosomes within the nucleus of a cell reaches the ribosomes for protein synthesis.
- 12** A template strand of DNA is found to contain the following bases:  
TAC GGA TCA TCG TGG GAA GCA GGC ATT
- Identify** the complementary DNA strand.
  - Using the above template strand of DNA, **determine** what the mRNA strand would look like.

**Analysing**

- 13 Construct** a flow chart summarising the key steps in transcription and translation.
- 14 Propose** what may occur if there was a problem with a certain protein in your body.

**Evaluating**

- 15** A template strand of DNA is found to contain the following bases:  
TCC TGA TGA TGG GGG GCA AAA CGC GTA
- Something went wrong during the transcription of this template strand and the mRNA strand contains the following bases:  
AGG ACU ACU ACC CUC CGU UUU GCG CAU
- Identify** the mistake in the mRNA strand above.
  - Predict** the outcome of this mistake on the protein produced.
- 



# 12.2 Passing on genetic information

## Learning goals

- 1 To describe the process and advantage of DNA replication
- 2 To describe the role of the two types of cell division: mitosis and meiosis
- 3 To define the terms: daughter cells, haploid, diploid and gametes
- 4 To outline the stages of mitosis and meiosis
- 5 To compare the number of daughter cells and chromosome numbers that result through mitosis and meiosis
- 6 To state the number of chromosomes in a human body and gamete cells



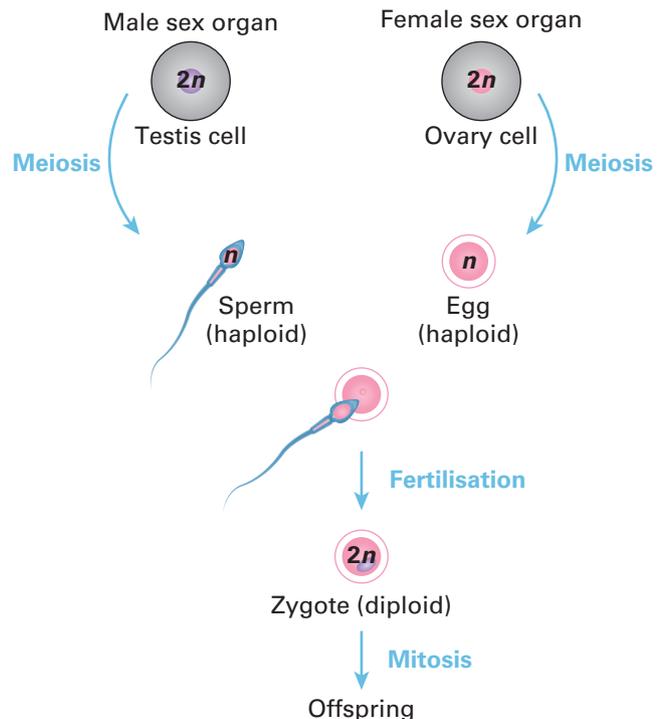
Two different forms of reproduction occur among organisms: asexual and **sexual reproduction**. Sexual reproduction requires two organisms of the same species to each contribute a sex cell, which combine to produce a new unique offspring. These cells, called **gametes**, are formed in the **gonads** of the male (testes) and the

female (ovaries). Each gamete contains half the genetic information needed to form a new organism of the same species. When the gametes – sperm and **ova** (eggs) – meet and fertilise, they form a **zygote** with the full set of genetic information. The zygote divides and as the number of cells increases, they begin to take on special functions. Eventually, the zygote becomes the **embryo** of the organism.

You will notice that Figure 12.12 has some new terms. Let us have a look at them.

- sexual reproduction**  
reproduction involving sex cells
- gametes**  
sex cells that combine to produce new offspring
- gonads**  
the sexual organs: testes in males and ovaries in females
- ova**  
eggs
- zygote**  
a fertilised egg produced by the fusion of male (sperm) and female (ovum or egg) gametes
- embryo**  
a zygote eventually becomes an embryo
- haploid ( $n$ )**  
a cell containing only one set of chromosomes
- diploid ( $2n$ )**  
a cell containing two sets of chromosomes
- somatic cells**  
the body cells of an organism

- When we talk about a cell containing only one set of chromosomes, we call it **haploid** and use the symbol  $n$ . Gametes like sperm and eggs are haploid.
- When we talk about a cell containing two sets of chromosomes, we call it **diploid** and use the symbol  $2n$ . **Somatic cells** (body cells) and the zygote are all diploid.



**Figure 12.12** Sexual reproduction involves gametes from a male and a female combining to form a zygote.

## Quick check 12.5

- 1 Copy the table below and define the terms in your own words.

Term	Definition
Meiosis	
Fertilisation	
Zygote	

- 2 Identify the missing words in the following sentence.  
Male gametes are called \_\_\_\_\_, whereas female gametes are called \_\_\_\_\_.

- **Meiosis** is the name of the process by which the gonads make the haploid gametes.
- **Mitosis** is the name of the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair.

In humans, the haploid number ( $n$ ) – the amount of genetic information carried by the sperm and eggs – is 23 single chromosomes. When the egg and sperm meet and fertilise, the two sets of chromosomes come together and form the diploid cell ( $2n$ ) called the zygote. The zygote contains 23 pairs of chromosomes, and therefore the diploid number ( $2n$ ) in humans is 46. The haploid and diploid numbers vary between species, but always remain the same for all of the organisms within that species.

### Did you know? 12.1

Interestingly, the diploid number of chromosomes in a species is not related to whether an organism is bigger or more complicated. For example, a koala, a particular species of kangaroo and garlic all have a diploid number of 16, but are clearly very different!



**Figure 12.13** Different organisms contain a different number of diploid chromosomes.

### Quick check 12.6

- 1 Differentiate between the terms 'haploid cell' and 'diploid cell', providing an example of each.
- 2 If a sheep's body (somatic) cell contained 54 chromosomes, calculate how many chromosomes would be found in their gametes.

## How does DNA copy itself?

Before a cell divides, the DNA has to be copied (replicated) to provide two copies of each chromosome. This occurs before mitosis and meiosis. This process of

DNA replication has to occur perfectly (without any errors), otherwise the code in the DNA might be affected and faults in replication can lead to mutations. The steps involved in DNA replication are summarised below and in Figure 12.14.

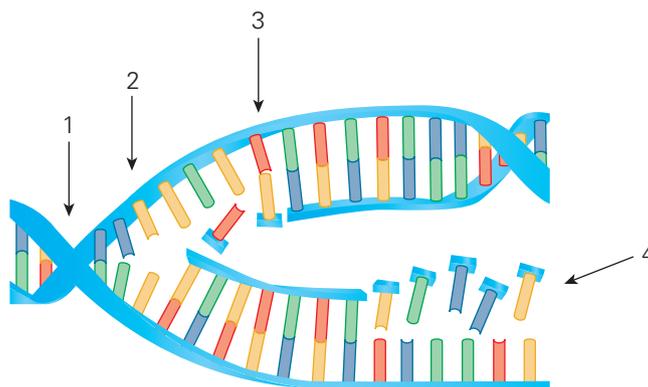
#### meiosis

the process by which the gonads make the haploid gametes

#### mitosis

the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

- 1 The DNA molecule begins to unwind with the help of a multi-enzyme complex.
- 2 The DNA then 'unzips' down the middle between the nitrogenous bases, breaking the hydrogen bonds. Again, this step happens with the help of an enzyme called DNA helicase. Unzipping is a good description because the bases are left exposed, hanging as two strands, each on the DNA backbone, just like the teeth on an open zipper.
- 3 Another enzyme called DNA polymerase then very quickly attaches new nucleotides to the exposed nitrogenous bases. The enzyme follows the complementary pairing rule, where adenine can only join with thymine, and cytosine can only join with guanine. This simple rule is of great importance because it means the two new strands of DNA will be identical to the original one that unzipped.
- 4 The newly added nucleotides are connected with new hydrogen bonds, which results in two identical strands of double-stranded DNA being formed. Each new strand is one-half of the original strand and one-half that was newly built. For this reason, replication is sometimes described as being semi-conservative.



**Figure 12.14** DNA replication: the DNA must first unwind and unzip and then the new DNA nucleotides can be added following complementary pairing rules. This results in two identical strands of DNA.

## Quick check 12.7

1 Explain the purpose of DNA replication.

2 Summarise the steps of DNA replication.

## Mitosis

Mitosis is a form of cell division that occurs during the growth and repair of cells, and also during asexual reproduction, when identical copies of cells need to be made. The diploid ( $2n$ ) parent cell divides into two cells that are genetically identical (so also diploid), called

daughter cells. This sequence is shown in Table 12.2. Within the human body, every cell is produced via this process, with the only exception being the formation of gametes, or sex cells, which are produced by meiosis and result in haploid ( $n$ ) cells.

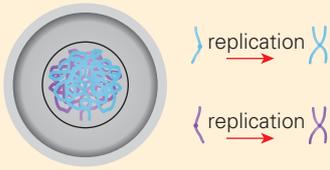
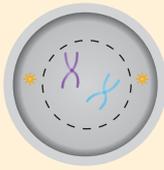
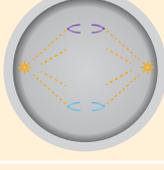
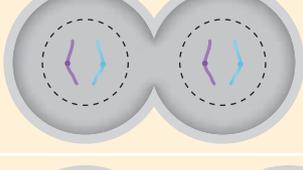
The stages of mitosis				
Before mitosis	Interphase $2n$		<ul style="list-style-type: none"> <li>• Parent cell is diploid.</li> <li>• DNA replication occurs.</li> <li>• Chromosomes are not visible.</li> <li>• The cell gets bigger.</li> <li>• Organelles replicate.</li> </ul>	
Stages of mitosis	Prophase		<ul style="list-style-type: none"> <li>• The nuclear membrane breaks down, DNA winds up and becomes distinct chromosomes.</li> <li>• Spindle fibres begin to form.</li> </ul>	
	Metaphase		<ul style="list-style-type: none"> <li>• Chromosomes are arranged along the centre of the cell.</li> <li>• Each chromosome is attached to a spindle fibre by the centromere.</li> </ul>	
	Anaphase		<ul style="list-style-type: none"> <li>• The chromatids split at the centromere and are pulled to either end of the cell by the spindle, centromere first.</li> <li>• Spindle fibres then begin to disappear.</li> </ul>	
	Telophase		<ul style="list-style-type: none"> <li>• The nuclear membrane reforms around the two sets of chromosomes, forming new nuclei. The chromosomes decondense and are no longer visible.</li> </ul>	
After mitosis	Cytokinesis $2 \times 2n$		<ul style="list-style-type: none"> <li>• Division of cytoplasm starts, the cell pinches in half, and the cell divides into two genetically identical diploid daughter cells.</li> </ul>	

Table 12.2 The stages of mitosis



### Quick check 12.8

- 1 State which cells undergo mitosis.
- 2 Summarise the steps of mitosis.

**Figure 12.15** Plant cells in the process of mitosis viewed under a light microscope. The central image shows the chromosomes moving to each end of the cell in anaphase. Can you identify some of the other stages?

## Practical 12.2

### Observing cells in a dividing root tip

#### Aim

To observe cells carrying out mitosis in a growing onion root tip.

#### Materials

- prepared, stained slide of the growing section of an onion root tip caught at different stages of cell division
- microscope

#### Procedure

- 1 Using the lowest magnification, place a prepared slide of a growing onion root tip on the stage of the microscope.
- 2 Position the slide so that the pointed narrow end of the root tip is clearly visible.
- 3 Look for a cluster of rapidly growing cells near this region.
- 4 Observe several different cells at various stages of cell division under the highest magnification of the microscope.

#### Results

Carefully choose one cell that clearly outlines the cell wall showing chromosomes in certain stages of cell division. Sketch a copy of what you observed, labelling the cell wall and the chromosomes. Remember to use a sharp pencil and to document the magnification the sketch is taken at.

#### Data processing

- 1 The mitotic index is a quantitative expression of the amount of cell division that a particular tissue is undergoing. It is the ratio of the number of cells undergoing mitosis to the number of cells that are not undergoing mitosis. It can be calculated using the following equation:

$$\text{Mitotic index} = \frac{\text{number of cells in the field of view undergoing division}}{\text{total number of cells in the field of view}}$$

Calculate the mitotic index for the tissue sample you have observed in your microscope.

- 2 Using the field of view in your microscope, complete the table and calculate the percentage of cells in each cell cycle stage.

#### Be careful

Ensure that the microscope is carried appropriately. Carry with one hand holding the arm and one hand under the base. Ensure big changes in magnification do not occur, so as not to damage the glass slide.

*continued...*

...continued

Cell cycle stage	Number of cells in that stage	% of cells in that stage
Interphase		
Prophase		
Metaphase		
Anaphase		
Telophase		
<b>Total number of cells</b>		

- 3 Use the calculated percentages to predict which cell cycle stage is the longest and which is the shortest in your sample of cells. Explain your answer.

### Discussion

- 1 Explain how you could tell which cells were dividing.
- 2 Describe the main features of each stage of cell division. Could you use these to identify the stage of mitosis for a particular cell?
- 3 List the structures in the cells you could observe. Which structures were present that you could not observe? Why might this be the case?

## Meiosis

### reduction division

cell division in which there is a reduction in the genetic material between parent and daughter cells

Meiosis is the process by which animals and plants produce gametes (sex cells) for sexual reproduction.

gametes), which are haploid ( $n$ ). Because of this reduction in genetic material between the parent and daughter cells, meiosis is also known as a **reduction division**.

The process of meiosis begins with a parent cell, which is diploid ( $2n$ ), and results in four 'daughter' cells (the

Just like in mitosis, meiosis consists of a number of distinct stages. The process of meiosis involves two divisions, called meiosis I and meiosis II. These steps are further subdivided into distinct stages, as shown in Table 12.3.

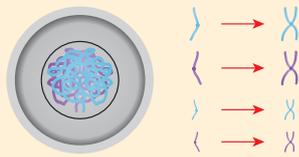
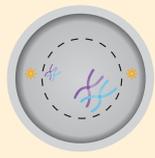
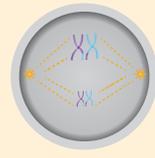
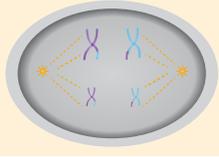
Meiosis I		
Interphase $2n$ (before meiosis)		<ul style="list-style-type: none"> <li>• Parent cell is diploid (<math>2n</math>).</li> <li>• The DNA is replicated and copied (<math>4n</math>).</li> </ul>
Prophase I		<ul style="list-style-type: none"> <li>• The nucleus 'disappears', the DNA winds up and chromosomes become visible.</li> <li>• Crossing over can occur.</li> </ul>
Metaphase I		<ul style="list-style-type: none"> <li>• Spindle fibres attach to the centromere of each homologous (matching) chromosome pair and pull the matching chromosomes into a line in the centre of the cell.</li> </ul>
Anaphase I		<ul style="list-style-type: none"> <li>• The matching chromosomes of a homologous pair are pulled to opposite ends of the cell by the spindle fibres.</li> <li>• Spindle fibres disappear.</li> </ul>

Table 12.3 The stages of meiosis I and meiosis II

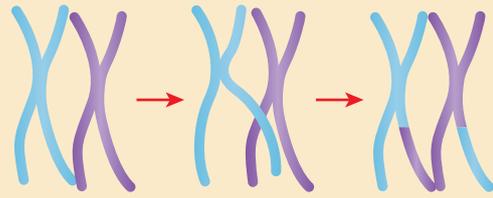
Meiosis II		
Prophase II		<ul style="list-style-type: none"> <li>Nuclear membranes disappear and spindle fibres re-form in both cells.</li> </ul>
Metaphase II		<ul style="list-style-type: none"> <li>Chromosomes move into the centre of the cell where spindle fibres attach to each chromatid.</li> <li>The centromeres start to divide.</li> </ul>
Anaphase II		<ul style="list-style-type: none"> <li>The chromosomes are pulled apart and the chromatids are pulled to opposite sides of the cell.</li> <li>The spindle fibres disappear.</li> </ul>
Telophase II		<ul style="list-style-type: none"> <li>The nuclear membrane re-forms.</li> <li>The chromosomes are no longer visible.</li> </ul>
Cytokinesis $4 \times n$		<ul style="list-style-type: none"> <li>Both cells pinch in half to produce four genetically different haploid daughter cells (<math>n</math>), each containing half the amount of DNA as was in the parent cell.</li> </ul>

Table 12.3 (continued)

## Did you know? 12.2

## Creating variation

You might have noticed in Table 12.3 that at prophase I of meiosis I, it says 'crossing over can occur'. Crossing over occurs when **homologous chromosomes** (matching pair of chromosomes) get so close together that some of their genetic material gets tangled and swaps. It results in the chromosomes being recombined with a new combination of **alleles**. This means that, when gametes are being made, the process of meiosis leads to more genetic variation between the gametes.



**Figure 12.16** Crossing over during prophase I results in the formation of **recombinant** chromosomes with new combinations of alleles.

## Quick check 12.9

- 1 Describe why the process of meiosis is also known as 'reduction' cell division.
- 2 Recall where meiosis occurs in humans.
- 3 Explain why crossing over is an important process during meiosis.

## Fertilisation

We know that the haploid gametes produced during the process of meiosis are called sperm and ova (eggs). In humans, each sperm or egg has 23 single chromosomes, so the haploid number is 23. After **fertilisation**, the zygote

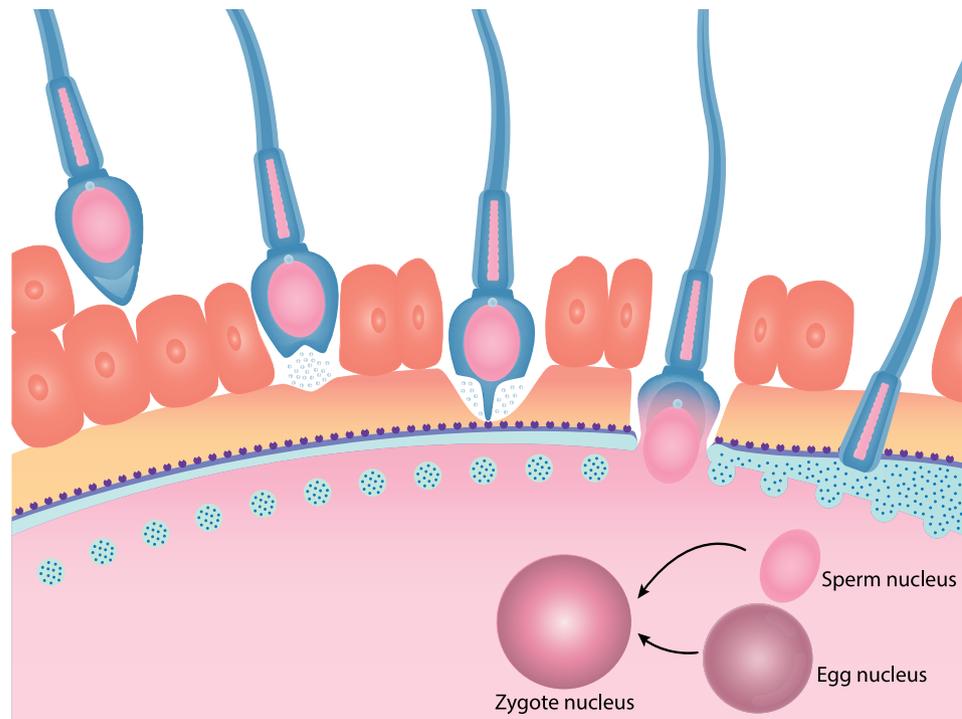
(which becomes the embryo that grows into the foetus) has 23 pairs of (or 46 single) chromosomes, so the human diploid number is 46. Keep in mind that the zygote has received half of its genetic information from the egg and half of its genetic information from the sperm.

**homologous chromosomes**  
matching chromosomes

**allele**  
different forms of the same gene

**recombinant**  
produced by combining genetic material from different places

**fertilisation**  
the fusing of an egg nucleus and sperm nucleus



**Figure 12.17** Once the sperm fertilises the egg, the nucleus of the sperm and the egg fuse.

## Explore! 12.2

**Two types of twins**

You, or someone you know, might have a twin sister or brother. There are many different types of twins, which vary greatly in the way they form!

- 1 Name two types of twins and how they are formed.
- 2 Draw a diagram to show how these types of twins are formed.
- 3 Describe the differences between the two types of twins that you have researched.

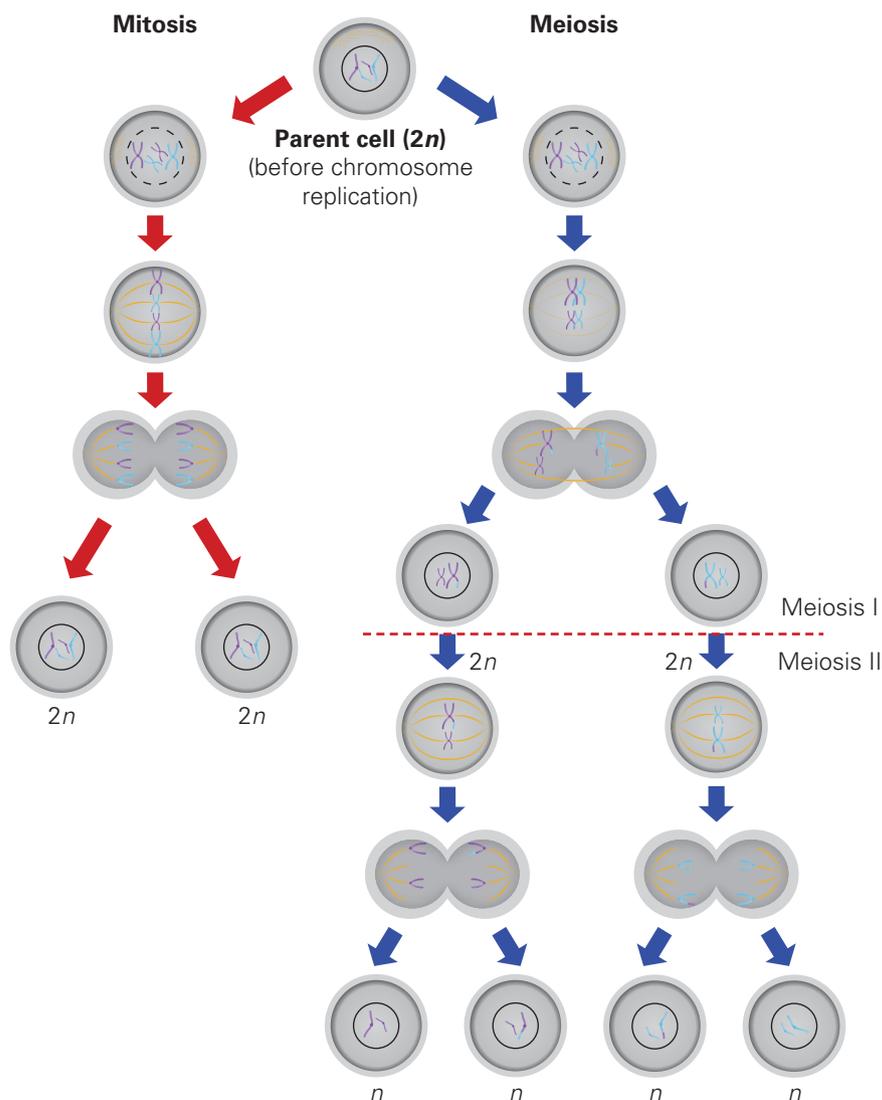
**Meiosis versus mitosis**

Although the processes of meiosis and mitosis have similarities, two distinct differences remain.

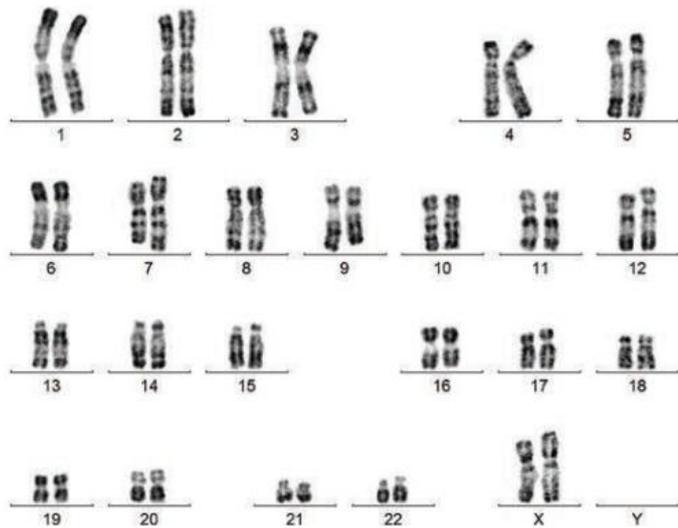
- In meiosis, the genetic material in chromosomes is reshuffled by crossing over, producing chromosomes with new combinations of genes. In mitosis, chromosomes are replicated to make identical copies of themselves.
- Meiosis produces four haploid ( $n$ ) daughter cells containing unique genetic material and half the number of chromosomes of the parent cell. Mitosis produces two diploid ( $2n$ ) daughter cells with identical genetic material to the parent cell.

**Karyotypes**

Although each species has its own particular number of chromosomes, the chromosomes in each body cell always occur as pairs. For example, we know humans all have a total of 46 chromosomes, or 23 pairs of chromosomes in every nucleus of every body cell. However, within the gametes, we know there are only half



**Figure 12.18** A diagram summarising the processes of mitosis (making copies of somatic cells) and meiosis (making gametes)



**Figure 12.19** The chromosomes seen under a microscope (left) can be arranged and paired up according to size and gene band patterns in a pictorial representation known as a karyotype (right).

of this number: 23 chromosomes. We can take a photo of a cell when it has undergone DNA replication and clearly see the chromosomes.

The chromosomes can then be arranged and paired according to their size and gene band patterns in a pictorial representation known as a **karyotype**.

#### karyotype

a pictorial representation of an organism's chromosomes

**non-homologous chromosomes**  
non-matching chromosomes

#### autosomes

in humans, chromosome pairs 1 to 22

#### sex chromosomes

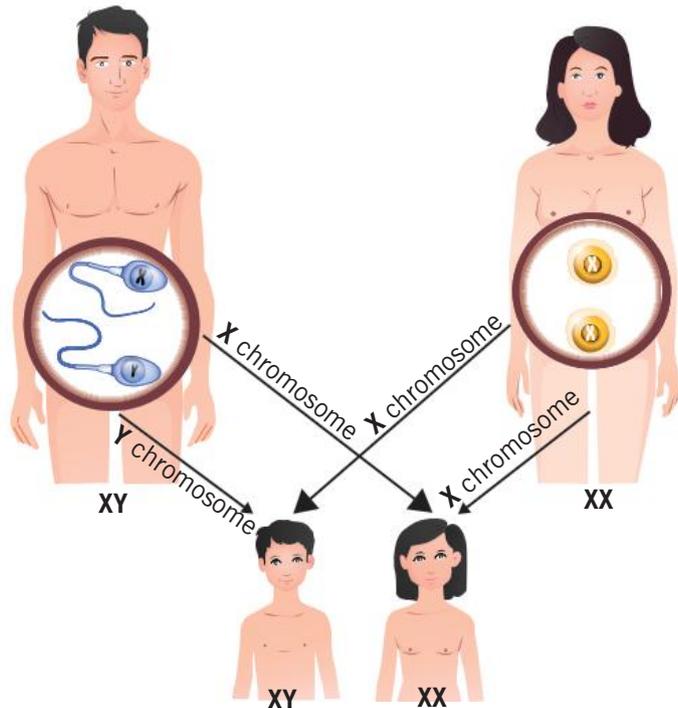
in humans, the 23rd pair of chromosomes that determines the sex of a person

The chromosomes always exist in pairs within the body cells because one was received from the male parent (paternal) via the sperm, and one was received from the female parent (maternal) via the egg. We call the

chromosome pairs that are matching homologous chromosomes, while those that do not match (for example, chromosomes from different pairs) are called **non-homologous chromosomes**. Notice in Figure 12.19 how homologous chromosomes (paired chromosomes) have the same length, centromere position and gene band patterns.

### Autosomes

Of the 23 pairs of chromosomes, pairs 1 to 22 are known as **autosomes**. These 44 chromosomes are found in both males and females.



**Figure 12.20** If an egg is fertilised by an X-carrying sperm, the child will be female. If an egg is fertilised by a Y-carrying sperm, the child will be male. Therefore, it is the male's sperm that determines the sex of the child.

### Sex chromosomes

In humans, the chromosomes of the 23rd pair are the **sex chromosomes**. They contain genes that determine the sex of the individual. Females receive two X chromosomes (one from each parent), whereas males receive one X chromosome (from the mother) and one Y chromosome (from the father).

### Practical 12.3

#### What are the chances?

##### Aim

To investigate the chances of conceiving a male or female at fertilisation.

##### Useful formula

$$\text{Theoretical probability (\%)} = \frac{\text{number of favourable outcomes (e.g. heads)}}{\text{total number of all possible outcomes (e.g. heads and tails)}} \times 100$$

$$\text{Experimental probability (\%)} = \frac{\text{number of favourable outcomes (e.g. heads)}}{\text{total number of all experimental trials (e.g. heads and tails)}} \times 100$$

$$\text{Percentage error (\%)} = \frac{(\text{experimental probability} - \text{theoretical probability})}{\text{theoretical probability}} \times 100$$

##### Materials

- coin

##### Procedure

- 1 Draw the table below in the results section into your science journal.
- 2 Calculate the theoretical probability of landing heads during the toss.
- 3 You will now calculate the experimental probability of your own experiment by tossing the coin 50 times, recording the number of heads and tails in the table.

##### Results

- 1 Calculate the experimental probability of receiving a head and a tail based on both the experimental data for your own and the class results.
- 2 Calculate the percentage error comparing the difference between the theoretical and experimental probabilities for both your own data and the class data.
- 3 Optional: Graph the relationships between the number of trials and percentage error.

	Individual results	Class results
Number of heads		
Number of tails		
Total number of trials		
Experimental probability		
Percentage error		

##### Discussion

- 1 Compare the experimental probability between your own and the class results.
- 2 If a head represents the Y chromosome and a tail represents the X chromosome, explain how accurately this models the process of fertilisation. What would the coin represent?
- 3 Make a claim about the chances of conceiving a male or female based on this activity.
- 4 Discuss if increasing the number of trials affects the percentage error of the experiment.

**Did you know? 12.3****Sex chromosomes in the animal kingdom**

In some animals, such as birds, females have two different sex chromosomes (ZW) while males have two of the same (ZZ). In some reptiles, the sex of the organism is determined by the temperature of the incubating environment of the developing embryo. In some insects, females are XX and males have just one X chromosome (written XO).

Jack jumper ants (*Myrmecia pilosula*) are unusual because they have the lowest possible number of chromosomes.

Female ants are diploid with their full **genome** on two sets of chromosomes. However, males are haploid and develop from unfertilised eggs ( $n = 1$ ).

**genome**  
the full set of genes  
in an organism



**Figure 12.21** Jack jumper ants are a venomous ant species native to Australia.

**Quick check 12.10**

- 1 Compare mitosis and meiosis in a Venn diagram.
- 2 Explain why karyotypes are useful.

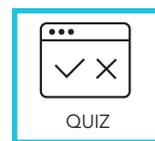
**Advances in science 12.2****Genetic counselling and karyotypes**

When a woman is pregnant, the doctor will conduct a number of tests to screen for genetic and chromosomal abnormalities. Creating a karyotype lets the doctor check for abnormalities in the number or length of chromosomes. If anything looks abnormal, the doctor can do follow-up tests to check for specific disorders. One such test is chromosomal microarray (CMA) testing, which is much more detailed genetic testing than karyotyping. Chromosomal microarray testing detects around one abnormality in every 70 foetal samples that had a normal karyotype. Scientists think that CMA testing will replace karyotyping for prenatal testing.

## Section 12.2 questions

## Remembering

- 1 **List** one key difference between mitosis and meiosis.
- 2 **Contrast** the daughter cells produced in mitosis vs. meiosis.
- 3 **Identify** in which phase of meiosis the pairs of matching chromosomes are separated.
- 4 **Draw** a diagram to represent the steps of mitosis for a cell with two pairs of chromosomes. Be sure to use a different colour for each pair of chromosomes.



## Understanding

- 5 **State** what the term 'homologous chromosome' means.
- 6 **Explain** why gametes need to be haploid.
- 7 **Explain** what is meant by the term 'reduction division'.
- 8 **Explain** why missing part of a chromosome may lead to a disorder or syndrome.
- 9 **Identify** when chromosomes are visible.

## Applying

- 10 **Explain** why the cells produced during meiosis are considered to be unique.
- 11 When cells reproduce themselves, the DNA is replicated. **Explain** why this is necessary.
- 12 **Identify** the missing information to complete the following table.

	Where it occurs	Purpose	Features of daughter cells
Mitosis			
Meiosis			

## Analysing

- 13 **Explain** the key difference between anaphase I in meiosis and anaphase in mitosis.
- 14 **Outline** how prophase I differs from prophase II in meiosis.
- 15 The table below shows a number of different organisms with their chromosome number.

Organism	Chromosome number
Chimpanzee	48
Human	46
Horse	64
Onion	16
House fly	12
Worm	20

- a **Identify** the organism with the highest number of chromosomes.
- b **State** the haploid number of the onion.
- c **Explain** whether the chromosome number of an organism reflects its intelligence. **Justify** your response.

## Evaluating

- 16 **Evaluate** the following claim: 'It is the male that determines the sex of his child.'
- 17 **Evaluate** the chances of a woman giving birth to a girl if she has already given birth to three boys. **Justify** your response.

## 12.3 Patterns of inheritance

### Learning goals

- 1 To outline Mendel's cross breeding experiments and explain his contribution to our understanding of genetics
- 2 To define the following terms: traits, dominant, recessive, homozygous, heterozygous, genotype and phenotype
- 3 To predict possible outcomes of offspring traits using Punnett squares of simple dominant/recessive crosses

### Inheriting traits from our parents



We now know that our genetic instructions (genes) come from our parents. This is called heredity or inheritance. We also know that

chromosomes are made up of DNA and that genes are found within the DNA. Chromosomes exist in pairs, so it is reasonable to suggest that genes must exist in pairs. Therefore, each characteristic or trait that we inherit is controlled by a pair of genes, which are found at the same location on their respective chromosomes. This is called the **locus** of a gene – another name for the location of the gene.

Genes are sections of DNA that code for a particular protein which contributes to our characteristics, such

#### locus

the location of a gene on a chromosome

#### genotype

the combination of alleles for a gene inherited from our parents

#### homozygous

having two identical alleles at a locus

#### heterozygous

having two different alleles at a locus

as a gene for eye colour.

However, not all forms of the gene are the same; for example, someone might have blue eyes and someone else might have brown eyes. We use the term allele to describe the different forms of a gene. The combination of alleles

for a gene inherited from the parents is known as the organism's **genotype**. If two identical alleles are present in a person's genotype, they are known as **homozygous** (or pure-breeding) for that particular trait. However, if there are two different alleles present for the same trait, then the person is known as **heterozygous** (or hybrid) for that trait.

For example, take the trait of having a widow's peak hairline. This trait is controlled by a single gene that is represented using two alleles: the allele of the dominant trait, which is the presence of a widow's peak (we assign it the capital letter 'H' to show it is dominant) and the allele for the recessive trait, which is the lack a widow's peak (we assign this allele a lower case 'h' to show it is representing the recessive trait). If you inherit the dominant allele (H) from both parents, you are said to be homozygous dominant for that trait and your genotype will be HH. If you inherit the non-widow's peak allele (h) from both parents, you are said to be homozygous recessive for that trait and your genotype will be hh. If you inherit a widow's peak allele (H) from one parent and a non-widow's peak allele (h) from the other parent, you are heterozygous for that trait and your genotype will be Hh.

### Did you know? 12.4

Many cultural groups have an understanding of inheritance patterns, recognising how traits can be passed down to the next generation. Traits and illnesses can appear in the children of closely related parents. Australia's First Nations peoples developed complex and sophisticated kinship systems, which allow individuals to understand who they are and how they fit into the social structure and even the universe. These kinship systems determine not only whom individuals can or cannot marry, but they can also determine how individuals behaviourally relate to other individuals, and the responsibilities each person has towards others, natural resources and the land.



**Figure 12.22** This girl has a widow's peak (v-shaped peak) in the centre of her hairline.

A trait or characteristic is described as **dominant** if you need only one allele for it to be expressed (HH or Hh, both of which result in the widow's peak hairline). For a **recessive** characteristic, the allele needs to be inherited from both parents in order for it to be expressed (hh, the normal non-widow's peak hairline is recessive).

**dominant**  
a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

**recessive**  
a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

**phenotype**  
the way an organism appears

The interaction of an organism's genotype with the environment results in its **phenotype**, or its physical appearance. So in this example, the ability to roll or not roll the tongue is the person's phenotype for that trait. Always remember that genes and alleles refer to the genotype, and the physical appearance of the trait refers to the person's phenotype.

To determine whether an allele represents a trait that is dominant or recessive, scientists look at the phenotype of a heterozygous organism. If the trait is expressed in this phenotype it must be the dominant trait.

### Quick check 12.11

- 1 Copy the table below and define the terms in your own words.

Term	Definition
Locus	
Allele	
Genotype	
Phenotype	

- 2 Explain why your genotype indicates you will have pale skin, but your phenotype is red skin.

### Practical 12.4

#### Inherited features

##### Aim

Use data to determine whether some key characteristics are dominant or recessive traits.

##### Materials

- mirror

Optional extension: collect information from other students or family members for further validity analysis.

*continued...*

...continued

### Procedure

#### Part 1: Prepare the results table

Copy the table shown in the results section into your science journal.

#### Part 2: Collect data on the variables

- 1 Identify whether you possess each of the inheritable features described below.
- 2 Record your results in the table.
- 3 Find out how many members of your class share the same features as you do. Record your results in the table.

Optional: Find out how many members of your family display the traits.

- a Attached ear lobes: are your earlobes attached or unattached to the side of your head?
- b Widow's peak: do you have a v-shaped peak in the centre of your hairline as shown in Figure 12.22?
- c Darwin's tubercle: do you have a point on your ear as shown in Figure 12.23? It looks like a small bump on the inside of your upper ear.
- d Tongue roll: can you roll your tongue as shown in Figure 12.24?
- e Front tooth gap: is there a definite gap between your two top front teeth as shown in Figure 12.25?
- f Mid-digital hair: is there any hair on the second joint of at least one of your fingers?
- g Long second toe: is your second toe longer than your big toe as shown in Figure 12.26?



**Figure 12.23** The presence of a bump on the outer rim of the ear called 'Darwin's tubercle' is due to a combination of genetic and environmental factors.



**Figure 12.24** Can you roll your tongue?



**Figure 12.25** This man has an obvious gap between his top front teeth.



**Figure 12.26** The second toe is longer than the big toe on this foot.

### Results

#### Collate the data for analysis of the variables

- 1 Calculate the total number of people sampled in this survey.
- 2 Calculate the percentage presence of the trait in your family and within the class.
- 3 Draw an appropriate graph/s to compare the percentage presence of each trait within your family compared to the whole class.

continued...

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Feature	Trait present in you? (Y/N)	Number of family members with trait	% presence of trait in family	Number of class members with trait	% presence of trait in class	% presence of trait in total sample
Attached ear lobes						
Darwin's tubercle						
Widow's peak						
Tongue roll						
Front tooth gap						
Mid-digital hair						
Long second toe						
Sample size = (Total number of people surveyed)	1					

### Discussion

- 1 Describe which traits were commonly found in your family.
- 2 Describe which traits were commonly found in the class.
- 3 Describe which traits were commonly found in the whole sample.
- 4 Do your findings support the idea that a feature such as tongue-rolling is inherited? Explain your answer.
- 5 Predict from the data whether each of the traits are likely to be recessive or dominant. Justify your answer with data.
- 6 If you repeated the survey on the same people, would you get a similar result? Support your answer relating back to the theory behind inheritance of traits.
- 7 Can reliable conclusions and predictions be drawn from the results?
- 8 Compare the values between your family and the class. Were there any significant differences with some traits? Justify your answer with data.
- 9 Compare the values between your family and several other student family results. Were there any significant differences with some traits? Justify your answer with data.
- 10 Can valid conclusions as to which traits are dominant and recessive be drawn from this data? Justify your response.
- 11 Sample size is a factor that commonly affects data in small surveys. Discuss how this relates to the activity.
- 12 Can you identify possible limitations of this method? Justify your answer.
- 13 Suggest any changes that could be made to the method to improve the quality of the data in future surveys. Justify your suggestions by explaining how each change will improve the data quality.

## Determining chances of inheritance

### Gregor Mendel

Gregor Mendel is known as the father of genetics. He was an Austrian monk who carried out experiments in his garden using pea plants and discovered some of the fundamental laws of heredity we still rely on today.

Mendel looked at the features of pea plants, which were either tall or short (dwarf). He assigned the following letters to represent these alternative characteristics (which we call alleles today): T = tall and t = dwarf. Mendel bred the plants and observed the height of the plants in the next generation. He discovered that tall pea

plants could be either pure breeding (TT or homozygous dominant) or hybrid (Tt or heterozygous). The dwarf plants would be tt (homozygous recessive). Today, we call this the plant's genotype.

Mendel also used the following notation to represent different levels of generations:

- P = parent generation
- F<sub>1</sub> = 1st filial generation
- F<sub>2</sub> = 2nd filial generation.

An easy way to predict the outcome of crossbreeding plants with certain traits is to use a **Punnett square**, a specialised grid invented by Reginald Punnett. To use a Punnett square, you need to

**Punnett square**  
a specialised grid to show genetic crosses

know the genotype of the parents and then work out what genetic information they could pass on to their offspring via the gametes. For example, we know a heterozygous, tall pea plant has the genotype Tt. This means that when the plant makes its gametes, they could contain either a T or a t, as gametes only carry one of the alleles from the parent. In contrast, a homozygous tall pea plant has the genotype TT, so its gametes will all contain a T.



**Figure 12.27** Gregor Johann Mendel (1822–1884) was the founder of heredity, using pea plants to show dominant and recessive traits within the field of genetics.

### Worked example 12.1

#### Cross between a pure-breeding tall plant and a pure-breeding dwarf plant

Parents: TT × tt

gametes	T	T
t	Tt	Tt
t	Tt	Tt

You will notice that all the predicted F<sub>1</sub> offspring (shaded) have the genotype Tt. We can write this as:  
F<sub>1</sub> genotype: 100% Tt

We can also see that offspring with Tt would all physically appear tall, as T stands for the tall allele which is dominant over the dwarf allele (t). So we can write this as:

F<sub>1</sub> phenotype: 100% tall plants.

### Worked example 12.2

#### Cross between two of the hybrid F<sub>1</sub> plants from worked example 12.1

F<sub>1</sub>: Tt × Tt

gametes	T	t
T	TT	Tt
t	Tt	tt

F<sub>2</sub> genotype: 25% TT; 50% Tt; 25% tt

F<sub>2</sub> phenotype: 75% tall plants; 25% dwarf plants

We can also write the predicted outcomes as ratios. In this case, when two heterozygous tall pea plants were crossed, there was a genotypic ratio of 1TT : 2Tt : 1tt and a phenotypic ratio of 3 tall : 1 dwarf.

## Huntington's disease

Huntington's disease is inherited as a dominant trait on an autosome. It usually appears in an affected person as neurological symptoms that develop around 30–50 years of age. The disease is lethal in the womb if an offspring is homozygous for the abnormal protein.

If we let H = abnormal Huntington's protein allele (Huntington's disease) and h = 'normal' protein allele (unaffected), then we can use these notations to help work out probable outcomes in the offspring.

**Worked example 12.3****Cross between two individuals unaffected by Huntington's disease**

Parents: hh × hh

gametes	h	h
h	hh	hh
h	hh	hh

F<sub>1</sub> genotype: 100% hhF<sub>1</sub> phenotype: 100% unaffected**Worked example 12.4****Cross between an individual with Huntington's disease and an unaffected individual**

Parents: Hh × hh (Remember, someone with two H alleles will not survive birth so the Huntington's disease individual must be Hh).

gametes	H	h
h	Hh	hh
h	Hh	hh

F<sub>1</sub> genotype: 50% Hh; 50% hhF<sub>1</sub> phenotype: 50% with Huntington's disease; 50% unaffected**Try this 12.2****Punnett squares**

- A black mouse mates with a brown mouse. Of a large number of offspring, all of them are black.
  - Which trait is dominant?
  - Draw a Punnett square and determine the genotypes of the offspring.
- A recessive gene causes a condition called cystic fibrosis. If a homozygous recessive female mates with a heterozygous male, what are their chances of producing offspring with cystic fibrosis?

**Quick check 12.12**

- Contrast genotype and phenotype.
- Brown eyes are dominant to blue eyes.
  - Select letters for the brown eye and blue eye alleles.
  - Create a Punnett square for a couple who are both heterozygous.
  - State the genotypic and phenotypic ratios of the offspring.
  - State the chances of this couple producing a blue-eyed child.

**Practical 12.5****Positive or negative**

One vital gene located on chromosome 1 in humans is the gene controlling for Rhesus (Rh) blood type. Due to Rh-positive blood being dominant to Rh-negative blood, we can assign the alleles D (Rh positive) and d (Rh negative). Therefore, an Rh-positive person can be either DD or Dd with respect to this gene, but an Rh-negative blood type can only be homozygous, dd.

**Materials**

Coloured counters (one for every person in the room)

Marker pens (preferably erasable)

**Aim**

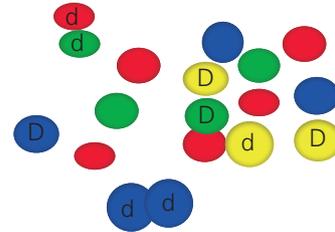
In this activity, we will use coloured counters and marker pens to model the passing of Rh alleles from heterozygous individuals to their offspring.

*continued...*

...continued

### Procedure

- 1 Copy the results table below.
- 2 Choose one coloured counter. Write D on one side and d on the other to represent the alleles of the chromosomes. This counter represents an individual who is Dd for Rh blood type; that is, able to produce gametes (eggs or sperm) of the type D and d in equal proportions.
- 3 Find a partner in the room (the counter colour does not matter).
- 4 Make an unbiased toss of your two counters to produce an offspring. The labels facing uppermost on the counters will represent the alleles of the gametes produced by the parents. Record the genotype of the offspring in the Family 1 row of the table below. Repeat this step three more times to produce a total of four children.
- 5 Generate a total of four families (by pairing up with three different sets of students) with each having produced four children.
- 6 Record the number of each child's genotype in each family in the table below. Pool your total results with those of the class.



### Results

	Genotype of children		
	DD	Dd	dd
Family 1			
Family 2			
Family 3			
Family 4			
<b>Total numbers across the class</b>			

### Discussion

- 1 Using the class data, calculate the probability of obtaining the offspring genotypes:
  - a DD
  - b Dd
  - c dd
- 2 What are the proportions of the different genotypes in your group of 16 children compared to those generated across the whole class? Discuss whether or not this is expected.
- 3 A woman with Rh-positive blood insisted that she was the daughter of a rich, elderly couple who both had Rh-negative blood. Use a Punnett square to show your working out to explain whether this woman's statement could be valid.

## Sex linkage

As we have seen, in humans the sex chromosomes are considered to be the 23rd pair. They contain genes that determine the sex of the individual. Daughters get two X chromosomes (one each from the mother and the father), whereas sons receive one X chromosome (from their mother) and one Y chromosome (from their father). Human females are therefore homozygous for the

X chromosome and males are not. It is also reasonable to conclude that the determination of sex in humans depends on the presence or absence of the Y chromosome.

Therefore, the father is responsible for determining the sex of the child, by passing on either an X or a Y chromosome. The mother can only pass on an X chromosome to the child.

The X chromosome also has many genes not related to sex determination (the Y chromosome has very few). Characteristics that do not necessarily have anything to do with the sex of the individual but are coded by genes on the X chromosome are said to be X-linked. When we predict X-linked traits using a Punnett square, we have to use the sex chromosomes in the Punnett square and use letters superscripted above the sex chromosomes to represent the trait. For example, haemophilia, a disorder where the blood

does not clot properly, is inherited as an X-linked recessive trait. The genotype for an unaffected female would be  $X^H X^H$ , a **carrier** female would be  $X^H X^h$ , and a haemophilic female would be  $X^h X^h$ . On the other hand, an unaffected male would be  $X^H Y$  and a haemophilic male would be  $X^h Y$ . As there is no gene for this condition found on the Y chromosome, we do not write H or h next to the Y.

**carrier**  
an individual with a recessive allele for a disease, but who does not have the disease due to being heterozygous

### Worked example 12.5

#### Cross between a heterozygote normal vision female (carrier) and a normal vision male

Colour blindness is inherited as an X-linked recessive trait. The genotype of a normal vision (carrier) female is  $X^B X^b$  and of a colourblind male is  $X^b Y$ .

Parents:  $X^B X^b \times X^b Y$

gametes	$X^B$	$X^b$
$X^B$	$X^B X^B$	$X^B X^b$
Y	$X^B Y$	$X^b Y$

$F_1$  genotype: 25%  $X^B X^B$ ; 25%  $X^B Y$ ; 25%  $X^B X^b$ ; 25%  $X^b Y$

$F_1$  phenotype: 25% normal vision female; 25% normal vision male; 25% carrier normal vision female; 25% colourblind male

### Codominance

When you have two equally dominant alleles for a trait, they will both show up in the heterozygote. We call this **codominance** – both the alleles in this situation are expressed equally in the phenotype. Look at the picture of the chickens in Figure 12.28. The colours black and white are equally dominant

(their alleles are both given capital letters), so when you cross a pure black chicken with a pure white chicken, you get a heterozygote. In the heterozygote, both colours are expressed equally, so you get a speckled chicken with black feathers and white feathers!

**codominance**  
both alleles are expressed equally in the phenotype

			
Genotype	WW	BB	BW
Phenotype	White	Black	Speckled



VIDEO  
Give an example of codominance

**Figure 12.28** White and black are equally dominant alleles and are said to be codominant. The evidence of this is their heterozygote offspring that has black and white feathers.

## Blood types

In humans, our blood type is a codominant trait. Our red blood cells have proteins on the surface called antigens, and it is these antigens that determine whether our blood is A, B, AB or O. Remember that the code for building proteins, like the antigens, is in our DNA, and the processes of transcription and translation are responsible for building the protein. So, your genetic code, which you inherit from your parents, is responsible for your blood type.

Each person has two copies of the ABO blood type gene: one from their mother and one from their father. The blood type gene is found on chromosome 9, and there are three alleles (versions) of the gene:

- $I^A$  = production of antigen A (type A blood) is dominant.

- $I^B$  = production of antigen B (type B blood) is dominant.
- $i$  = production of neither antigen (type O blood) is recessive.

However, because we only have two copies of chromosome 9, we can only have a maximum of two versions at one time:

- Type A blood can have genotypes  $I^A I^A$  or  $I^A i$ .
- Type B blood can have genotypes  $I^B I^B$  or  $I^B i$ .
- Type AB blood has the genotype  $I^A I^B$ .
- Type O blood can only have genotype  $ii$ .

$I^A$  and  $I^B$  are both dominant over  $i$ , but equally dominant when together.

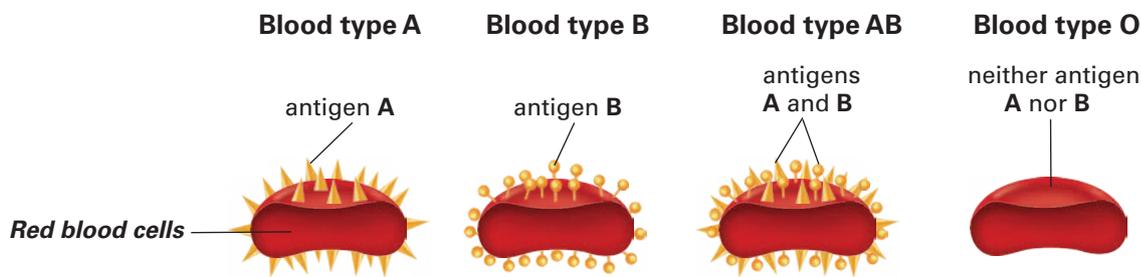


Figure 12.29 Different antigens on the surface of red blood cells of different types

### Worked example 12.6

#### Cross between heterozygous blood type A and heterozygous blood type B

Parents:  $I^A i \times I^B i$

gametes	$I^A$	$i$
$I^B$	$I^A I^B$	$I^B i$
$i$	$I^A i$	$ii$

$F_1$  genotype: 25%  $I^A I^B$ ; 25%  $I^B i$ ; 25%  $I^A i$ ; 25%  $ii$

$F_1$  phenotype: 25% AB blood type; 25% B blood type; 25% A blood type; 25% O blood type

## Explore! 12.3

**Incomplete dominance**

**Incomplete dominance** is a form of inheritance in which neither of the alleles is dominant over the other, resulting in a third phenotype which is a combination of both alleles. The colour of eggplant fruit is an example of incomplete dominance. Breeding deep purple eggplants with light green or white eggplants results in violet fruit.

- 1 The flower colour of snapdragons is an example of incomplete dominance. Draw an example of a cross for a white flower and a red flower.
- 2 Research some other examples of incomplete dominance.



**Figure 12.30** Deep purple (left), violet (middle) and light green eggplants (right)

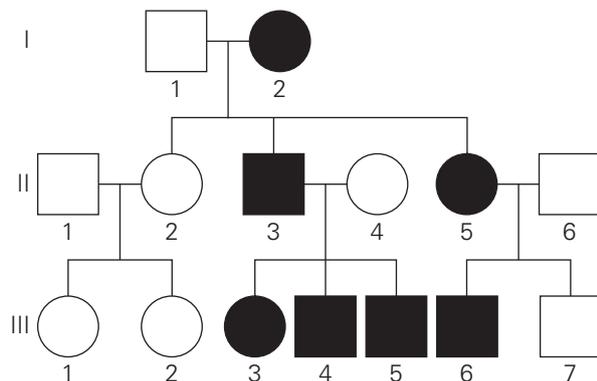
## Quick check 12.13

- 1 Explain why males are much more affected by recessive X-linked disorders than females.
- 2 Describe codominance.

**Pedigrees**

One way of finding out how a trait is inherited is to follow the inheritance pattern over two or more generations. This technique is called pedigree analysis. To study patterns of inheritance in humans, geneticists investigate the frequency and occurrence of a particular gene over many generations to determine whether the traits are dominant or recessive. The chart formed is called a **pedigree** and it is just like a family tree.

You can see in Figure 12.31 that each generation (numbered in Roman numerals) forms a row on the



**Figure 12.31** An example of a pedigree showing three generations of a family. Individuals affected by a particular trait are shown in black. Note how male I-1 and female I-2 had three children, and their eldest is an unaffected female (II-2).

pedigree, with individuals numbered (using Arabic numbers) from left to right on each row. The symbols used are:

- Unaffected females
- Unaffected male
- Female with the trait being investigated
- Male with the trait being investigated
- Carrier of trait or
- Mated represented by a horizontal line
- Vertical line connects offspring to parents

**incomplete dominance**  
a form of inheritance in which neither allele is dominant over the other, producing a third phenotype

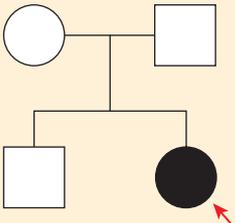
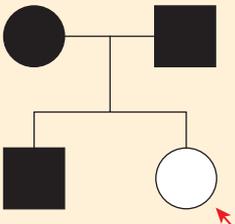
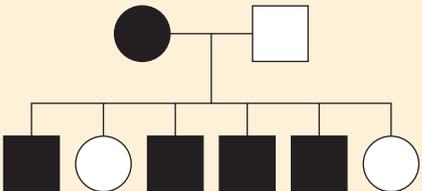
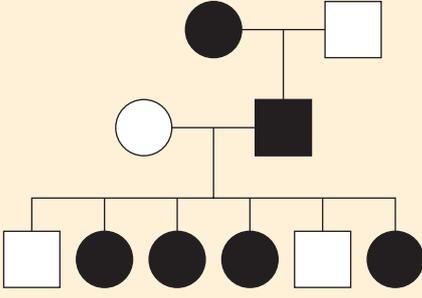
**pedigree**  
a chart formed to study patterns of inheritance over generations

**Reading a pedigree**

There are some points to keep in mind when reading a pedigree and determining inheritance.

- A trait that is common in a population is not necessarily dominant.
- If you are asked to determine a genotype in a pedigree, first you will need to work out the mode of inheritance. You can use Punnett squares to help you.

- Remember that if a couple has four male offspring it does not mean their next child is going to be female. Every time the parents have a child, the chance of getting a male or female is the same 50/50. The same goes for the chance of inheriting traits.

Type of inheritance	Pedigree chart	What to look for	Examples
Autosomal recessive		If two unaffected parents have an affected child, the trait cannot be dominant. Males and females can be equally affected. The trait may disappear from a branch of pedigree and then reappear in later generations. Two affected recessive parents must have all affected recessive children.	Albinism, cystic fibrosis and thalassaemia
Autosomal dominant		If two affected parents have an unaffected child, the trait must be dominant. With a dominant trait, a person only needs one allele to show the trait. Males and females can be equally affected, yet all of the affected individuals must have at least one parent affected.	Huntington's disease and a form of Alzheimer's disease
X-linked recessive		If an affected mother has all affected sons, the trait could be carried on the X chromosome and be recessive.	Colour blindness, haemophilia and muscular dystrophy
X-linked dominant		If a father is affected and all his daughters are affected, this suggests the trait is X-linked and dominant. Also an affected father <i>cannot</i> pass the trait to his sons, yet an affected homozygous female will pass the trait on to all of her daughters and sons. And an affected heterozygous female has a 50% chance of passing the trait on to her daughters and sons.	X-linked hypophosphatemic rickets

**Table 12.4** Different modes of inheritance and how to identify them in a pedigree chart

## Quick check 12.14

Study the pedigree chart in Figure 12.32. It illustrates the inheritance of achondroplasia (dwarfism) in humans.

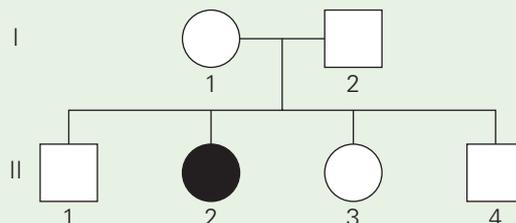


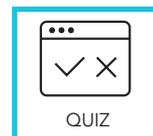
Figure 12.32 Pedigree chart

- Identify a piece of evidence that suggests that this condition is recessive and not dominant.
- Identify the genotype of individuals I-1, I-2, II-1 and II-2.
- Suppose individual II-2 marries a man who does not have achondroplasia but is a carrier for the condition. Determine the chance of having a child with achondroplasia and the chance of having a child without achondroplasia. Use a Punnett square to show how you arrived at your answer.

## Section 12.3 questions

## Remembering

- State** how many copies of each gene we have and where they come from.
- Recall** the name of the person known for being the father of genetics.
- Describe** what pedigrees are useful for.
- Outline** the difference between codominance and incomplete dominance.
- Provide** an example of codominance and incomplete dominance.



QUIZ

## Understanding

- Explain** how sex linkage is different to other types of inheritance.
- Explain** why for a particular characteristic two homozygous recessive individuals can only produce homozygous recessive children.
- Explain** what is meant by the term 'carrier'.
- Explain** why males have more chance than females of inheriting an X-linked recessive trait.

## Applying

- Dimples is dominant to no dimples.
  - Assign** letters for these alleles.
  - Identify** the genotypes and phenotypes of:
    - a person homozygous recessive for dimples
    - a person heterozygous for dimples
    - a person homozygous dominant for dimples.
  - Identify** the person above who would be considered a carrier for dimples.
- In fruit flies, eye colour is determined by an autosomal gene. The red eye allele is dominant over the white eye allele.
  - Assign** letters to the alleles.
  - Draw** a Punnett square for a male heterozygous fly that mates with a female homozygous recessive fly.
  - State** the genotypic and phenotypic ratios of the offspring.

**12 Construct** a pedigree with the following information.

A woman with Huntington's disease marries a man who does not have Huntington's disease. They have three children. The first child is a male, the second child is a female and both do not have the disease. The third child, a male, does get the disease. Remember that Huntington's disease is an autosomal dominant genetic disorder.

**13** In mice, black hair is dominant to brown hair. Mice with black hair can be either homozygous or heterozygous.

**Describe** how you would find out if a mouse with black hair was homozygous or heterozygous. **Justify** your response with a Punnett square.

**Analysing****14** The pedigree in Figure 12.33 shows the inheritance pattern of a disease that is caused by a single gene.

- Identify** the sex of the person labelled 7.
- State** whether the disease is dominant or recessive. Justify your response.
- Identify** the genotype of individual 7. **Justify** your response.

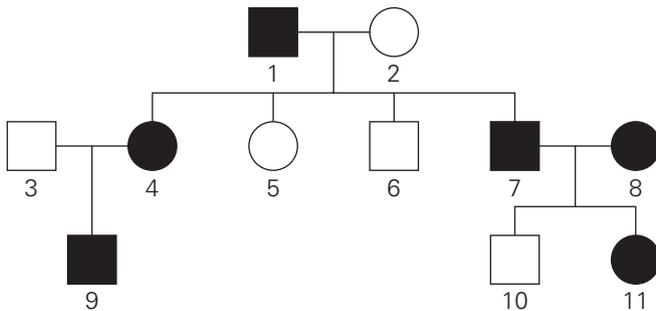


Figure 12.33 Inheritance pattern of a disease caused by a single gene

**15** The pedigree in Figure 12.34 shows the inheritance patterns for haemophilia. Haemophilia is an X-linked recessive disorder.

- State** how many children couple 1 and 2 had.
- Use evidence from the pedigree to **demonstrate** that haemophilia is recessive.

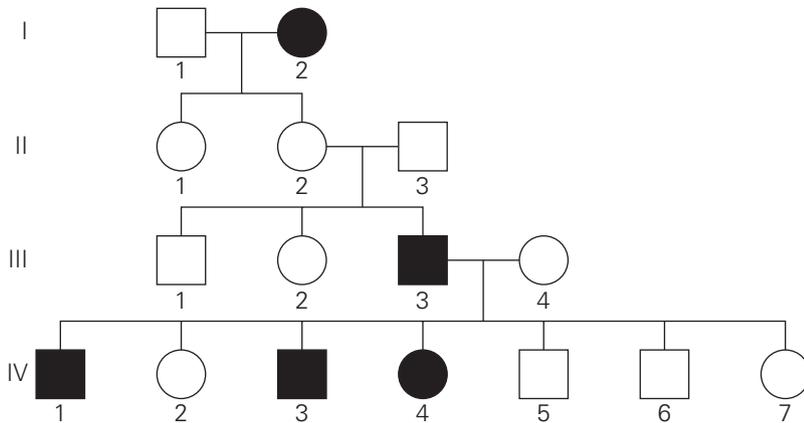


Figure 12.34 Inheritance pattern for haemophilia

**16** Chondrodystrophy is an autosomal recessive condition that is governed by a single gene with two alleles. In turkeys, affected embryos die approximately 16 days after fertilisation, so they do not survive long enough to hatch. Two turkeys that are heterozygous for the condition are crossed. Show all of your working to **determine** the phenotypic and genotypic ratios of the offspring who are born.

Let C = normal turkey; c = turkey with chondrodystrophy.

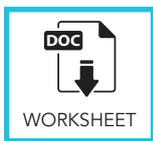
**Evaluating**

- Explain** what is meant by the statement 'nature versus nurture'.
- If a brown-eyed male and a blue-eyed female produced all blue-eyed children, does that mean that blue eyes is the dominant trait? **Justify** your response.

# 12.4 Changes in DNA

## Learning goals

- 1 To identify the role of genes and the environment in determining the features of an organism
- 2 To define the terms mutation and chromosomal abnormality
- 3 To describe one example of a chromosomal abnormality / mutation and its consequences to the individual
- 4 To describe the effects of mutations in cells
- 5 To define gene technology and biotechnology
- 6 To define the terms stem cell research, IVF and vaccines
- 7 To discuss the advantages and disadvantages of the use and application of biotechnology
- 8 To discuss the ethical issues associated with gene technology and biotechnology



The genetic code is translated into proteins that then determine cellular structure and function. Sometimes, however, there are errors in the genetic code of the cell. Often these errors are quickly repaired by the cell, but when they are not, they become permanent changes in the genome of the cell and are known as **mutations**. Mutations may be small, such as the changing of a single nucleotide (**point mutations**), or large, involving huge segments of DNA within a chromosome (**chromosome mutations**).

A mutation can be described as being **spontaneous** (naturally occurring) or being **induced** due to exposure

to **mutagenic** agents like radiation (X-rays, ultraviolet or nuclear) or chemicals. The mutations that occur within the gametes can be inherited and will influence the next generation. These are called **germline mutations**. If the mutation occurs within the body cells (somatic cells), this will only affect the individual and not be passed down to future generations. This form of mutation is known as a **somatic mutation**.

### mutation

a change in the genetic code of a cell

### point mutation

a mutation in which a single nucleotide is changed

### chromosome mutation

a mutation involving large segments of DNA

### spontaneous mutation

a naturally occurring mutation

### induced mutation

a mutation produced by environmental factors

### mutagenic

causing mutations in DNA

### germline mutation

a mutation of DNA in gametes which can be inherited

### somatic mutation

a mutation that occurs in somatic (body) cells which cannot be inherited

## Explore! 12.4

### Mutagens

Many factors in the environment are known as 'mutagens' – that is, they cause mutations.

- 1 Research environmental mutagens and create a list.
- 2 From the list created in Question 1, divide your mutagens into categories according to their source, such as chemical mutagens, radiation and mutagens in food.



**Figure 12.35** Radiation from the Sun can cause mutations in the DNA of skin cells.

## Beneficial, harmful and neutral mutations

There are three possible consequences of mutations.

**1 No effect – neutral:** Neutral mutations are non-lethal and make no difference to the organism's ability to survive and reproduce in its environment. Such mutations accumulate in the gene pool and give rise to genetic variation within a population.

**2 Negative effect – harmful:** Harmful mutations may cause the death of the organism or in some way make it less likely that the genetic material will be passed on to the next generation.

**3 Positive effect – beneficial:** Beneficial or advantageous mutations give rise to variations that increase the chance that the organism will survive and reproduce to pass its genetic material to the next generation.

### Quick check 12.15

- 1 If a mutation is to be passed on to the next generation, recall where it must occur.
- 2 State what usually results when mutations occur in somatic cells.

## Point mutations

Point mutations involve changes to any of the four nitrogenous bases in the nucleotides (ATCG) which make up the genes. Changing the nucleotides could change the message carried by the gene so that there may be a change in the order of amino acids making up the protein.

There are four types of point mutations:

**1 A substitution** mutation occurs when one nucleotide is swapped for another (for example, ATG becomes ACG). This mutation only changes the DNA code for a single amino acid. Or it could code for the same amino acid (this is called a silent mutation). An example of a disease caused by a

substitution mutation is sickle cell anaemia.

**2 An insertion** mutation occurs when an extra nucleotide (or more than one) is inserted into the DNA sequence (for example, ATG becomes ATCG). This type of mutation changes the DNA code for all amino acids that follow and is called a

frameshift mutation. An example of a disease caused by an insertion mutation is fragile X syndrome.

**3 A deletion** mutation occurs when a nucleotide is deleted from the sequence (for example, ATG becomes AG). This type of mutation changes the DNA code for all amino acids that follow and is also called a frameshift mutation. An example of a disease caused by a deletion mutation is Duchenne muscular dystrophy.

**4 An inversion** mutation occurs when two nucleotides reverse their order in the DNA (for example, ATG becomes AGT). This mutation only changes the DNA code for a single amino acid, or it could code for the same mutation (silent mutation). An example of a disease caused by an inversion mutation is haemophilia.

## Chromosomal changes

### Chromosomal mutations

If a mutation occurs in a gene on one of the pair of homologous chromosomes, there will still be a normal copy of the gene on the other chromosome. The same applies with chromosome mutations – the insurance is that they occur as homologous pairs, so if one chromosome is abnormal the other is still likely to be normal. The different types of chromosomal mutations are illustrated in Figure 12.36.

#### substitution

a type of point mutation in which one nucleotide is swapped for another

#### insertion

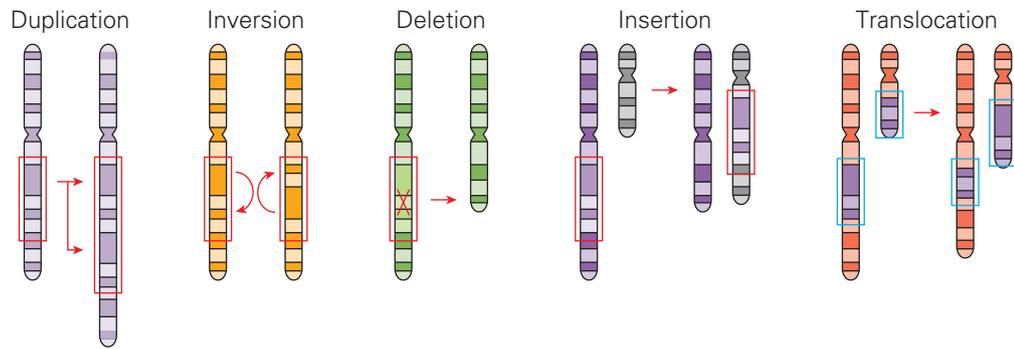
a point mutation in which an extra nucleotide (or more than one nucleotide) is inserted into the DNA

#### deletion

a point mutation in which a nucleotide is deleted from the sequence

#### inversion

a point mutation in which two nucleotides reverse their order

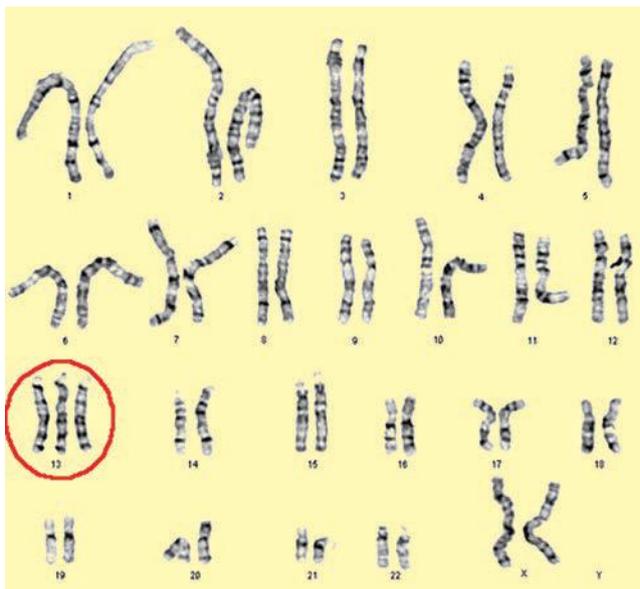


**Figure 12.36** The five different types of chromosome mutation. Can you identify what is changing in each type?

## Chromosome number abnormalities

Certain individuals may have one more or one less chromosome as a result of **non-disjunction** during meiosis. Non-disjunction means that the chromosomes failed to separate correctly when making gametes, so the gametes end up with an abnormal number of chromosomes (**aneuploidy**).

**Trisomy** occurs when an organism has a third copy of a chromosome that should only be present in two copies, and is therefore an example of aneuploidy. The most common trisomy among embryos that survive to birth is Down syndrome, or trisomy 21. People with this inherited disorder have short stature and digits, facial distinctions including a broad skull and large tongue, heart problems and developmental delays.



**Figure 12.37** There are other types of trisomy apart from trisomy 21. Trisomy 13 and 18 result in more severe conditions. The trisomy depicted here is trisomy 13.

## Quick check 12.16

- 1 Describe a substitution point mutation.
- 2 Recall what the term 'aneuploidy' means.

## DNA testing for mutations

A person's DNA can provide information relating to their risk of developing certain diseases. Genetic testing can be performed to analyse a person's DNA to find out whether they carry a gene which confers higher risk for a disease, and whether they are at risk of passing a genetic mutation on to their children.

**non-disjunction**  
when the chromosomes failed to separate correctly in meiosis

**aneuploidy**  
when an individual has an abnormal number of chromosomes

**trisomy**  
when an organism has a third copy of a chromosome

**genetic screening**  
genetic tests that are available for anyone in the population

## Types of testing

If an individual has a family history of a disease, they may be able to be genetically tested for that specific disease or condition. **Genetic screening** refers to tests routinely done for anyone in the population, even if they have not shown a family history of the disease. This screening is usually done during pregnancy and at birth. Pregnant women are able to have their foetus screened for Down syndrome and neural tube defects, and all newborn babies are tested for cystic fibrosis, phenylketonuria and hypothyroidism. Early diagnosis of a genetic condition like phenylketonuria means that action can be taken to treat or manage the condition – this allows some people to live longer and healthier lives than they would have without the appropriate intervention.

**bioinformatics**

an analysis tool that is able to sort biological data using computers

**Bioinformatics** involves using very powerful computers to sort and analyse

biological data. DNA chips are used to detect the presence of particular genes in a person's genome. Short fragments of genes are attached to a chip, and by adding a person's DNA, an area of the chip will light up if a certain gene is present.

With increasing knowledge about the human genome and disease-causing genes, we can gain an incredible amount of information about an individual. However, with this information comes some important questions. For instance, what happens with your genetic information once the tests have been completed? Who has access to that information? Could the results of these genetic tests affect things like health insurance?

**Explore! 12.5****Non-invasive prenatal testing**

During pregnancy, some of the baby's DNA passes into the mother's bloodstream. This DNA can be used to screen all of the baby's chromosomes for abnormalities. Because the baby's DNA is obtained from the mother's blood, it is a safe and non-invasive test.

- 1 What are the main disorders that a non-invasive prenatal test (NIPT) looks for?
- 2 How early in a pregnancy can this test be performed?
- 3 What advantage does NIPT have over other prenatal screening tests?
- 4 Why might a pregnant mother choose to have NIPT?

**Advances in science 12.3****Going mainstream!**

Genetic testing is going mainstream, with companies like *Ancestry.com* and *23andme* giving insight into an individual's genetic make-up. However, new research indicates that up to 40% of widely available genetic testing contains incorrect readings in the raw data. This can obviously be very stressful if unexpected inaccurate information is obtained. The advice from researchers is that these sorts of tests still need to be interpreted by professionals.



**Figure 12.38** Genetic screening can identify risks for certain cancers.

**Quick check 12.17**

- 1 Explain why an individual might choose to be screened for genetic diseases.
- 2 Identify some ethical issues with genetic testing.

## Manipulating DNA

**Genetic engineering** technology allows scientists to manipulate genetic material and transfer genes between different organisms. One of the most exciting developments of the last decade is CRISPR (stands for ‘clusters of regularly interspaced short palindromic repeats’), a technology that can edit genetic material quickly and cheaply. Developed by Jennifer Doudna and Emmanuelle Charpentier, CRISPR has almost endless potential, including editing crops so they’re more nutritious or able to survive in different conditions, curing genetic diseases, producing powerful new drugs or even resurrecting extinct species.

### Genetically modified organisms

A **genetically modified organism** (GMO) is an organism whose genome has been altered by humans. Many foods come from genetically modified organisms, and we call them GM foods. For example, some plants have been genetically engineered to grow with less water so that they are more resistant to changing weather patterns.

Some genetic changes are helping to alleviate global malnutrition and disease. A type of rice called golden rice has been engineered to prevent blindness in children from vitamin A deficiency. Another type of GM rice had been developed that has four times more iron than normal rice.

### Transgenic organisms

**Transgenic organisms** (TGOs) are another type of genetic modification. These organisms possess a ‘foreign’ gene, or a segment of ‘foreign’ DNA, in their genome, as a result of human experimentation. Scientists have transferred human genes into bacteria and cows, and bacterial genes into cotton plants. They are examples of transgenic organisms.

Human genes have been engineered into other mammals in order to supply the protein products of those genes, usually for medical purposes. For example, transgenic hamster cells have been genetically engineered to contain the human gene that codes for the production of

follicle-stimulating hormone (FSH). FSH is commonly used in in vitro fertilisation (IVF) treatments. Some women do not produce enough FSH to allow their eggs to mature so may have difficulty becoming pregnant. Fertility drugs must contain FSH to stimulate the eggs to mature in the ovary and thus optimise the chance of pregnancy.

**genetic engineering**  
technology that allows genetic material to be manipulated and enables genes to be transferred between any two species

**genetically modified organism**  
an organism that has had its genome altered by humans

**transgenic organism**  
an organism that possesses a ‘foreign’ gene or segment of ‘foreign’ DNA in its genome as a result of human experimentation

**gene therapy**  
a process by which a copy of a functional gene is introduced into an organism

The supply of this recombinant FSH is more reliable, larger and purer than the FSH traditionally derived from human urine.

Another example is the use of transgenic cows with the gene for human serum albumin, which is often given in blood transfusions. These cows produce large amounts of recombinant human serum albumin in their milk, much more than can be extracted from human blood donations.

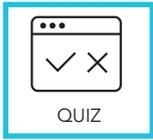
### Gene therapy

**Gene therapy** is a process by which a copy of a functional gene is introduced into an organism. The gene is then switched on to produce the functional protein that is missing. This technique aims to treat inherited disorders like cystic fibrosis by directly targeting the genotype (unlike symptomatic treatments that target the phenotype). Technical difficulties may arise when trying to specifically target the cells of affected tissue, and when targeting one specific gene without interfering with the function of other essential genes. Ethical issues also arise. Some people argue that gene therapy should be restricted to somatic tissue only, so the introduced gene is not transmitted through to the next generation. What do you think about this issue?

#### Quick check 12.18

- 1 Recall what GMO stands for.
- 2 Describe the process of gene therapy.

## Section 12.4 questions



## Remembering

- For a mutation to be passed on to the next generation, **identify** where must it have occurred and how you know.
- Define** the term 'mutagen' in your own words.
- Describe** the difference between a spontaneous mutation and an induced mutation.
- Recall** the definition of a genetically modified organism.

## Understanding

- Explain** what will happen if a nucleotide is deleted from the sequence of nucleotides within a gene.
- Explain** what usually results when mutations occur in non-germ cells.
- Explain** whether or not all mutations are detrimental/harmful.
- Explain** how a mutated gene can lead to a genetic disorder.
- Explain** the difference between a genetically modified organism and a transgenic organism.

## Applying

- Explain** why the substitution of one nucleotide is not as critical to the functioning of the protein as is a deletion or insertion of a nucleotide.
- Draw** a diagram to outline how non-disjunction may occur and cause aneuploidy.
- Using the DNA sequence ACAATTGGTAGCTGAGTTGGCCCGTA, **demonstrate** an example of:
  - an inversion
  - a deletion
  - an insertion.

## Analysing

- Using the chart below, answer the following questions.

		2nd letter in the codon					
		U	C	A	G		
1st letter in the codon	U	UUU   Phe (F) UUC   UUA   Leu (L) UUG	UCU   UCC   Ser (S) UCA   UCG	UAU   Tyr (Y) UAC   UAA   STOP UAG   STOP	UGU   Cys (C) UGC   UGA   STOP UGG   Trp (W)	U C A G	
	C	CUU   CUC   Leu (L) CUA   CUG	CCU   CCC   Pro (P) CCA   CCG	CAU   His (H) CAC   CAA   Gin (Q) CAG	CGU   CGC   Arg (R) CGA   CGG	U C A G	
	A	AUU   Ile (I) AUC   AUA   AUG   Met (M) START	ACU   ACC   Thr (T) ACA   ACG	AAU   Asn (N) AAC   AAA   Lys (K) AAG	AGU   Ser (S) AGC   AGA   Arg (R) AGG	U C A G	
	G	GUU   GUC   Val (V) GUA   GUG	GCU   GCC   Ala (A) GCA   GCG	GAU   Asp (D) GAC   GAA   Glu (E) GAG	GGU   GGC   Gly (G) GGA   GGG	U C A G	

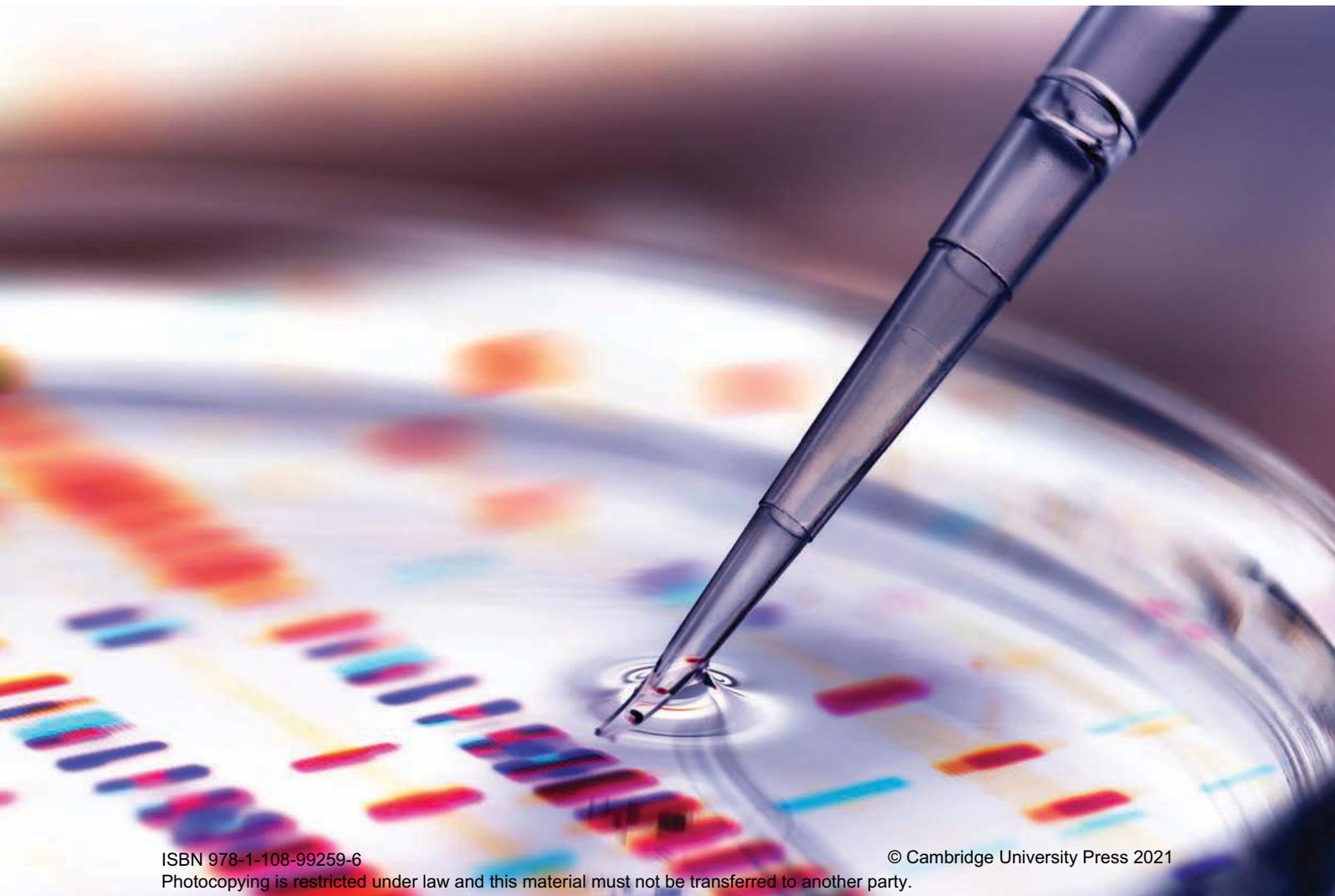
The original DNA strand is GTC GGG ATA CGG CTC. A point mutation occurs, whereby the C in the first codon is replaced with a T, resulting in GTT GGG ATA CGG CTC.

- State** the name of this point mutation.
- State** the mRNA strand that was copied from the original DNA strand.
- State** the new mRNA strand produced from the mutated DNA strand.

- d **State** whether the amino acids stay the same or change.
- e Another mutation occurs, whereby a C was added to the beginning of the above original DNA strand:  
CGTC GGG ATT CGG CTC  
**State** the name of this mutation and **describe** how it would affect the subsequent amino acids that it codes for.
- f **Identify** the mRNA code for this mutation and identify the corresponding amino acids.
- 14 An abandoned baby was handed in to the police station. Later, two different women claimed to be the baby's mother. Blood studies revealed that woman 1 had blood type A, and that woman 2 was blood type AB. The baby was blood type O. **Deduce** which woman could possibly be the baby's mother, and which woman can be ruled out completely. Show your working.

### Evaluating

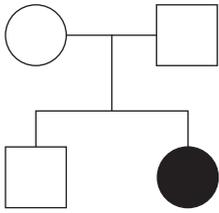
- 15 **Suggest** an explanation for the relationship between increased rates of skin cancer and the thinning of the ozone layer.
- 16 **Construct** a mind map that shows the different types of mutations that may occur.
- 17 Personal genome screening can be readily ordered over the internet. **Evaluate** the pros and cons of having DNA testing so readily available for an affordable cost.
- 18 You had genome screening and found out that your genes conferred a 25% chance of developing a disease. However, you also know that environmental and lifestyle factors play a large role in whether or not you develop the disease.
- a **Evaluate** how this information would affect your life.
- b **Discuss** how this scenario is different from knowing about a disease that is not influenced by lifestyle factors.



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>12.1 I can describe the structure of DNA.</b> e.g. Describe the structure of a molecule of DNA.	
<b>12.1 I can recall the relationship between DNA, genes and chromosomes.</b> e.g. Describe the relationship between DNA and chromosomes.	
<b>12.1 I can describe the structure of RNA.</b> e.g. Compare the structure of DNA and RNA.	
<b>12.1 I can recall the role of protein in living organisms.</b> e.g. State the function of haemoglobin in the body.	
<b>12.1 I can describe the process of protein synthesis.</b> e.g. Summarise the processes of transcription and translation.	
<b>12.2 I can distinguish between haploid and diploid cells.</b> e.g. Calculate the haploid number of a kangaroo if its liver cells contain 12 chromosomes.	
<b>12.2 I can describe the process of mitosis.</b> e.g. Recall the stages of mitosis.	
<b>12.2 I can describe the process of meiosis, including how it causes variation.</b> e.g. Describe what happens during anaphase II of meiosis.	
<b>12.3 I can demonstrate how traits are inherited from parents.</b> e.g. Use a Punnett square to demonstrate how two brown-eyed parents can have a blue-eyed child.	
<b>12.3 I can explain sex linkage.</b> e.g. Explain why haemophilia is more likely to be found in males.	
<b>12.3 I can distinguish between codominance and incomplete dominance.</b> e.g. Explain why blood groups are an example of codominance.	
<b>12.3 I can use a pedigree diagram to determine the type of inheritance that is occurring.</b> e.g. Determine what sort of inheritance is occurring from this pedigree diagram:	
<b>12.4 I can explain the different types of mutations, including their causes and effects.</b> e.g. To describe the effects of mutations in the following cells: body (somatic) cells – cancer; sex (gamete) cells – disorder to the whole body	
<b>12.4 I can describe some ways in which DNA can be manipulated.</b> e.g. Recall the definition of a transgenic organism.	



## Reflections

- 1 What **connections** come to mind when you think about genetics and your everyday life?
- 2 What new concepts have **extended** your thinking about genetics and inheritance?
- 3 What information did you find **challenging** or confusing?

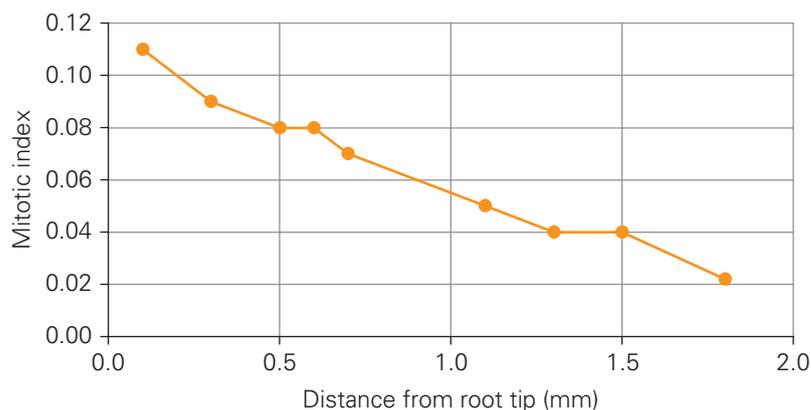
### Data questions

A student prepared an onion root-tip slide and examined the cells using a light microscope. She recorded the number of cells in each stage of the cell cycle.

The table shows her results.

Stage of cell cycle	Number of cells recorded
Interphase	340
Prophase	13
Metaphase	4
Anaphase	3
Telophase	6

She then calculated the mitotic index for different areas of the root tip. The graph shows her results.



- 1 The mitotic index of dividing tissue is calculated with the following formula:

$$\text{Mitotic index} = \frac{\text{number of cells seen that were undergoing mitosis}}{\text{total number of cells seen}}$$

**Calculate** the mitotic index of the tissue shown in the table.

- 2 The duration of any phase of the cell cycle can be calculated with the following formula:

$$\text{Phase duration (minutes)} = \frac{\text{number of cells seen in that phase}}{\text{total number of cells seen}} \times \text{cell cycle duration of the organism}$$

The cell cycle duration for the onion is 24 hours.

**Calculate** the duration of metaphase.

- 3 **Identify** the trend shown in the graph.
- 4 **Extrapolate** the data in the graph to estimate the mitotic index of the cells found at 2 mm from the root tip.

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

### Background information

Genetics forms the foundation of all life on Earth. It differentiates one species from another, and one individual from another within a species. Look around and you will notice everyone is unique. This genetic 'encyclopaedia' is not perfect. As with ancient scribes transcribing texts, errors are made each time a copy is produced. Errors in the genetic 'encyclopaedia', or genetic code, are known as mutations. The different types of mutations can be thought of as spelling, punctuation or grammar errors. Mutations create variations within a species and allow for evolution.

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

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

### Activity instructions

#### Suggested materials

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

#### Research and feasibility

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

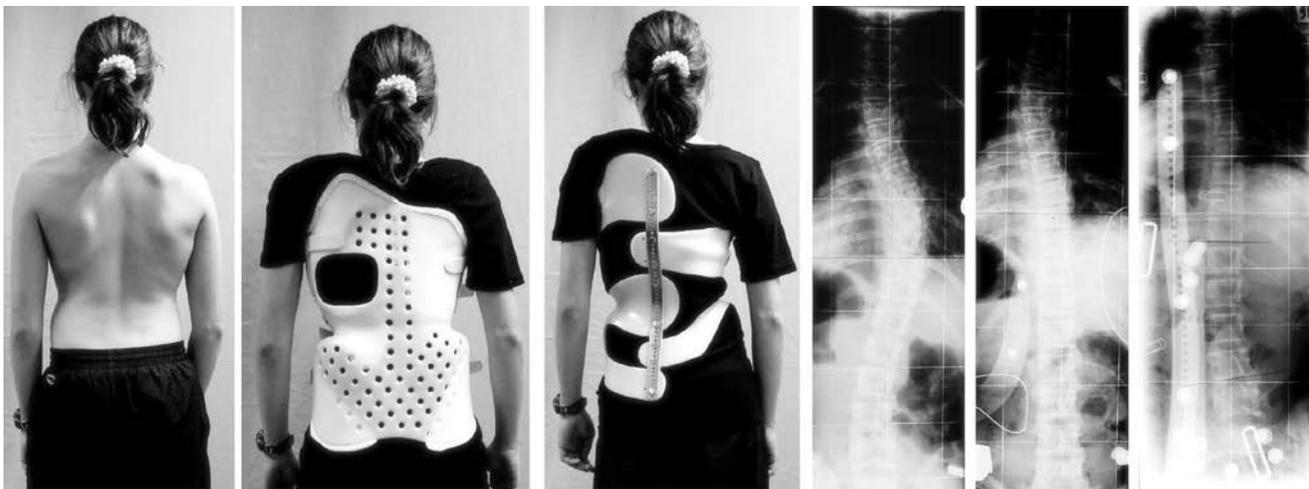


Figure 12.39 Various brace designs can be used for the treatment of scoliosis.

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

### Design and sustainability

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

### Create

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

### Evaluate and modify

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

Genetic disease cause	Effects on part of body	Ideas to help
e.g. Muscular dystrophy Muscle loss	Reduced joint movement	Brace and orthotics for feet
e.g. Haemophilia Blood doesn't clot effectively	Whole body can be bruised easily	<b>1</b> Creation of children's play suit <b>2</b> Creation of some type of buffing edging that could be applied to furniture

# Chapter 13

## Evolution



### Inquiry questions

How can evolution be used to justify the biodiversity on Earth?

What process can be used to describe the mechanism of evolution?

Why can't organisms evolve but a species can?

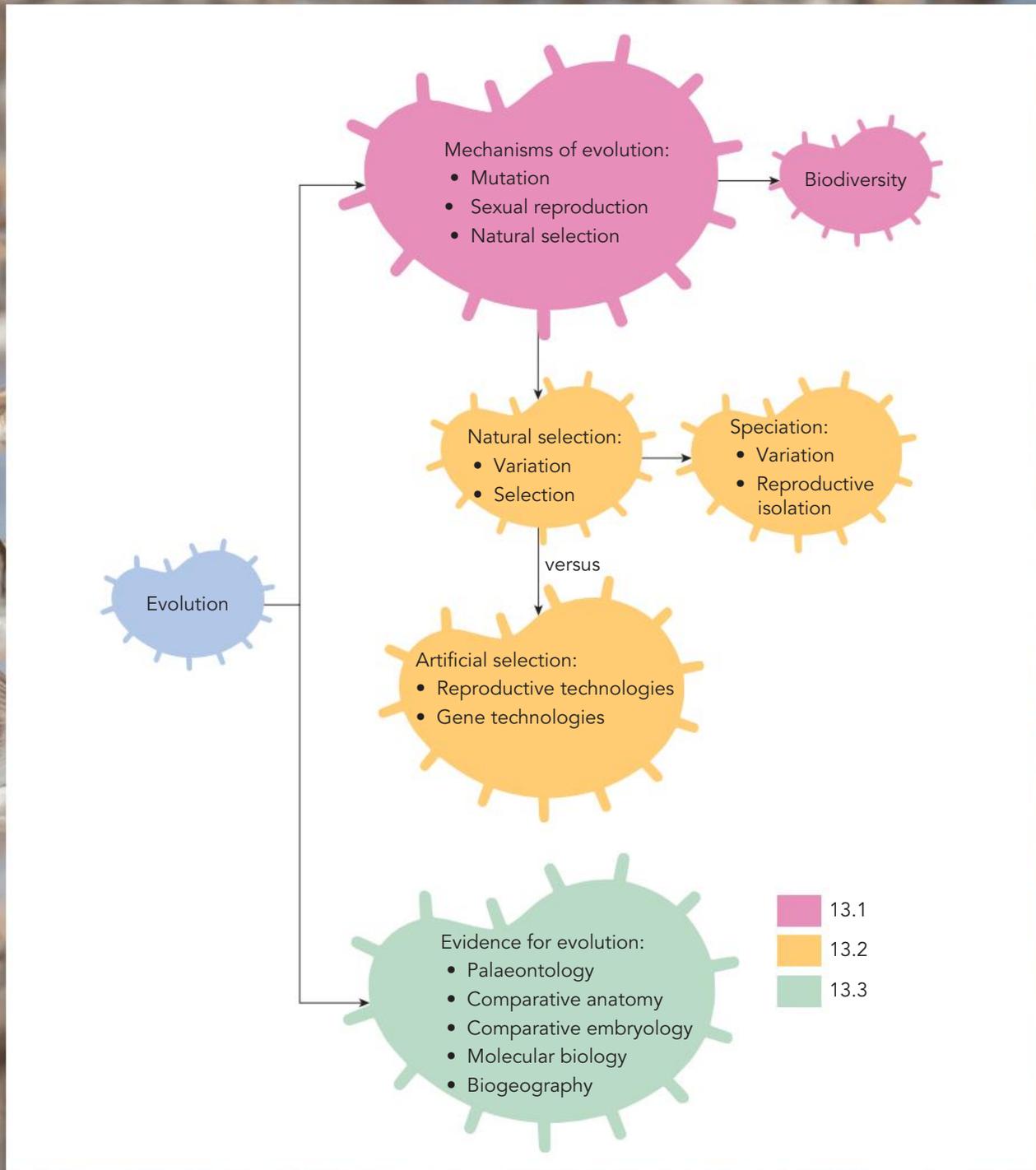
What evidence can we use to support the theory of evolution?



### Chapter introduction

How can there be so many different species on Earth? How are species suited to particular environments? Biodiversity is the key and can be explained through evolution. Evolution refers to the genetic changes in a species' population over a very long period of time. The theory of evolution is supported by the evidence we see in the fossil record, genetics and other fields of science. In this chapter, we will look at the significant evidence that supports the theory for evolution and evaluate the key processes involved.

# Chapter map



# 13.1 Evolution

## Learning goals

- 1 To define and understand the mechanisms of evolution
- 2 To understand the link between the survival of a population and variation
- 3 To discuss possible reasons why Australia's flora and fauna are unique
- 4 To describe case studies of an extinct species and a species at risk of extinction
- 5 To describe the impact of mass extinction on species diversity



**Evolution** refers to the genetic changes in a population over a very long period of time. When we talk about a **population**, we mean the members of a single species

### evolution

the genetic changes in a population over a long period of time

### population (ecological)

a group of a particular species living in the same geographical area at the same time

### variation

genetic differences within a population

### adaptation

characteristic that contributes to a species' suitability for its environment

living in the same region (geographical area) at the same time. Hence, evolution is understood by looking at the variation of a population of a particular species, not at individuals.

**Variation** occurs when members of a population differ in one or more characteristics.

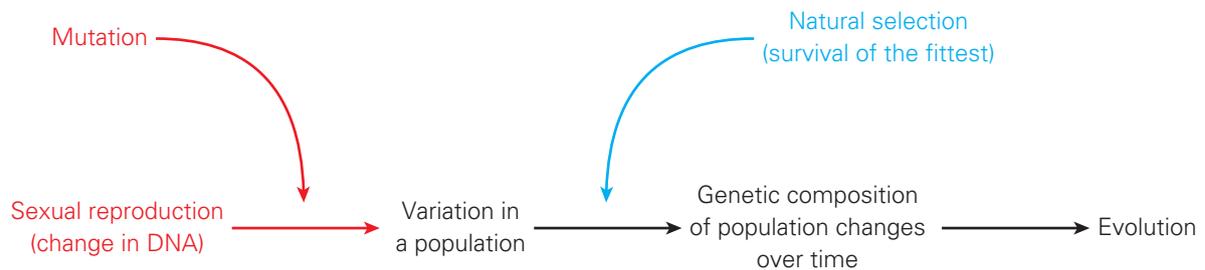
For example, we can notice many types of variation in humans, such as skin and hair colour, height, blood types, fast or slow metabolism, and food preferences.

Variations that contribute to an organism's ability to survive and reproduce in their environment are called **adaptations**.

## Mechanisms of evolution

Evolution can take place through three key mechanisms. Remember, evolution is all about the change in genetic composition of a particular species' population over time, so each of these processes changes the genetic make-up of a population in some way:

- mutation
- natural selection
- sexual reproduction – including the processes of 'crossing over' in meiosis and the random combination of genetic information from two parents.



**Figure 13.1** Changing genetic information changes the variation within a population and this leads to an overall change in the genetic composition of a population, which means evolution is occurring.

## Mutation

For evolution to occur, there must be a change in the genetic make-up of at least one individual. Recall that a mutation is a spontaneous or induced change in the genetic sequence of an organism's DNA. A mutation, if present in gamete cells, can be passed down to future generations.

Mutation is a random process in that the change can occur anywhere in a length of DNA. Mutations may have various effects on the phenotype of organisms, ranging from no change at all through to large changes. These large changes include genetic diseases that are associated with a loss of function that can negatively

affect the individual's chance of survival, meaning they are often not passed on to future generations. However, in some circumstances, mutations can produce a positive outcome if they occur in certain areas.

Genetic disease	Some of the outcomes
Albinism	No or little colour in skin, hair and eyes Reduced sun protection
Cystic fibrosis	Thicker mucus lining organs Respiratory and other health problems Fatigue
Duchenne muscular dystrophy	Progressive muscle weakness
Haemophilia	Blood cannot clot properly Abnormal bleeding
Sickle cell anaemia	Sickle-shaped red blood cells can interrupt blood flow Pain and fatigue Resistance to malaria, which is <i>beneficial</i> in areas where malaria is common

**Table 13.1** Some examples of genetic mutations and their outcomes in humans

As a mechanism of evolution, it is mutations that introduce the variation in new alleles. If the mutation happens to be advantageous and occurs in the gametes, it may lead to a shift in the genetic composition in the population of a species. In addition to natural selection, mutations are one of the main drivers of evolution, and without it, evolution cannot occur.

### Did you know? 13.1

#### Thyroxine

Researchers have found that approximately half of the Aboriginal population of Western Australia have a mutation that makes them produce a different amount of thyroxine, a hormone that regulates metabolism, including body temperature. This provides an advantage in areas that can regularly exceed 45°C.

**Figure 13.2** Marble Bar is Australia's hottest town. It is located in the Pilbara region of Western Australia where temperatures in excess of 45°C are common during December and January.



**natural selection**  
the process that results in the continued existence of only the organisms that are best suited to the conditions in which they live

#### Natural selection

You may have heard the saying 'survival of the fittest'.

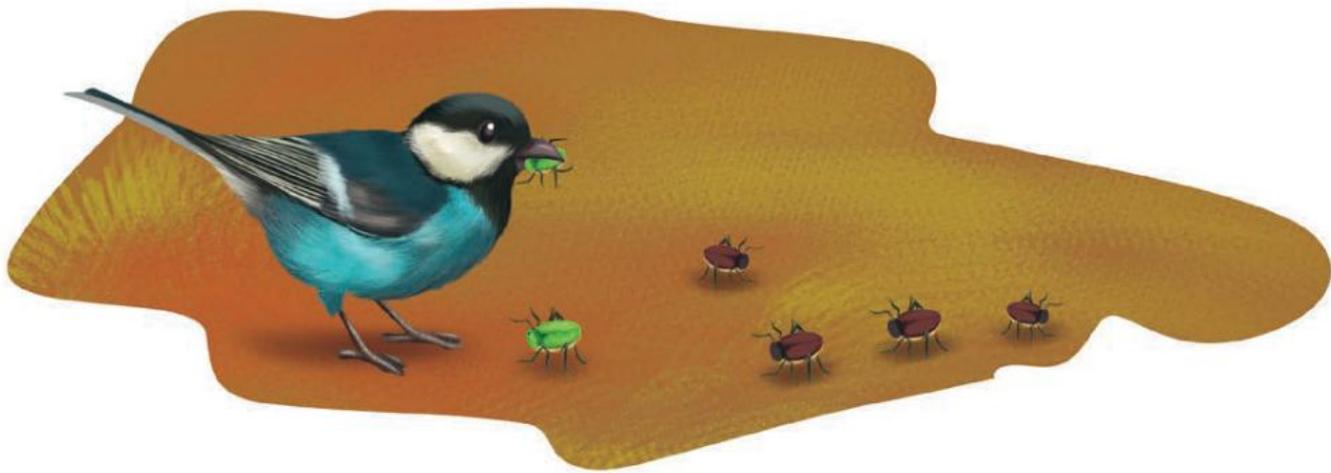
This is what **natural selection**

is all about. It means that those organisms that are best suited to their environment – that is, have the best adaptations – are far more likely to survive, reproduce and pass on their genetic information. For example,

look at Figure 13.3. These beetles live in the leaf litter on the forest floor and show natural variation in their colour: they can be green or brown. The birds eat more green beetles, not because they prefer them but because they are easier to spot. So being green is a disadvantage if you want to survive and not be eaten for dinner by the birds.



**VIDEO**  
Give an example of natural selection



**Figure 13.3** Some variations within a species are less likely to be passed on to the next generation because they have a disadvantage.

### Quick check 13.1

- 1 Define the terms 'evolution', 'population', 'variation' and 'adaptation'.
- 2 Outline three mechanisms of evolution.

The brown beetles have the best colour for surviving (adaptation), which means they will be more likely to survive and pass on their genetic information to their offspring.

## Biodiversity as a consequence of evolution

**Biodiversity** (biological diversity) refers to the immense variety of life on Earth. It includes both **species diversity** (the number of different species within an ecosystem) and **genetic diversity** (range of genetic traits within a species). Over time, populations within a species can become so different as to become a different species, increasing biodiversity. Therefore, it is evolutionary processes that have resulted in the biodiversity we see today.

Australia's unique biodiversity is best explained as the result of our plants and animals being isolated over a long period of time

from the plants and animals of other continents and land masses. Australia was once part of a great southern supercontinent called Gondwana that even earlier was the southern portion of the giant Pangaea land mass. Gondwana was made up of the continents and countries that we know today as South America, Africa, Australia, India and Antarctica. Gondwana is thought to have begun breaking up approximately 140 million years ago.

#### **biodiversity**

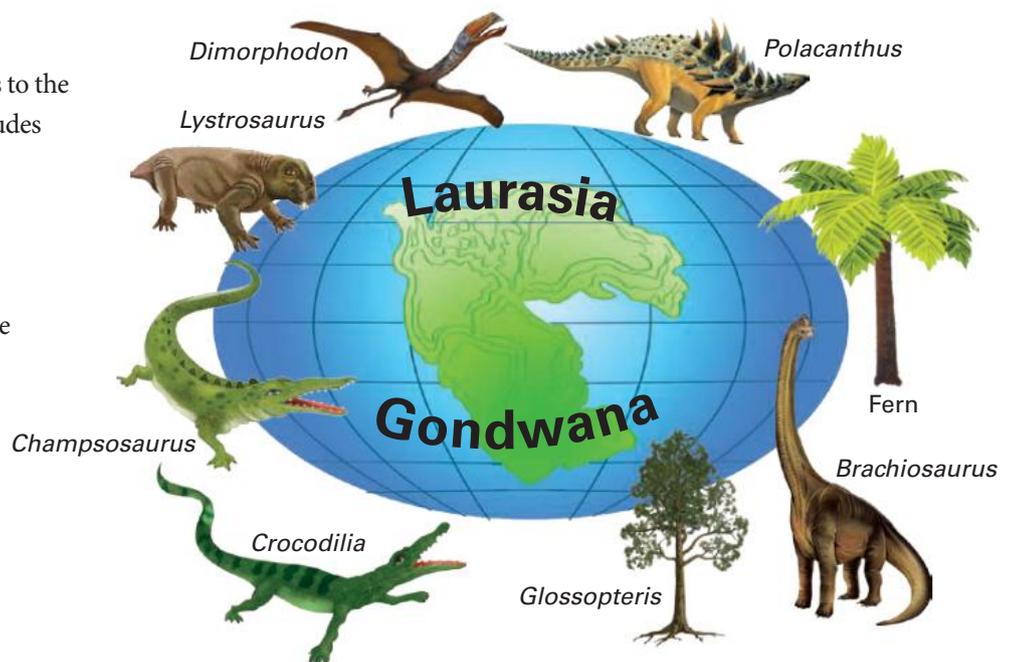
the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur

#### **species diversity**

the number and abundance of different species in a given area

#### **genetic diversity**

the range of genetic traits within a species



**Figure 13.4** This map shows the supercontinent Pangaea before it separated into a northern Laurasia and a southern Gondwana.

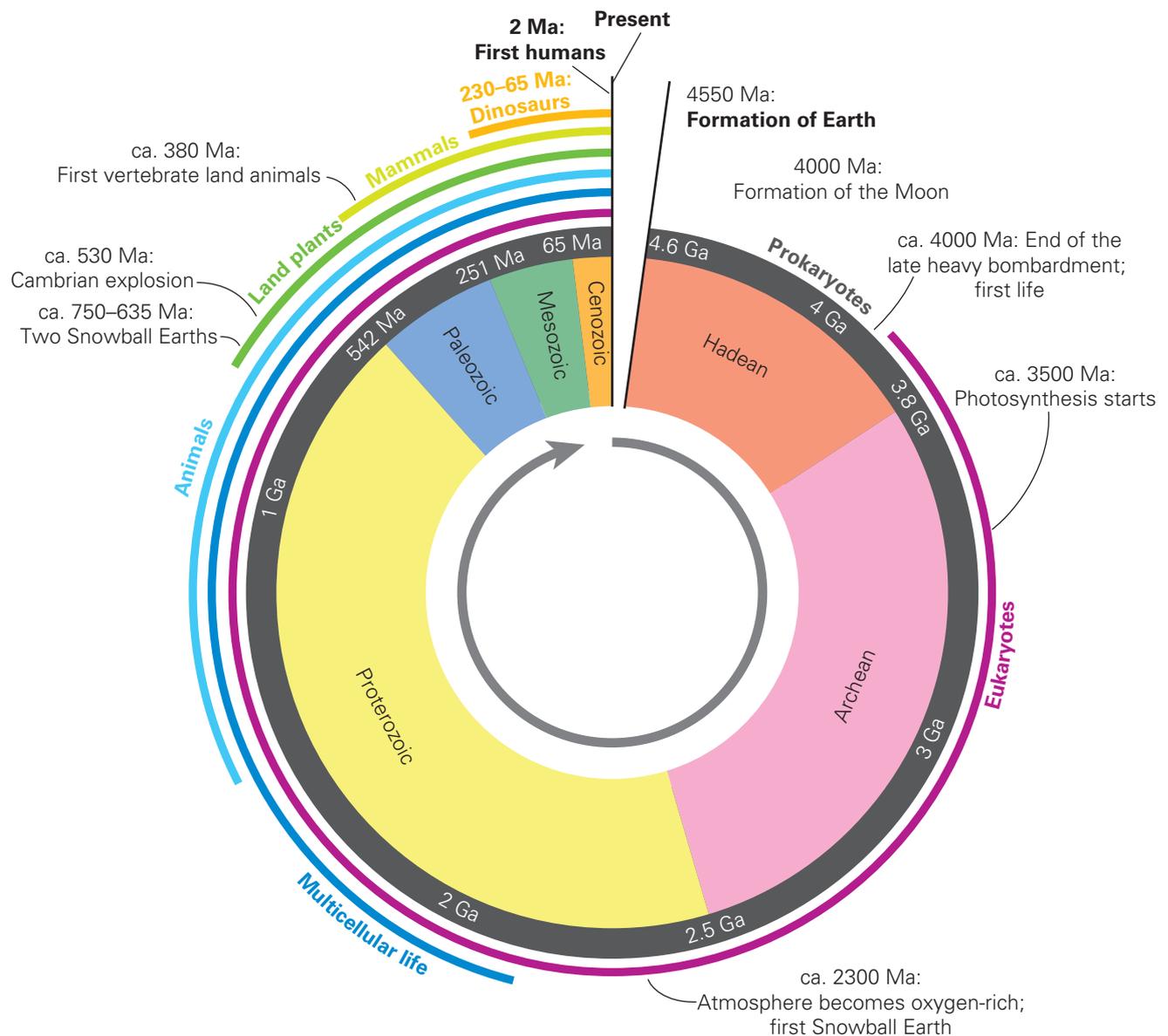
As the continents moved across the surface of Earth, so too did their assemblages of plants and animals. This not only created geographical barriers (like oceans, mountain ranges and large rivers), but over time it also brought new combinations of species together.

### Quick check 13.2

- 1 State what is meant by the term 'biodiversity'.
- 2 Recall what supercontinent Australia was once part of.
- 3 Explain how the movement of continents led to the biodiversity among species.

### Biodiversity through time

Our understanding of the origin of life on Earth is based upon the scientific evidence of the fossil record and genetic comparisons to modern life forms. The most primitive cells lived some 3.5 billion years ago. Although life appeared early in Earth's history (Earth is approximately 4.5 billion years old), evolution beyond the simple cell stage did not occur until much later – approximately 600 million years ago. Since then, the biodiversity that exists on Earth has fluctuated depending on changes in the environment. Figure 13.5 shows a timeline of the major stages in the development of life on Earth.



**Figure 13.5** A timeline of Earth's history (ages are abbreviated from Latin: Ga (giga-annum) represents a billion years, Ma (mega-annum) is a million years)

Historically, one of the best-known causes of a mass extinction on Earth is an asteroid impact that may have killed off the dinosaurs. However, the asteroid is suspected to be implicated in just one case of mass extinction, while volcanic activity has been implicated in at least four. Here are some hypothesised causes for the biggest mass extinctions on Earth:

- volcanic activity
- climate change
- changes in deep ocean oxygen levels
- changes in sea level.

A combination of the above causes may have contributed to mass extinctions, which caused major and rapid changes in the Earth's biota.

If there is sufficient genetic variation in a species when an environmental change occurs, some organisms within a population will be better suited to that new environment than others. The survival of the better-adapted individuals will result in a change in the genetic composition of the species' population, resulting in their evolution over time.

### When did humans arrive in Australia?

Many researchers believe that humans first arrived in Australia 60 000 years ago. The fossil record indicates that Australia's **megafauna** were present at the start of the last glacial cycle

**megafauna**  
large animals with a body mass of over 45 kilograms

(120 000 years ago) and survived for the first 70 000 years of the cycle, but were probably extinct by 45 000 years ago.

It is hypothesised that at least five major ice ages have occurred on Earth. The earliest ice age is thought to have occurred over two billion years ago, and the most recent one began approximately three million years ago – and continues today. So, we are currently living in a warm interglacial period that began about 11 000 years ago. Interglacial periods are the warmer periods of time between ice ages where sea levels rise and glaciers retreat.

The fossil record suggests that the Australian megafauna went extinct after the arrival of Aboriginal and Torres Strait Islander peoples. Scientists question the timing of these two events to determine if the extinction of the megafauna was caused by a changing climate, or if there are other factors that contributed to the mass extinction of mega fauna.

There are examples of species hunted to extinction such as the dodo, the passenger pigeon, the great auk and quaggas. Could the megafauna of Australia have been hunted to extinction by a small population of hunter-gatherers? Modern humans, the most formidable predator on the planet, first appeared in Africa around 200 000 years ago. Our ancestors had been evolving, first as omnivores in the middle of the food chain and later as top predators in Africa, for over three million years, and in Europe and Asia for around 1.5 million years. This allowed the megafauna in these areas, such as elephants and lions, to gradually adapt to survive in the presence of human hunters.

The megafauna that once roamed Australia included giant marsupials (mammals who carry their young in a pouch), reptiles and birds. One such marsupial is



**Figure 13.6** Reconstructions of *Palorchestes azael* (left) and *Diprotodon optatum* (right), the largest known marsupial, two examples of extinct species classified as Australian megafauna

known as the *Diprotodon optatum* (Figure 13.6) – with a shoulder height of 1.8 metres and weighing close to 3 tonnes – was the largest marsupial ever to have lived. The arrival and spread of modern humans in Australia and climate change are believed to have led to its demise.

By making changes to the environment, humans have also changed the genetic composition of populations of native plants and animals, thus altering the course of evolution and affecting species diversity.

### Maintaining biodiversity

Maintaining biodiversity is extremely important, and loss of it due to human actions (such as clearing forests, overfishing, polluting the environment, consuming animals and introducing new species) can cause huge impacts on ecosystems and result in loss of species that are beneficial to us. Maintaining diversity means keeping the full range of species in our ecosystems in order to conserve the variety of organisms on Earth. Species are considered **endangered** if they meet the criteria set by the International Union for Conservation

of Nature (IUCN). These include species whose numbers have experienced a reduction of 70% in a decade and species with a current population size of fewer than 250 mature individuals.

Endangered species are at risk of becoming **extinct**, especially if there is not enough genetic variation in the population. Species can be at risk even if their population is still large. Changes in the environment that may cause extinction include new diseases, new predators, competition with another better adapted species and loss of habitat.

Many zoos have captive breeding programs in which they breed captive animals to help the survival of endangered species. Such programs aim to reintroduce the species back into the wild, which aids in keeping population numbers up and limiting inbreeding.

**endangered**  
a species that is in danger of becoming extinct

**extinct**  
no longer existing

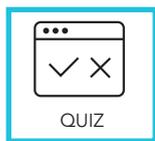


**Figure 13.7** The now extinct Tasmanian tiger (thylacine) is pictured in an enclosure at the Hobart Zoo Tasmania in 1933. This is an example of an extinct Australian species.

### Quick check 13.3

- 1 Define the terms 'biodiversity', 'endangered' and 'extinct' in your own words.
- 2 Explain the link between biodiversity and evolution.
- 3 Name one change in the environment that may lead to the extinction of a species.
- 4 Discuss how humans have affected biodiversity and therefore evolution.

## Section 13.1 questions

**Remembering**

- 1 **Define** the terms 'evolution' and 'population' in your own words.
- 2 **Name** one extinct Australian species.
- 3 **Define** the term 'variation' in your own words and give four different examples of variation within a species not provided in the text.
- 4 **List** where variation in a population comes from.

**Understanding**

- 5 **Distinguish** an extinct species from an endangered species.
- 6 **Outline** how mutations contribute to variation within a species and consequently evolution.
- 7 **Explain** why 'survival of the fittest' does not necessarily mean survival of the biggest and strongest.

**Applying**

- 8 **Summarise** how a change of only one nucleotide in DNA can result in a different phenotype and eventually cause evolution.
- 9 **Describe** an example of variation in a species that:
  - a increases the species chances of survival
  - b decreases the species chance of survival
  - c does not affect the species chance of survival.

**Analysing**

- 10 **Distinguish** between species diversity and genetic diversity.
- 11 In your own words, **explain** how extinctions can stimulate new biodiversity among species.

**Evaluating**

- 12 **Propose** why genetic biodiversity is important for the survival of a species.
- 13 In Earth's past, some species have been wiped out after an environmental change. **Explain** if this suggests the species had low or high genetic biodiversity, and give reasons why this would occur.



## 13.2 Natural and artificial selection

### Learning goals

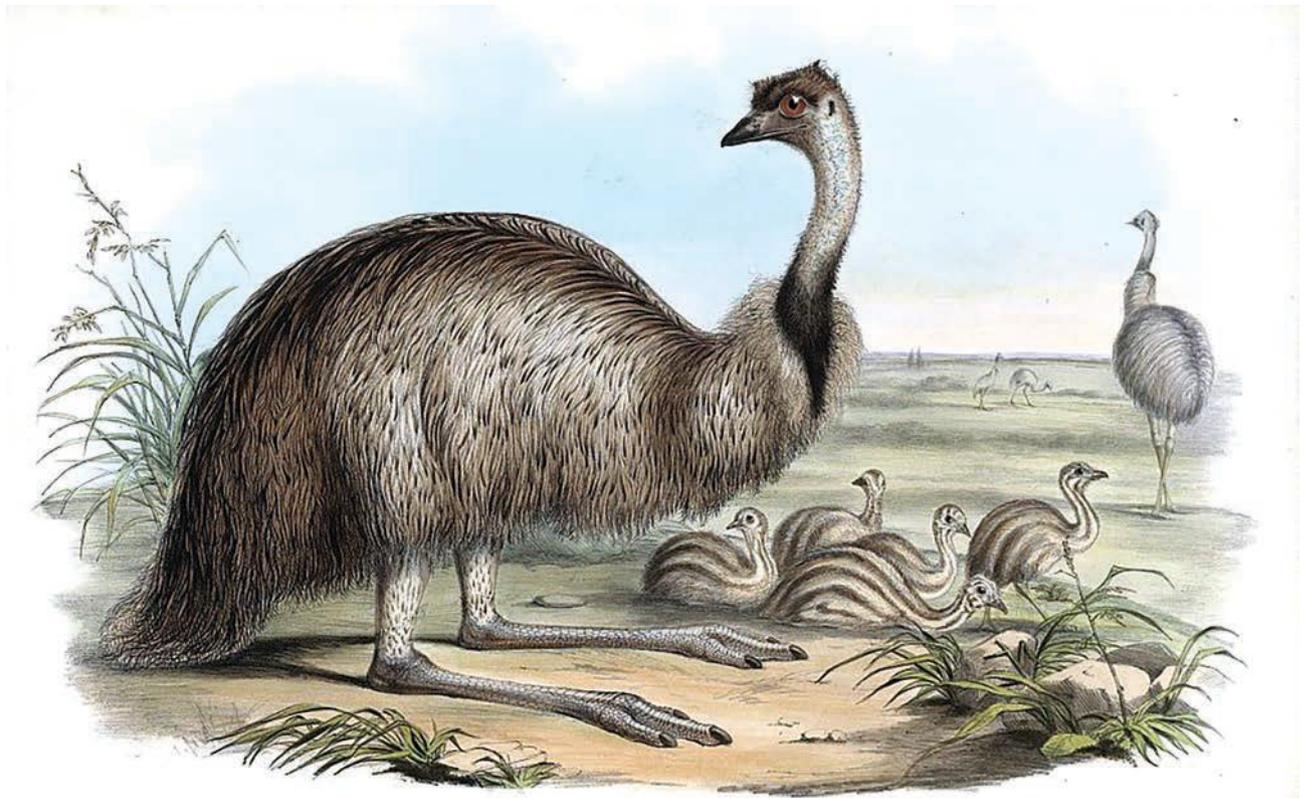
- 1 To describe the process of natural selection as a mechanism for evolution
- 2 To identify processes that can lead to variation within a population
- 3 To distinguish between natural and artificial selection

In 1831, at the age of just 22, the young naturalist Charles Darwin boarded the ship named the *HMS Beagle* and set out on a five-year voyage around the world to study and collect animal, plant and rock specimens. The *HMS Beagle* visited the remote Galapagos Islands off the coast of Ecuador, and it was here that Darwin recorded the plant and animal species of the island.

On his return to London, Darwin needed help in identifying some of the bird specimens that he had collected. Initially, he took little interest in his collection of finches, but this changed when the eminent ornithologist (a person who studies birds), John Gould classified them as 12 new species. Gould had noticed

that they showed great variation in their beaks. It was his observations that helped Darwin with the development of his theory of evolution.

Darwin speculated that although the different islands had similar animals and plants, many seemed to have specialised features that meant they were better suited to their local environments. Each finch species' beak was suited to eating the particular food source that was available in the habitat they occupied on their island. Darwin explained how species change over time, using the theory we know today as 'natural selection'.



**Figure 13.8** John Gould published the first comprehensive survey of birds in Australia. He was accompanied by his wife, Elizabeth Gould, who was a talented ornithologist and illustrator in her own right. This illustration was taken from his book, *The Birds of Australia*, published throughout 1840 and 1848 in seven volumes.

## The process of natural selection



The following four steps outline the process of evolution through natural selection.

- 1 Genetic variation naturally exists in the population due to processes such as sexual reproduction, crossing over, mutations and gene flow.
- 2 This genetic variation means that some individuals within the population have traits better suited to their environment.
- 3 Individuals with favourable traits are more likely to survive and reproduce than others of their species and pass on those traits to the next generation. We say those favourable traits are 'selected for' by environmental (or selection) pressures – that is, the process of natural selection.
- 4 Over time, the individuals with the favourable traits become more numerous in the population. That is the process of evolution by natural selection.

An example of natural selection is the case of the light and dark peppered moths (*Biston betularia*) in Britain. There are two varieties within the one species – one is light coloured, the other is dark coloured – and the colour is genetically determined. Look at the moths in Figure 13.9 – the light-coloured variety of the peppered

### selective advantage

a characteristic that enables an organism to survive and reproduce better than other organisms in a population

moth initially had the favourable trait (we can say the light-coloured moth was at a **selective advantage**) as

it blended well with the lighter lichen-covered bark of the trees. This meant when a hungry bird (the selecting agent) came by, it would be more likely to see the dark-coloured moth and eat them more often. Consequently, the dark-coloured moths were rare. The light-coloured moths were best adapted to survive and reproduce, so they were able to pass on their genetic information to the next generation.

However, during the Industrial Revolution, the bark of trees became darkened because of the pollution. This gave the dark-coloured moths a selective advantage, as they were now better camouflaged against the trees and not as easily spotted by predators. Now the roles were reversed: the light-coloured moths were at a disadvantage and their numbers fell. The darker moth was the 'fittest' or best adapted in this new environment and so was able to survive, reproduce and pass on its genetic information to the next generation. The proportion of dark moths rose. Interestingly, cleaner air in recent decades has seen the light-coloured moths favoured once again.

### Quick check 13.4

- 1 Recall where Charles Darwin collected his finch specimens.
- 2 Create a flow chart of the four steps involved in the process of evolution by natural selection. Then, annotate your flow chart with how each step relates to the peppered moth example.



**Figure 13.9** There are two variations of peppered moth: light and dark coloured. Can you see both moths in each image? The picture on the left shows the moths against a light tree bark. The picture on the right shows the moths against a dark tree bark.

### Variation

Natural selection occurs when an environmental factor acts on the phenotype. That is, some individuals in the population are different from others, and those differences provide an advantage or disadvantage for survival and reproduction. All around us, organisms are producing offspring that vary. This variation, which results from crossing over in meiosis as well as the random combination of genetic information during sexual reproduction, can make an individual better or less suited to the environment. Those organisms best suited to an environment where there is a selection pressure are more likely to survive and produce offspring.

### Selection

Those organisms that are best suited to the pressures of their environment are the ones that are more likely to survive, reproduce and pass on their genetic information to the next generation. We call these

pressures **selection pressures** because they determine which variations provide individuals with better survival chances.

**selection pressure**  
an external agent that affects an organism's chances of survival depending on their genotype (genetic variations)

Selection pressures can be biotic (living) or abiotic (non-living) conditions that affect an organism's survival chances in a given environment. Selection pressures can increase or decrease the occurrence of



Figure 13.10 Some variations of adult males of the frog species, *Pristimantis leopardus*

a trait in a population and may change with time or with other changes in the environment.



Category	Examples of selection pressures
Resources	Food availability (biotic) Shelter (abiotic) Availability of mates (biotic)
Physical environment	Temperature (abiotic) Weather (abiotic) Geography (abiotic)
Biological factors	Predators (biotic) Diseases (biotic)

Table 13.2 Selection pressures can be grouped in various categories.

## Try this 13.1

**Drug-resistant bacteria and traditional medicines**

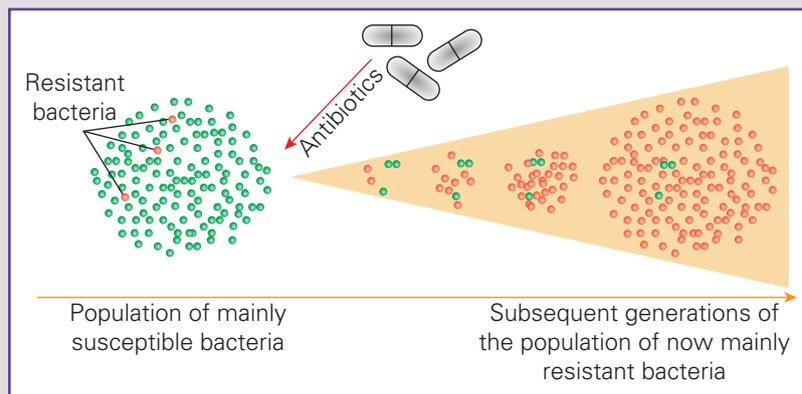
Antibiotics are medicines used to prevent and treat bacterial infections. However, some bacteria have mutations that mean they are resistant to the effects of the drugs. The World Health Organization has identified antibiotic resistance as one of the greatest threats to human health today, potentially causing up to 10 million deaths per year by 2050 if left untreated.

Currently, some researchers are focusing on studying traditional bush medicines, which have been used by Aboriginal and Torres Strait Islander peoples for generations, as alternatives to pharmaceutical antibiotics. Plants such as tea tree (*Melaleuca alternifolia*) and emu bush (*Eremophila* sp.) have been found to have the same strength as some established antibiotics and may provide a solution for the current resistance crisis.



**Figure 13.11** *Eremophila longifolia* is one of many species of plants that can be referred to as 'emu bush'.

Consider the following diagram carefully and then answer the questions that follow.



- 1 What variation between bacteria can you see in the original population?
- 2 Which variation is selected for (the fittest)? Which was selected against?
- 3 Which variation will contribute less to the next generation?
- 4 Which variation will survive in greater numbers, to reproduce and pass on its genetic information to the next generation?
- 5 Identify the selecting agent.

## Explore! 13.1

**Bush medicines**

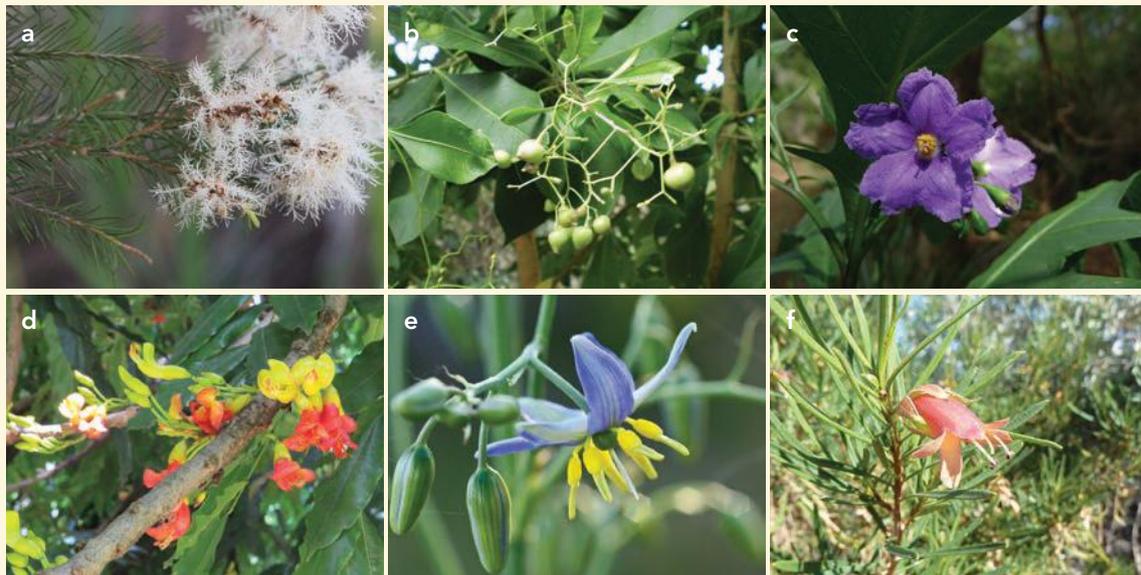
The diagram in Try this 13.1 demonstrates how bacteria can become resistant to certain drugs. The combination of evolutionary pressures and high use of antibiotics in contemporary society has seen the emergence of strains of diseases that are resistant to many drugs.

Since the first European settlers came to Australia, they have looked to Aboriginal and Torres Strait Islander peoples knowledge of bush medicines. These medicines have been developing over millennia through observation and experimentation, and the knowledge has been passed down to each subsequent generation. Now, there is increasing research directed at identifying compounds in traditional medicines for use in pharmaceuticals.

Unfortunately, there has been a historical problem of Australia's First Nations peoples merely having the role of informants, rather than being considered as collaborators in the production of new medicine. However, there is now a greater appreciation for the valuable input that Aboriginal and Torres Strait Islander communities provide. One example is a dual patent being granted to Griffith University and the Jarlmadangah Burru Aboriginal Corporation for an invention that relates to new analgesic (pain relieving) compounds. John Watson, an elder from the Jarlmadangah Burru community, had his finger bitten off while on a crocodile hunting trip. He chewed the bark of the marjala plant and applied it to his wound, then travelled to a hospital. The pain had been stopped so effectively that it led to a collaboration with Griffith University to explore the commercial benefits of the plant.

Conduct some research into at least one of the plants in Figure 13.12 used in the pharmacopeia of Aboriginal and Torres Strait Islander peoples, and find out:

- what ailment it treats
- which part of the plant is used as a remedy or medicine
- how it is processed
- what new medicines (if any) scientists are trying to develop using the plant.



**Figure 13.12** (a) tea tree (*Melaleuca alternifolia*), (b) corkwood tree (*Duboisia myoporoides*), (c) kangaroo apple (*Solanum laciniatum*), (d) Moreton Bay chestnut (*Castanospermum australe*), (e) pale flax-lily (*Dianella longifolia*), (f) crimson turkey-bush (*Eremophila latrobei*)

## Practical 13.1

## Modelling natural selection

## Aim

To simulate natural selection in a population of jellybeans and analysing the consequences.

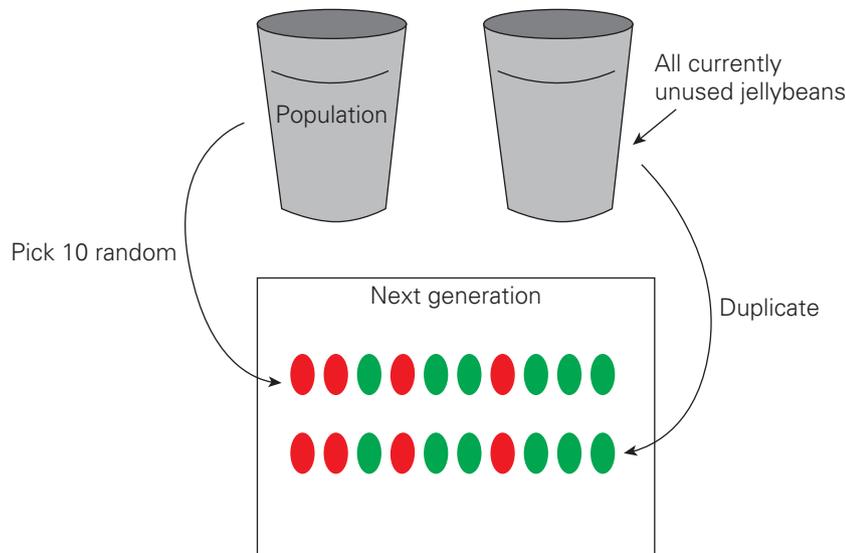
**Be careful**

No food is to be consumed.

## Materials

Jellybeans: 20 red and 20 green (or anything similar e.g. coloured paper, paddle pop sticks)

- 2 cups, label one of them 'Population'
- 1 piece of paper, label it 'Next generation'



## Procedure

- 1 Start with 10 red jellybeans and 10 green jellybeans and place them in your 'Population' cup. Record this in your results table.
- 2 Imagine that green has a selective disadvantage (the opposite of a selective advantage). Pick out three green jellybeans from the population and move them into the cup for unused jellybeans.
- 3 With your eyes closed, pick 10 random jellybeans from the population cup and place them on the piece of paper.
- 4 Duplicate the 10 jellybeans on the piece of paper (using the remaining jellybeans and/or the unused jellybeans). These are the alleles present in your new generation, record the number of each allele (red and green jellybeans) present in the next row of your results table.
- 5 Throw the remaining jellybeans from your population cup (previous generation) into the cup for unused jellybeans and place the new generation alleles into the population cup.
- 6 Repeat steps 2–5 until you have 10 rows of data, or until one colour is eliminated.

## Results

Generation	Number of alleles	
	Red	Green
1	10	10
2		

*continued...*

...continued

### Discussion

- 1 Plot your results on a graph.
- 2 Describe what happened. How do the results compare to what you would expect for each process?
- 3 Did your results show any colour (alleles) becoming extinct in your population?
- 4 Compare your results with another classmate or group. Account for any contradicting trends in the results.
- 5 Propose what step 2 of this simulation could represent in natural selection within a population.
- 6 Propose what step 4 of this simulation could represent in natural selection within a population.
- 7 Imagine that there was a mutation in one of the jellybeans that turned it orange. How could this affect future generations?
- 8 What assumptions have we made about the red and green alleles in this simulation?
- 9 Can reliable conclusions and predictions be drawn from the results? Justify your answer.
- 10 List some limitations of this simulation compared to what happens in real life. Justify your response.
- 11 What are some ways the simulations can be improved?

### Quick check 13.5

- 1 Variation is essential for the process of natural selection to occur.  
Explain what 'variation' means, including where it comes from in a population.
- 2 Define the term 'selection pressure' in your own words and explain how it contributes to natural selection.

## Speciation

Sometimes, natural selection can lead to a new species forming, which is called **speciation**. For this to occur, there needs to be one extra step in the process of natural selection: reproductive isolation.

Before we look at speciation, we need to be clear about what a species is. A **species** is a group of organisms that are phenotypically and genetically similar and are capable of interbreeding with each other to produce **fertile** and **viable** offspring. For example, the offspring of a male and female horse will be a horse that is able to mate and produce offspring with another horse. However, the offspring of a female horse and a male donkey is a mule. A mule is infertile, which means it is unable to produce offspring. This is evidence that horses and donkeys are two different species – they cannot produce fertile and viable offspring.

## Geographic isolation

An essential feature in speciation is isolation of populations from one another. Isolation is not required for natural selection to occur but is necessary for speciation to result. Isolation may be caused by a geographical or physical barrier (for example, a large river, a desert or mountain range) or even a natural disaster like a fire, flood or volcanic eruption. The consequence is the original population is divided into two populations, not necessarily the same size.

### speciation

the process by which new types (species) of living things are thought to develop from existing ones by evolution

### species

a set of animals or plants in which the members have similar characteristics to each other and can breed with each other

### fertile

able to reproduce

### viable

able to survive and reproduce

## Selection

The isolated populations may now be exposed to different selection pressures; for example, one environment may be cooler than the other. Just like we saw in the process of natural selection, those organisms that are best suited to their environment are the ones that will survive, reproduce and pass on their genetic information to the next generation. On the cold side of the mountain, individuals with thicker fur will be selected for, while on the sunny side of the mountain, those with a thinner coat will be selected for.

**reproductively isolated**  
unable to breed successfully with related species due to genetic differences

## Reproductive isolation

Over time, the different selection pressures on the two populations will change the genetic composition of the two populations in different

ways. Eventually, enough differences may accumulate between the two populations that individuals cannot interbreed with one another to produce fertile and viable offspring. The two populations are now **reproductively isolated**. This is when we know that we have a new species.

### Advances in science 13.1

#### Rock wallabies

Did you know there are 16 species of rock wallaby? Six of these species are found in north-east Queensland, and they have different numbers of chromosomes. They are different species, meaning that they cannot reproduce to create fertile and viable offspring. However, scientists recently found that gene flow somehow occurs between them, meaning that despite being six different species with different numbers of chromosomes, they *can* interbreed. Scientists now know that their evolution is a lot more complex than previously thought, and the way that new species form may need to be reinvestigated as a consequence.



Figure 13.13 A yellow-footed rock wallaby

### Quick check 13.6

- 1 Define the term 'species' in your own words.
- 2 Speciation can occur as a consequence of natural selection with one additional step. Recall what must also occur and its role in speciation.
- 3 Describe how you could determine if two populations were the same species.



VIDEO  
What is artificial selection?

## Artificial selection

**Artificial selection**, as the name suggests, is selection that does not happen naturally and therefore does not occur randomly. In other words,

humans purposefully choose the characteristics they want passed onto the next generation, that is, only breed those organisms with favourable traits. Thus,

**artificial selection**  
intentional breeding of plants and animals to produce desirable traits

**selective breeding**  
artificial selection

humans select who reproduces, not the environment. For example, a farmer wants her cows to produce lots of milk, so she selectively breeds the best milk-producing cows and prevents the poorer producers from mating. Artificial selection is also called **selective breeding**, and

humans have been using these techniques for thousands of years. Can you think of any other examples?

Artificial selection is certainly beneficial for humans who want plants and animals to show particular traits, but how does this manipulation affect biodiversity and evolution? Sadly, biodiversity is often reduced. The outcome is often a population that is genetically very similar and has low variation. For example, there is a worldwide decline in agricultural crop diversity. In Mexico, farmers are cultivating only 20% of the corn types that were grown there in 1930. Chinese farmers are producing only 10% of the 10 000 varieties of wheat that were recorded there in 1949, and more than 95% of known apple varieties that existed in the United States in 1900 are no longer being cultivated.

These crops are artificially selected for their production values, but what are the chances of the population surviving if it is exposed to a change in environment

or a new disease? Reduced variation in the population may mean the population is more susceptible to threats like these.



**Figure 13.14** Artificial selection in action: each of these organisms was selectively bred for particular characteristics.

### Did you know? 13.2

#### Broccoli and kale are the same?

Did you know that broccoli, kale, cabbage, Brussels sprouts, cauliflower and gai lan are all the same plant species? The plant is of the genus and species *Brassica oleracea*. There are more variations of this plant, and each of the variations is called a 'cultivar', which is a plant variety produced by selective breeding.



**Figure 13.15** Some of the many varieties of the plant *Brassica oleracea*

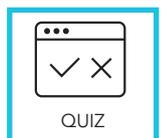
### Quick check 13.7

- 1 Define the term 'artificial selection' in your own words and provide an example.
- 2 Contrast natural selection and artificial selection.
- 3 Discuss whether artificial selection increases or decreases variation and therefore biodiversity.

### Section 13.2 questions

#### Remembering

- 1 **Identify** the key processes involved in natural selection.
- 2 **Identify** a geographical barrier that could divide a bird population, an eel population and a mammal population.
- 3 **Identify** three examples of abiotic selection pressures and three examples of biotic selection pressures.
- 4 **Outline** what is meant by the concept of variation in the field of evolution.



**Understanding**

- 5 **Describe** what is meant by the term 'selective advantage'.
- 6 **Summarise** the three processes in speciation.
- 7 Tomato breeders have created the most sweet and juicy tomato ever. **Summarise** how they would have done this, given that they started with a not-so-sweet and not-so-juicy crop of tomatoes.

**Applying**

- 8 **Explain** why variation is necessary for natural selection to occur.
- 9 **Explain** why isolation is necessary for speciation to occur.

**Analysing**

- 10 **Distinguish** between artificial and natural selection, providing examples for each.
- 11 The Galapagos finches share similar features but are recognised as distinct species. **Describe** what test could be used to identify if two similar kinds of finches are different species or subspecies of the one species.
- 12 **Determine** how speciation, biodiversity and evolution are linked.

**Evaluating**

- 13 **Justify** whether humans are evolving by natural selection.
- 14 **Predict** what will happen if a particular species has low genetic variation and there are changes in the environment in which they live.
- 15 **Demonstrate** the advantages and disadvantages of artificial selection.



# 13.3 Evidence for evolution

## Learning goals

- 1 To recall how fossils are formed and explain why the fossil record is incomplete
- 2 To explain some fossil-dating techniques and how they relate to evolution
- 3 To explain how each of the following supports evolution:
  - embryology
  - biogeography
  - comparative anatomy
  - biochemistry
- 4 To discuss human evolution

Evolutionary theory is supported by a multitude of evidence and findings from observations and experiments, including the sources in Table 13.3.



Field of science	Evidence
Palaeontology	The study of fossils, including their identification and interpretation
Comparative anatomy	The study of the structure of specific organs and limbs of different organisms
Embryology	The study of the development of the embryo in different organisms
Molecular biology	The ability to sequence DNA to indicate the degree of relatedness between organisms
Biochemistry	Similarities and differences in the biochemical make-up of organisms that can help distinguish differences and similarities
Biogeography	The study of the geographic distribution of organisms which can help ascertain where a species may have originated from

**Table 13.3** Sources of scientific evidence for the theory of evolution

## Palaeontology

The term **fossil** refers to any parts of, or impressions made by, a plant or animal that is preserved following death. Normally, an organism decomposes after it dies, and after a time, no trace of it remains. On rare occasions, evidence of the organism is preserved in the form of a fossil. Fossils may be the hard parts of an organism, like its bones and teeth (called **direct evidence**, or evidence of an organism's presence, like footprints, burrows and faeces (called **indirect evidence**



or **trace fossils**.). The process of forming a fossil is called **fossilisation**. However, because fossilisation is rare, and usually only organisms with hard parts tend to form fossils, there are a lot of gaps in our

**fossil record**. There is also the problem that we cannot dig up everywhere looking for fossils, so many go undiscovered.

Fossils are most likely to be found in sedimentary rock. Where the sediments have not been disturbed by later events, they nearly always show an age sequence, with the oldest fossils deepest under the ground and youngest at the top. Often these fossil sequences allow us to see the change in a species over time. This highlights how

**fossil**  
the shape or impression of a bone, a shell, or a once living organism that has been preserved in rock for a very long period of time

**direct evidence**  
evidence that supports an assertion without intervening inferences

**indirect evidence**  
evidence that requires inferences to be made

**trace fossil**  
a trace of an animal, such as footprint or imprint, that has become fossilised

**fossilisation**  
the process of forming a fossil

**fossil record**  
the record of past life and evolution inferred from fossils



**Figure 13.16** This marine reptile fossil of the Triassic period, named *Pachypleurosaurus*, was found high in the Swiss Alps.

the fossil record is amazingly valuable for collecting evidence of evolution. For example, fossils have provided evidence for the evolution of modern horses from the ancient four-toed mammal, and the discovery of *Archaeopteryx* gave us evidence of the link between reptiles and birds. The fossil record also tells us more about organisms that are now extinct and what Earth was like when particular species existed.



**Figure 13.17** Fossil remains of the *Archeopteryx* show a transition organism which possesses characteristics of both reptiles and birds.

## Fossilisation

For an organism to be fossilised, the following special circumstances must be addressed:

- **Rapid burial:** organisms must be buried quickly in oxygen-poor sediments. Usually this happens when organisms die in seas, lakes, floods or mud slides. Organisms can also be preserved in ice or amber or buried under ash from volcanic eruptions (lava will usually incinerate any remains).
- **Decomposition is prevented:** bacteria, which normally cause the decay of organisms, need to be reduced. For example, many bacteria that cause decomposition will die in the absence of oxygen or water, or in conditions of high acidity or extreme cold. Soft tissue and organs break down chemically, so they do not usually get fossilised.
- **Remains lie undisturbed:** predators and scavengers do not dig up the remains.

If all of these conditions are met, which is rare, over millions of years the sediments or other material covering the dead organism become more and more compressed and eventually form rock, preserving the fossil within.

## Types of fossils

Trace fossils are important tools in understanding extinct animals as they give some insight into their behaviour – how they lived and how they interacted with the environment. Queensland is home to one of the world's most famous trace fossil sites. Lark Quarry Conservation Park near Winton is the only known site of a dinosaur stampede, providing the most concentrated set of dinosaur footprints in the world. Over 3000 footprints can be seen in an area approximately the size of a tennis court. Trace fossils can provide important information relating to the size and walking or running posture of an extinct species.

## Explore! 13.2

**Fossil terminology**

There are many different types of fossils and many different terms we use to categorise fossils. Copy the following table and carry out some research online to complete it.

Term	Description	Example (include picture where possible)
Mould		
Cast		
Body fossil		
Replacement fossil		
Carbon imprint		

## Quick check 13.8

- 1 State two sources of evidence for evolution.
- 2 Recall some of the evidence for evolution that you can find out from fossils.
- 3 Explain why it is rare to find fossils.
- 4 Summarise the circumstances required for fossilisation.
- 5 Describe what is meant by a 'trace' fossil.

## Did you know? 13.3

**Living fossils?**

Charles Darwin coined the phrase 'living fossils' and, despite not being a scientific term, it has remained in use. It describes modern species of plants and animals that are almost identical to species that lived in ancient geological ages. This means they have survived mass extinctions, the various ice ages and comets hitting Earth! Examples include the Wollemi pine, the Queensland lungfish, mountain shrimp and the Australian ghost shark.



**Figure 13.18** The Queensland lungfish (*Neoceratodus forsteri*) is a 'living fossil' as it was prevalent in the Devonian period, some 400 million years ago!

**Dating fossils: relative dating**

Until last century, **relative dating** was the only method available for dating fossils. As the term suggests, relative dating techniques only work out how the age of a fossil compares in relation to other fossils. For example, it can tell you that fossil X is older than fossil Y, but it cannot tell you the actual numerical age of the fossil. Relative dating is used to order rocks and geological events into a time sequence. The study of the order of the layers of rock (strata) is called **stratigraphy**.

**relative dating**  
determining the order of past events without the specific age

**stratigraphy**  
the branch of geology studying the rock layers

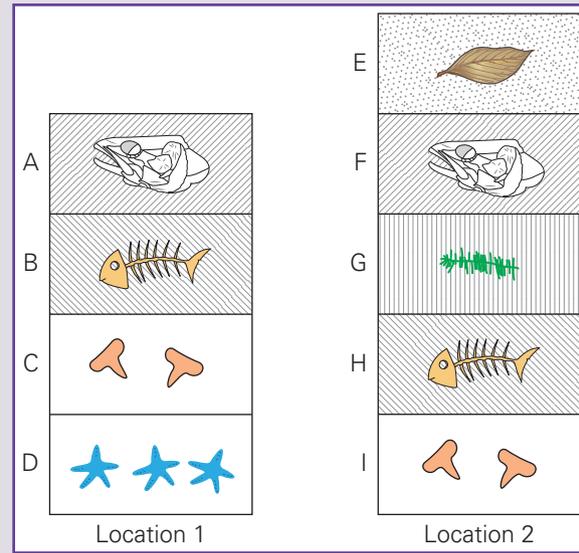
## Try this 13.2

**Stratigraphy**

The diagrams in Figure 13.19 represent the strata (rock layers) found at two different locations (1 and 2). Each layer has a letter associated with it and you can see the different fossils found in each layer. Knowing that the youngest layers are on the top and the oldest down below, work out the relative age of all of the layers in both locations from oldest to youngest. Then list the clues you used to work this out.

For example, layer G is younger than layer B, but older than layer A.

**Figure 13.19** Relative dating: the different strata and their relative positions at locations 1 and 2 help us date the fossils in each layer relative to other fossils.

**biostratigraphy**

a branch of stratigraphy focused on dating rock layers using the fossils found in them

**index fossil**

a fossil used as the base for dating the strata it occupied

**absolute dating**

determining the actual age of a material

Fossils are important for working out the relative ages of sedimentary rocks too.

Fossils can help to match rocks of the same age, even when you find those rocks a long way apart. This matching process is called correlation,

and it has been important in constructing geological timescales. Throughout the history of life, different organisms have appeared, flourished and become extinct. Some of these organisms became fossilised in sedimentary rocks. Geologists have studied the order in which fossils appeared and disappeared through time and rocks. This study is called **biostratigraphy**.

To help identify matching strata, and to compare strata in different locations, indicator or **index fossils** can be used. An index fossil is a fossil of known age found in a particular type of sedimentary rock layer. It can be used to indicate the age of any deposit in which it is found, at any locality. For example, trilobites are wonderful index fossils as they were very common at the time they existed (between 488 and 225 million years ago), they are easy to recognise, they are well preserved as fossils because of their hard exoskeleton and they evolved



**Figure 13.20** Fossil of a trilobite, *Albertella helena*

rapidly, which means there were different species present at different times.

**Dating fossils: absolute dating**

**Absolute dating** is where a precise age (within certain error margins) is obtained for a fossil or more commonly for the rock or soil in which the fossil is

found. For example, you can work out that fossil X is 233 million years old and fossil Y is 100 million years old. Absolute dating uses radiometric techniques, which means looking at the level of radioactivity detected in rocks containing certain naturally occurring **radioactive isotopes (radioisotopes)**. These isotopes are known to exist in living things, and have a known rate of radioactive decay. By measuring the amount of radioactive isotope left in the sample, we can work out how long an organism has been dead. The time in which

half of the sample of the radioactive isotope (parent) has decayed to a more stable form (daughter) is known as its **half-life** and is unique to each isotope. Knowing this helps us determine the best isotope to use to work out the absolute age of a fossil. The longer the half-life, the older the fossil or rock that can be dated.

**radioisotope**

a version of a chemical element that has an unstable nucleus and emits radiation during its decay to a stable form

**half-life**

the length of time needed for the radioactivity of a radioactive substance to be reduced by half

Radioactive isotopes (parent to daughter)	Half-life (years)	Estimated age range of fossils they can date
Carbon-14 to nitrogen-14	5730	Up to 60 000 years ago
Uranium-235 to lead-207	710 000 000	1000 to 1 million years ago
Potassium-40 to argon-40	1 300 000 000	500 000 million years and older

**Table 13.4** Each radioactive isotope has a different half-life. The longer the half-life, the older the fossil or rock that can be dated.

### Did you know? 13.4

*Zygomaturus trilobus* was a large wombat-like marsupial, approximately the size of a bull. Dating using uranium shows that a fossil specimen of *Zygomaturus* died 33 000 years ago. We know that Australia's First Nations peoples arrived in the same area at least 50 000 years ago. Uranium dating shows that people and megafauna coexisted for at least 17 000 years. This coexistence is further supported by paintings in Arnhem Land rock shelters, of species such as *Genyornis newtoni* and *Palorchestes parvus*.



**Figure 13.21** The painting of the megafauna species *Palorchestes* displays two prominent tufts of chest hair and is accompanied by a smaller (younger?) version of the same animal.

### Practical 13.2

#### Modelling half-lives

##### Materials

- 100 M&Ms or counters with one side marked (do not consume M&Ms after they have been handled)
- graph paper
- plastic container with lid
- plastic tray
- gloves

...continued

...continued

### Procedure

- 1 Draw the table shown in the results section into your science journal.
- 2 Predict the number of M&Ms that will 'decay' into daughter isotopes at each time trial. Place all 100 M&Ms parent isotopes on your plastic tray with the 'm' side up.
- 3 Record your original number of parent isotopes in your results table for time 0.



Parent isotope → m-side up, radioactive

Daughter isotope → m-side down, stable

- 4 Place all the isotopes in the plastic container and shake for 10 seconds.
- 5 Pour your isotopes back onto the plastic tray.
- 6 With your gloves on, remove all the stable daughter isotopes from the tray and set them aside.
- 7 Count the remaining M&Ms (parent isotopes), which will be a percentage of the original number since that was 100, and record this in your results table for time 1.
- 8 Repeat steps 4–7 another eight times.

### Results

Time	Number of removed daughter isotopes	Number of remaining parent isotopes	Percentage undecayed parent isotopes $= \frac{\text{Number of remaining parent isotopes}}{100} \times 100$	Class mean percentage undecayed parent isotopes
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

- 1 Collate the class results on the board and calculate means for each time.
- 2 Calculate the percentage of undecayed parent isotopes for each time period.
- 3 Draw a graph of the time (x-axis) versus percentage undecayed parent isotopes (y-axis) using the class results.
- 4 Calculate the half-life of your isotope by using your graph to identify the time in which half of the parent isotopes had decayed into daughter isotopes.

**Quick check 13.9**

- 1 Describe relative dating.
- 2 Define the terms 'stratigraphy' and 'index fossil' in your own words.
- 3 Describe absolute dating.
- 4 Name one isotope that could be used to accurately measure the absolute age of a fossil.

**Advances in science 13.2****Recent fossil finds**

In 2018, an international team of palaeontologists identified the world's oldest lizard. They found a 240-million-year-old fossil, *Megachirella wachtleri*, which is believed to be the oldest known ancestor of all modern lizards and snakes. Scientists used computed tomography (CT) scans, DNA analysis, and data from living and extinct lizards to work out that this fossil lizard is 75 million years older than previously thought.

Also in 2018, researchers found what they believe are fossilised lungs preserved inside a 120-million-year-old bird. Scientists have previously found four fossils of this ancient bird, *Archaeorhynchus spathula*, but never with plumage or suspected lungs. As you know, it is extremely rare for soft tissues to survive the pressure, heat and chemical changes needed for fossilisation to occur. But nowadays, scientists are increasingly reporting finding fossilised skin and even brain material preserved along with bones.



**Figure 13.22** New fossils are providing key insights into the evolution of modern lizards and snakes.

**Comparative anatomy**

There is a remarkable diversity of forms among closely related organisms. But have you ever thought about how some animals display remarkable physical likeness despite not being closely related at all? For example, sugar gliders and flying squirrels look remarkably alike, sharing similar characteristics such as size, big eyes and a distinctive white belly. They have thin, loose skin between their limbs which keeps them stable when stretched while they glide.

However, sugar gliders (native to Australia) and flying squirrels (native to Asia, central and North America, and Europe) also have many differences. Sugar gliders are marsupials so they have a pouch to protect their tiny babies, whereas flying squirrels are placental mammals, having larger babies and no pouch.

By studying their genes and other traits, biologists discovered that sugar gliders and flying squirrels are not very closely related at all. So why do they share some common physical characteristics?



**Figure 13.23** A sugar glider (top) and a flying squirrel (bottom) have many common characteristics, but they are not closely related.

**analogous structure**  
structure that has a similar function but evolved separately

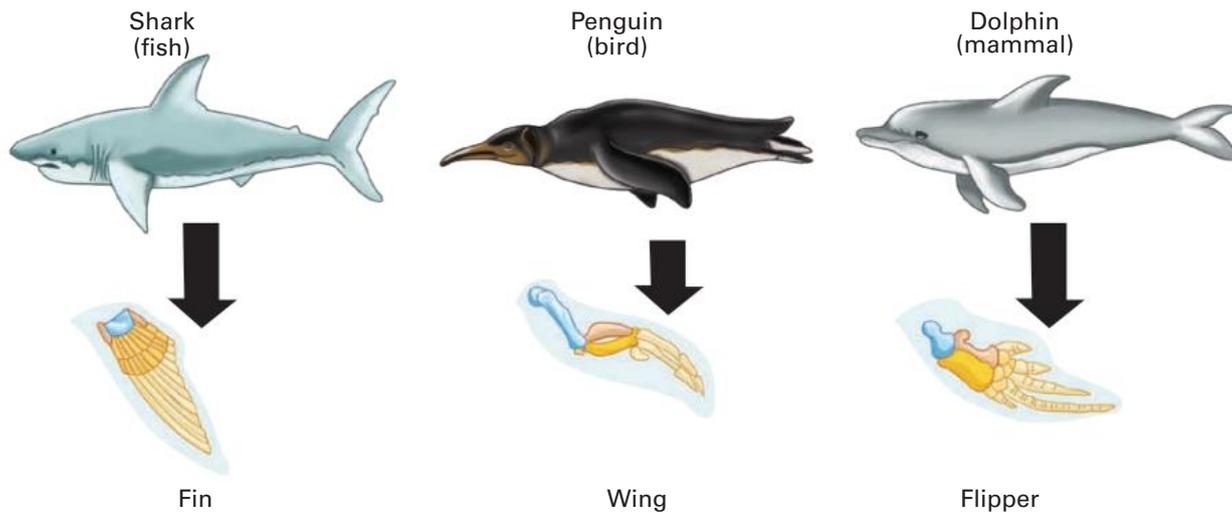
**homologous structure**  
structure that is similar because it has evolved from the same ancestor

The characteristic ‘wings’, which are flaps of skin, are known as **analogous structures**. These are structures that have a similar function but have evolved independently. The two organisms have evolved from different

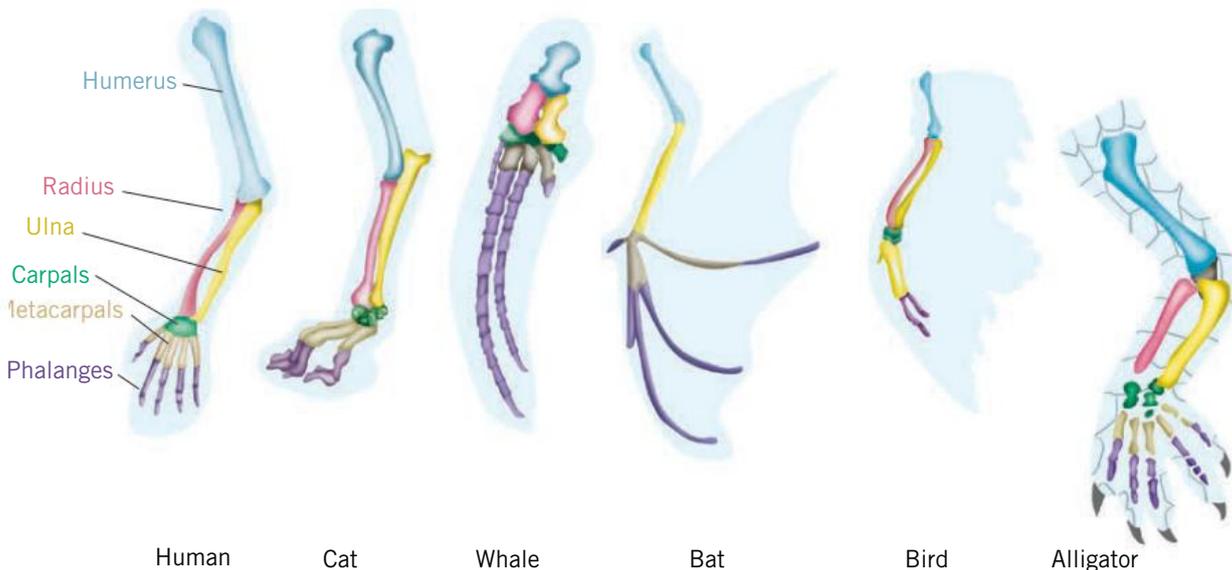
ancestors but in similar environments, so the same selection pressures have caused the same feature to be selected for. The fin shape of sharks (a fish), penguins (a bird) and dolphins (a mammal) is another example of an analogous structure (Figure 13.24). The shape of their fin (or the wing of the penguin and flipper of the dolphin) is adapted for swimming through water. The three types of animals faced similar selection pressures in their aquatic environment, and evolved

into a similar shape, but they do not share a recent common ancestor.

**Homologous structures** are structures that organisms inherit from a common ancestor. ‘Homo’ comes from the Greek word *homos* meaning ‘same’, and hence they inherited the same general body plan from the same ancestor. We say these structures have a common evolutionary origin. Homologous structures have similar underlying anatomy, but have evolved in different ways over time due to different selection pressures. An example of a homologous structure is the pentadactyl limb. The limbs of different tetrapod vertebrates (amphibians, reptiles, birds and mammals) show basic similarities in the bones present and how they are arranged, even though the limbs may serve different functions (Figure 13.25).



**Figure 13.24** The shark, penguin and dolphin have analogous structures; that is, structures with the same function. These arose because they live in similar environments and face similar selection pressures.



**Figure 13.25** The limbs of different tetrapod vertebrates have a common structure and are called homologous, despite having different functions, such as grasping, swimming or flying.

They are the same bones arranged for different uses. If homologous structures can be found in different organisms, that suggests they had a relatively recent common ancestor, which helps to explain their evolutionary path.

### Quick check 13.10

- 1 Describe analogous structures, providing an appropriate example.
- 2 Describe homologous structures, providing an appropriate example.

## Practical 13.3

### Dissection of a chicken wing

#### Aim

To compare the structure of a chicken wing to the structure of a human arm.

#### Materials

- fresh chicken wing
- dissecting board
- dissecting scissors
- probe
- disposable gloves
- human skeleton model

#### Procedure

##### Part 1: Examining the chicken wing

- 1 Hold the chicken wing at the shoulder and the tip and then stretch out the wing. Identify where the joints are and in which direction they bend.
- 2 Use your fingers to feel the bones and muscle under the skin.
- 3 Using dissecting scissors, carefully remove the skin from the chicken wing, taking care not to cut the muscles, ligaments and tendons.
- 4 Identify the muscles of the wing and see if you can work out how each one is attached to the bones of the wing.
- 5 Look for the tendon, which is white and tough and attaches the muscle to the bone.
- 6 Try squeezing the muscle in the wings and observe what happens to the bones. You may notice there are two muscles which can flex or extend the wing.
- 7 Look at the surface of each bone where it forms a joint. It should appear white, shiny and slippery – this is called cartilage. Can you find the cartilage at the joint between the humerus and the radius and ulna?

##### Part 2: Examining your arm

- 1 Identify the humerus, ulna and radius in your arm (see Figure 13.26). What other features of the chicken wing and your arm are similar?
- 2 Bend your arm at the elbow and hold it tight. Notice that your bicep muscle shortens. Now, extend your arm and feel your bicep lengthen.
- 3 Now, look at your hand and identify where the muscles are that move your fingers. You may need to press on your wrist or forearm to figure this out.

...continued

#### Be careful

Take care when using scissors and probes. Ensure benches are cleaned and hands are washed before leaving the laboratory.

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- 4 With a partner, raise and lower a textbook by bending your arm at the elbow. Which muscles were acting as you raise and lower?

### Results

Take a photo of the finished dissection of the chicken wing.

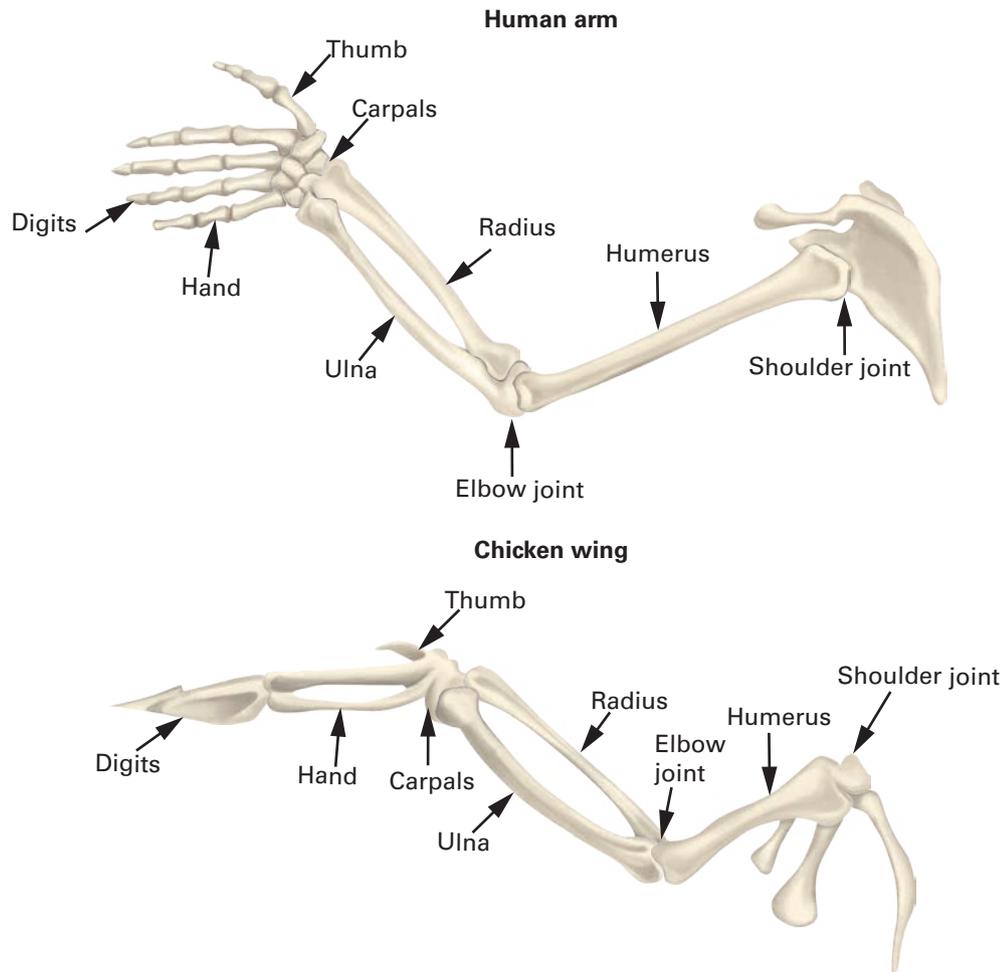


Figure 13.26 A human arm and a chicken wing

### Discussion

- 1 Compare the structure of a chicken wing with the skeletal structure of a human arm.
- 2 Define the term 'analogous structures' and explain what they can tell us about the evolution of a species.
- 3 Define the term 'homologous structures' and explain what they can tell us about the evolution of a species.
- 4 Would the chicken bones and human bones be considered homologous or analogous structures? Discuss.

**evolutionary tree**  
a diagram used to represent evolutionary relationships between organisms

Scientists can construct **evolutionary trees** using fossil evidence and radiometric

dating to estimate when different groups of species diverged from a common ancestor. Evolutionary trees

can also be constructed when scientists have studied the anatomy of different species to determine which ones have homologous structures. Only homologous traits are evidence of a shared ancestry. An example of an evolutionary tree is shown in Figure 13.27.

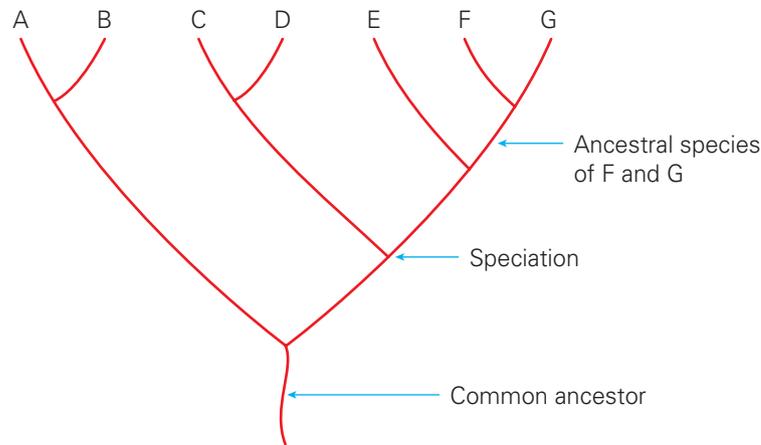


Figure 13.27 An example evolutionary tree

For example, humans, chimpanzees and gorillas all have thumbs that are very similar anatomically and are considered to be homologous (Figure 13.28). The giant panda also has a thumb, but it has been found to

be analogous to these primate thumbs. This suggests that humans, chimpanzees and gorillas are much more closely related to one another than any of them is related to giant pandas.

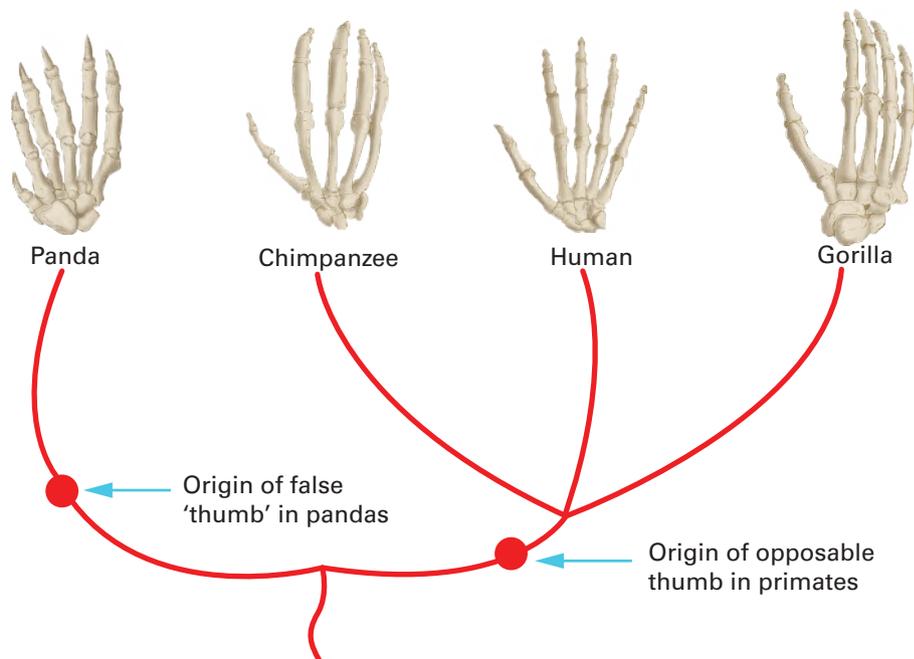
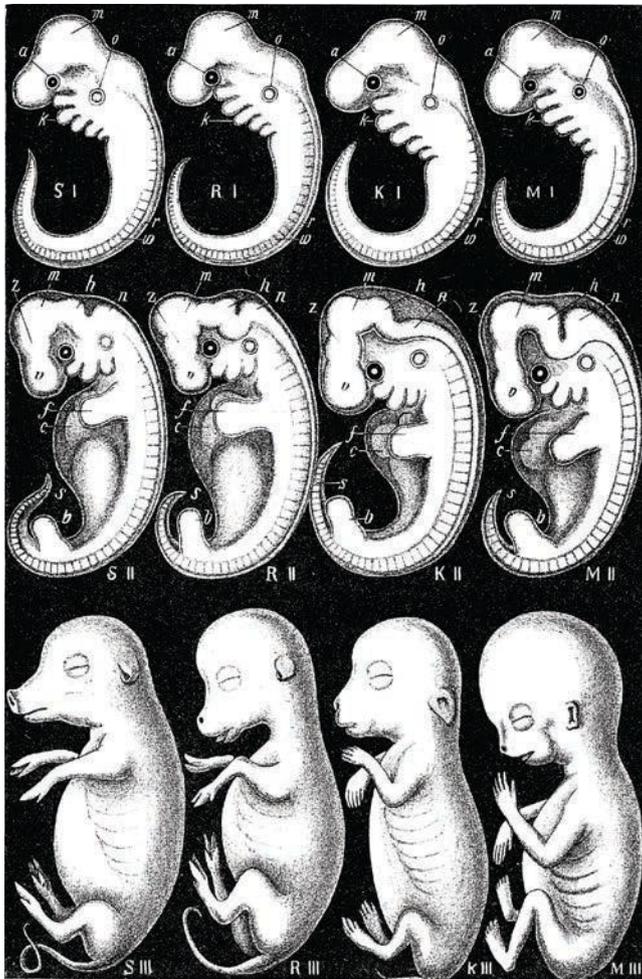


Figure 13.28 An evolutionary tree showing how their homologous opposable thumbs mean that humans, chimpanzees and gorillas have a recent common ancestor

## Comparative embryology

The embryos of vertebrate animals look very similar in the early stages, which suggests that they share some of the genetic information that contributes to embryo development. The explanation is that this genetic information has been inherited from a common

ancestor. For example, a very early stage human embryo has gill slits, a tail and a simple heart, similar to that of a fish. At later stages, the human embryo develops body proportions similar to the embryos of reptiles and then apes.



**Figure 13.29** Comparative embryology drawings of embryos at three stages from (left to right): a pig, cow, rabbit and human

of the fish and mammalian circulatory systems has been inherited from a common ancestor.

### Quick check 13.11

- 1 Describe an evolutionary tree.
- 2 Explain how embryology provides evidence for evolution.

## Molecular biology

Substances that are found in most or all living things are very useful in the investigation of evolutionary relationships. For example, all living things contain DNA, so it is commonly used to compare organisms. This is what the study of molecular biology is all about – investigating DNA, its code and the proteins it codes for. Molecular biology lets evolutionary scientists:

- trace ancestors of species
- estimate how long ago one species diverged into two
- discover how closely related two species are.

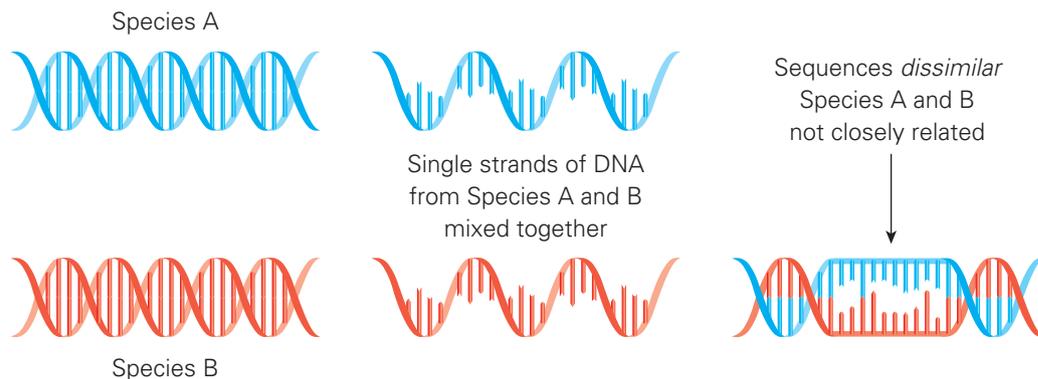
## DNA analysis

**DNA hybridisation** is a technique to compare the DNA sequences of two species to find out how closely they are related. First, as seen in Figure 13.30, the DNA from each organism is extracted and heated so it forms two single strands. When the single strands from the two organisms are mixed together and allowed to cool, complementary nitrogenous bases will bind together (or hybridise). The degree to which the single strands form a stable double-stranded DNA molecule is an indication of the relatedness of the species. For example, if there is a lot of hybridisation, there must be a lot of complementary bases, which means the organisms are similar and, therefore, have a recent common ancestor.

**DNA hybridisation**  
a technique that measures genetic similarity between two organisms

Comparative embryology also finds evidence for evolution in the circulatory system of

fish and mammals. Adult fish and mammals have quite different circulatory systems. However, during embryonic development you can see that the circulatory systems are based on the same pattern. This suggests that the genetic information responsible for the development

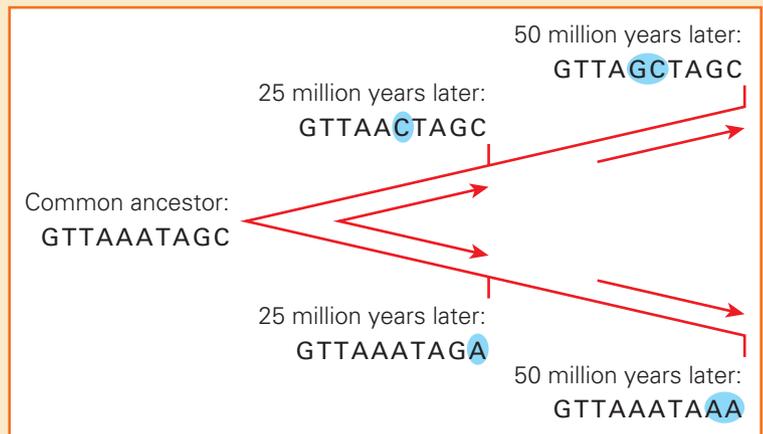


**Figure 13.30** The process of DNA hybridisation allows scientists to determine the relatedness of two organisms by comparing their DNA.

## Did you know? 13.5

**Molecular clocks**

The molecular clock concept says that mutations accumulate in biomolecules at a roughly constant rate because they occur by chance. Due to this, we can use this mutation rate to deduce the time when life forms diverged. The biomolecular data that is normally used for calculations are DNA nucleotide sequences, including those found in mitochondrial DNA (mtDNA), the DNA found in the mitochondria.



**Figure 13.31** In the same way that a clock tells the time, a molecular clock allows scientists to determine how long ago two species diverged.

**Protein analysis**

As we know, proteins are made up of building blocks called amino acids. Scientists can analyse the differences in the amino acid sequences, knowing that this relates to how similar proteins are in the different organisms. The number of different amino acid sequences in the proteins of different species is an indicator of the number of mutations and hence the degree of separation of species. In other words, a

large difference in amino acid sequences between two organisms means they had a distant common ancestor, while a small difference in amino acid sequences mean they had a recent common ancestor. The cytochrome c protein is often studied as it is involved in cellular respiration and found in most eukaryotic organisms. Table 13.5 shows the differences in the amino acid sequence for cytochrome c between humans and other organisms.

Organism	Number of differences in the amino acid sequence for cytochrome c compared to humans.
Horse	12
Chicken	13
Dog	11
Moth	31
Tuna	21
Monkey	1

**Table 13.5** The differences in the amino acid sequence for cytochrome c between humans and other organisms

**Quick check 13.12**

- 1 Describe DNA hybridisation and how it provides evidence for evolution.
- 2 Describe how the number of differences in the amino acid sequence for cytochrome c can be used to establish the relationship in evolutionary terms between organisms.

## Biogeography

**biogeography**  
the study of the  
geographical distribution  
of plants and animals

**Biogeography** is the study of the geographical distribution of plants and animals, both today and in the past. Biogeography provides us with additional evidence for evolution. For example, ancient fossils in one area may resemble modern organisms in that same area and have a similar pattern of distribution (for example, fossil and modern platypuses are both found in Australia). The similarity of fossil and modern organisms suggests that the modern organisms have descended from ancestors living in same areas.

Remember that the continents were once grouped together in one big supercontinent, and ancestral organisms were distributed across more than one continent. When the continents split up and drifted apart, the separated populations evolved into different but related organisms. For example, the emu of Australia, the ostrich of Africa, the cassowary of Papua New Guinea and northern Australia and the rhea of South America are all large, flightless birds. Despite being found on different continents with oceans between them, one possible explanation for their similarity is that they descended from a common ancestor that occurred on the ancient Gondwana supercontinent.



**Figure 13.32** (Left to right, top to bottom) While the emu and cassowary can be found in Australia, the rhea live in South America and the ostrich in sub-Saharan Africa.

### Quick check 13.13

- 1 Define the term 'biogeography' in your own words.
- 2 Explain how biogeography provides evidence for evolution.

## Evolution of humans: bringing it all together

In order to understand human origins, we need to first look at what humans are. Humans are in the animal kingdom, phylum Chordata, class Mammalia, order Primates, family Hominidae, genus *Homo* and species *Homo sapiens*.

The primates living today gradually evolved over 65 million years from ancestral primates that were small tree-dwelling mammals. We did not evolve from apes and monkeys, but we share a common ancestor with them. About six million years ago, the line that led to humans is thought to have diverged from the chimpanzee line due to different habitats and different selection pressures.

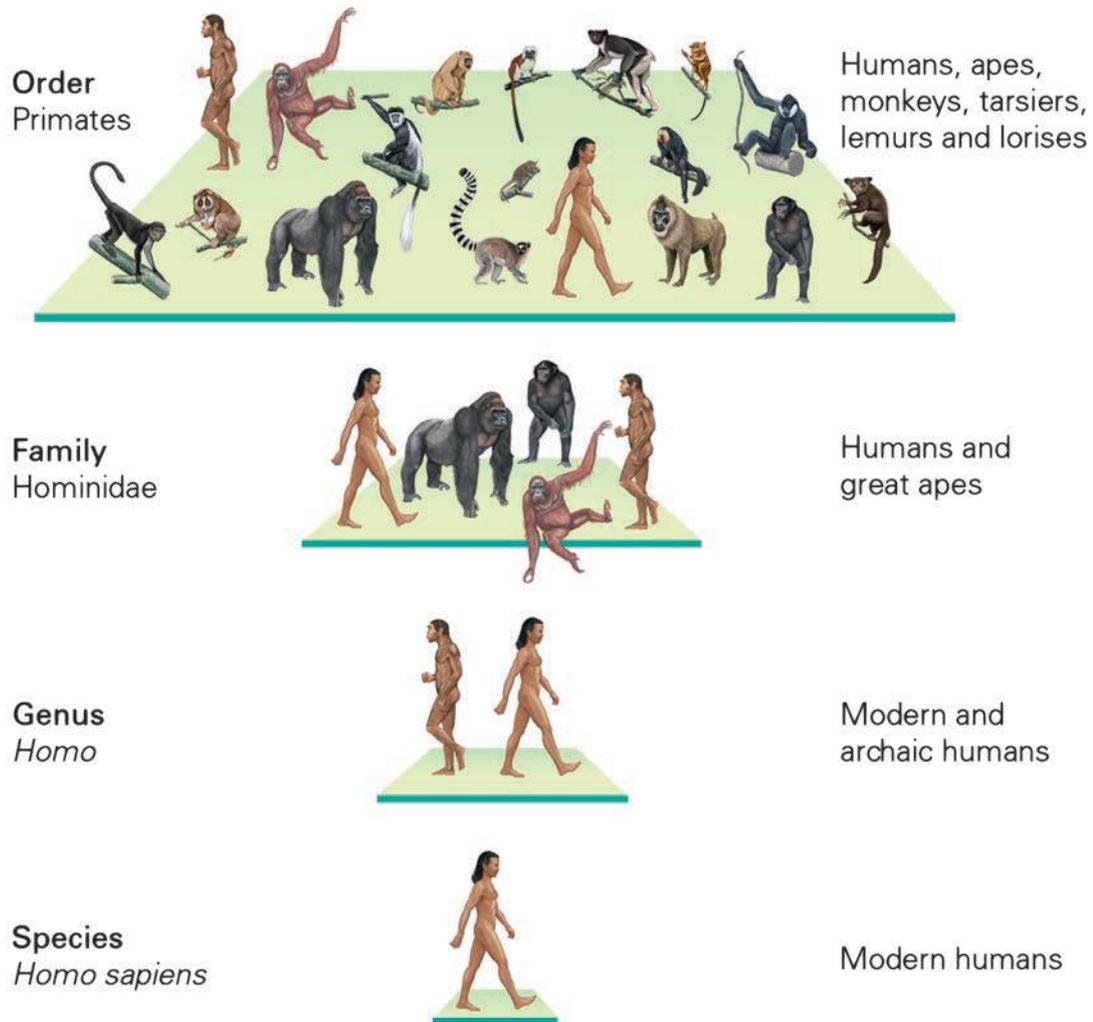
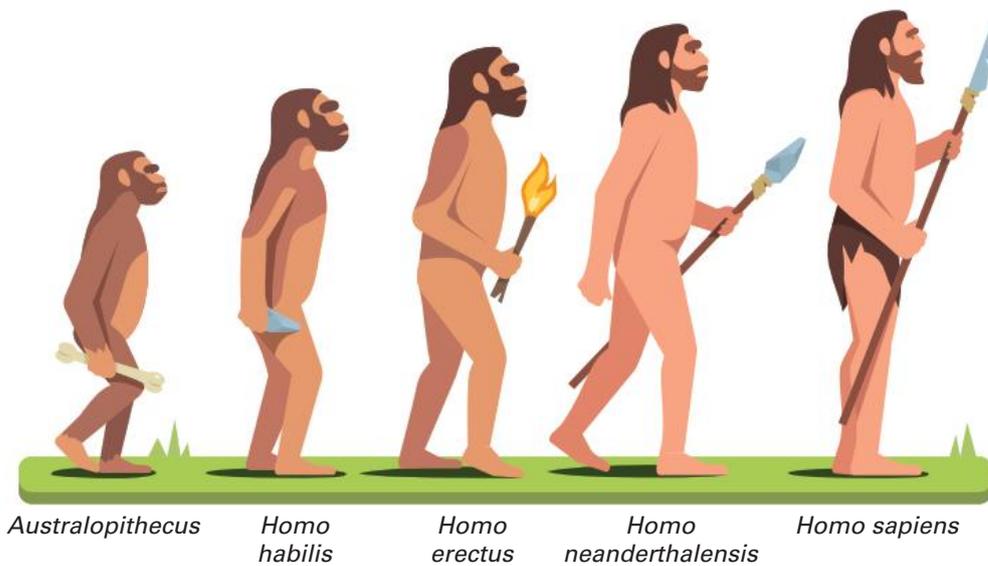


Figure 13.33 Classification of *Homo sapiens* within the order Primates

Over the course of human evolution there have been two main genera: the earlier genus *Australopithecus* and the later genus *Homo*. Modern humans are more similar to other species in the genus *Homo* than to any *Australopithecus* species.



**Figure 13.34** The biologist and anthropologist Thomas Henry Huxley (1825–1895) was the first to suggest that humans and other species were related to a common ancestor.

### Explore! 13.3

#### Evidence for human evolution

In this section you have learned all about the different ways that we can gather evidence about evolution: palaeontology, comparative anatomy, embryology, molecular biology and biogeography. However, we have not investigated how they have informed us about human evolution.

- 1 Research the fossil evidence of human evolution. Summarise what fossils teach you about the evolution of humans and use pictures to illustrate what you find.
- 2 Research homologous and analogous structures related to human evolution. Summarise what comparative anatomy teaches you about the evolution of humans and use pictures to illustrate what you find.
- 3 Research the DNA evidence of human evolution. Summarise what DNA teaches you about the evolution of humans and use pictures to illustrate what you find.

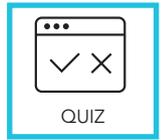


**Figure 13.35** An archaeological excavation uncovers human remains

## Section 13.3 questions

## Remembering

- 1 **List** the five sources of evidence for evolution.
- 2 **Outline** what is meant by the term 'fossil'.
- 3 **Identify** what biogeography refers to.



## Understanding

- 4 **Describe** what an analogous structure is. Provide an example.
- 5 **Suggest** why the scales of reptiles and the feathers of birds can be considered homologous structures.
- 6 **Explain** how DNA hybridisation can show that two organisms share a common ancestor.
- 7 **Explain** how amino acid sequences can provide evidence for evolution.

## Applying

- 8 **Summarise** why fossils of soft-bodied organisms are relatively rare.
- 9 Scientists excavated an abandoned quarry and found a set of dinosaur footprints that could be up to 145 million years old. The trails of 90 uninterrupted prehistoric footprints are thought to have been made by a sauropod – a class of heavy dinosaurs with long necks and tails. Identify what type of fossil a dinosaur footprint is known as, and **summarise** how they are formed.
- 10 The following image represents the layers of rock found within a cave. **Identify** the layer (1 to 5) where you would expect to find the oldest group of fossils, giving reasons for your answer.

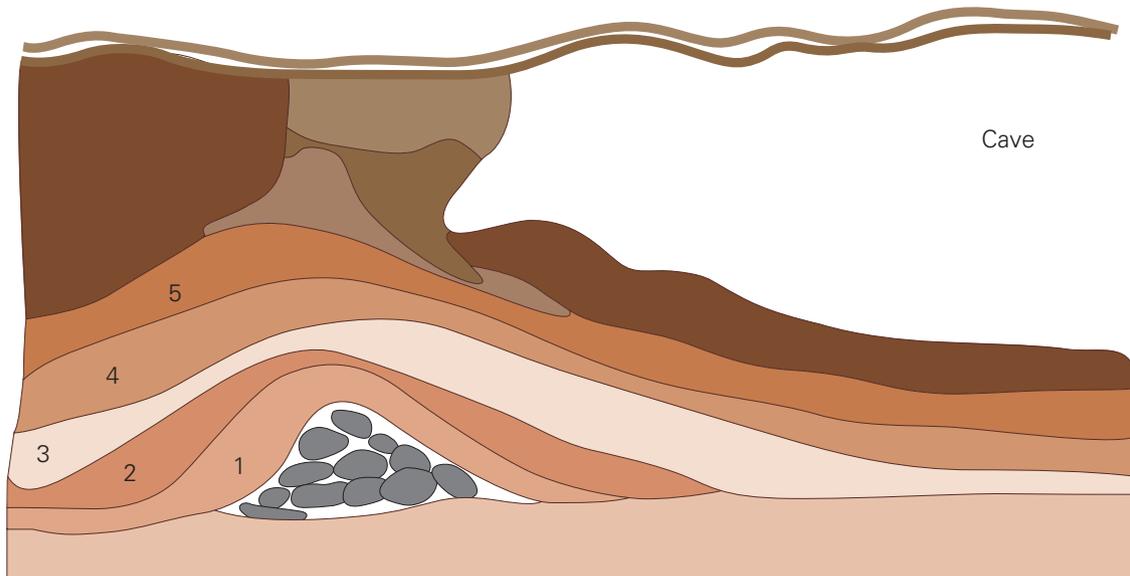


Figure 13.36 Layers of rock within a cave

- 11 **Distinguish** between absolute and relative dating techniques.

12 Figure 13.37 shows a timeline for the evolution of some dinosaurs. The average mass of each dinosaur is shown in brackets under its name.

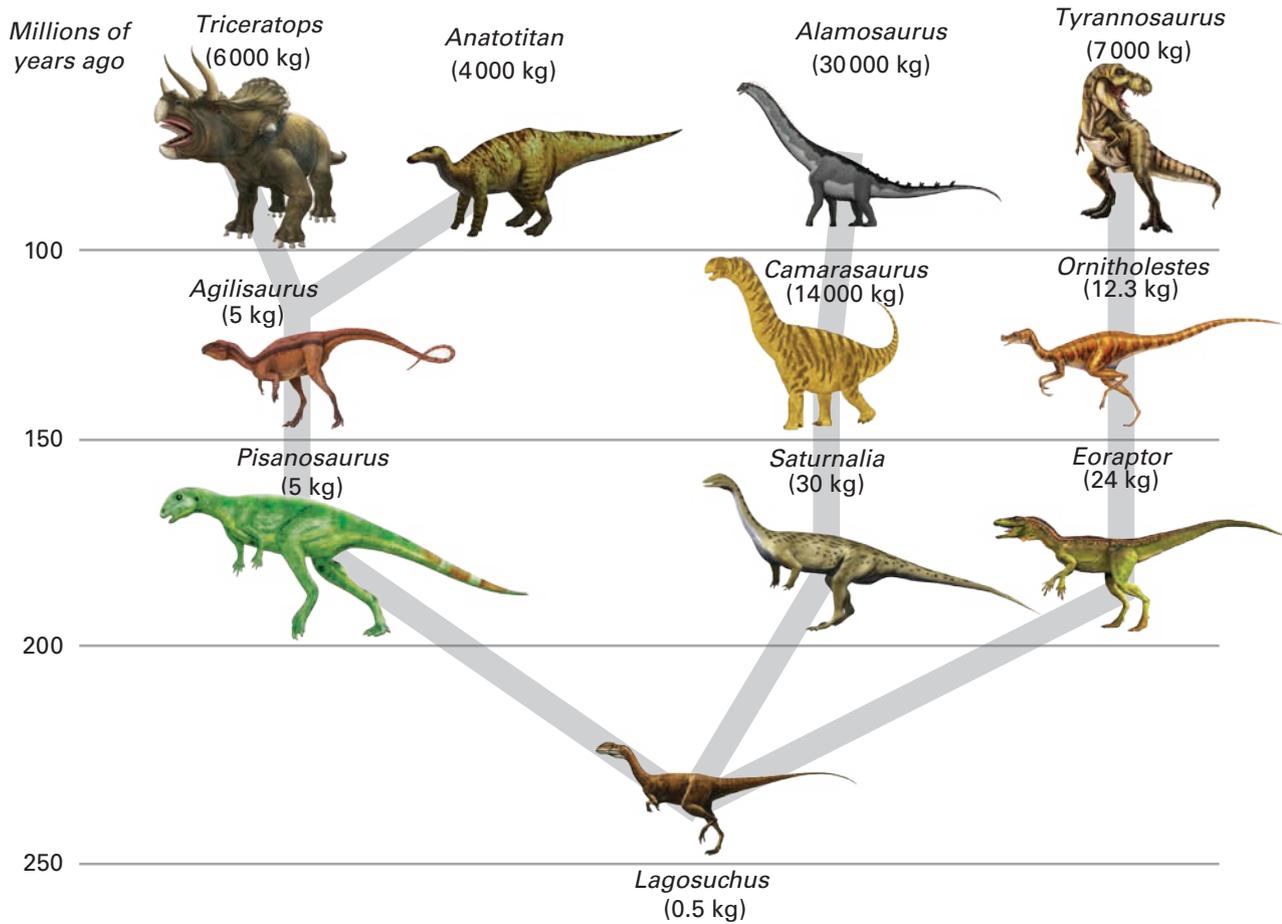


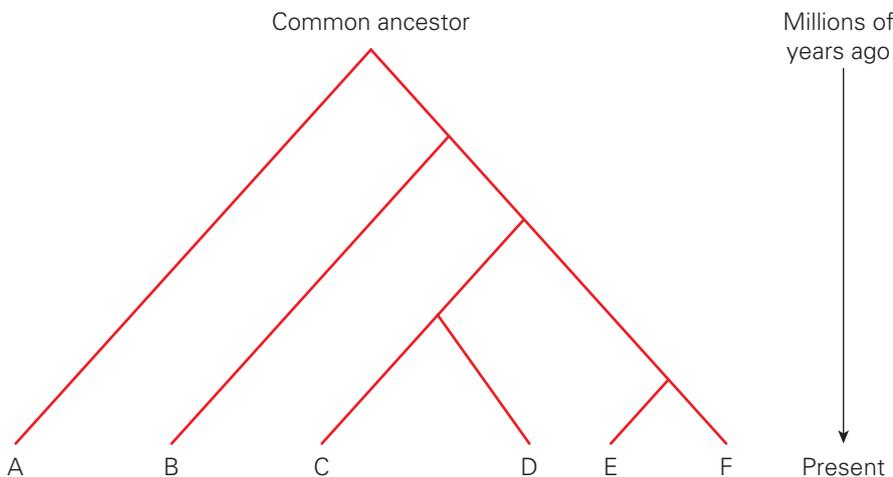
Figure 13.37 Evolutionary tree of dinosaurs that evolved from *Lagosuchus*

**Determine:**

- a The dinosaur that lived the longest time ago is the \_\_\_\_\_
- b The dinosaur/s that evolved from *Agilisaurus* is/are the \_\_\_\_\_
- c The dinosaur from which *Camarasaurus* evolved is the \_\_\_\_\_
- d The dinosaur with the largest average mass is the \_\_\_\_\_

**Analysing**

13 The following figure shows the evolutionary tree for six organisms from a common ancestor.



- a According to the diagram, **identify** the present day organism that is least closely related to the others. **Justify** your response.
- b **Determine** which two organisms have the most recent common ancestor and **justify** your response.
- 14 Refer to Figure 13.38 of the possible evolutionary relationships between chimpanzees and the various genera of humans to **determine** the following question.  
The most recent common ancestor of Homo and Kenyanthropus is represented on the diagram at letter

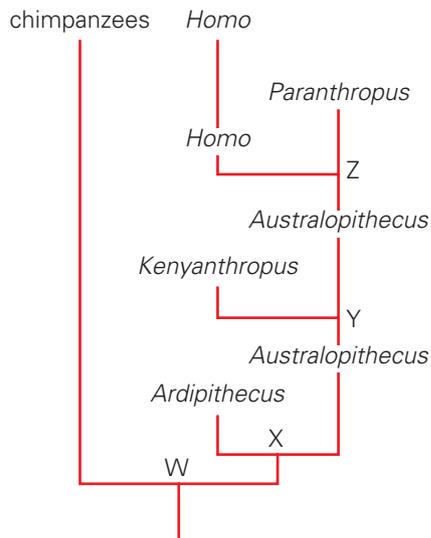


Figure 13.38 Evolutionary relationship for chimpanzees and humans

- 15 The table below shows the number of nucleotide differences between a region of mitochondrial DNA in humans, chimpanzees and a Neanderthal fossil found 25 000 years ago.

	Human 2	Chimpanzee 1	Chimpanzee 2	Neanderthal
Human 1	15	77	76	20
Human 2		79	80	27
Chimpanzee 1			23	72
Chimpanzee 2				71

- a Based on the table, **identify** which organism is most closely related to the Neanderthal.
- b Based on the table, **identify** which organism is the least closely related to the Neanderthal.
- c **Propose** which method could be used to estimate the absolute age of the Neanderthal fossil.
- d **Propose** which method could be used to estimate the relative age of the Neanderthal fossil.

### Evaluating

- 16 **Propose** how you would investigate whether birds are more closely related to mammals or reptiles. Include what evidence you would expect if the organisms were related or not related.
- 17 **Draw** a concept map that shows the links between the different ways we can gain evidence for evolution. Please include how each method sheds light on evolution.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>13.1 I can recall the definition of evolution.</b> e.g. Define the term 'evolution' in your own words.	
<b>13.1 I can describe three drivers of evolution (mutation, natural selection, sexual reproduction).</b> e.g. Contrast mutation and natural selection.	
<b>13.1 I can describe the concept and importance of biodiversity.</b> e.g. Explain the impact of mass extinction on biodiversity.	
<b>13.2 I can explain the process of natural selection.</b> e.g. Discuss how both reproductive and geographic isolation can result in a new species.	
<b>13.2 I can distinguish between artificial and natural selection.</b> e.g. Describe how selective breeding is considered artificial selection.	
<b>13.3 I can recall the main evidence for evolution.</b> e.g. Describe how palaeontology can provide evidence for evolution.	



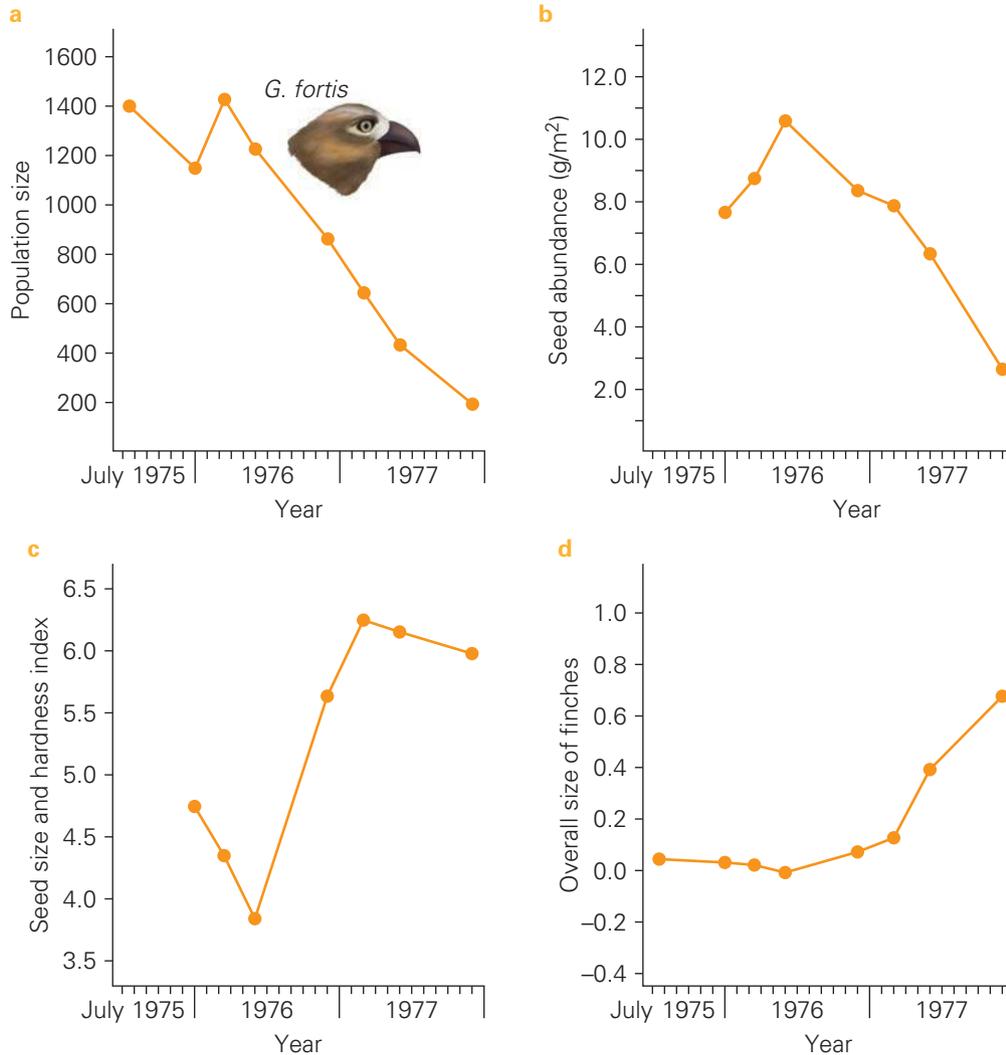
## Reflections

- 1 What **connections** come to mind when you think about natural selection and your everyday life?
- 2 What new concepts have **extended** your thinking about natural selection and evolution?
- 3 What information did you find **challenging** or confusing?



## Data questions

*Geospiza fortis* is a ground finch that feeds on seeds on Daphne Major, one of the Galápagos islands. From 1975 to 1977, the island experienced a severe drought. The graphs below show the population size of *G. fortis* and the island's seed abundance during these years.



- 1 Calculate** the percentage decrease in population size between July 1975 and December 1977.
- 2 Justify** any relationships you can find in the graphs.
- 3 Infer** why the size of the finches increased as the drought continued.

## STEM activity: Designing a wheelchair to aid dogs with genetic problems

### Background information

Inbreeding occurs when genetically similar individuals from a species breed with each other. There are many examples of inbreeding in humans and other species that are bred selectively, like dogs. In these cases, the problem is not that a population could be wiped out by an environmental change, but that genetic conditions that would be very rare in wider populations continue to be passed onto subsequent generations.

A famous example of this occurred with haemophilia, a condition resulting from a mutation on the X chromosome. In people with this condition, blood does not clot properly so injury can cause excessive bleeding. Haemophilia spread throughout European royal families in the 19th and 20th centuries because of arranged marriages among the related royal families.

Humans have bred dogs for thousands of years, originally to serve a specific purpose or job like herding and hunting. All modern dog breeds exist as a result of human selective breeding. Inbreeding occurs when genetically similar individuals from a species breed with each other. Unfortunately, many purebreed dogs suffer from genetic conditions because of inbreeding. For example, purebred dachshunds commonly suffer from knee problems as a result of their short legs and non-ideal angle for the knees. They also often have hip dysplasia and spinal problems because of their long bodies, and eye problems like cataracts.

While dog owners can take preventive measures to reduce the effects of these disorders, often reactive treatment is the method used to give affected dogs a good quality of life. Wheelchairs are a potential solution to help with mobility for dachshunds that have hip and knee problems.

**Design brief:** Design a wheelchair to aid dachshunds with genetic knee and hip problems.

### Activity instructions

In small groups, research the features of dog wheelchairs.

Some research into the specific genetic problems occurring in dachshunds may be necessary to make sure you are catering for the dogs' needs.

### Suggested materials

- cardboard
- fabric/felt
- glue
- scissors
- wheels
- icy-block/craft sticks
- elastic bands
- straws
- sticky tape

### Research and feasibility

- 1 Research and list all the features that make a wheelchair comfortable and functional.

Feature	Functionality
e.g. padded seat	Comfortable to use for long amounts of time

- 2 Research current dog wheelchairs available and how they are used for dogs with hip and knee problems. List all the problems that may exist with the current model and solutions that could be included.
- 3 Research the dog breed, dachshunds, and make note of the size of the dog breed and the common hip and knee problems that exist.

### Design and sustainability

- 4 Design a prototype of a wheelchair specifically for a dachshund. Annotate your diagram and include all design features and the functionality it provides.
- 5 Reflect on the sustainability of the materials used, and the life cycle of the wheelchair prototype in regard to its durability.

### Create

- 6 Construct the prototype using available materials.

### Evaluate and modify

- 7 Describe any difficulties you came across when constructing your model. Explain how you overcame these difficulties.

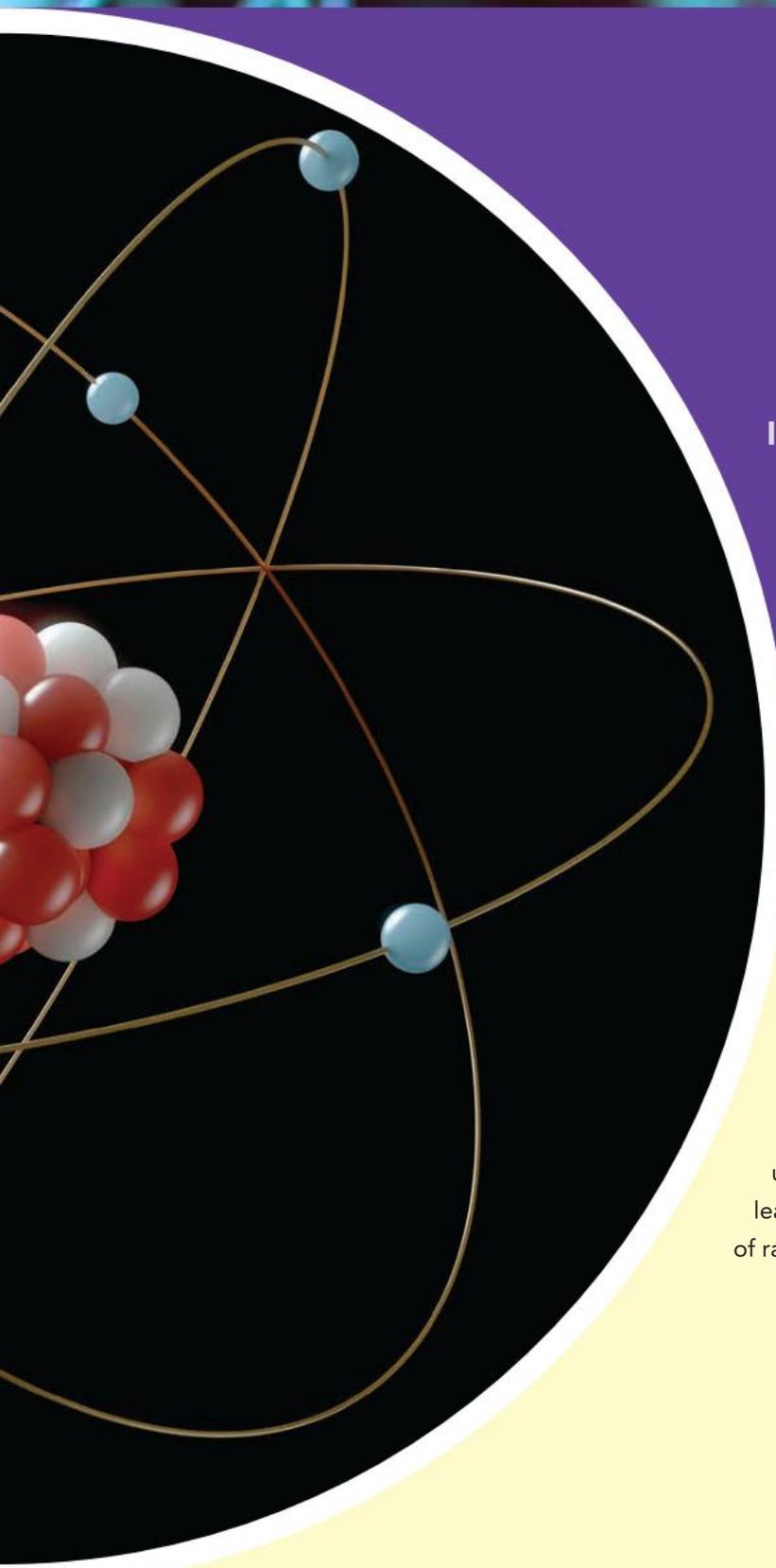
- 8 Propose some improvements to the design of your wheelchair to improve comfort and functionality.
- 9 Depending on the size of your model, you may be able to test it by using your wrist or palm as the back of the dog and your index and middle fingers as the front legs to pull it along. Test it with different amounts of downward pressure to represent different dog sizes and weights. Comment on how your wheelchair fared in your tests.



Figure 13.39 Dachshunds are not the only dog breed that may need the aid of a wheelchair.

# Chapter 14

## Atoms

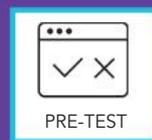


### Inquiry questions

What are atoms made up of?

Why is the development of the atomic model such a good example of the importance of collaboration within the scientific community?

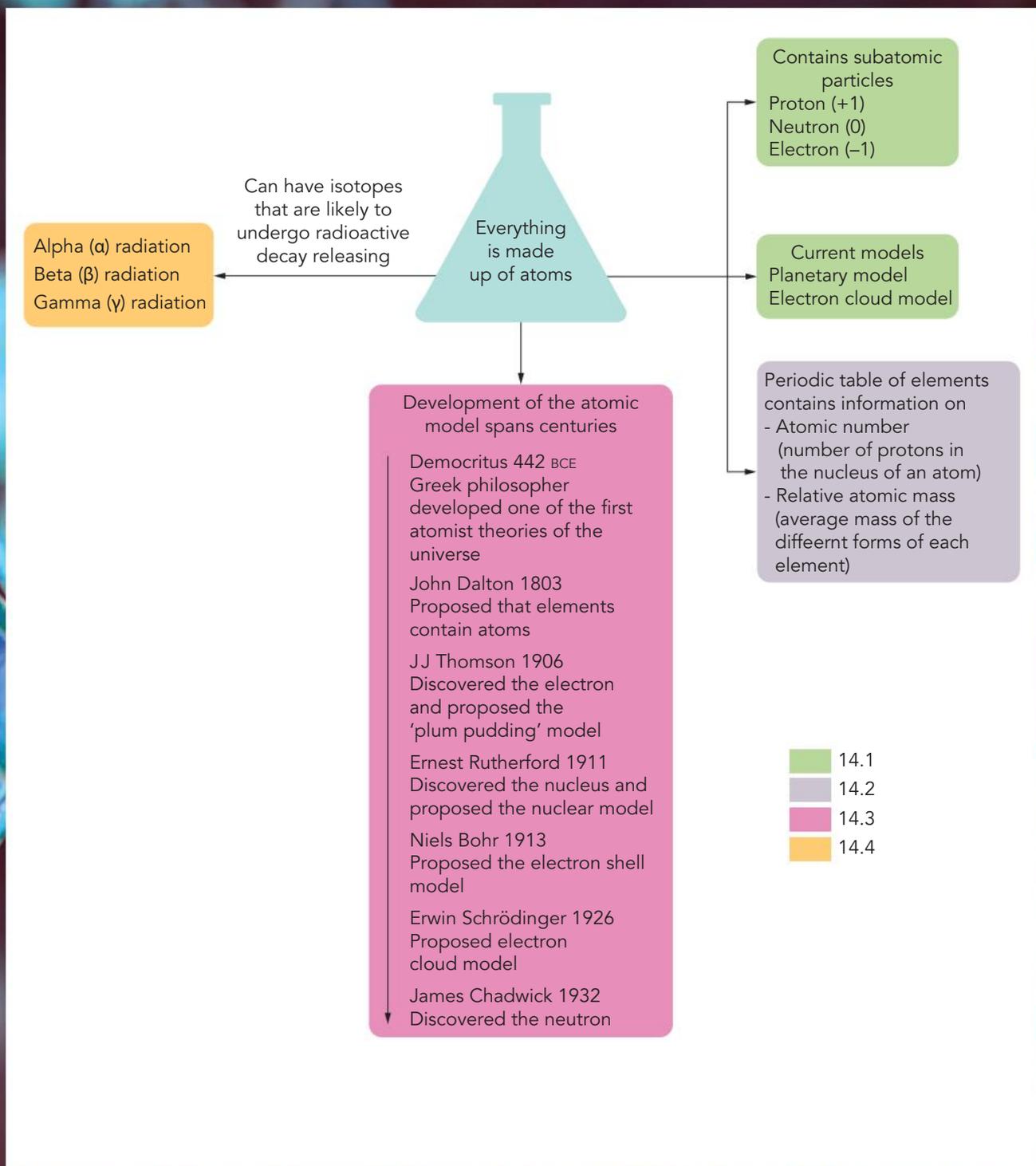
Why are the uses and management of radioactive isotopes so important?



### Chapter introduction

This chapter is all about atoms. You will learn that atoms are made of very small subatomic particles called protons, neutrons and electrons. You will compare the masses and charges of these subatomic particles. You will learn about the many different scientists who contributed to the current knowledge and understanding of atomic structure. You will also learn how unstable atoms release different forms of radiation.

# Chapter map



# 14.1 Atomic structure

## Learning goals

- 1 To recall the composition of an atom
- 2 To describe the structure of an atom in terms of its subatomic particles



## Atoms

Someone once told me not to trust **atoms** because they make up everything! To

**atom**  
the building block of matter

develop a language, you need an alphabet; similarly, to build complex chemical substances, you need atoms. The word 'atom' comes from the Greek word *atomos*, which means

## Did you know? 14.1

### You are a star!

More than 98% of all the atoms in the universe come from the two lightest elements: hydrogen and helium. The heavier elements are created at the end of a large star's lifecycle in a massive explosion called a supernova. So, next time your teacher calls you a star, they may be right! You can be safe in the knowledge that the elements that make up all humans have, at one point, come from a star.



Figure 14.1 A digital impression of an exploding supernova

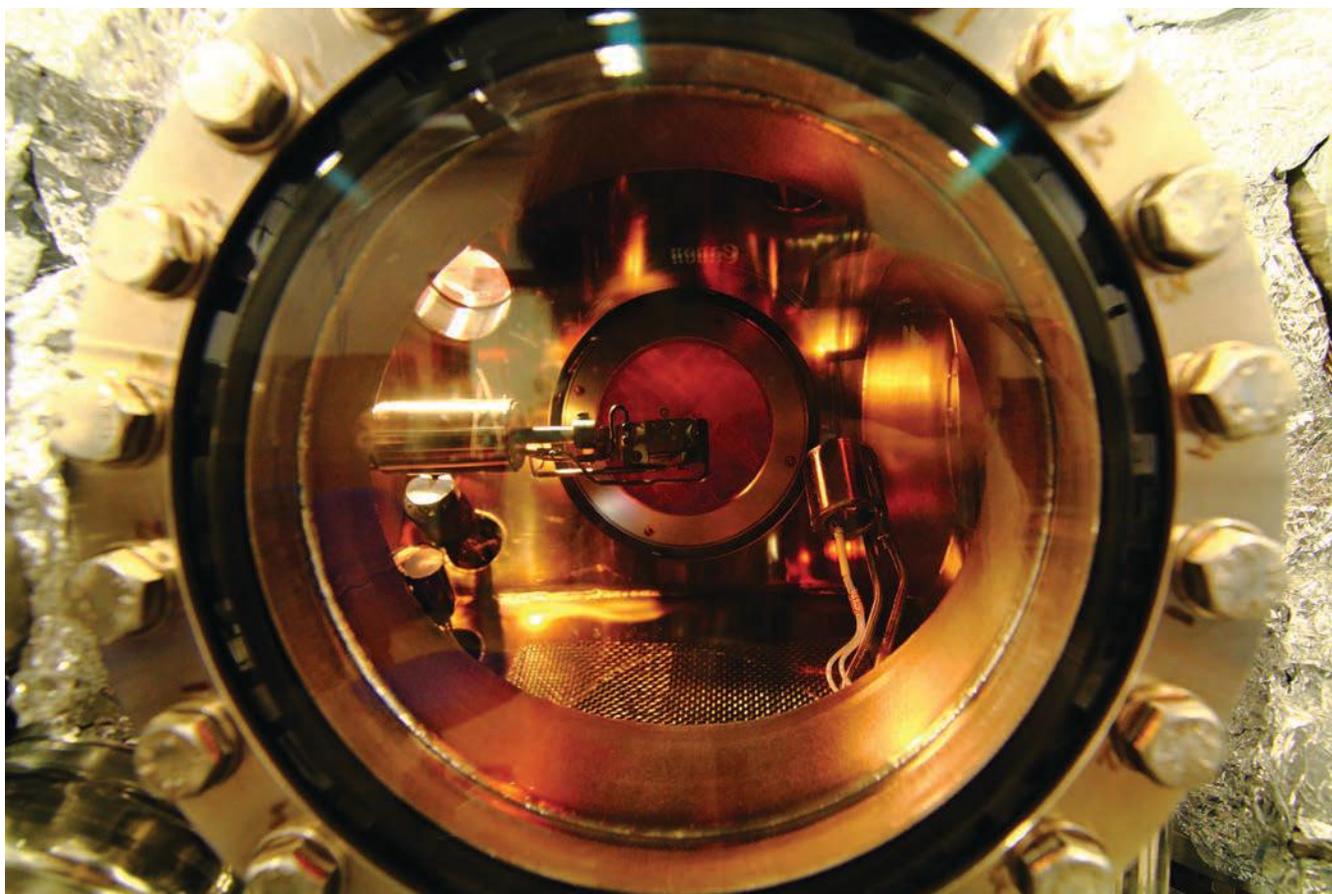
'indivisible' or 'un-cuttable'. If you had a silver ring and cut that ring in half and then in half again and continued to do this, you would eventually be left with an atom of silver. It was thought that this silver atom could not be divided into smaller pieces. Modern physics now shows this is not true, which will be discussed later in the chapter.

An atom is the smallest possible form of an element on the periodic table, and there is a unique atom for every element. For example, if you cut an atom of silver in half, you would no longer be in possession of the element silver.



Figure 14.2 A ring made of silver atoms

Atoms are so small that you will probably never see one. Take a human hair for example – it is about as thick as 500 000 carbon atoms stacked over each other. Even with examples like this, it is almost impossible to truly understand how small atoms are. You can only see an atom with a highly specialised microscope called a scanning tunnelling microscope, as shown in Figure 14.3 on the opposite page. The world's first images of atoms were produced by a research team at IBM. In 1981, physicists Gerd Binnig and Heinrich Rohrer developed the first scanning tunnelling microscope. They were awarded a Nobel Prize for Physics in 1986 for their efforts. This discovery allowed scientists to view images of many different atoms that had previously been unseen.



**Figure 14.3** The interior of a scanning tunnelling microscope used to view the first image of an atom

### Advances in science 14.1

#### The world's smallest movie

In 2013, researchers at IBM created the world's smallest movie. They used carbon monoxide **molecules** and moved them using the small tip of the scanning tunnelling microscope. The movie is called *A Boy and His Atom* – a boy meets an atom and they become friends. It was created using individual frames that were put together using stop-motion software. You can search for this film in your preferred web browser. Although it was constructed for fun, it shows just how far physics has come in the study of atomic and molecular systems.

**molecule**  
a group of two or more atoms that are held together by chemical bonds

#### Quick check 14.1

- 1 Define the term 'atom' in your own words.
- 2 Recall the name of the microscope which allowed scientists to view atoms.

## Practical 14.1

### Splitting molecules into atoms

#### Aim

To split molecules into atoms.

#### Materials

- baking soda
- distilled water
- 250 millilitres (mL) beaker
- 250 mL measuring cylinder
- stirring rod
- safety glasses
- spatula
- 2 power leads
- 2 alligator clips
- power pack

#### Procedure

- 1 Using the 250 mL measuring cylinder, measure 150 mL of distilled water and pour into the beaker.
- 2 Add a heaped spatula of the baking soda to the beaker and stir using the stirring rod until the baking soda has dissolved in the water. Note: the baking soda will enhance the conductivity of the solution, but it is not involved in the chemical reaction.
- 3 Attach each lead to the DC terminals on the power pack, setting the voltage to 9 volts (V).
- 4 To the other end of each lead, attach an alligator clip, making sure the wires do not touch each another.
- 5 Put the ends of the leads with the alligator clips into the beaker of baking soda solution, again making sure the leads do not touch each other at any point.
- 6 Leave this set up for 10 minutes. During this time you should see bubbles forming at each alligator clip.

#### Results

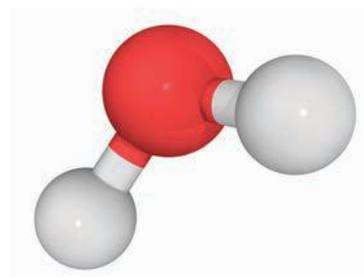
Compile a list of the observations that you made from this experiment. Remember, observations are things that you can see happening, not an explanation of what is happening.

#### Discussion

- 1 In this experiment, you split up water molecules into their atoms. Identify which atoms make up water molecules and how many of each single atom there are.
- 2 Distilled water is water that has undergone a process to remove impurities. Propose a reason why the use of distilled water was specified and suggest what, if any, effect this may have had on the outcome.

#### Be careful

Ensure connectors of the leads are separated and not in contact with each other when attached to the switched-on power pack.



**Figure 14.4** This molecular model of a water molecule shows two hydrogen atoms (white) and one oxygen atom (red).

#### subatomic particle

one of the particles that make up an atom

#### proton

a subatomic particle with a positive charge found in the nucleus of an atom

#### neutron

a subatomic particle with a neutral charge found in the nucleus of an atom

#### electron

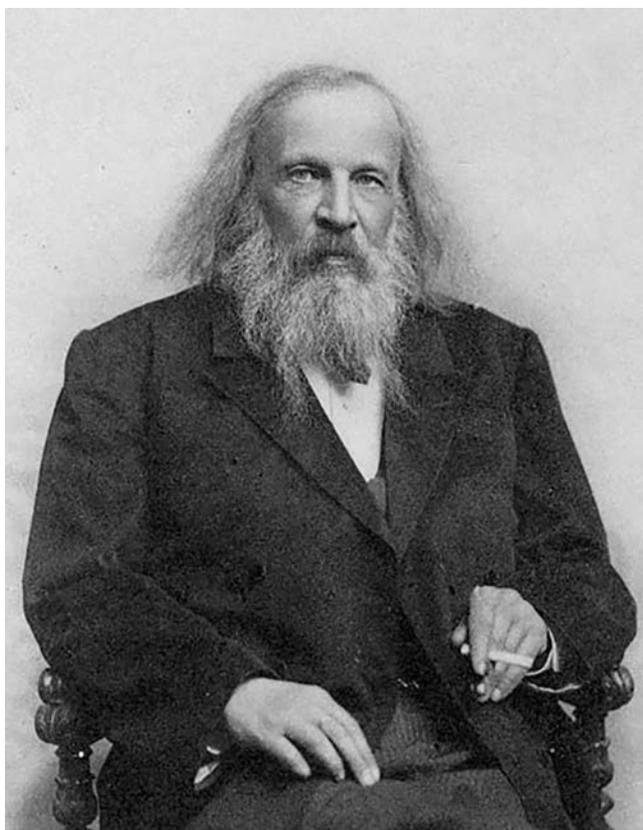
a subatomic particle with a negative charge found outside the nucleus in all atoms

## Subatomic particles

You have already learned that the word ‘atom’ comes from the Greek word *atomos* meaning ‘indivisible’. This idea, despite having a long history, only became widely accepted in the twentieth century. Even Dmitri Mendeleev, who many call the

‘father of the modern periodic table’, for a while refused to believe that atoms existed. The periodic trends he observed formed the basis of the table of the elements that he first published in 1869.

As new technologies developed, physicists discovered that the atom is made up of three **subatomic particles**: **protons**, **neutrons** and **electrons**. There are different numbers of these subatomic particles in each element, which will be discussed in more detail later in this chapter.



**Figure 14.5** Dmitri Mendeleev, often called the 'father of the modern periodic table'

### Explore! 14.1

#### Particles smaller than the electron

There was once a time when scientists thought that the atom was the smallest particle that existed. You know that protons, neutrons and electrons make up the atom, but is there anything that makes up these subatomic particles? Because of its wavelike properties, it is extremely hard to define or measure the size of an electron. Some quantum physicists think that an electron could even be in two places at one time.

Research the particles that make up protons, neutrons and electrons. What are their names? What is known about them?



**Figure 14.6** These Russian dolls fit inside each other, getting progressively smaller just like an atom and the subatomic particles within it.

### Did you know? 14.2

#### Ordinary hydrogen – an unusual element

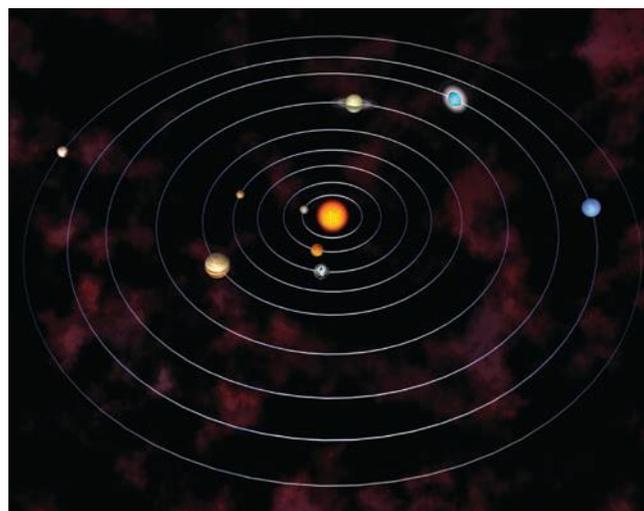
Hydrogen is the only element that does not contain all three subatomic particles. A hydrogen atom only contains one proton and one electron. It is missing a neutron!

### Modern atomic models

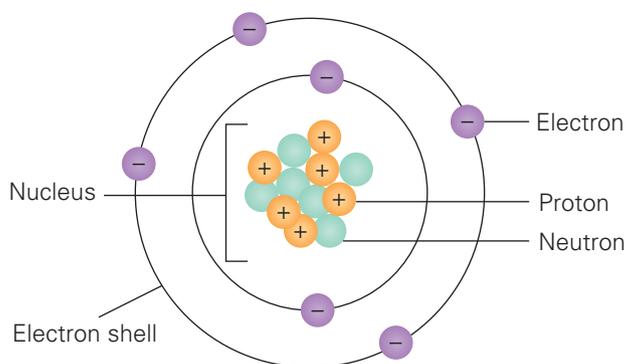
Even with the most powerful microscopes, scientists cannot see inside the atom, so they create models of the atom to represent ideas that cannot be observed. To help visualise the structure of the atom, model it as a mini solar system. In the middle of our solar system is the Sun and orbiting the Sun are the planets, with most of the rest of the solar system being empty space.

The atom has a similar kind of structure. In the middle of the atom is a structure called the **nucleus**, which is where the protons and neutrons are situated. Orbiting the nucleus in shells or orbits are the electrons. The shells are drawn as circles and are

**nucleus**  
(plural: nuclei) the central part of the atom containing its protons and neutrons



**Figure 14.7** The solar system. The planetary model of the atom is based on the structure of our solar system.

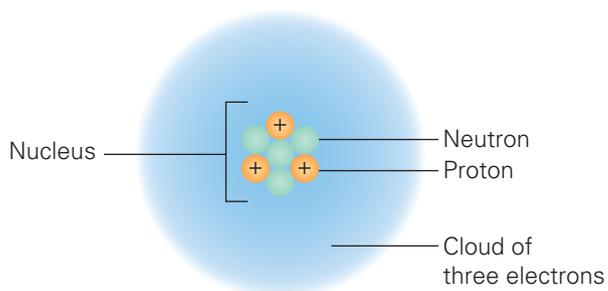


**Figure 14.8** A Bohr diagram shows the positively charged nucleus (containing both protons and neutrons) and electrons orbiting in shells of different energy levels.

at different energy levels depending on how far they are away from the nucleus. This planetary-style model was proposed by Niels Bohr in 1913 and is often referred to as a Bohr diagram.

Just like the solar system, most of the atom is made up of empty space. To give you an idea of how empty, if the atom was an Olympic athletics track, then the nucleus would only be the size of a pea in the middle of it!

Another model of the atom is the electron cloud model. As electrons are moving around the nucleus continuously, it is difficult to predict exactly where each electron will be at a given moment. Therefore, the electron cloud model shows large areas in the atom where electrons are most likely to be situated (orbitals).



**Figure 14.9** The electron cloud model shows the nucleus in the middle of an atom (lithium) surrounded by a cloud of electrons.

### Try this 14.1

Build your own model of the atom using everyday household objects. Make sure you include labels.

### Quick check 14.2

- 1 What is the name of the structure at the centre of the atom and what does it contain?
- 2 Where are the electrons located?

## Properties of subatomic particles

To understand more about atoms and how they behave, you need to know more about the three subatomic particles within them.



VIDEO  
What are subatomic particles?

## Charge

You may be wondering what keeps the electrons inside the atom. If they are whizzing around at an enormous speed inside the atom, why don't they just fly off into space? Why they remain has to do with the electrical charges of the subatomic particles. Remember, the protons in the nucleus in the middle of the atom have a positive charge (+1). Electrons orbiting the nucleus have a negative charge (-1). Positive and negative charges follow two basic rules of electrostatics: opposite charges attract and like (the same) charges repel. This means that the protons and electrons in an atom are attracted to each other, stopping the electrons from flying off into space. Neutrons are electrically neutral, which means they have no charge at all (0). Table 14.1 summarises what you need to know about the charges of the subatomic particles.

Subatomic particle	Charge
Proton	+1 (positive)
Neutron	0 (neutral)
Electron	-1 (negative)

**Table 14.1** The charges of the three subatomic particles

## Try this 14.2

**Demonstrating the attractions between charged objects**

Investigate attractions between charged objects with the following two activities.

**Activity 1**

Follow the instructions using 2 balloons, 2 pieces of string about 1 metre (m) long, and a plastic tube.

- 1 Blow up both balloons and tie one piece of string to each balloon.
- 2 Hang both balloons from a common point on the ceiling.
- 3 Charge a plastic tube by rubbing it on some fabric.
- 4 Note the position of the two balloons.
- 5 Put the plastic tube between the two balloons and observe the effect.

**Activity 2**

Follow the instructions using a balloon.

- 1 Rub the balloon on the hair of a friend.
- 2 Bring the balloon away from their head and observe what happens.

**Analysis**

- 1 Determine which experiment showed repulsion. Suggest a reason for your answer.
- 2 Determine which experiment showed attraction. Suggest a reason for your answer.
- 3 Discuss what is happening in both experiments at an atomic level.

**Mass**

As well as knowing the charge of the subatomic particles, you also need to be able to recall their masses. Protons and neutrons have very similar masses: a proton has a mass of  $1.673 \times 10^{-24}$  grams (g) and a neutron has a mass of  $1.675 \times 10^{-24}$  g. These numbers are very small and almost the same, so for practical reasons, both protons and neutrons are assigned a mass of 1 atomic mass unit (amu). These values are much easier to remember and

work with. Electrons have a mass  $\frac{1}{1840}$  of a proton or a neutron. Table 14.2 summarises what you need to know about the masses of the three subatomic particles.

Subatomic particle	Relative mass (amu)
Proton	1
Neutron	1
Electron	$\frac{1}{1840}$

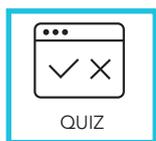
**Table 14.2** The relative mass of the three subatomic particles

**Quick check 14.3**

Complete this table summarising the differences in charge and relative mass of the three subatomic particles.

Subatomic particle	Symbol	Location	Charge	Relative mass (amu)
Proton	$p^+$			
Neutron	$n^0$			
Electron	$e^-$			

## Section 14.1 questions

**Remembering**

- Name** the two most common elements in the universe.
  - Name** the three subatomic particles that make up the atom.
  - Identify** which subatomic particle has the smallest mass.
  - Recall** the name of the structure at the centre of the atom where the protons and neutrons are located.
- 5 In the table below, **match** the subatomic particle to the correct charge.

Subatomic particle	Charge (e)
Proton	0
Neutron	-1
Electron	+1

**Understanding**

- 6 **Compare** and **contrast** the properties of protons, neutrons and electrons.

**Applying**

- 7 Water ( $\text{H}_2\text{O}$ ) is made up of two different elements: hydrogen (H) and oxygen (O). **Determine** how many different elements make up vinegar ( $\text{CH}_3\text{COOH}$ ).
- 8 **Construct** a labelled diagram that shows the planetary model of the atom.

**Analysing**

- 9 **Draw** the electron cloud model of the atom. Comparing it to the Bohr/planetary model, **examine** the similarities and differences between the two models.

**Evaluating**

- 10 **Propose** several reasons why models are so useful in science. **Explain** the limitations of using models.

# 14.2 Atomic number and mass number

## Learning goals

- 1 To recall the definitions of atomic and mass number
- 2 To be able to distinguish between the composition of the atoms of some common elements
- 3 To describe and explain what happens to an element when it loses or gains electrons

1 <b>H</b> 1.008 Hydrogen																	2 <b>He</b> 4.003 Helium				
3 <b>Li</b> 6.941 Lithium	4 <b>Be</b> 9.012 Beryllium															5 <b>B</b> 10.81 Boron	6 <b>C</b> 12.01 Carbon	7 <b>N</b> 14.01 Nitrogen	8 <b>O</b> 16.00 Oxygen	9 <b>F</b> 19.00 Fluorine	10 <b>Ne</b> 20.18 Neon
11 <b>Na</b> 22.99 Sodium	12 <b>Mg</b> 24.31 Magnesium															13 <b>Al</b> 26.98 Aluminium	14 <b>Si</b> 28.09 Silicon	15 <b>P</b> 30.97 Phosphorus	16 <b>S</b> 32.06 Sulfur	17 <b>Cl</b> 35.45 Chlorine	18 <b>Ar</b> 39.95 Argon
19 <b>K</b> 39.10 Potassium	20 <b>Ca</b> 40.08 Calcium	21 <b>Sc</b> 44.96 Scandium	22 <b>Ti</b> 47.87 Titanium	23 <b>V</b> 50.94 Vanadium	24 <b>Cr</b> 52.00 Chromium	25 <b>Mn</b> 54.94 Manganese	26 <b>Fe</b> 55.85 Iron	27 <b>Co</b> 58.93 Cobalt	28 <b>Ni</b> 58.69 Nickel	29 <b>Cu</b> 63.55 Copper	30 <b>Zn</b> 65.38 Zinc	31 <b>Ga</b> 69.72 Gallium	32 <b>Ge</b> 72.63 Germanium	33 <b>As</b> 74.92 Arsenic	34 <b>Se</b> 78.97 Selenium	35 <b>Br</b> 79.90 Bromine	36 <b>Kr</b> 83.80 Krypton				
37 <b>Rb</b> 85.47 Rubidium	38 <b>Sr</b> 87.62 Strontium	39 <b>Y</b> 88.91 Yttrium	40 <b>Zr</b> 91.22 Zirconium	41 <b>Nb</b> 92.91 Niobium	42 <b>Mo</b> 95.95 Molybdenum	43 <b>Tc</b> Technetium	44 <b>Ru</b> 101.1 Ruthenium	45 <b>Rh</b> 102.9 Rhodium	46 <b>Pd</b> 106.4 Palladium	47 <b>Ag</b> 107.9 Silver	48 <b>Cd</b> 112.4 Cadmium	49 <b>In</b> 114.8 Indium	50 <b>Sn</b> 118.7 Tin	51 <b>Sb</b> 121.8 Antimony	52 <b>Te</b> 127.6 Tellurium	53 <b>I</b> 126.9 Iodine	54 <b>Xe</b> 131.3 Xenon				
55 <b>Cs</b> 132.9 Caesium	56 <b>Ba</b> 137.3 Barium	57–71 Lanthanoids	72 <b>Hf</b> 178.5 Hafnium	73 <b>Ta</b> 181.0 Tantalum	74 <b>W</b> 183.8 Tungsten	75 <b>Re</b> 186.2 Rhenium	76 <b>Os</b> 190.2 Osmium	77 <b>Ir</b> 192.2 Iridium	78 <b>Pt</b> 195.1 Platinum	79 <b>Au</b> 197.0 Gold	80 <b>Hg</b> 200.6 Mercury	81 <b>Tl</b> 204.4 Thallium	82 <b>Pb</b> 207.2 Lead	83 <b>Bi</b> 209.0 Bismuth	84 <b>Po</b> Polonium	85 <b>At</b> Astatine	86 <b>Rn</b> Radon				
87 <b>Fr</b> Francium	88 <b>Ra</b> Radium	89–103 Actinoids	104 <b>Rf</b> Rutherfordium	105 <b>Db</b> Dubnium	106 <b>Sg</b> Seaborgium	107 <b>Bh</b> Bohrium	108 <b>Hs</b> Hassium	109 <b>Mt</b> Meitnerium	110 <b>Ds</b> Darmstadtium	111 <b>Rg</b> Roentgenium	112 <b>Cn</b> Copernicium	113 <b>Nh</b> Nihonium	114 <b>Fl</b> Flerovium	115 <b>Mc</b> Moscovium	116 <b>Lv</b> Livermorium	117 <b>Ts</b> Tennessine	118 <b>Og</b> Oganesson				
			57 <b>La</b> 138.9 Lanthanum	58 <b>Ce</b> 140.1 Cerium	59 <b>Pr</b> 140.9 Praseodymium	60 <b>Nd</b> 144.2 Neodymium	61 <b>Pm</b> Promethium	62 <b>Sm</b> 150.4 Samarium	63 <b>Eu</b> 152.0 Europium	64 <b>Gd</b> 157.3 Gadolinium	65 <b>Tb</b> 158.9 Terbium	66 <b>Dy</b> 162.5 Dysprosium	67 <b>Ho</b> 164.9 Holmium	68 <b>Er</b> 167.3 Erbium	69 <b>Tm</b> 168.9 Thulium	70 <b>Yb</b> 173.1 Ytterbium	71 <b>Lu</b> 175.0 Lutetium				
			89 <b>Ac</b> 138.9 Actinium	90 <b>Th</b> 232.0 Thorium	91 <b>Pa</b> 231.0 Protactinium	92 <b>U</b> 238.0 Uranium	93 <b>Np</b> Neptunium	94 <b>Pu</b> Plutonium	95 <b>Am</b> Americium	96 <b>Cm</b> Curium	97 <b>Bk</b> Berkelium	98 <b>Cf</b> Californium	99 <b>Es</b> Einsteinium	100 <b>Fm</b> Fermium	101 <b>Md</b> Mendelevium	102 <b>No</b> Nobelium	103 <b>Lr</b> Lawrencium				

**Figure 14.10** The periodic table gives you information about each element's atoms. Note that the table is continually being updated as new discoveries and decisions are made by the scientific community.

The number of subatomic particles in an atom depends on the type of element being considered. Look at the periodic table, and you will notice that each element has a symbol and two numbers. These numbers provide information about the number of protons, neutrons and electrons in each atom.

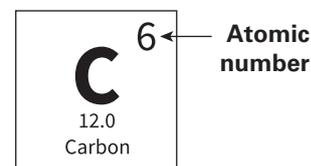
## Atomic number

The lower of the two numbers given with each element is called the **atomic number**. This number is usually located at the top of the box for each element (as seen in Figure 14.11), but in some periodic tables it is positioned differently. This is why it is important that you remember the atomic number as the lower of the two numbers.

## Number of protons

The atomic number is sometimes called the proton number as it tells you how many protons the element has. For example, the atomic number of carbon is 6, therefore carbon has six protons.

You will not find another element that contains six protons. This is because the atomic number defines the element.



**Figure 14.11** For the element carbon the atomic number is 6. You can therefore conclude that it has six protons.



WORKSHEET

**atomic number**  
the number of protons in an atom of an element

Any atom that contains six protons will always be carbon, no matter how many neutrons and electrons it contains. If another proton is added to carbon, then an element with seven protons would be formed – otherwise known as nitrogen. Carbon is a black solid and nitrogen is a colourless gas; one proton can make a big difference to an element's properties.



Figure 14.12 Carbon, a black solid with an atomic number of 6



Figure 14.13 Liquid nitrogen, a colourless gas cooled down to  $-196^{\circ}\text{C}$ , with an atomic number of 7

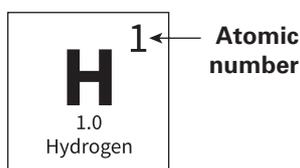


Figure 14.14 For the element hydrogen the atomic number is 1, so you can conclude that it has one proton.

### Quick check 14.4

Using an element of your choice as an example, explain what the atomic number tells you about the atom.

### Number of electrons and formation of ions

The atomic number also gives you information on the number of electrons in an atom of an element. Recall that protons have a positive charge and electrons have a negative charge. An atom is neutral, meaning that it has an overall charge of zero. So, what does that mean about the numbers of protons and electrons? An atom must have the same number of positive protons and negative electrons for the overall charge to equal zero (neutral). Carbon has an atomic number of 6, meaning it has six protons (six positively charged particles). Therefore, for the atom to have zero charge, it must have six electrons (six negatively charged particles). So, the atomic number also tells you how many electrons an atom has.

Changing the number of electrons in an element will not change the type of element, unlike a change in proton number, but it will change the chemical properties of the element. The atom is now referred to as an **ion** and is said to become charged. This is denoted by a superscripted plus (+) or minus (–) sign after the chemical symbol. A plus sign indicates the atom has become more positive (lost negatively charged electrons), whereas a minus sign indicates the atom has become more negative (gained negatively charged electrons). For example,  $\text{Mg}^{2+}$  denotes a magnesium atom that has lost two electrons and is now carrying an overall charge of +2. It has 12 protons in the nucleus, but as it has given away 2 electrons it now only has 10 electrons.

**ion**  
a charged version of an atom that has either gained or lost electrons

### Quick check 14.5

- 1 How does an atom become positively or negatively charged?
- 2 Using your knowledge of the number of protons and electrons in an atom, explain why atoms become charged when the number of electrons is changed.

## Practical 14.2

### Investigating which ions cause water hardness

#### Aim

To investigate the effect of different ions on water hardness.

#### Planning

- 1 Research some background information about water hardness, what influences it and what problems hard water can cause. Summarise your findings.
- 2 Identify the independent and dependent variables for this experiment.
- 3 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
- 4 Develop a hypothesis to predict which ions will cause the most water hardness.
- 5 Complete a risk assessment for this investigation, describing how any risks will be controlled.

#### Materials

- 8 test tubes
- 8 test-tube corks/bungs
- test-tube rack
- dropping pipettes
- 100 mL beaker
- marker pen
- 50 mL soap solution in industrially denatured alcohol (IDA). This can be made by dissolving soap flakes (or shavings from a bar of soap) in IDA.
- 10 mL distilled or deionised water
- 10 mL sodium chloride, 0.1M
- 10 mL calcium chloride, 0.1M
- 10 mL magnesium chloride, 0.1M
- 10 mL potassium nitrate(V), 0.1M
- 10 mL sodium sulfate(V), 0.1M
- 10 mL iron(II) sulfate(VI), 0.1M
- 10 mL magnesium sulfate(VI), 0.1M

#### Procedure

- 1 Set up eight labelled test tubes in a test-tube rack, each containing 1 centimetre (cm) depth of the distilled water or one of the seven different ion solutions.
- 2 Use a dropping pipette to transfer approximately 1 cm depth of soap solution to each test tube.
- 3 Seal the test tubes with a bung or cork and shake well.
- 4 Record which test tubes contain a lather (mass of bubbles) at the end of the shaking, and if a lather is present, the depth of it.

#### Results

Draw a results table that will allow the collection of sufficient and relevant raw data.

#### Discussion

- 1 Identify the ion/s that cause the most water hardness. Justify your answer with data.
- 2 Discuss the purpose of the distilled water test tube.
- 3 Identify any potential sources of error in this experiment.
- 4 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 ions and water hardness. Justify your answer with data.

## Relative atomic mass

The second number listed on the periodic table for each element is the **relative atomic mass**. This is the average mass of all the different forms of each element and is

**relative atomic mass**  
the average mass of the different forms of each element

**mass number**  
the sum of the protons and neutrons in the nucleus of an atom

therefore seldom a whole number. This is because every element consists of a mixture of atoms that have the same number of protons but different numbers of

neutrons. Such atoms are called ‘isotopes’ and will be discussed later in the chapter.

## Mass number

The **mass number** of an atom is the sum of the protons and neutrons contained in the nucleus. The mass number is a whole number and cannot be found on the periodic table. It is not to be confused with the relative atomic mass. Electrons are not considered when calculating the mass number because they have a much smaller mass than protons and neutrons.

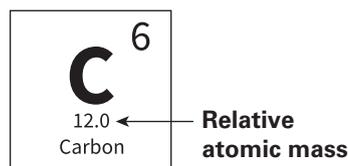
## Number of neutrons

The mass number of the isotope of an element in greatest abundance can be obtained by rounding off the relative atomic mass to the nearest whole number. It can be used to calculate the number of neutrons in the nucleus of an atom. You know that the mass number is the number

of protons and neutrons in an atom, and you have also learned that the atomic number is the number of protons. Therefore, if you subtract the atomic number from the mass number, you are left with the number of neutrons:

$$\text{number of neutrons} = \text{mass number} - \text{atomic number}$$

Recall the example of carbon. Carbon has a mass number of 12 (rounded to the nearest whole number) and an atomic number of 6. Using the equation just mentioned, you can calculate that carbon has a total of six neutrons.



**Figure 14.15** The atomic symbols for carbon, showing the atomic number of 6 and relative atomic mass of 12. These numbers can be used to calculate the number of neutrons in a carbon atom.

$$\begin{aligned} \text{Number of neutrons in a carbon atom} \\ &= \text{mass number} - \text{atomic number} \\ &= 12 - 6 \\ &= 6 \end{aligned}$$

Unlike for protons, changing the number of neutrons in an element will not change the type of element, but it will change how it behaves. You will learn more about this later in this chapter.

### Quick check 14.6

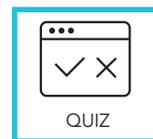
Using their atomic numbers and mass number, state the number of protons, neutrons and electrons each atom contains.

	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
Nitrogen	7	14			
Sodium	11	23			
Sulfur	16	32			
Gold	79	197			

## Section 14.2 questions

## Remembering

- 1 **State** the names of the two numbers that accompany each element on the periodic table.
- 2 **Identify** the subatomic particles that have nearly the same mass.
- 3 **Identify** which of the two numbers, relative atomic mass or atomic number, is always the largest.
- 4 **Name** the element that has an atomic number of 20.
- 5 If an atom has 18 protons, **state** how many electrons it has.



## Understanding

- 6 **Explain** why the mass of the electron is not considered in the mass number.
- 7 An atom has a mass number of 45 and an atomic number of 16. **Calculate** how many neutrons it has. Show your working.
- 8 **Explain** why atoms of elements have a neutral overall charge.

## Applying

- 9 Apply your knowledge of the overall charge of an atom to **explain** what would happen to an oxygen atom if it had an extra electron (nine electrons).

## Analysing

- 10 **Compare** the mass number and the atomic number of an element.
- 11 **Identify** the missing information in the table using the information in the periodic table.

Element	Mass number	Number of protons	Number of neutrons	Number of electrons
Hydrogen	1			
Oxygen	16			
Potassium	39			
Aluminium	27			

## Evaluating

- 12 'The mass number determines the identity of the element.' **Propose** whether this statement is true or false. **Justify** your answer.
- 13 **Justify** why there are no elements on the periodic table with the same atomic number.
- 14 **Evaluate** why you do not find carbon dioxide (CO<sub>2</sub>) on the periodic table.
- 15 'Atoms always are neutral.' Is the statement true or false? **Justify** your answer.

## 14.3 Development of the atomic model

### Learning goals

- 1 To recall the contributions of various scientists to our understanding of the atomic model
- 2 To describe how the atomic model has been contested and refined over time
- 3 To explain the importance of peer review in the scientific process



Discussions about the atom and its structure have been going on within the scientific community for hundreds of years. In this section you will examine the major discoveries that have contributed to our understanding of the atom and which highlight how new experimental evidence can lead to a scientific model being updated or replaced.

### Democritus 460–370 BCE

Democritus was the first scientist to theorise about the atom. In the year 442 BCE, he said that if you take an object and cut it into smaller and smaller pieces, eventually you would reach a point where you could no longer cut it anymore. You would end up with a piece that was indivisible. It was Democritus that called this piece *atomos*, which means ‘indivisible’ in Greek.

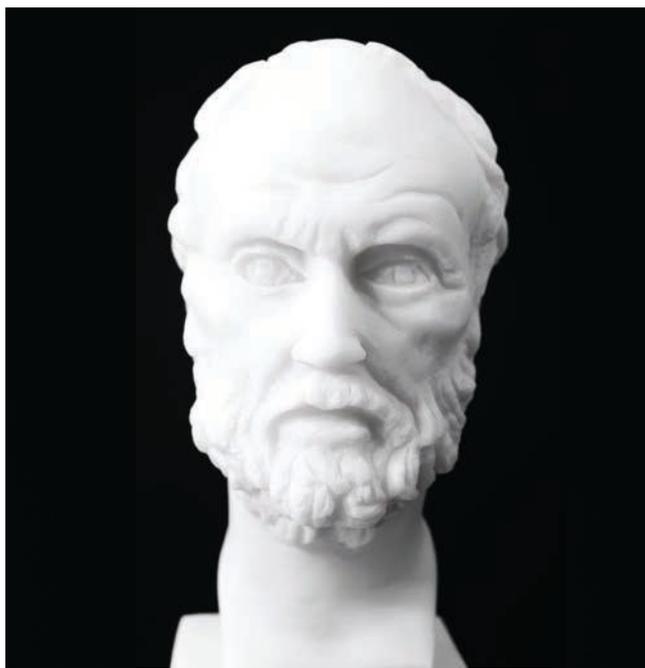


Figure 14.16 Sculpture of the Greek philosopher Democritus

### Aristotle 384–322 BCE

Aristotle rejected the ideas of Democritus, instead believing that matter on Earth was made up of four elements – earth, air, fire and water – and the amounts of these elements determined how materials behaved.

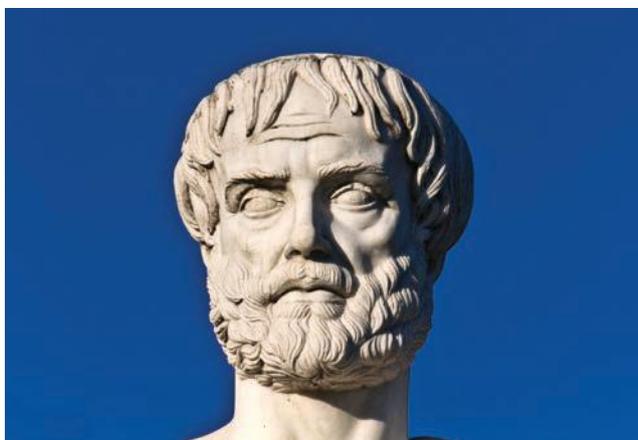


Figure 14.17 Sculpture of the Greek philosopher Aristotle

### John Dalton 1766–1844

Dalton is credited for igniting research into modern atomic theory in 1803, more than 2000 years after Democritus first proposed his ideas on the atom. Dalton suggested that all elements, which are now arranged in the periodic table, contained atoms, and that atoms of the same element would be identical in size, shape and mass. He also stated



Figure 14.18 John Dalton was an English chemist, physicist and meteorologist. He is best known for sparking research into modern atomic theory.

that compounds were a combination of elements. The question he could not answer, though, was why atoms behaved the way they do.

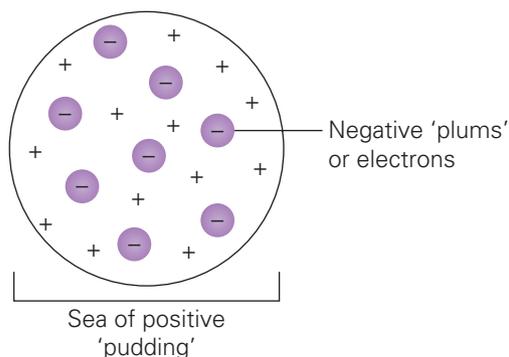
### Joseph John Thomson 1856–1940

Thomson was the first scientist to discover particles smaller than the atom, disproving Dalton's and Democritus' theories. Surprisingly, the first subatomic particle to be discovered was the lightest – the electron – and Thomson won a Nobel prize for his work in 1906. By studying 'rays' within a cathode ray tube, Thomson was able to determine that these 'rays' had a mass 1000 times smaller than a hydrogen atom, the lightest piece of matter known to science at the time. These particles were also attracted to a positively charged metal plate, indicating that they themselves were likely to be negatively charged. He named these particles 'corpuscles', now called electrons.



**Figure 14.19** J J Thomson proposed the 'plum pudding' model and is credited with discovering the electron.

The first model of the structure of the atom was proposed by Thomson and named the plum pudding model. Thomson knew that electrons were negatively charged and that atoms were neutral, so he theorised that there must also be positive charge within the atom that equalled the negative charge of its electrons. He imagined the atom as negatively charged electrons (plums) embedded in a large 'sea' of positively charged 'pudding'.



**Figure 14.20** The plum pudding model, comprising negative electrons (the plums) scattered through a sea of positive charge (the pudding)

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### Ernest Rutherford 1871–1937

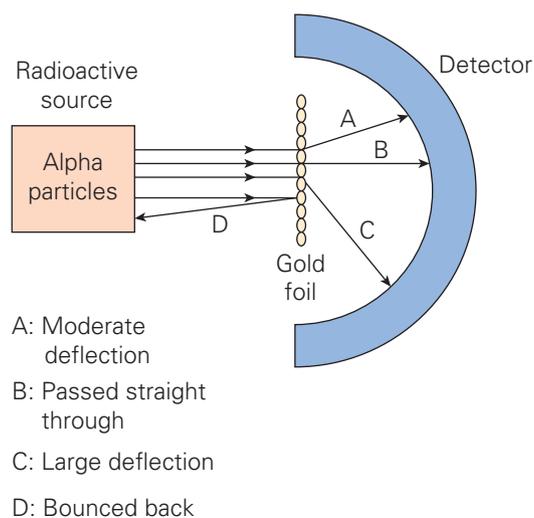
In 1911, Ernest Rutherford and colleagues Hans Geiger and Ernest Marsden fired **alpha particles** (helium nuclei) at a thin piece of gold foil, in the famous gold foil experiment.



**Figure 14.21** Ernest Rutherford stated that there was a large concentration of charge and mass situated in the centre of the atom and that most of the atom was empty space.

Rutherford predicted that if the atom was like Thomson's plum pudding model, then all the alpha particles should pass straight through the atom undisturbed. This is not what happened! It was true that almost all (99.99%) of the alpha particles passed straight through the foil and were detected at the other side by the detector, indicating that the atom was mainly empty space. However, some of the alpha particles surprisingly bounced back or were deflected as if they had hit something (see Figure 14.22). Rutherford concluded that there must be an area of charge, concentrated in the middle of the atom, with enough mass to cause the alpha particles to deflect or bounce back, thus disproving the plum pudding model altogether.

**alpha particle**  
a positively charged particle ejected spontaneously from the nuclei of some radioactive elements

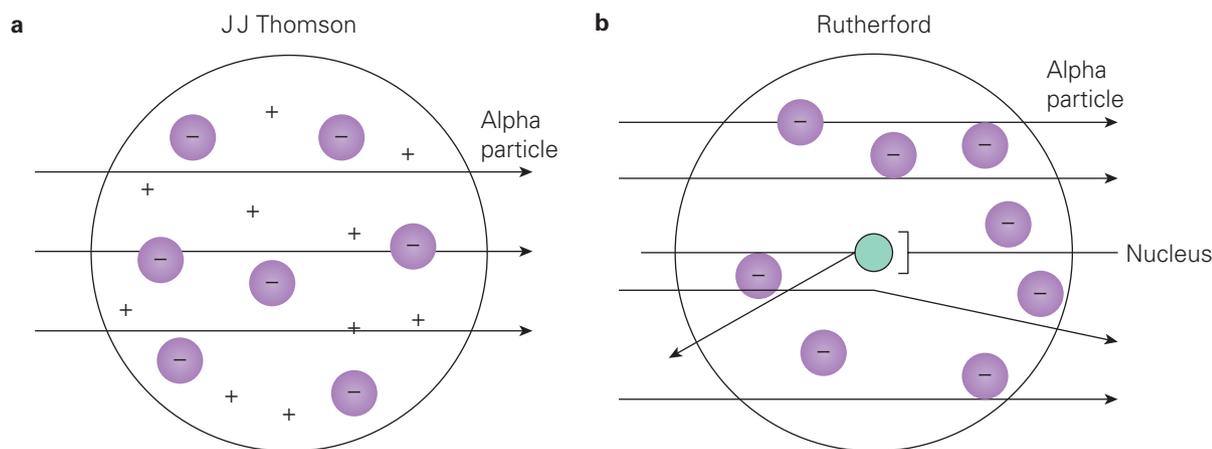


**Figure 14.22** The gold foil experiment conducted by Ernest Rutherford and colleagues proved that most of the atom was empty space and that there was an area of charge and mass concentrated in the middle of the atom.

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In analysing the results of this experiment, Rutherford devised his own model of the atom. This model depicts a charged area with substantial mass concentrated in the middle of the atom, called the nucleus. The nucleus was assumed by Rutherford and many other scientists working in the field at the time to be positively charged as it repelled the positively charged alpha particles.

Rutherford concluded the negative electrons orbited around this central region. Rutherford's model is often called the 'nuclear' or 'planetary' model of the atom. While many other scientists contributed to the developing knowledge at the time, it was Rutherford who named the positively charged particles in the nucleus 'protons'.



**Figure 14.23** Comparison between atomic models: (a) Thomson's plum pudding and (b) Rutherford's central region of mass and charge

### Quick check 14.7

- 1 Recall what Aristotle believed all matter on Earth was composed of.
- 2 State the name of the subatomic particle that Thomson discovered and the name of his atomic model.
- 3 Complete the sentences below using the word list.

alpha                      empty space                      plum pudding model  
nucleus                      passed through

Rutherford conducted the gold foil experiment, firing \_\_\_\_\_ particles at a thin piece of gold foil. Most of the alpha particles \_\_\_\_\_; however, a small number were deflected back.

Rutherford hypothesised that the reason for this was that the alpha particles either passed through a region of \_\_\_\_\_ or hit a central region of concentrated mass and positive charge, which he called the \_\_\_\_\_, disproving the \_\_\_\_\_.

### Practical 14.3: Teacher demonstration

#### Invisible spaces in water

##### Aim

To investigate the three-dimensional structure of molecules.

##### Materials

- 100 mL propan-2-ol
- 250 mL beaker
- 100 mL measuring cylinder

*continued...*

...continued

### Procedure

- 1 Draw the results table shown in the Results section.
- 2 Predict what will happen to the total volume when 100 mL of alcohol is added to 100 mL of water. Propose what the total volume of the solution will be.
- 3 Measure 100 mL of water using the 100 mL measuring cylinder and pour into the beaker.
- 4 Using the same measuring cylinder, measure 100 mL of propan-2-ol and pour into the beaker already containing water.
- 5 Note the actual total volume when the two solutions are mixed together.

### Results

Prediction of volume with 100 mL of water and 100 mL of alcohol	
Actual volume with 100 mL of water and 100 mL of alcohol	

### Discussion

Discuss whether the actual final volume differed from your prediction, and why this was the case.

## Try this 14.3

### Most of an atom is empty space

In this activity, you are going to make a scale model of a hydrogen atom. A hydrogen atom contains one proton and one electron; it is the simplest atom on Earth. You may need a larger space than the classroom to do this – a corridor or playing field may be more suitable. To complete the experiment correctly, you need to know these following important facts:

- The distance between an electron and a proton is 50 000 times the diameter of a proton.
- The mass of a proton is 1840 times greater than the mass of an electron.

### Materials

- calculator
- metre ruler
- measuring wheel
- various spherical objects such as marbles, table tennis balls, dried peas
- pencil
- 30 cm ruler
- scissors
- ball of string
- compass (for drawing a circle)
- A4 plain paper

### Procedure

- 1 Draw the results table shown in the Results section.
- 2 Using the compass, draw a small circle on a piece of paper and record the exact diameter in the results table. This represents a proton.
- 3 Using the important facts at the start of the activity, calculate the relative distance of the electron from the proton.
- 4 Measure a piece of string to the distance calculated in step 3 and record the length in the results table. If you are outside on a field, you could stick the metre ruler into the grass, tie the string around it and draw out how big the atom would be for the proton drawn on your paper.

continued...

...continued

- 5 Repeat the calculation with one of the spherical objects to represent a different proton. Measure the diameter of your chosen spherical object with the 30 cm ruler and record it in the results table.
- 6 This is the diameter of your new hydrogen proton. Now calculate the relative distance of the hydrogen electron from the proton.
- 7 Measure a piece of string to the distance calculated in step 6 and record the length in the results table. Again, if you are on a field, you could stick the metre ruler into the grass, tie the string around it and draw out how big the atom would be.
- 8 If you have time, repeat for the other spherical objects.

### Results

Diameter of spherical object (cm)	Length of string/radius of the atom (cm)
Your circle	

### Discussion

- 1 Propose how this experiment supports the work of Ernest Rutherford on the atom.
- 2 Design another way in which you can show the relative size of an atom.
- 3 State a conclusion about the size of the proton and the distance between it and the electron.

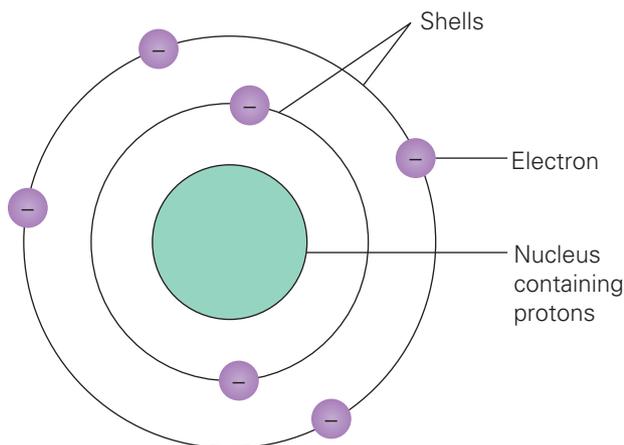
## Niels Bohr 1885–1962



**Figure 14.24** Niels Bohr proposed that electrons were not just spread across the atom randomly but were arranged in discrete energy levels or shells.

Niels Bohr proposed his model of the atom (a modification of Rutherford's theory) in 1913 after looking at the behaviour of electrons. He said electrons moved in fixed circular orbits around the nucleus in structures called shells, and that these shells were specific distances away from the nucleus and the same for all atoms. Electrons located in shells that were further

away from the nucleus had higher energies than those closer to it. These electrons were able to move from one energy level to another by gaining or losing energy.



**Figure 14.25** Bohr's model of the atom is sometimes called the planetary model. It shows electrons in fixed shells around a central nucleus.

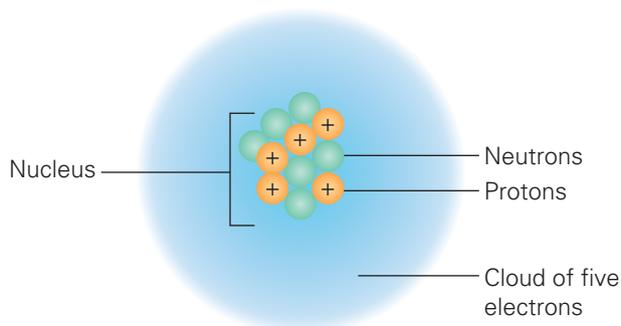
Scientists now know that Bohr's model was flawed, but it provided some important understanding about the behaviour of electrons. Perhaps more importantly, it is the model that you will recognise and use the most in your studies.

## Erwin Schrödinger 1887–1961



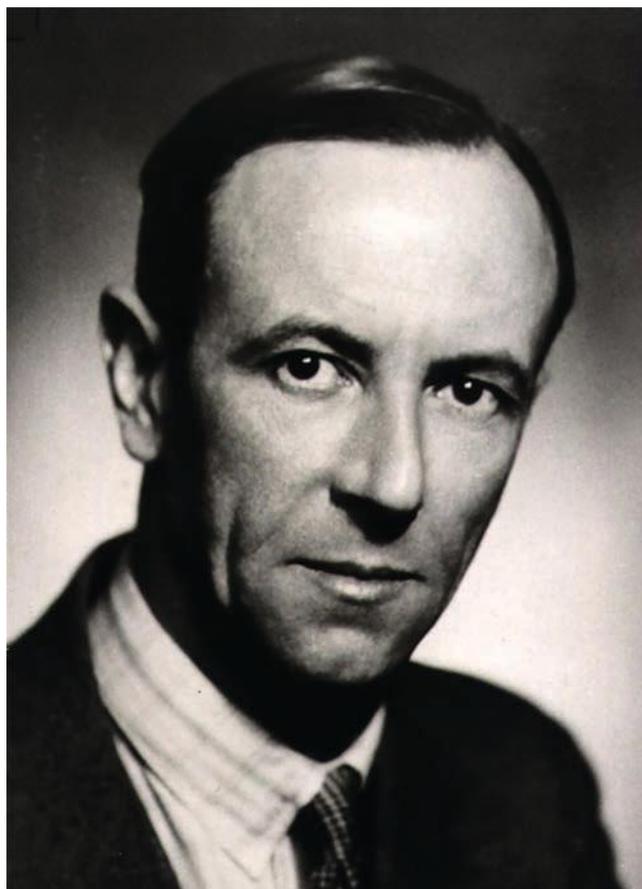
**Figure 14.26** Erwin Schrödinger proposed the electron cloud model, contradicting Bohr's model of fixed electron shells.

Erwin Schrödinger stated that it is impossible to predict where a specific electron will be situated in the atom at any given time. The only thing you can predict is where in the atom you are most likely to find an electron. This contradicted Bohr's idea of electrons being in fixed shells around a central nucleus. Schrödinger proposed the electron cloud model, which shows the locations in the atom with the greatest probability of finding an electron.



**Figure 14.27** The electron cloud model of a boron atom

## James Chadwick 1891–1974



**Figure 14.28** James Chadwick discovered the neutron, completing the atomic model in use today.

There is one subatomic particle yet to be discussed. You may not be surprised that the neutron was the last of the three subatomic particles to be discovered. As it has no charge and does not repel the protons in the nucleus, it was relatively undetectable. This was the case until James Chadwick started working with beryllium atoms and alpha particles in 1932. When he smashed these two particles together, an unknown radiation made up of neutrally charged particles was released. He named these particles neutrons. With this discovery, a relatively accurate model of the atom was now available to scientists.

### Quick check 14.8

- 1 Recall the name Bohr gave to the structures that contained electrons.
- 2 Describe how this explanation of these structures differed from Rutherford's model.
- 3 Identify the subatomic particle that James Chadwick discovered.

## Advances in science 14.2

**The Higgs boson**

Our understanding of the structure of the atom and the particles within it did not stop with James Chadwick in 1932. In 1960, a British-born theoretical physicist named Peter Higgs proposed the existence of a particle that later was named after him: the Higgs boson. The detection of this particle now became his goal as well as the goal of many other theoretical physicists.

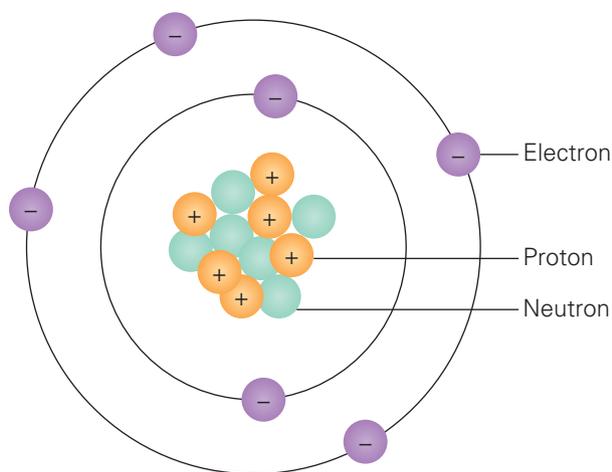
In 2012, the European Organization for Nuclear Research (CERN) announced that they had conducted experiments on the Large Hadron Collider which showed promising results of a particle that could be a Higgs-like boson. You can imagine the excitement Higgs must have been feeling after all this time! In 2013, after almost 55 years of research, CERN finally had enough evidence to confirm that they had recorded the presence of a Higgs boson, and Higgs was awarded a Nobel Prize for Physics in the same year. This is a great example of how, with hard work and persistence, you can eventually achieve your goals!



**Figure 14.29** Peter Higgs (1929–present) discovered the presence of a new particle, which was named the Higgs boson.



**Figure 14.30** Engineers attending to a part of the Large Hadron Collider at CERN where the Higgs boson was discovered



**Figure 14.31** The Bohr model is used because it is a simplification of the electron cloud model.

The evolution of the atomic model is an excellent example of how different scientists individually contributed to and continue to revise our understanding of atomic structure. However, it is important to note that they still may not be right! After all, there was a time when it was thought that the plum pudding model was correct. It is important that scientists continue to ask questions, conduct experiments and critique other people’s work to increase our understanding of atomic structure. Figure 14.32 summarises the development of the modern atomic model.

**Explore! 14.2**

**Other significant developments in the atomic model throughout history**

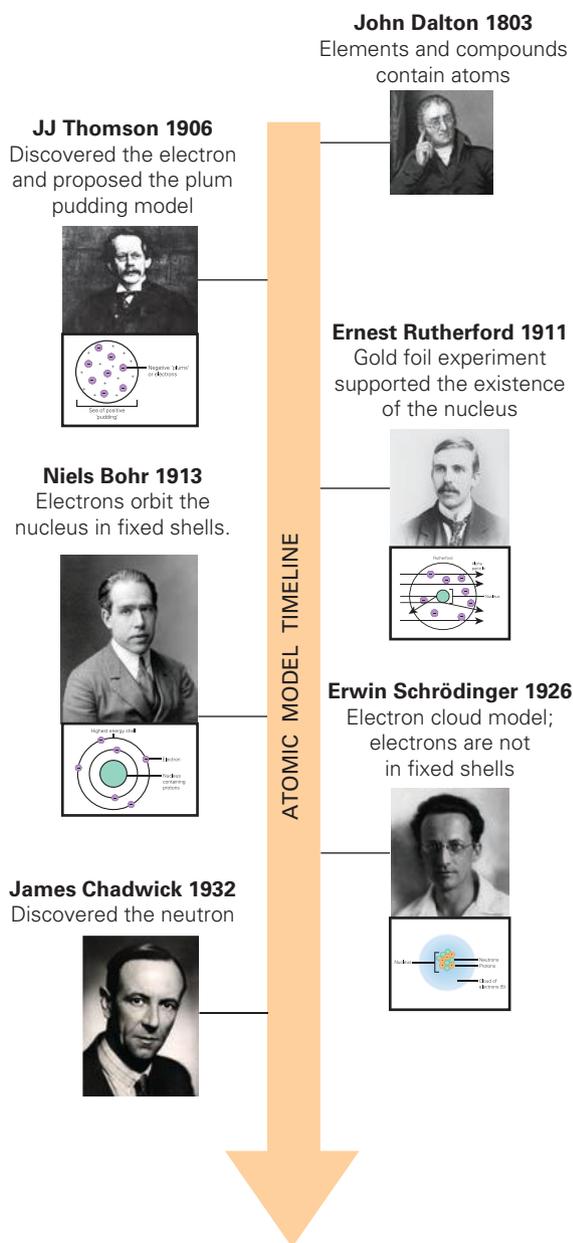
A number of other scientists have been involved in developing our understanding of atomic structure.

Research the following scientists, noting their significant discoveries and how each discovery changed our understanding of the atom around at that time.

Maria Goeppert Mayer, Lise Meitner, Robert Millikan, Werner Heisenberg

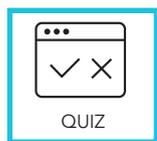


**Figure 14.33** Nobel Laureate Maria Goeppert Mayer



**Figure 14.32** A summary of the development of the atomic model

## Section 14.3 questions

**Remembering**

- 1 **Recall** what the Greek word *atomos* means in English. How does this relate to the word 'atom'?
- 2 **State** who discovered the neutron.

**Understanding**

- 3 Before carrying out the gold foil experiment, **summarise** what Rutherford thought would happen when alpha particles were fired at Thomson's plum pudding model.
- 4 **Compare** and **contrast** Rutherford's model of the atom with the plum pudding model.

**Applying**

- 5 **Identify** the reason why some alpha particles bounced back towards the detector in Rutherford's gold foil experiment.
- 6 **Explain** why the neutron was difficult to discover.

**Analysing**

- 7 **Analyse** the differences between Schrödinger's and Bohr's models of the atom.
- 8 Democritus and Aristotle were philosophers, not modern scientists. **Examine** in what ways were their thoughts 'scientific' and in what ways were they 'not scientific'.

**Evaluating**

- 9 **Describe** and explain the evidence that led to Rutherford concluding that most of the mass and all the positive charge of the atom was concentrated in the centre.
- 10 **Suggest** why the atomic model has changed and why it may continue to do so.
- 11 'The current atomic model is perfect and accurate.' **Appraise** the accuracy of this statement.
- 12 Do you expect the atomic model to change significantly in the future? **Justify** your answer.
- 13 **Deduce** why there is usually such a long period between a scientist proposing a theory and the theory being supported or refuted by valid scientific evidence.

# 14.4 Isotopes

## Learning goals

- 1 To recall the definition of an isotope
- 2 To describe the process of radioactive decay releasing particles and energy
- 3 To evaluate the benefits and risks of nuclear energy in medicine and industry

Earlier in this chapter, you learned how changing the number of protons in an atom results in a totally different element. You also saw how changing the number of electrons results in a charged atom called an ion. Now you will learn what happens when the number of neutrons in an atom is altered.

## What are isotopes?

Two atoms that have the same atomic number but different mass numbers are called **isotopes**. This means that they have the same number of protons as each other (same atomic number, therefore the same element), so their differing mass numbers must be explained by having a different number of neutrons.

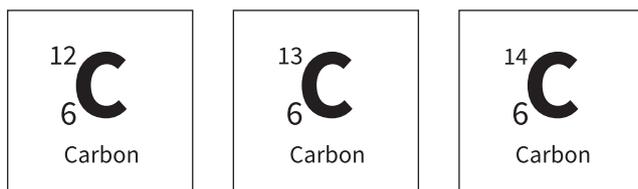


**Figure 14.34** Frederick Soddy discovered isotopes in 1913 in his work on uranium.

### isotopes

atoms of the same element with the same number of protons but a different number of neutrons

Let's take a look at an example. Carbon exists naturally in three forms (see Figure 14.35). All three of these forms are the element carbon as they all have an atomic number of 6 (6 protons).



**Figure 14.35** The three naturally occurring isotopes of carbon. Each shows the mass number (superscripted) and atomic number (subscripted) of the isotope.

Notice that the three forms of carbon have different mass numbers. This difference in mass number is because they

have different numbers of neutrons. Remember that the number of neutrons in an atom is calculated by taking away the atomic number from the mass number. Therefore, the first form of carbon has six neutrons, the second has seven and the third has eight. As they have different numbers of neutrons but the same atomic number, they are called isotopes of carbon.

## Naming isotopes

When writing the symbols for isotopes, the convention is to write the mass number on the top left hand side of the element symbol and the atomic number on the bottom, as this time it is the mass number that defines the isotope (see Figure 14.35). Another way of representing an isotope is to write the name of the element followed by the mass number. For example, the three isotopes of hydrogen are hydrogen-1 (H-1), also known as protium, hydrogen-2 (H-2), known as deuterium, and hydrogen-3 (H-3), known as tritium.



## Explore! 14.3

### Unusual mass numbers

The relative atomic mass of chlorine on the periodic table is 35.5. If you were to use this number to work out the number of neutrons, then it would have 18.5 neutrons. This is clearly incorrect as half a neutron does not exist. Conduct some research to answer the following questions.

- 1 Why is the relative atomic mass of chlorine recorded as 35.5 on the periodic table?
- 2 Chlorine has two naturally occurring stable isotopes, Cl-35 and Cl-37. What is the difference between Cl-35 and Cl-37?
- 3 Which isotope of chlorine do you think is the most abundant form in nature?

## Stable and unstable isotopes

The stability of an isotope is based on whether it is likely to break down or decay into other elements.

### radioisotopes

unstable isotopes that are likely to break down or decay into other elements to try to achieve a stable nucleus

### radioactive decay

when an unstable nucleus emits radiation (alpha and beta particles or gamma waves) and breaks down to form another element

### beta particle

a charged particle (electron) that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom

Often, heavy isotopes (that is, having many more neutrons than protons) are unstable compared to lighter isotopes (having similar numbers of neutrons and protons), which are stable. Unstable isotopes, such as the isotopes of the element uranium, are often called **radioisotopes**.

In these types of isotopes,

**radioactive decay** (splitting of the nucleus) occurs to try to achieve a stable nucleus (as discussed later in this section). On the other hand, stable isotopes are not radioactive as their nucleus is stable and therefore not prone to radioactive decay. Elements can have more than one stable isotope, such as carbon-12 and carbon-13. Table 14.3 summarises the differences between stable and unstable isotopes.

Stable isotopes	Unstable isotopes
Have a stable nucleus	Have an unstable nucleus
Not radioactive	Radioactive

Table 14.3 A comparison between stable and unstable isotopes

### Did you know? 14.3

#### No relative atomic mass?

Look at francium (Fr) on the bottom left of the periodic table. The relative atomic mass is not listed. In other periodic tables, you may see the relative atomic mass listed as '(223)' with brackets around it. Elements written like this are radioactive, so they are very unstable. Most of their isotopes decay into other elements relatively quickly. The relative atomic mass in parentheses represents the most stable isotope of that element – the one that exists the longest.

Can you find other radioactive elements on the periodic table?

### Quick check 14.9

- 1 Define the term 'isotope' in your own words.
- 2 Recall the characteristics of unstable isotopes.

## Radioactive decay

Emissions from radioactive decay are commonly alpha ( $\alpha$ ), beta ( $\beta$ ) or gamma ( $\gamma$ ) radiation.

### Alpha decay

An alpha particle consists of two protons and two neutrons, which is the same as the nucleus of a helium atom. Therefore, when an atom undergoes alpha decay, the atomic number decreases by 2 and the mass number decreases by 4. You know that when the atomic number changes, a new element is formed. The equation in Figure 14.36 shows what happens when an atom of uranium undergoes alpha decay.

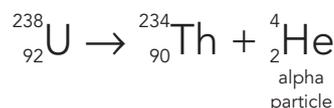


Figure 14.36 When a uranium-238 nucleus undergoes alpha decay, it becomes a thorium-234 atom. The atom of uranium has changed into an atom of thorium.

### Beta decay

**Beta particles** are simply fast-moving electrons emitted from the nucleus. During beta decay, a neutron is converted into a proton and an electron. Consequently, the atomic number will increase by one, which changes the identity of the element altogether. The mass number of the remaining atom will not be affected as it has lost a neutron but gained a proton. The equation in Figure 14.37 shows what happens during beta decay.

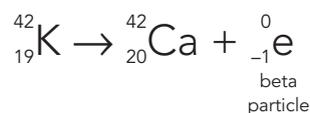


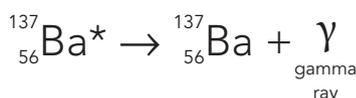
Figure 14.37 When a potassium-42 nucleus undergoes beta decay, it becomes a calcium-42 atom and emits a beta particle.

## Gamma decay

Gamma decay is different from alpha and beta decay in that the atom undergoing gamma decay is not changed; that is, the mass and atomic numbers are not altered. This is because gamma decay involves the emission of a high-energy wave called a **gamma ray**,

**gamma ray**  
a high energy wave emitted from the nucleus of radioactive elements during radioactive decay

rather than a particle. The equation in Figure 14.38 shows gamma decay of radioactive barium.



**Figure 14.38** When radioactive barium decays, a gamma ray is emitted. The asterisk indicates that barium is initially in an excited and therefore unstable state.

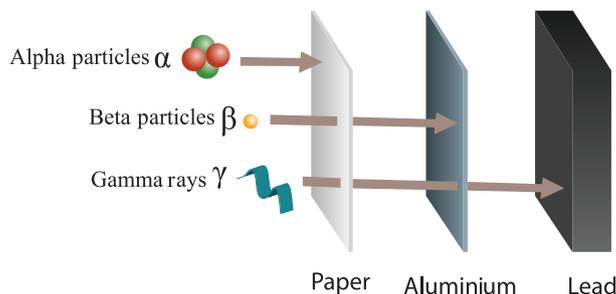
Type of radiation	Penetrating power	Ionisation power
Alpha	Least penetrating. It can be stopped by a sheet of paper.	Very strongly ionising; can cause the most damage, especially if they are inside the body
Beta	It can penetrate paper but is stopped by a thin aluminium sheet.	Not as ionising as alpha particles but more than gamma rays
Gamma	The most penetrating. It can only be stopped by thick pieces of lead or concrete.	Not very ionising so causes the least damage; can penetrate the body, and high-energy gamma rays are used to kill cancer cells

**Table 14.4** Properties of the three different types of radiation

## Ionising and penetrating powers

How dangerous a type of radiation is depends on its ability to penetrate materials and how much damage it

can do (how ionising it is). Table 14.4 and Figure 14.39 summarise the properties of the three types of radiation.



**Figure 14.39** The penetrating powers of alpha, beta and gamma radiation

### Quick check 14.10

- 1 If an atom emits alpha radiation, what particle does it give off and how is the atom changed as a result?
- 2 If an atom emits beta radiation, what particle does it give off and how is the atom changed as a result?
- 3 Describe how gamma radiation differs from alpha and beta radiation.

## What are isotopes used for?

There are around 90 naturally occurring elements with around 250 stable isotopes and about 3200 unstable radioisotopes. Both stable isotopes and radioisotopes have important uses.

Perhaps the most well-known use for isotopes is in medicine to diagnose and treat illnesses: cobalt-60 (Co-60) is used in radiotherapy to treat cancer cells; strontium-90 (Sr-90) is used in the treatment of skin cancer in pets; and gamma rays are produced when radioisotope decay is used to kill bacteria that may be present on medical equipment.



Figure 14.40 A patient undergoing radiotherapy for cancer

Other isotopes used in daily life include sodium-24 ( $\text{Na-24}$ ), which is used in detecting leakages in pipes that are difficult to access; carbon-14 ( $\text{C-14}$ ), which is used in dating archeological artefacts; and nitrogen-14 ( $\text{N-14}$ ), which is used in detecting explosives.

As well as in medicine, nuclear energy produced from radioactive decay has its uses in industry. It can be used:

- in power stations to produce electricity
- as fuel on space missions
- as a weapon in war.

Table 14.5 summarises the benefits and problems of nuclear energy for use in medical and industrial environments.

	Medical	Industrial
Benefits	<ul style="list-style-type: none"> <li>• Provides us with information about the functionality of the body</li> <li>• Scans are produced in lots of detail</li> <li>• Can determine the status of cancer</li> <li>• Amount of radiation given to the patient is minimal</li> </ul>	<ul style="list-style-type: none"> <li>• Fuel can be re-used</li> <li>• Large amount of energy produced per gram of fuel</li> <li>• Reduces greenhouse gas emissions compared with using fossil fuels</li> </ul>
Problems	<ul style="list-style-type: none"> <li>• May adversely affect women who are pregnant or breastfeeding</li> <li>• Threat of severe allergic reactions</li> <li>• Expensive compared to other diagnostic tools</li> </ul>	<ul style="list-style-type: none"> <li>• Expensive to store and dispose of the fuel</li> <li>• Threat of an accident when working with nuclear energy and of radiation poisoning</li> <li>• Expensive to build nuclear power stations</li> </ul>

Table 14.5 Benefits and problems of using nuclear energy in medicine and industry

### Advances in science 14.3

#### Radiocarbon dating rock art

Carbon-14 is an isotope of carbon that primarily decays via beta radiation to nitrogen-14 on a consistent time scale. Scientists are able to predict the age of a fossil by examining the relative amounts of carbon-14 and carbon-12 (which does not decay) in an organic fossil, in a technique known as radiocarbon dating. Carbon dating techniques are continuously improving, allowing for more accurate dating.

In late 2019, a \$1.34 million grant from the Australian Research Council funded a team of researchers, including rock art researchers from Griffith University. The purpose of the 5-year project is to investigate and catalogue Quinkan art, which can be found in Queensland. Many paintings have been dated to 6000 years ago, but there are some that date up to 30000 years ago.

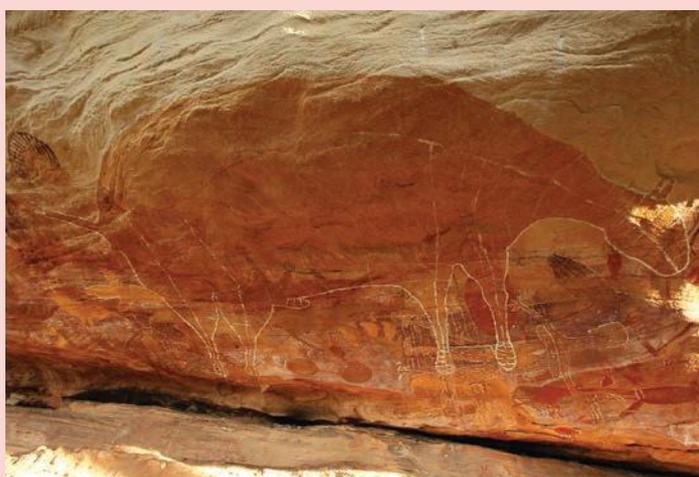


Figure 14.41 An example of rock art from Quinkan country

## Explore! 14.4

**Marie Curie**

Marie Curie was an exceptional scientist, and is the only person to date to have been awarded two Nobel Prizes in different scientific fields: Physics in 1903 (with her husband, Pierre Curie, and Henri Becquerel) and Chemistry in 1911. Research the work of Marie and Pierre Curie that led to their scientific discoveries in radiation.



**Figure 14.42** Marie Curie (right) and Pierre Curie's eldest daughter, Irène Joliot-Curie (left), jointly won the Nobel Prize in Chemistry in 1935 with her husband, Frédéric Joliot-Curie, for their discovery of artificial radiation.

**Practical 14.4: Self design and teacher demonstration****Investigating the penetration of alpha, beta and gamma radiation**

You have been provided with the following materials. Suggest an experiment that could be done using this equipment to show the penetrating properties of alpha, beta and gamma radiation. You may wish to draw a diagram or write a method to demonstrate that you have done this task.

**Aim**

To investigate the penetrative strengths of ionising radiation.

**Materials**

- alpha radiation source
- beta radiation source
- gamma radiation source
- Geiger–Müller tube (detects radiation)
- absorbing materials: sheet of paper, aluminium sheet, lead sheet

**Procedure**

Your teacher will demonstrate the experiment. Due to the dangerous radiation that is emitted, this experiment can only be performed by a teacher and under strictly controlled conditions.

**Results**

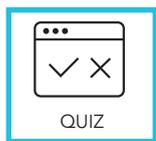
Copy and complete the table below.

Radiation	Material that stops most of the radiation from passing through	Penetrating power
Alpha		
Beta		
Gamma		

**Discussion**

- 1 Identify the most penetrating radiation and justify your choice.
- 2 Propose which type of radiation you think could cause the most damage if it gets into our bodies.
- 3 Research the effects that radiation can have on the body to explain why it is so damaging.
- 4 Discuss how the experiment could be modified to show the effectiveness of the radiation over different ranges and thickness of absorbing materials.

## Section 14.4 questions



## Remembering

- 1 **Define** the term 'isotope' in your own words.
- 2 **Name** three important uses of radioisotopes.
- 3 **Name** the particle that is released during alpha decay.

## Understanding

- 4 **Compare** and **contrast** these isotopes of sodium: Na-23 and Na-24.
- 5 **Outline** the relationship between the mass of an isotope and its stability.
- 6 **Summarise** what happens to the nucleus of an element during alpha decay.
- 7 **Complete** the equation to show the particle released during alpha decay.



- 8 **Copy** and **complete** the following table to summarise the three main isotopes of neon.

Isotope	Mass number	Number of protons	Number of neutrons	Number of electrons
${}_{10}^{20}\text{Ne}$				
${}_{10}^{21}\text{Ne}$				
${}_{10}^{22}\text{Ne}$				

## Applying

- 9 **Construct** an equation to show the alpha decay of uranium-235 to thorium-231.
- 10 **Deduce** the relationship between the mass of an element and how stable it is.
- 11 **Explain** why radioactive sources in schools must be stored in lead-lined boxes.

## Analysing

- 12 **List** the main differences between stable isotopes and radioisotopes.
- 13 Ionising radiation is used in smoke detectors. **Determine** the type of radiation you would choose for this and **explain** why.
- 14 **Analyse** the benefits and problems of the use of nuclear energy in medicine and in industry.

## Evaluating

- 15 An element undergoes radioactive decay; its atomic number and mass number are not affected. **Deduce** the type of decay. Give a reason for your answer.
- 16 During the radioactive decay of an isotope a high-energy electron is released. **Deduce** the type of decay. Give a reason for your answer.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>14.1 I can describe the structure of an atom</b> e.g. Describe the subatomic particles within an atom	
<b>14.1 I can determine the subatomic particles found in an atom using information from the periodic table.</b> e.g. Determine how many protons, electrons and neutrons an atom has if it has an atomic number of 6 and an atomic mass of 12.	
<b>14.2 I can describe how an ion is formed.</b> e.g. Describe how an atom of magnesium can become an ion of $\text{Mg}^{2+}$ .	
<b>14.3 I can discuss how the model of the atomic structure was developed.</b> e.g. Describe what Ernest Rutherford discovered from his gold foil experiment.	
<b>14.4 I can describe how isotopes of an element differ from each other.</b> e.g. Distinguish between the three isotopes of hydrogen.	
<b>14.4 I can discuss the different forms of radioactive decay.</b> e.g. Describe alpha decay.	



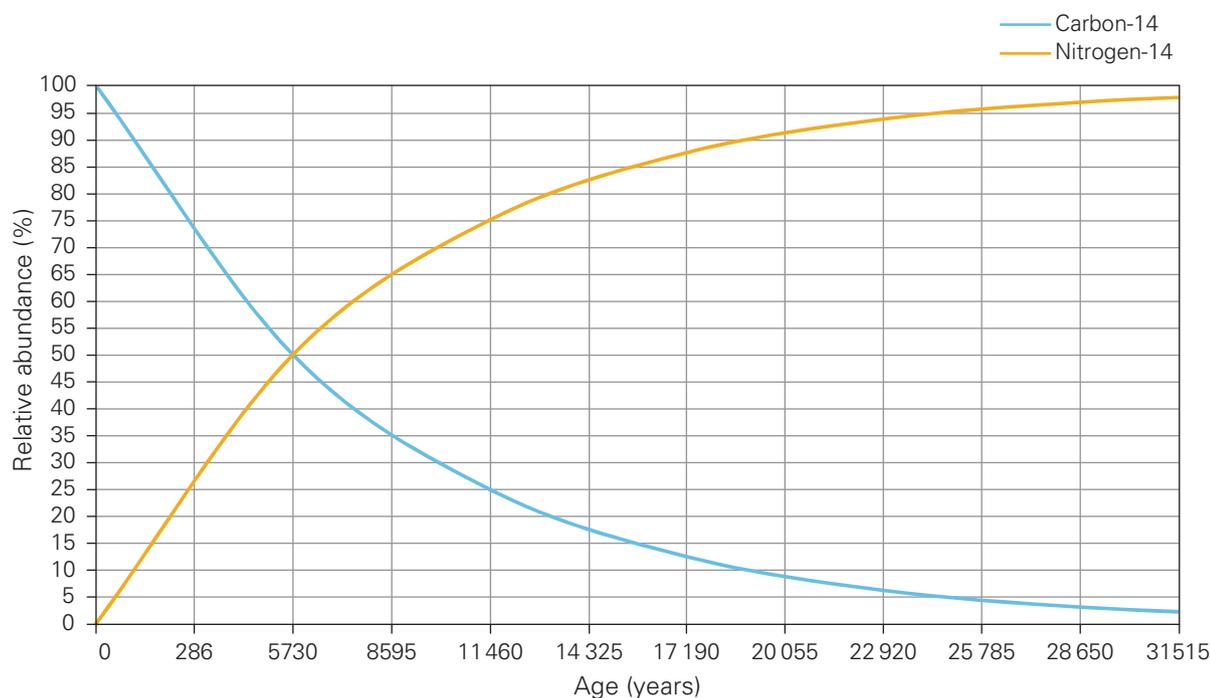
## Reflections

- 1 What **connections** come to mind when you think about atoms and your everyday life?
- 2 What new concepts have **extended** your thinking about atoms and variants of atoms (ions, isotopes)?
- 3 What information did you find **challenging** or confusing?



### Data questions

The isotope carbon-14 decays via beta radiation to form nitrogen-14 atoms, following the decay curves presented in Figure 14.43. Scientists are able to predict the age of a fossil using analytical techniques that measure the relative abundances of carbon-14 and nitrogen-14 in the fossil, and comparing these with the decay curves.



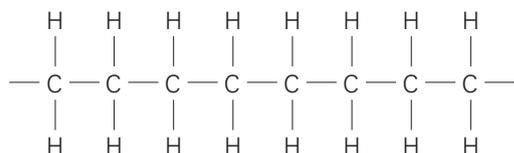
**Figure 14.43** Relative abundance of carbon-14 (blue line) and nitrogen-14 (orange line) in an initial sample of carbon-14 over 31 515 years

- 1 A scientist has measured the relative abundance of carbon-14 in a sample of ancient kangaroo fossil at 25% compared to nitrogen-14. **Determine** the age of the fossil.
- 2 The relative abundance of nitrogen-14 in a kangaroo fossil sample is 40%. **Calculate** the relative abundance of carbon-14.
- 3 **Identify** the relative abundance of nitrogen-14 in a fossil dated at 8595 years old.
- 4 **Contrast** the two curves and comment on the relative rate of decay of carbon-14 and growth of nitrogen-14.
- 5 **Deduce** the half-life (time taken for half of the carbon-14 to decay to nitrogen-14) of carbon-14.
- 6 After 28 650 years, the relative abundance of carbon-14 is 3.125%. **Predict** the relative abundance of nitrogen-14 after another 5730 years (34 380 years total).
- 7 **Predict** and **explain** whether it would be possible to find a fossil with a relative abundance of carbon-14 of 0%.
- 8 The use of radiocarbon dating is most efficient with fossils less than 20 000 years old. **Compare** the carbon-14 decay curve before and after 20 000 years and elaborate on this comment.

# STEM activity: Designing and creating using bioplastics

## Background information

Molecules are atoms that are bonded together. Chemically, plastic consists of long chains of molecules called polymers. This is why the names of many plastics start with 'poly'. The polymers are made up of carbon and hydrogen, and sometimes oxygen, nitrogen, sulfur, phosphorus, fluorine or silicon.



**Figure 14.44** Polyethylene is the simplest plastic, consisting of a long chain of carbon atoms and hydrogen atoms.

**bioplastic**  
a type of plastic made from renewable resources like plants

**Bioplastics** are a type of plastic made from renewable resources like

plants. They can easily be made at home with readily available ingredients. While they cannot solve the plastic problem alone, they can reduce carbon dioxide emissions, and some have the potential to biodegrade more easily than traditional plastics.

**Design brief:** Design and create a product using bioplastics.

## Activity instructions

In groups of two or three, your task is to think of a product that is made of plastic and find a way of making it out of bioplastic.

## Suggested materials

- corn starch
- vinegar
- glycerine
- water
- food dye (optional)
- saucepan
- wooden spoon

### Be careful – Safety glasses

Extreme care must be taken when working around the hotplate and handling the hot mixture. Ensure the hotplate is cool before moving it.

- hotplate
- non-stick/baking paper/aluminium foil and tray
- cookie cutters or moulds to shape the plastic
- safety glasses

## Research and feasibility

- 1 Discuss different plastic products you use in your everyday life, and list all the benefits to manufacturing this as a bioplastic.
- 2 List all the restrictions you have to consider in your design based on the materials and space you have available.
- 3 Research how you would use the suggested materials, or other materials safe for use in a school science laboratory, to manufacture the bioplastic.

## Design and sustainability

- 4 Decide on a plastic product that you could make using a bioplastic, justify your choice in your group by considering your constraints.
- 5 Design the method for manufacturing the bioplastic.
- 6 Design the mould you will use.

## Create

- 7 Create the mould you will use for your bioplastic product.
- 8 Follow your design method and construct your bioplastic product solution.

## Evaluate and modify

- 9 Describe any difficulties you encountered.
- 10 Suggest ways that the design of your product could be improved.
- 11 List the physical properties of your bioplastic and comment on how appropriate these properties were.
- 12 Test your product by using it for its intended purpose under different conditions.
- 13 Evaluate the effectiveness of your product.

# Chapter 15

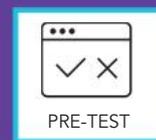
## The periodic table

### Inquiry questions

What is the periodic table?

How does the periodic table arrange elements?

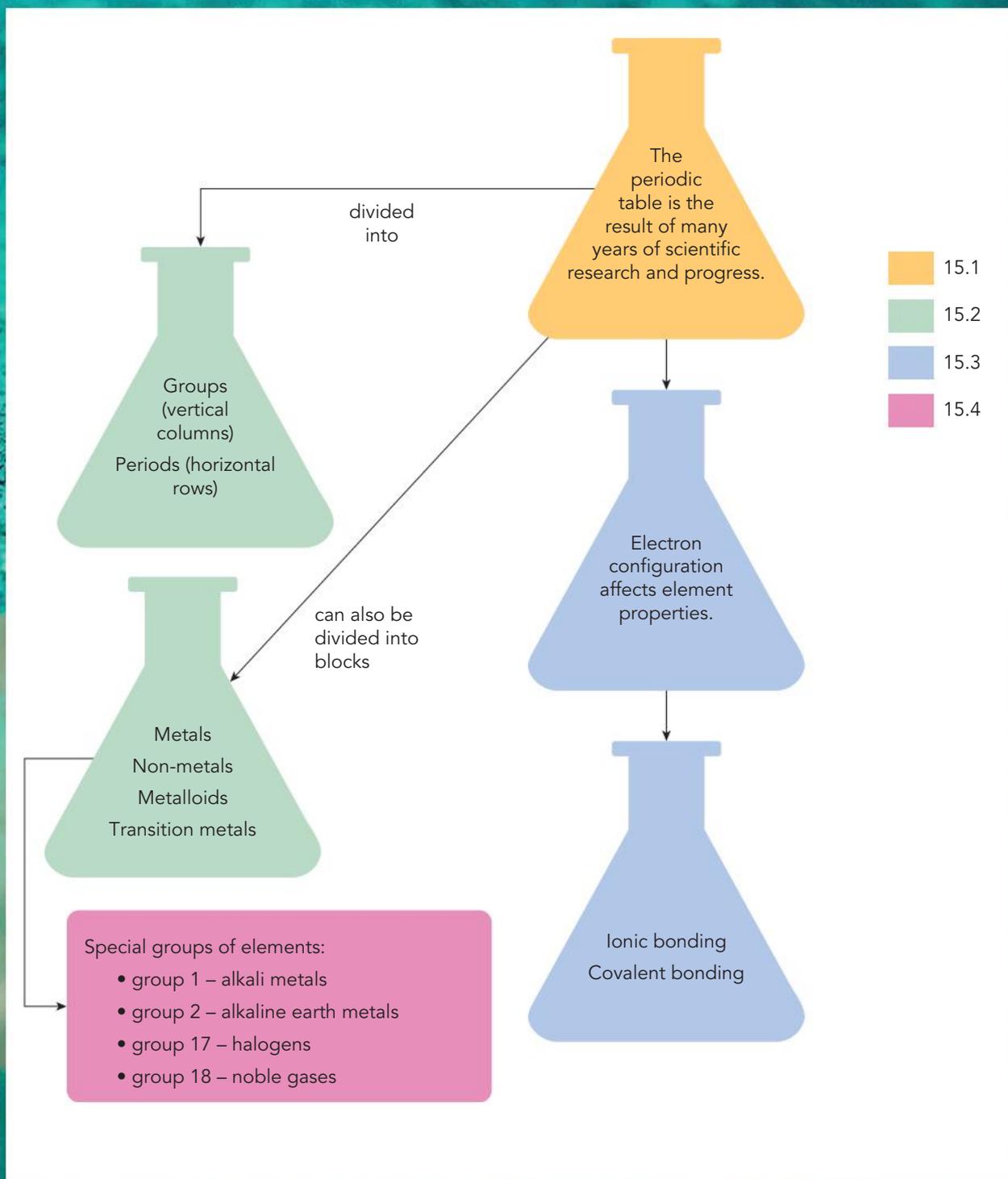
How do electrons affect the properties of elements?



### Chapter introduction

For hundreds of years, since the discovery of elements, scientists have been trying to classify them into groups based on how they behave. The outcome of this is the periodic table of elements. This chapter covers how elements are arranged, the information that can be determined from that arrangement and the properties of particular groups of elements in the periodic table. You will learn about Dmitri Mendeleev, the scientist who established the foundation for the modern-day periodic table.

# Chapter map



# 15.1 Development of the periodic table

## Learning goals

- 1 To describe the contribution of scientists to the arrangement of the elements
- 2 To outline how creativity and logical reasoning helped to develop the periodic table
- 3 To explain the significance of Mendeleev's contribution to the periodic table



Throughout history the question of how best to organise chemical **elements** has intrigued scientists. In this section, we will summarise the attempts of six scientists and see the progress made over time in understanding the nature of elements.

**element**  
substance made up of only one type of atom

## Timeline of the periodic table

1789



### Antoine Lavoisier

- In 1789, there were thought to be 33 elements (including light!). Lavoisier sorted these elements into gases, metals, non-metals and earths, constructing the first list of the known elements.
- His table of elements quickly became outdated as new elements were discovered.

1808



### John Dalton

- Dalton was responsible for developing early atomic theory and publishing a table of relative atomic weights.
- He allocated symbols to the 36 known elements.

ELEMENTS			
Hydrogen	1	Strontian	87
Azote	5	Barytes	68
Carbon	5	Iron	56
Oxygen	7	Zinc	56
Phosphorus	9	Copper	56
Sulphur	13	Lead	90
Magnesia	24	Silver	190
Lime	24	Gold	190
Soda	28	Platina	190
Potash	41	Mercury	167

Figure 15.1 Dalton's element symbols

1817



### Johann Wolfgang Döbereiner

- Döbereiner noticed that known elements could be arranged into groups of three by their similarities in appearance and reactions. He called these groups triads (for example, lithium, sodium, potassium). He found that when the elements in a triad were placed in order of their atomic weight, the middle element had a mass which was the average of the other two.

Alkali formers	
Li	7
Na	23
K	39

$$((39 + 7) \div 2 = 23)$$

Salt formers	
Cl	35.5
Br	80
I	127

$$((127 + 35.5) \div 2 = 81)$$

Figure 15.2 Two Döbereiner triads

1863

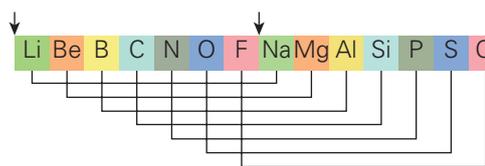
**Alexandre-Émile Béguyer de Chancourtois**

- De Chancourtois arranged known elements by increasing atomic weight.
- He wrapped his list around a cylinder which allowed sets of similar elements to line up.
- De Chancourtois' system showed repetition in the properties of elements at certain, regular intervals.

1864

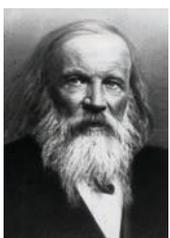
**John Newlands**

- Newlands listed the known elements in order of their atomic weights into horizontal rows, seven elements long.
- He stated that the eighth element would have similar properties to the first element in the series.



**Figure 15.3** Newland's law of octaves. Every eighth element in the row has similar properties. Track the lines and investigate what is similar about each element.

1869

**Dmitri Mendeleev**

- By 1869, there were 56 known elements, with a new element being discovered approximately once every year.
- Mendeleev organised the elements into a table with rows and columns, grouping elements by properties and in order of their atomic mass.
- Mendeleev left space in his table for elements he thought would be discovered.

Tabelle II.

Reihen	Gruppe I. R <sup>0</sup>	Gruppe II. R <sup>0</sup>	Gruppe III. R <sup>0</sup>	Gruppe IV. RR <sup>0</sup> R <sup>0</sup>	Gruppe V. RR <sup>0</sup> R <sup>0</sup>	Gruppe VI. RR <sup>0</sup> R <sup>0</sup>	Gruppe VII. RR <sup>0</sup> R <sup>0</sup>	Gruppe VIII. R <sup>0</sup>
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140				
9	(—)							
10			?Er=178	?La=180	Ta=182	W=184		
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208			
12				Th=231		U=240		

der chemischen Elemente.

**Figure 15.4** Mendeleev's early attempt at arranging the known elements into a table

## Quick check 15.1

1 Work out the relative atomic mass of element Y using Döbereiner's method.

Element	Relative atomic mass
X	24
Y	
Z	58

2 How was Mendeleev's attempt similar to those made by other scientists?

3 How did Mendeleev's attempt differ from attempts made by other scientists?

## Predicting future elements

Although Mendeleev's approach was similar to that of other scientists, his arrangement did one thing that the others had missed. Mendeleev realised that new elements were consistently being discovered, and concluded that he must allow for this when grouping the elements together. He therefore left gaps in his table for elements that had yet to be discovered. You can see in Figure 15.5 that he drew lines to show where he thought a discovery would be made. His prediction of new discoveries was remarkable; however, what makes many people consider him as the father of modern chemistry was that he also predicted the properties of these unknown elements – years before they were discovered.

To explain how Mendeleev made his predictions we will look at an example: he left a gap between silicon (Si) and tin (Sn). He named this element eka-silicon

and made the predictions shown in Table 15.1 based on the known properties of the elements above and below it in the periodic table.

14	Si 28.09 Silicon
	?
50	Sn 118.69 Tin

Figure 15.5 Mendeleev predicted that there would be an element between silicon and tin.

Element	Mass	Density (g/cm <sup>3</sup> )	Density of its chloride (g/cm <sup>3</sup> )	Boiling point of its chloride (°C)
Eka-silicon	72	5.5	1.9	100

Table 15.1 Mendeleev's predictions for the chemical properties of eka-silicon

How close was he? In 1886, the element germanium (Ge) was discovered which had the properties shown in Table 15.2.

Element	Mass	Density (g/cm <sup>3</sup> )	Density of its chloride (g/cm <sup>3</sup> )	Boiling point of its chloride (°C)
Germanium	73	5.3	1.88	86

Table 15.2 The chemical properties of germanium

Compare these properties of germanium with Mendeleev's predictions for eka-silicon. He was incredibly close! Luckily, the discovery of germanium occurred within Mendeleev's lifetime and confirmed his arrangement. Unbelievably, Mendeleev did not receive a Nobel Prize for his efforts, but he does have a chemical element named after him: element 101, mendelevium (Md).

100 <b>Fm</b> Fermium (257) [Rn]5f <sup>12</sup> 7s <sup>2</sup> 6.50	101 <b>Md</b> Mendelevium (258) [Rn]5f <sup>13</sup> 7s <sup>2</sup> 6.58	102 <b>No</b> Nobelium (259) [Rn]5f <sup>14</sup> 7s <sup>2</sup> 6.65
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Figure 15.6 Mendelevium has the atomic number 101.

### Explore! 15.1

#### Breaking his own rule

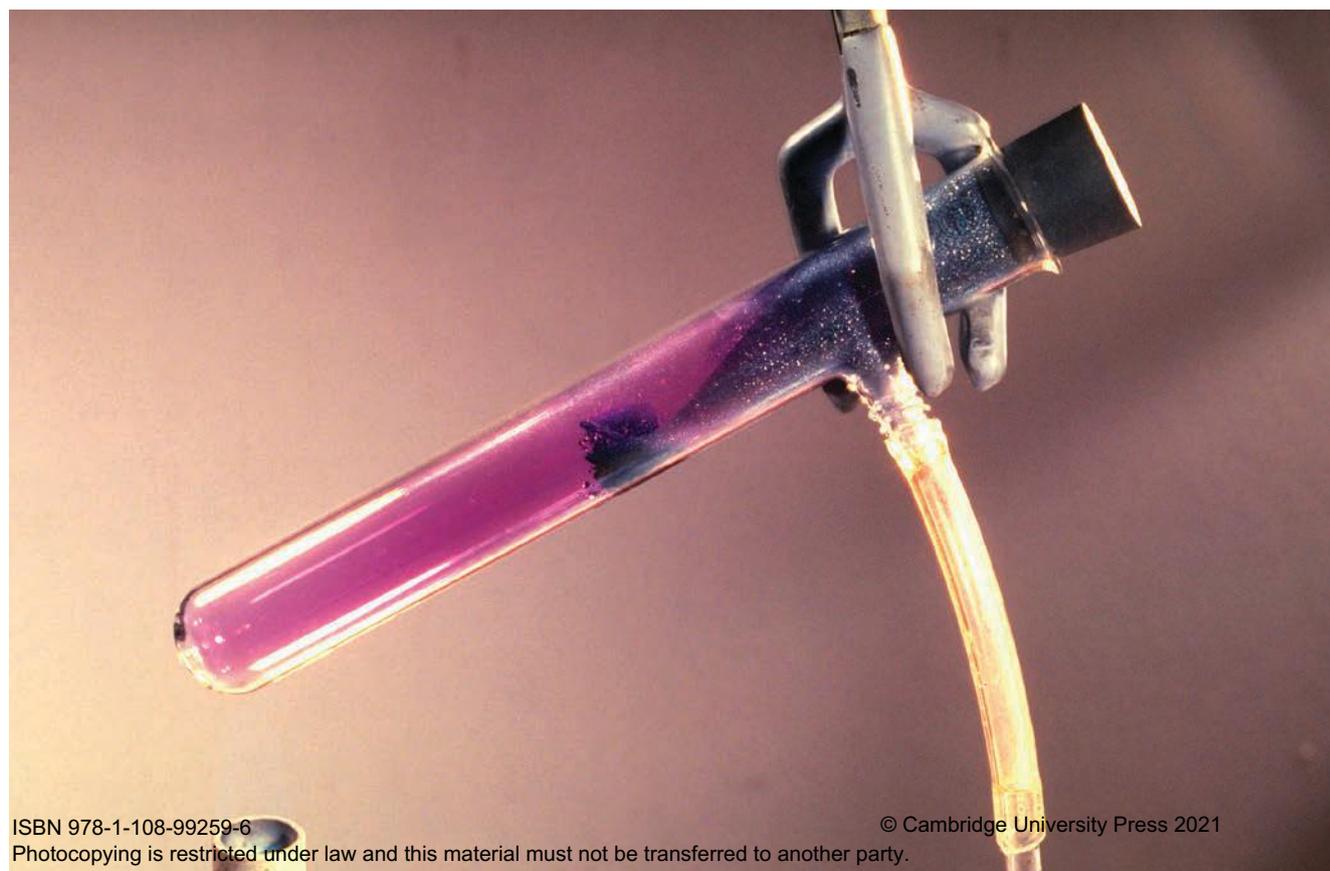
We have already discussed that Mendeleev arranged the elements in order of their relative atomic mass, which meant that elements with similar properties were placed in the same groups. However, this did not work in all cases. Take the elements tellurium (Te) and iodine (I) which, when arranged in order of mass, are in group 17 and group 16 respectively. You will need to consult secondary sources to gather information to help you answer these questions.

- 1 On the modern-day periodic table, which groups do iodine and tellurium belong to?
- 2 Mendeleev broke his rule of ordering by relative atomic mass for iodine and tellurium. Why do you think this was the case?
- 3 How is the periodic table arranged now to account for these exceptions?
- 4 Why didn't Mendeleev order his periodic table in the way it is arranged now?

53 <b>I</b> 126.90 Iodine	52 <b>Te</b> 127.60 Tellurium
------------------------------------	--

Figure 15.7 Iodine and tellurium when arranged by relative atomic mass

Figure 15.8 Pure iodine exists in both solid and gaseous forms



## Practical 15.1

### Predicting properties of elements

#### Aim:

To investigate the relationship between the position of an element in the periodic table and its density.

#### Useful formulas

$$\text{Density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

$$\text{Percentage difference} = \frac{(\text{actual value} - \text{predicted value})}{\text{actual value}} \times 100$$

#### Materials

- sample elements
  - carbon rod
  - zinc
  - tin
- 50 mL measuring cylinder
- graph paper
- balance
- ruler
- weigh boats (small container to hold sample elements)

#### Procedure

##### Part 1: Prepare the results table

- 1 Draw the table shown in the results section into your science journal.
- 2 Identify and label the independent variable and its independent variable groups in the table in terms of the position of each element on the periodic table. You will need to refer to the periodic table (or alternatively, an online version like ptable.com).
- 3 Identify and label the dependent variable in the table. (Hint: which property are you investigating?)

##### Part 2: Measure the mass of each sample element

- 1 Place a weigh boat onto the balance and zero the balance by pressing 'tare'.
- 2 Place the first sample element on the empty weigh boat and record the mass in the table.
- 3 Remove the sample element.
- 4 Repeat steps 1–3 with the other sample elements.

##### Part 3: Measure the volume of each sample element

- 1 Half fill a 50 mL measuring cylinder with water and record the initial volume in cm<sup>3</sup> (1 mL = 1 cm<sup>3</sup>).
- 2 Place the first sample element into the measuring cylinder gently and record the new volume in the table.
- 3 Remove the sample element by tipping the water out of the measuring cylinder.
- 4 Repeat steps 1–3 with the other sample elements.

#### Results

##### Calculate and graph the densities

- 1 Calculate the volume of each sample element in cm<sup>3</sup> and record it in the results table.
- 2 Calculate the density of each sample element using the density formula above and record it in the results table.
- 3 Draw a scatter plot to analyse the relationship between the period number of each metal and its density.

*continued...*

...continued

- 4 Add a line of best fit to the graph, if possible. Note the type of line that fits best to reflect the relationship between the two variables.

Independent variable		Dependent variable						
Element sample	Position in periodic table (group, period)	Mass (g)	Initial volume in measuring cylinder (cm <sup>3</sup> )	Final volume in measuring cylinder (cm <sup>3</sup> )	Volume of element (cm <sup>3</sup> )	Calculated density (g/cm <sup>3</sup> )	Actual density (g/cm <sup>3</sup> ) (secondary data source)	Percentage difference (%)
Carbon								
Zinc								
Tin								

### Discussion

- Describe the trend or pattern that is found when the line of best fit was applied to the graph. What type of relationship was found?
- Predict the density of germanium (row 4 of the periodic table) and lead (row 6) using your graph. Record in your science journal.
- Compare the actual densities for each element with its calculated densities.
- Compare the actual densities for carbon, zinc and tin to the densities calculated mathematically by calculating the percentage difference using the formula above.
- Was the calculated density data reliable enough to base predictions on? Justify your response with data.
- Research online to find the actual densities of germanium and lead (the 'properties' tab at ptable.com is a good resource to use). Record the actual densities for each in your science journal.
- Compare the actual densities for germanium and lead to the densities predicted mathematically by calculating the percentage difference using the formula above.
- Can reliable conclusions and predictions be drawn from the results? Justify your response with data.
- Can you identify possible limitations of this method? Justify your answer using data if possible.
- 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.

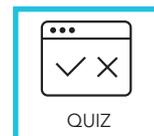
### Conclusion

What can you conclude from this experiment about the position of an element on the periodic table and its density?

## Section 15.1 questions

### Remembering

- Name** three scientists who attempted to organise elements.
- Name** the scientist who created the first version of the modern periodic table.
- Recall** the method most scientists used to arrange chemical elements.
- Identify** what modern-day arrangement of the elements Döbereiner's triads were similar to.
- Identify** the group of elements that is missing from Mendeleev's periodic table.



### Understanding

- Compare** and **contrast** Newlands' and Mendeleev's arrangements.
- Explain** why de Chancourtois' arrangement was superior to Döbereiner's.

- 8 **Summarise** how Mendeleev made his predictions surrounding the properties of elements which had yet to be discovered.

### Applying

- 9 Using Döbereiner's law of triads, **calculate** the mass of the middle element.

Element	Mass
A	12
B	
C	34

### Analysing

- 10 **Analyse** the reasons why Mendeleev's periodic table was accepted.

### Evaluating

- 11 **Assess** the reasons why there were multiple ways proposed throughout history to arrange chemical elements.

- 12 **Deduce** the properties of the middle element in the tables below.

a

	Lithium	Sodium	Potassium
Mass	7		39
Melting point (°C)	180		63

b

	Silicon	Germanium	Tin
Mass	28		119
Melting point (°C)	1414		232

c

	Chlorine	Bromine	Iodine
Mass	35.5		127
Melting point (°C)	-101		114

- 13 **Criticise** the earlier arrangements of the chemical elements.
- 14 **Determine** why the modern periodic table has remained relatively unchanged since it was reordered by atomic number instead of relative atomic mass.

# 15.2 Structure of the periodic table

## Learning goals

- 1 To describe the structure of the modern-day periodic table
- 2 To explain the organisation of the elements using their atomic number

The modern-day periodic table is a list of all the known elements in order of their atomic number. The atomic number is the number of protons in an element. This makes hydrogen (H) the first element in the periodic table as it has one proton and therefore an atomic number



**Figure 15.9** Oganesson is currently the last element on the periodic table, with an atomic number of 118.

of 1. Oganesson (Og), a synthetic element discovered by Russian scientists in 2002 and officially named in 2016, is currently the last element, with an atomic number of 118.



## Explore! 15.2

### Naming the elements

Many elements on the periodic table have 'weird' symbols that do not match their name. There are also elements named after scientists.

For the following elements, research why they have that name or symbol:

- sodium (Na)
- iron (Fe)
- curium (Cm)
- mendeleevium (Md)
- rutherfordium (Rf)

**group**  
the vertical columns in the periodic table

## Groups of the periodic table

The periodic table is arranged into vertical columns called **groups**. There are 18 groups in total.

Groups → 1

18

Atomic number		Relative atomic mass		Symbol of element		Name of element	
1	H	1.008	Hydrogen	79	Au	197.0	Gold
3	Li	6.941	Lithium	10	Ne	20.18	Neon
4	Be	9.012	Beryllium	18	Ar	39.95	Argon
11	Na	22.99	Sodium	36	Kr	83.80	Krypton
12	Mg	24.31	Magnesium	54	Xe	131.3	Xenon
19	K	39.10	Potassium	86	Rn	222	Radon
20	Ca	40.08	Calcium	88-91	Lanthanoids		
21	Sc	44.96	Scandium	89-103	Actinoids		
22	Ti	47.87	Titanium	104	Rf		Rutherfordium
23	V	50.94	Vanadium	105	Db		Dubnium
24	Cr	52.00	Chromium	106	Sg		Seaborgium
25	Mn	54.94	Manganese	107	Bh		Bohrium
26	Fe	55.85	Iron	108	Hs		Hassium
27	Co	58.93	Cobalt	109	Mt		Meitnerium
28	Ni	58.69	Nickel	110	Ds		Darmstadtium
29	Cu	63.55	Copper	111	Rg		Roentgenium
30	Zn	65.38	Zinc	112	Cn		Copernicium
31	Ga	69.72	Gallium	113	Nh		Nihonium
32	Ge	72.63	Germanium	114	Fl		Flerovium
33	As	74.92	Arsenic	115	Mc		Moscovium
34	Se	78.97	Selenium	116	Lv		Livermorium
35	Br	79.90	Bromine	117	Ts		Tennessee
36	Kr	83.80	Krypton	118	Og		Oganesson
57	La	138.9	Lanthanum	65	Tb	158.9	Terbium
58	Ce	140.1	Cerium	66	Dy	162.5	Dysprosium
59	Pr	140.9	Praseodymium	67	Ho	164.9	Holmium
60	Nd	144.2	Neodymium	68	Er	167.3	Erbium
61	Pm		Promethium	69	Tm	168.9	Thulium
62	Sm	150.4	Samarium	70	Yb	173.1	Ytterbium
63	Eu	152.0	Europium	71	Lu	175.0	Lutetium
64	Gd	157.3	Gadolinium	89	Ac		Actinium
65	Tb	158.9	Terbium	90	Th		Thorium
66	Dy	162.5	Dysprosium	91	Pa		Protactinium
67	Ho	164.9	Holmium	92	U		Uranium
68	Er	167.3	Erbium	93	Np		Neptunium
69	Tm	168.9	Thulium	94	Pu		Plutonium
70	Yb	173.1	Ytterbium	95	Am		Americium
71	Lu	175.0	Lutetium	96	Cm		Curium
				97	Bk		Berkelium
				98	Cf		Californium
				99	Es		Einsteinium
				100	Fm		Fermium
				101	Md		Mendelevium
				102	No		Nobelium
				103	Lr		Lawrencium

**Figure 15.10** Groups are the vertical columns of the periodic table.



This arrangement into groups and periods causes elements to have a specific position on the periodic table. For example, carbon (C) is placed in group 14, period 2, and helium (He) is in group 18, period 1.

### Quick check 15.3

- Decide whether the following statements are true or false.
  - Periods are the horizontal rows in the periodic table.
  - Lithium is in period 1.
- State the position (group and period) of the following elements in the periodic table.
 

<ol style="list-style-type: none"> <li>Copper (Cu)</li> </ol>	<ol style="list-style-type: none"> <li>Neon (Ne)</li> </ol>
<ol style="list-style-type: none"> <li>Calcium (Ca)</li> </ol>	<ol style="list-style-type: none"> <li>Aluminium (Al)</li> </ol>

## Metals, non-metals and metalloids

The elements can be classified into three groups: metals, non-metals or metalloids (which share some properties of both metals and non-metals).

### Metals

Metals make up the majority of the elements in the periodic table. In fact, 91 of the 118 known elements are metals, and they sit on the left-hand side of the periodic table. Almost all the metals in the periodic table are solids;

the exception is mercury (Hg), which is a liquid at room temperature.

**transition metals**  
the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

### Transition metals

The **transition metals** are a large block of metals containing the elements from groups 3 to 12 in periods 4 to 7. They are generally hard and dense. Iron, silver, copper and gold are important transition metals.

## Advances in science 15.1

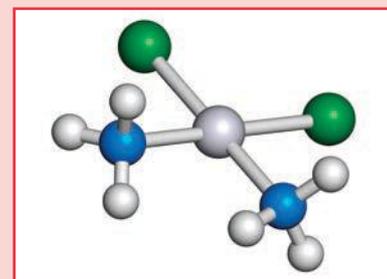
### Killer asteroid killing cancer?

How can a metal found in the asteroid that may have killed the dinosaurs help in our fight against cancer? Transition metals have been used in medical treatments for decades now. The transition metal platinum has been used for many years in the chemotherapy drug cisplatin. This has led to scientists researching the potential applications of other transition metals such as iridium for use in the medical industry.

Iridium is the world's second densest metal. It is rarely found on Earth, but has been brought to us from space via asteroids, including the giant asteroid whose impact is thought to have led to the extinction of the dinosaurs.

### Destroying cancer cells using iridium

Iridium can be used to kill cancer cells by filling them with a deadly version of oxygen. Oxygen in the form of  $O_2$  is harmless and, of course, beneficial to cells. But when  $O_2$  is converted into a single oxygen atom (O), it is poisonous and can actually kill cells. This can be done to treat cancer without harming healthy cells. The process works by giving patients a drug which contains the iridium. In 2017, trials on a model tumour found that the iridium drug had infused into every layer of the tumour. A visible laser shone on to the skin where the cancer is located activates the drug, causing it to produce the harmful form of oxygen which can kill cancer cells. This is a very promising breakthrough for cancer patients.



**Figure 15.13** Platinum is used in the anti-cancer drug cisplatin,  $Pt(NH_3)_2Cl_2$ .

## Quick check 15.4

- 1 The block of elements in the middle of the periodic table, containing groups 3 to 12 is called the \_\_\_\_\_.
- 2 Identify which of the following is a transition metal.  
sodium (Na), tungsten (W), europium (Eu), aluminium (Al)

## Non-metals

Non-metals are located on the right-hand side of the periodic table (except hydrogen). There are fewer non-metals than metals, but their properties are much more varied. They consist of one liquid – bromine (Br) – five solids and 11 gases.

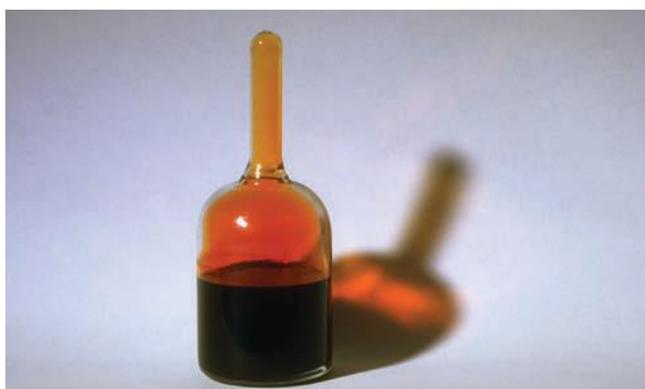


Figure 15.14 A bottle of liquid bromine, the only liquid non-metal

## Metalloids

The elements located between the metals and non-metals, are called **metalloids**. These elements tend to

**metalloids**

elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

look like metals, but behave more like non-metals. For example, tellurium is shiny and a fair conductor of electricity like a metal, but brittle like a non-metal.

Table 15.3 summarises the properties of metals and non-metals.

Metals	Non-metals
Shiny	Dull
High density	Low density
Good conductors of heat and electricity	Poor conductors of heat and electricity
Malleable	Brittle
High melting and boiling points	Low melting and boiling points
Ductile	

Table 15.3 Properties of metallic and non-metallic elements

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Figure 15.15 Arsenic, found in rock, is a metalloid.

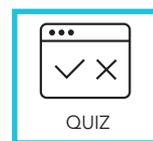
## Quick check 15.5

- 1 Recall the side of the periodic table where metals are located.
- 2 Select the correct word to complete this sentence:  
The name given to elements which behave like metals and non-metals is \_\_\_\_\_.

## Section 15.2 questions

**Remembering**

- 1 **Recall** how many groups there are on the periodic table.
- 2 **Name** an element in:
  - a period 3
  - b group 15
  - c the transition metals.
- 3 **Identify** which period hydrogen and helium are in.

**Understanding**

- 4 **Classify** the following elements as either metals or non-metals.

Element	Metal or non-metal
Oxygen (O)	
Boron (B)	
Aluminium (Al)	
Iodine (I)	
Nickel (Ni)	

**Applying**

- 5 **Identify** the element that is in:
  - a period 4, group 6
  - b period 2, group 13
  - c period 5, group 18
  - d period 7, group 1
  - e period 6, group 15.

**Analysing**

- 6 **Categorise** the following elements as transition metals, metals or metalloids.

Element	Category
Rubidium (Rb)	
Arsenic (As)	
Vanadium (V)	

**Evaluating**

- 7 **Explain** why elements close to the 'step ladder' separating metals from non-metals are classified as metalloids.
- 8 **Decide** what happens to the number of protons as you move to the right across a period.
- 9 **Determine** the relationship of an element's atomic number, number of electrons and its position in the periodic table.

# 15.3 Electron configurations of the elements

## Learning goals

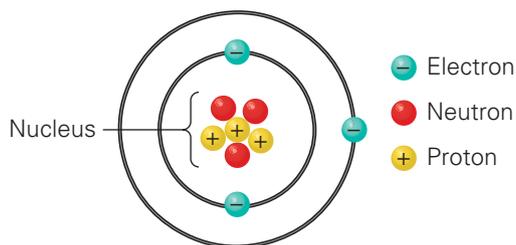
- 1 To recall the electronic arrangement of some of the elements
- 2 To explain how the electronic arrangement of elements relates to their properties
- 3 To predict the properties of elements using the periodic table



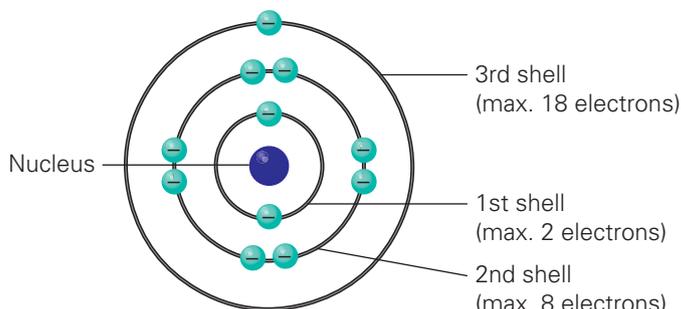
## Where are the electrons?

Previously, you may have learned about the atomic model, so you should be able to recall that electrons are located in shells, and that they 'orbit' the centre of the atom, known as the nucleus. You should also know that the nucleus houses the protons and neutrons of an element. You can work out how many electrons an element has by finding its atomic number or its position on the periodic table.

The way electrons arrange themselves around the nucleus of an atom is not random; they arrange themselves in a very organised manner that affects



**Figure 15.16** A Bohr atomic model for lithium is a simplified picture of an atom.



**Figure 15.17** Diagram of how electrons arrange themselves in shells around the nucleus of a sodium (Na) atom

the properties of elements. Electrons generally fill the **electron shell** closest to the nucleus first. This is because it is the lowest energy state for an atom, also known as the ground state. Electrons, being negatively charged, are strongly attracted to the positively charged nucleus, which is why the closest shell is filled first. Each shell can only hold up to a specific number of electrons.

Table 15.4 summarises how many electrons can be housed in each electron shell.

**electron shell**  
houses the electrons which orbit the nucleus of an atom

Shell	Maximum number of electrons it can house
1st (lowest energy level)	2
2nd	8
3rd	18
4th (higher energy level)	32

**Table 15.4** The number of electrons housed in each shell

## Quick check 15.6

- 1 How do electrons arrange themselves in an atom?
- 2 Complete the sentence by picking the correct words:  
The electron shell *closest to/furthest from* the nucleus is the *first/last* to be filled.
- 3 What is the maximum number of electrons which can be housed in the following?
 

a First shell	c Third shell
b Second shell	d Fourth shell

## Electron configurations of the elements

The **electron configuration** shows how the electrons for a particular element are arranged.

Magnesium (Mg) has an atomic number of 12, so it has 12 electrons. It has an electron configuration of 2,8,2. This shows that there are two electrons in the first shell, eight in the second and two in the third. Figure 15.18 shows the electron arrangement of a magnesium atom. As you can see from the diagram, shell 4 is empty, as magnesium does not have enough electrons for this shell to be occupied.

The sum of all the numbers in the electron configuration should add up to the total number of electrons in that atom.

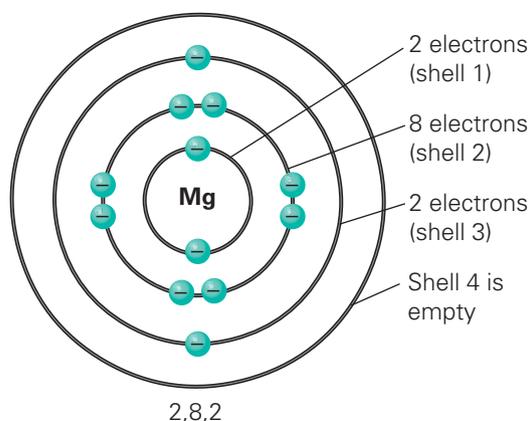


Figure 15.18 The electron configuration of magnesium

### Quick check 15.7

- 1 State the name given to atoms when they are at their lowest energy level.
- 2 State the number of electrons an element with an electron configuration of 2,8,3 has.
- 3 State the atomic number of an element which has 18 electrons.
- 4 State the electron configuration of oxygen (8 electrons).

## Electron configuration and element properties

The way atoms react is largely determined by the arrangement of their electrons. Protons and neutrons are

situated in the centre of the atom and therefore are not affected when particles bump into one another during chemical reactions. It is the electrons, and mainly the outermost electrons, which are the most affected.

The outermost electrons in an atom are called **valence electrons**. It is these electrons in the outer shell that are most affected when atoms bump into one another during chemical reactions.

**electron configuration**  
the arrangement of an atom's electrons in the shells around the nucleus

**valence electrons**  
the electrons in the outer shell of an element

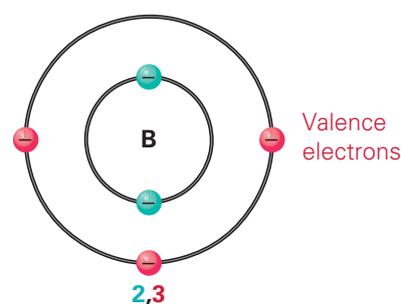
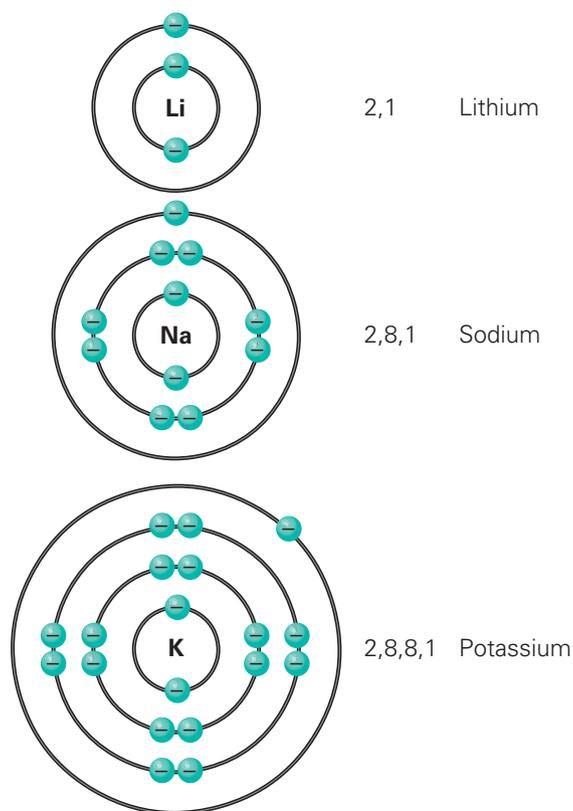


Figure 15.19 Boron (B) has an electron configuration of 2,3. It therefore has three valence electrons (red).

The biggest influence on an element's chemical and physical properties is the number of electrons in the outermost shell. This means that elements with the same number of valence electrons are grouped together in the periodic table. For example, all elements in group 1 have one valence electron. Their electron configurations all end in the number one. The last digit of group 17 tells us that elements in this group have seven valence electrons. This handy trick works for all the elements up to calcium (Ca).

We can also determine the period an element is in using its electron configuration. For example, if an electron configuration contains two numbers (as for lithium), then it is in period 2.



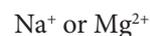
**Figure 15.20** These elements in group 1 have one valence electron.

### Quick check 15.8

- 1 Recall what the reactivity of a chemical element is determined by.
- 2 State the group that the element with the electron configuration 2,8 belongs to, and why.
- 3 State the period that the element with the electron configuration 2,8,4 belongs to, and why.

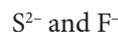
## Valency and bonding

The number of valence (outer shell) electrons an atom possesses determines how it will bond with other atoms. Metals, located on the left side of the periodic table, have fewer than four electrons in their outer shell. Metals tend to want to lose electrons and obtain a full, outer shell – this makes them stable. When they lose electrons, they form positively charged **ions** (known as **cations**) represented like this:



A single + sign indicates the atom has lost one electron, while a number before the + sign indicates how many electrons were lost.

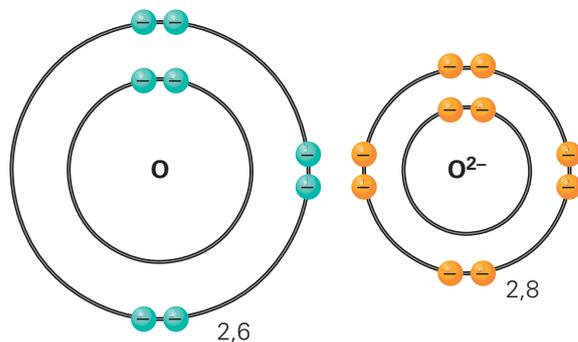
Non-metals, located on the right-hand side of the periodic table, have outer shells that are almost full. To achieve stability, they tend to gain electrons – forming negatively charged ions (known as **anions**) represented like this:



A single – sign indicates the atom has gained one electron, while a number before the – sign indicates how many electrons were gained.

Cations and anions are collectively known as ions; that is, a charged version of an atom.

An atom's willingness to lose or gain electrons is an indicator of its chemical reactivity.



**Figure 15.21** An oxygen atom has an electron configuration of 2,6. It tends to gain two electrons to achieve a stable outer shell, giving it an electron configuration of 2,8. It now has a net negative charge and is represented as  $\text{O}^{2-}$ .

**ion**  
a charged version of an atom, formed from the loss or gain of electrons

**cation**  
a positively charged ion formed from the loss of electrons

**anion**  
a negatively charged ion formed from the gain of electrons

## Explore! 15.3

## The Large Hadron Collider

The Large Hadron Collider (LHC) is used for much international scientific research and is based at CERN on the border of Switzerland and France. The LHC is a particle accelerator that can make particles, like protons and ions, collide at close to the speed of light!

Use your preferred search engine to find the Large Hadron Collider page on the CERN website. Explore the facts and figures for answers to the following questions.

- 1 How long is the ring in which particles are accelerated at the LHC?
- 2 What is a hadron?
- 3 What is one of the main goals of the LHC?

## Ionic bonding

When an electron is donated from one atom to another, positive and negative ions are formed (Figure 15.22). Positively charged cations are attracted to negatively

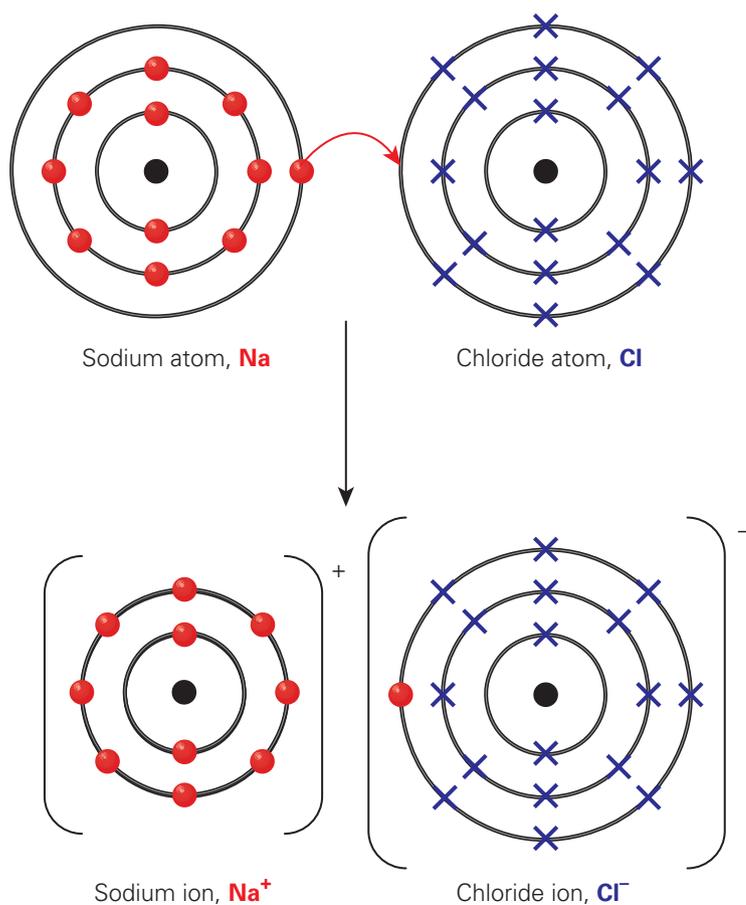


Figure 15.22 Ionic bonding in sodium chloride

charged anions, and this attraction is known as an **ionic bond**. Strong electrostatic forces bond the ions together into an ionic compound, which tend to take on a lattice structure. The structure of a sodium chloride lattice is shown in Figure 15.23. Because the bond is strong, ionic compounds tend to have high melting temperatures. For example, table salt (NaCl) has a melting point of 801°C.

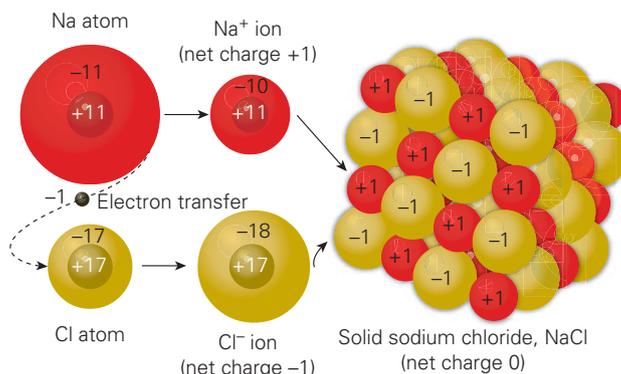


Figure 15.23 A sodium atom donates an electron to a chlorine atom (left). The sodium atom now forms a positively charged cation and the chlorine atom forms a negatively charged anion. These ions are attracted to each other and bond into an ionic compound (right). A crystal lattice configuration is a common way to represent an ionic compound.

## Covalent bonding

When two non-metals bond together, they both require some electrons to complete their outer shell but neither is prepared to lose theirs! Instead, these two atoms can share electrons, forming a molecule which is held together by a strong **covalent bond**.

An oxygen (O) atom has an electron configuration of 2,6. As we have seen previously, it requires two electrons to complete its outer shell.

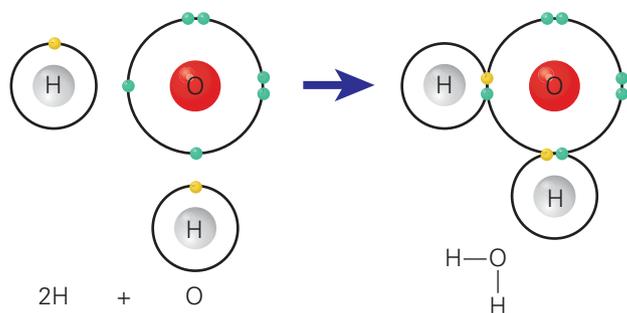
Instead of receiving electrons from a metal atom and forming an ionic bond, it can instead share electrons with another non-metal, such as hydrogen, and form a covalent bond. It will need to do this with two hydrogen atoms to have a stable outer shell. Refer to the molecule in Figure 15.24: each hydrogen atom has a full outer shell (two electrons) and the oxygen atom has a full outer shell (eight electrons). Each bond in a covalent molecule is actually a shared pair of electrons.

**ionic bond**

a strong bond between an anion and a cation, formed via electron donation

**covalent bond**

a strong bond, almost always between two non-metals which share electrons to form a molecule

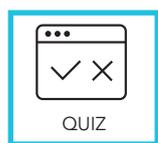


**Figure 15.24** Two hydrogen atoms and an oxygen atom covalently bond to form a water molecule. The lines between the atoms represent covalent bonds.

### Quick check 15.9

- Recall what valence electrons are.
- Define these terms in your own words:
  - ion
  - cation
  - anion.
- Explain why certain elements are likely to form cations while others tend to form anions.
- Does covalent bonding involve donation or sharing of electrons?

### Section 15.3 questions



#### Remembering

- Identify the missing information in the following table:

Electron shell	Maximum number of electrons housed
1st	
	32
3rd	
	8

- Recall why the shell closest to the nucleus filled with electrons first.
- For the following electronic configurations:
  - Name the element.
  - Identify the number of valence electrons.
  - Identify the period and group they are in.

a 2,8,1                      b 1                      c 2,7                      d 2,8,8
- Determine the electronic configurations for the following elements.
 

a Helium (He)                      b Beryllium (Be)                      c Phosphorous (P)                      d Potassium (K)

#### Understanding

- The electronic configuration of carbon is 2,4. List all the information you can determine from this.
- Describe and explain the order in which electrons fill shells around the nucleus.
- Compare the number of protons and electrons in an uncharged atom with those in an ion.

#### Applying

- Apply your knowledge of electron arrangement to explain what is significant about the electronic configurations of group 18 elements.
- Chlorine has the electronic configuration 2,8,7. Construct a diagram showing the arrangement of the electrons within a chlorine atom.

#### Analysing

- Distinguish between valence electrons and other electrons of an atom.
- Compare how an oxygen atom would participate in an ionic bond versus a covalent bond.

#### Evaluating

- Helium, a group 18 element, has the electronic configuration 2, meaning that it has two valence electrons. Explain why helium is not located next to hydrogen with the other group 2 elements, which also have two valence electrons.
- Explain why atoms in the same group have similar properties.

# 15.4 Special groups of elements

## Learning goals

- 1 To recall the properties of elements in specific groups
- 2 To compare the reactivities of groups in the periodic table
- 3 To relate elements in the same groups' electronic configuration to their common properties

When scientists were trying to organise the elements, their aim was to group together elements that had similar properties. In the modern-day periodic table, elements with similar properties are grouped together in columns, which are known as groups.

You have already read about the differing behaviours of metals and non-metals, so you may be wondering

why they are put in the same group as they seem to be so different. They are grouped this way because they all have the same number of valence electrons, so they usually bond with other substances in the same way. You can also see in Figure 15.25 that the elements in group 14 look similar.



Carbon (C)



Silicon (Si)



Germanium (Ge)



Tin (Sn)



Lead (Pb)

Figure 15.25 Group 14 elements

3	<b>Li</b> 6.941 Lithium
11	<b>Na</b> 22.99 Sodium
19	<b>K</b> 39.10 Potassium
37	<b>Rb</b> 85.47 Rubidium
55	<b>Cs</b> 132.9 Caesium
87	<b>Fr</b> Francium

Figure 15.26 The elements in group 1 are also known as the alkali metals.

## The alkali metals (group 1)

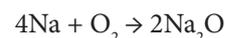
The **alkali metals** (group 1) make up the first group of the periodic table. We will focus on the first three elements of this group as these are the elements that you may have access to in the classroom; you will find out why later on in the section.

### Physical properties

Unlike most metals you will have come across, lithium (Li), sodium (Na) and potassium (K) are soft and can be cut with a knife. When they are cut open, they have a shiny appearance on the inside compared to their dull outer surface. This is because their outer surfaces readily react with oxygen in the air, forming dull metal oxides.

This reaction can be written as the following word and balanced chemical equations.

sodium + oxygen → sodium oxide



**alkali metals**  
group 1 metals that form an alkaline solution when they react with water

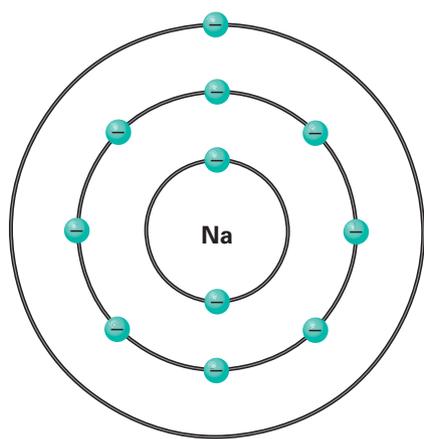


Figure 15.27 A piece of sodium metal which has been cut by a knife. It is shiny on the inside and dull on the outside.

When placed in water, lithium, sodium and potassium will float as they are less dense than water. Again, this is unlike most other metals you may have encountered.

### Reactivity

All group 1 metals are highly reactive due to their one valence electron. Elements are stable when they have a full outer shell of electrons, so group 1 metals are more than happy to react with other substances and give up their one valence electron. When they do this they all form ions with a +1 charge.



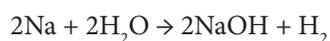
**Figure 15.28** The one valence electron makes group 1 elements highly reactive.

The reactivity of group 1 metals actually increases down the group. This is because it becomes easier to remove the outer electron as the atom gets bigger and the outer shell gets further away from the nucleus.

Alkali metals are most famous for their reaction with water and this is where they get their name. All group 1 metals react violently with water, producing hydrogen gas and an alkaline solution.

The word and balanced chemical equations show what happens when sodium reacts with water.

sodium + water  $\rightarrow$  sodium hydroxide + hydrogen

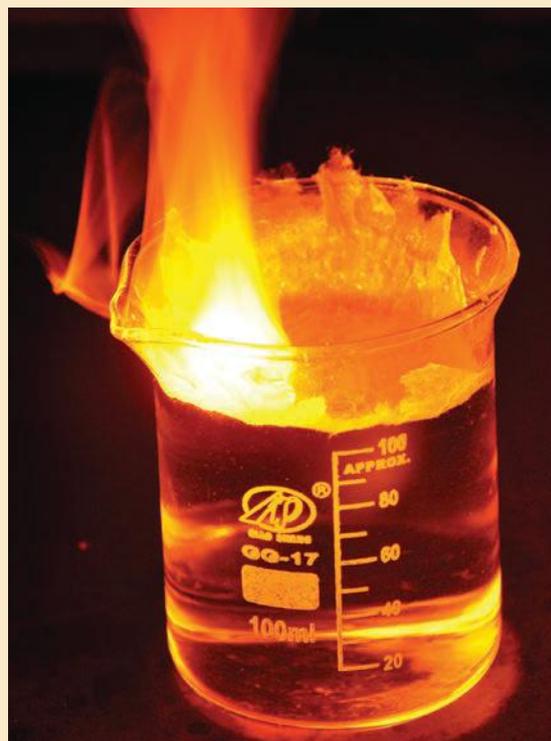


You can use these equations to predict what will happen when other alkali metals react with water.

### Did you know? 4.1

#### Do not touch group 1!

At school, all the group 1 metals will be stored in bottles of oil and teachers will never touch them with their hands. They are so reactive that even coming into contact with water vapour in the air and sweat on your hands, can cause them to react violently!



**Figure 15.29** What happens when sodium reacts with water? Here, the hydrogen gas produced has ignited.

### Quick check 15.10

- 1 Why are group 1 metals also known as alkali metals?
- 2 Why do alkali metals form +1 ions when they react with other substances?
- 3 Why are alkali metals shiny on the inside and dull on the outside?
- 4 True or false?
  - a Alkali metals are denser than water so they float.
  - b Alkali metals are hard.
- 5 Other than an alkali, what other product is formed when alkali metals react with water?
- 6 Which metal is the most reactive in group 1?

**Practical 15.2: Teacher demonstration****Investigating the reactivity of group 1 metals****Aim**

To determine the order of reactivity of two group 1 metals.

**Materials**

- lithium and sodium metals (Note: If any of these metals are unavailable, there are many online videos which show these reactions.)
- universal indicator
- large, thick-walled glass bowl
- scalpel
- white tile
- blotting paper
- tweezers
- safety screen
- disposable gloves

**Procedure**

- 1 Write a prediction in your science journal stating which you think will be the most reactive metal out of lithium and sodium.
- 2 Copy the results table below.
- 3 The teacher is to half fill the large glass bowl with water and add a few drops of universal indicator until the colour can be seen throughout the liquid.
- 4 Using the tweezers, the teacher is to take a piece of lithium from its bottle and place it on the white tile.
- 5 The teacher is to use the scalpel to cut off a small piece of the metal and observe the appearance of the metal on the inner and outer surfaces.
- 6 Making sure that all students are behind the safety screen, the teacher is to add the small piece of metal to the water. Record your observations.
- 7 Repeat for sodium.

**Results**

	Hard or soft	Appearance when cut	More or less dense than water	Observations during reaction
Lithium				
Sodium				

**Risk assessment**

- 1 Explain the decision to use tweezers rather than hands to pick up the metals.
- 2 Why was a safety screen necessary when conducting this experiment?

**Discussion**

- 1 Describe the purpose of the universal indicator.
- 2 Describe any patterns, trends or relationships in your results.
- 3 Describe how you determined the reactivity of each of the metals investigated.
- 4 How did you determine whether the metals were more or less dense than water?
- 5 Explain how the reactivity of the metals changes as you go down group 1.

**Conclusion**

- 1 Propose a conclusion regarding the varying levels of reactivity of the group 1 metals based on this experiment.
- 2 Support your statement by using the data you gathered.

4 <b>Be</b> 9.012 Beryllium
12 <b>Mg</b> 24.31 Magnesium
20 <b>Ca</b> 40.08 Calcium
38 <b>Sr</b> 87.62 Strontium
56 <b>Ba</b> 137.3 Barium
88 <b>Ra</b> Radium

## The alkaline earth metals (group 2)

### Physical properties

The naturally occurring alkaline earth metals tend to be shiny and silvery white, and they have low melting and boiling points. Magnesium and calcium are abundant in Earth's crust and are considered essential to all living organisms.

### Reactivity

All group 2 elements are reactive, but not as reactive as group 1 elements. This is because they have two valence electrons compared to one in group 1 elements. Group 2 elements therefore form ions

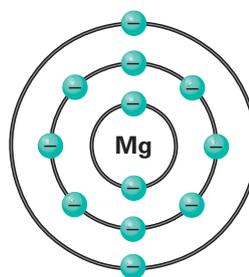


Figure 15.30 Group 2 elements have two valence electrons.

with a charge of +2 as they lose two electrons when they react.

Just like group 1 metals, alkaline earth metals also react with oxygen to form metal oxides and with group 17 elements to form metal salts. Table 15.5 shows the names and formulas of the products formed.

Element	Product formed when reacting with oxygen	Product formed from reacting with chlorine
Beryllium (Be)	Beryllium oxide BeO	Beryllium chloride BeCl <sub>2</sub>
Magnesium (Mg)	Magnesium oxide MgO	Magnesium chloride MgCl <sub>2</sub>
Calcium (Ca)	Calcium oxide CaO	Calcium chloride CaCl <sub>2</sub>

Table 15.5 The products formed when group 2 metals react with oxygen and chlorine

### Quick check 15.11

- List four of the alkaline earth metals.
- What charge do alkaline earth metals tend to form when they react?

### Practical 15.3: Teacher demonstration

#### Investigating the reactivity of group 2 metals

##### Aim

To investigate the relationship between the position of a group 2 element in the periodic table and its reactivity with acid.

##### Background

##### Prior understanding

Metals in group 2 of the periodic table are less reactive than those in group 1. This investigation will determine the order of reactivity within group 2.

Recommended: Use a spreadsheet to analyse the data for this experiment and calculate uncertainty.

#### Be careful

To reduce risk of skin burn from acid:

- ensure appropriate personal protective equipment is worn
- safety glasses are to be worn at all times
- wash hands after practical.

*continued...*

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### Useful formula

Change in volume (mL) = final volume (mL) – initial volume (mL)

$$\text{Rate of gas produced (mL/min)} = \frac{\text{mean change in volume (mL)}}{\text{mean reaction time (min)}}$$

### Materials

- 3 similarly sized samples of calcium (approximately 5 mm in diameter)
- 3 similarly sized samples of magnesium (approximately 5 mm in diameter)
- 30 mL hydrochloric acid (1 M)
- 6 test tubes
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- test-tube holder
- rubber stopper with glass tubing inserted through to fit the test tube
- rubber stopper to fit the 100 mL measuring cylinder
- 4 mm plastic tubing (minimum 30 cm)
- 1 large bowl
- retort stand, bosshead and clamp
- stopwatch
- tweezers

### Planning

- 1 Develop a hypothesis by predicting how a change in the periodic position of the group 2 metal will affect its reactivity.
- 2 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
- 3 Complete a risk assessment for this investigation, describing how any risks will be controlled.

### Procedure

#### Part 1: Prepare the results table

Draw the table shown in the results section into your science journal.

#### Part 2: Measure the reactivity of the first metal sample

- 1 The teacher is to fill the large bowl with tap water.
- 2 Fill the 100 mL measuring cylinder with tap water.
- 3 Stopper the measuring cylinder using the rubber stopper (a complete seal will not be possible).
- 4 Invert the measuring cylinder into the large bowl and clamp it in place with the stopper below the water line, as shown in Figure 15.31.
- 5 Remove the stopper from the measuring cylinder.
- 6 Attach the plastic tubing to the glass tubing on the rubber stopper. Place beside the measuring cylinder for easy access later.
- 7 Measure 5 mL of 1 M hydrochloric acid and pour into a test tube.
- 8 Using tweezers, add a piece of the first metal sample into the acid in the test tube. Be careful not to splash the acid.
- 9 Attach the rubber stopper with the plastic tubing to the test tube and position the end of the plastic tubing underneath the measuring cylinder so the gas can be collected.
- 10 Measure the initial volume of the gas in the inverted measuring cylinder and record in your table. Start the stopwatch.
- 11 After five minutes, record the final volume of the gas in the inverted measuring cylinder in your table.
- 12 Remove the rubber stopper and tubing from the test tube. Store the test tube and contents in the test-tube holder.

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13 Repeat steps 7–12 with the other two samples of the first metal.

14 Remove the measuring cylinder and refill with tap water.

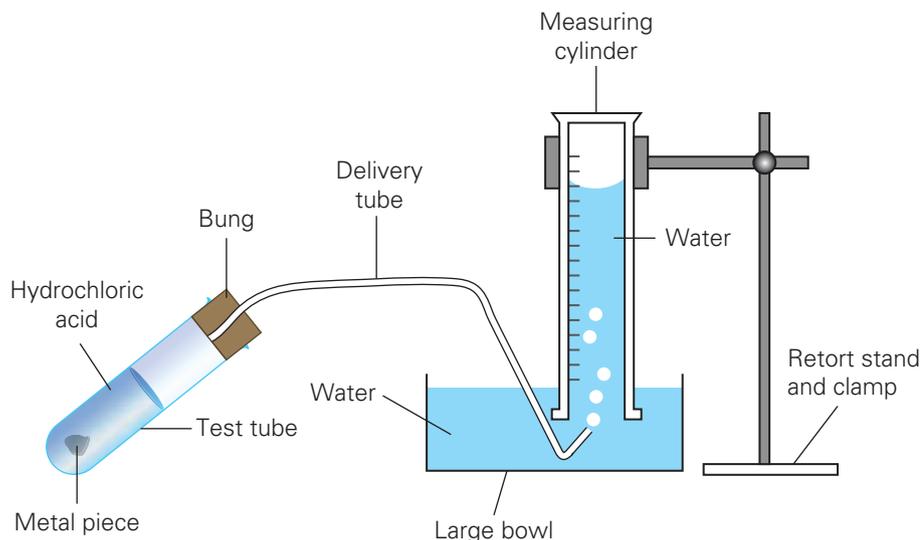


Figure 15.31 Diagram of experimental set-up

15 Stopper the measuring cylinder using the rubber stopper.

16 Invert the measuring cylinder into the large bowl and clamp it in place with the stopper below the water line.

17 Remove the stopper from the measuring cylinder.

### Part 3: Measure the reactivity of second metal sample

Repeat steps 7–12 with the other second metal samples.

#### Results

##### Calculate the mean reaction rate for each metal sample

- 1 Calculate the change in gas volume for each trial and record it in the results table.
- 2 Calculate the rate of gas production in mL/min for each metal and record it in the results table.
- 3 Draw a scatter plot to analyse the relationship between the period number of each metal and its reaction rate.
- 4 Calculate the uncertainty for each metal.
- 5 Optional: format the graph and insert a copy below the results table into your science journal.

	Measurements	Trial 1	Trial 2	Trial 3	Mean rate of gas production (mL/min)	Uncertainty of rate of gas production: $\frac{\text{max} - \text{min}}{2}$
<b>Period 2</b> <b>Magnesium</b>	Initial volume (mL)					
	Final volume (mL)					
	Change in volume (mL)					
	Rate of gas production (mL/min)					
<b>Period 3</b> <b>Calcium</b>	Initial volume (mL)					
	Final volume (mL)					
	Change in volume (mL)					
	Rate of gas production (mL/min)					

continued...

...continued

### Discussion

- 1 Compare the mean rate of gas production for the different elements.
- 2 Predict the trend in reactivity for group 2 elements that have been positioned lower on the periodic table.
- 3 Draw a conclusion as to how increasing the period position of different elements might affect the rate of gas production in reactions with acids.
- 4 Compare the uncertainties for each element. Which were the best results? Justify your answer with data.
- 5 Critique your management of the controlled variables. Were they managed properly to ensure they did not change and affect the measurements?
- 6 Could these results be used to predict reactivity trends in other groups on the periodic table? Explain your reasoning.
- 7 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

### Conclusion

- 1 Propose a valid conclusion that can be drawn from these results.
- 2 Justify this conclusion using data from your results.
- 3 State whether or not your hypothesis is supported.

9	<b>F</b>	19.00	Fluorine
17	<b>Cl</b>	35.45	Chlorine
35	<b>Br</b>	79.90	Bromine
53	<b>I</b>	126.9	Iodine
85	<b>At</b>		Astatine
117	<b>Ts</b>		Tennesine

## The halogens (group 17)

Group 17 elements are also known as the **halogens**.

### Physical properties

At room temperature, fluorine and chlorine are gases, bromine is a liquid and iodine is a solid. The halogens are used as bleaching agents and can kill bacteria. This is why chlorine is added to the water in public pools!

### Reactivity

All group 17 elements have seven valence electrons. When they react with other substances, they gain an electron to make a full outer shell of eight electrons. This means that they form ions with a charge of  $-1$ .

As shown in Table 15.6, the reactivity of group 17 elements decreases as you move down the group. This is because as the size of the atom increases down the group, it is harder for it to gain an

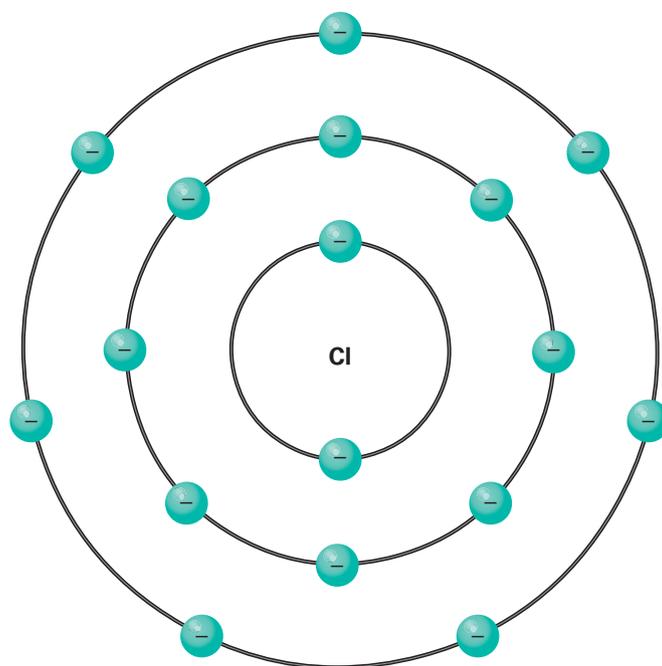


Figure 15.32 Group 17 elements have seven valence electrons.

electron. This is the opposite of group 1.

**halogens**  
group 17 elements (e.g. chlorine and iodine)

They all also form molecules that are made up of two atoms – so we call them diatomic, for example,  $\text{Br}_2$ .

Halogen	Formula	State at 25°C	Colour	Melting point (°C)	Boiling point (°C)	Reactivity
Fluorine	F <sub>2</sub>	Gas	Pale yellow	-220	-188	Reactivity increases up the group 
Chlorine	Cl <sub>2</sub>	Gas	Pale green	-101	-35	
Bromine	Br <sub>2</sub>	Liquid	Brown	-7.2	58.8	
Iodine	I <sub>2</sub>	Solid	Purple	114	184	

Table 15.6 Some properties of the halogens

## Quick check 15.12

- 1 Name three elements in group 17.
- 2 Give the charge of a group 17 ion.
- 3 State one physical or chemical trend that can be observed going down group 17.

## The noble gases (group 18)

**noble gases**  
group 18 elements (e.g. neon and krypton)

Group 18 elements are also known as the **noble gases**.

## Physical properties

The noble gases tend to be colourless, odourless and non-flammable. Their applications include neon signs, medical imaging and radiotherapy to treat cancer.

## Reactivity

Unlike the other groups we have discussed, noble gases are extremely unreactive. They were once called inert gases because it was thought that they did not react with anything.



Figure 15.33 Neon is used in fluorescent signs.

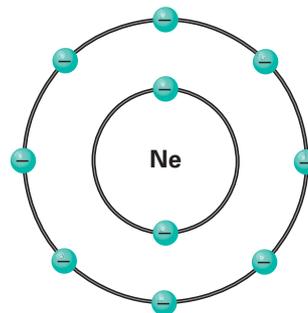


Figure 15.34 Group 18 elements all have eight valence electrons and therefore a full outer shell.

## Quick check 15.13

- 1 Name three elements in group 18.
- 2 Why don't noble gases form ions?

## Explore! 15.4

**The Hindenburg disaster**

The Hindenburg airship could travel from Europe to North and South America in half the time of the fastest ocean liner. The airship was filled with hydrogen rather than helium due to export restrictions that the USA imposed against Nazi Germany.

In 1937, while trying to land in New Jersey, USA, the Hindenburg caught fire and burst into flames. It was completely destroyed. Out of 97 people on board, 35 were killed.

- 1 What was the problem with using hydrogen gas in the Hindenburg airship?
- 2 Why would helium have been a safer alternative?
- 3 Why is helium able to be used to fill airships?
- 4 Helium is heavier than hydrogen and therefore provides less lift. Why is this a problem for airship designers?



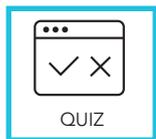
**Figure 15.35** The Hindenburg airship was a revolution in travel.



**Figure 15.36** The Hindenburg bursting into flames on arrival in New Jersey, USA



## Section 15.4 questions



## Remembering

- 1 **Identify** the group number of the following:
 

<ol style="list-style-type: none"> <li>a alkaline earth metals</li> <li>b halogens</li> </ol>	<ol style="list-style-type: none"> <li>c noble gases</li> <li>d alkali metals.</li> </ol>
---	---
- 2 **Recall** what happens to the reactivity as you move down group 1.
- 3 **State** whether these statements are true or false.
  - a All halogens are gases.
  - b All alkali metals form hydrogen when they react with water.
  - c Noble gases do not form ions.
  - d Alkaline earth metals form ions with a +2 charge.
  - e The general formula of a halogen molecule is  $X_2$ .
- 4 **State** how many valence electrons each of the following groups has:
  - a alkali metals
  - b alkaline earth metals
  - c halogens
  - d noble gases.
- 5 A new element is discovered. It is shown to form an ion with a charge of +2. **Identify** the group it should belong to.

## Understanding

- 6 **Explain** why group 2 elements are less reactive than group 1.
- 7 Helium does not have eight valence electrons. **Explain** why it is still classified as a noble gas.
- 8 **Explain** why alkali metals are stored in oil or even sealed in inert gases.

## Applying

- 9 **Predict** the products of the following reactions:
  - a potassium and water
  - b magnesium and chlorine
  - c calcium and oxygen
  - d sodium and fluorine.

## Analysing

- 10 **Analyse** the properties of the halogens in Table 15.6. Astatine (At) is also a group 17 element placed below iodine. Use Table 15.6 to **predict** some properties of astatine.
- 11 **Classify** the following elements as alkali metals, alkaline earth metals, halogens or noble gases:
  - a magnesium
  - b argon
  - c sodium
  - d potassium
  - e iodine.
- 12 **Compare** and **contrast** the properties and reactions of group 1 and 2 elements.

## Evaluating

- 13 **Deduce** why group 18 was not present in Mendeleev's periodic table.
- 14 Would you expect strontium to be, chemically, more similar to calcium or rubidium? **Justify** your choice.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>15.1 I can outline the development of the periodic table.</b> e.g. Discuss some of the changes that occurred in the arrangement of the periodic table over the years.	
<b>15.2 I can describe the structure of the periodic table in terms of groups and periods.</b> e.g. Determine which group and period of the periodic table that carbon is in.	
<b>15.2, 15.4 I can recall some of the properties of different elements and groups in the periodic table.</b> e.g. Contrast the properties of group 1 and group 17 elements.	
<b>15.3 I can determine the electron configuration of different elements.</b> e.g. Magnesium has an atomic number of 12. Determine its electron configuration.	
<b>15.3 I am able to describe how electron configuration is linked to an element.</b> e.g. Explain how the number of valence electrons affect an element's reactivity.	
<b>15.3 I can describe the different types of bonding that elements can undergo.</b> e.g. Contrast ionic and covalent bonding.	
<b>15.4 I can describe the properties of special groups of elements.</b> e.g. Contrast halogens and noble gases.	



## Reflections

- 1 What **connections** come to mind when you think about the periodic table of elements in your everyday life?
- 2 What new concepts have **extended** your thinking about elements and the periodic table?
- 3 What information did you find **challenging** or confusing?

## Data questions

Magnesium and calcium are group 2 alkaline earth metals and can be taken as general health supplements to aid regulation of bodily functions including muscle function and bone development. A scientist is testing the claim from eight different supplement brands that their magnesium and calcium tablets contain 200 mg of each element. Each supplement was analysed and the amount of magnesium or calcium present in each tablet is presented in Figure 15.37.

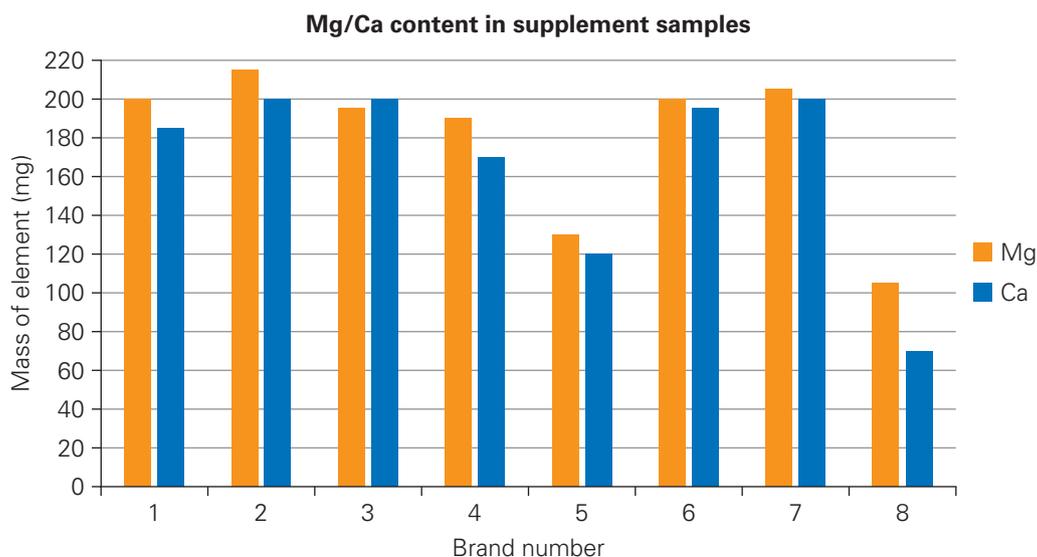


Figure 15.37 Mass of magnesium or calcium found in eight commercial supplement samples

- Identify** all samples that had less than the advertised 200 mg of magnesium.
- Brand 3 advertised that the magnesium content was  $200 \text{ mg} \pm 10\%$ . **Calculate** the minimum amount of magnesium that could be present in this advertised sample.
- Use your answer to Question 2 to **determine** whether the analysed brand 3 has a magnesium content within the advertised range.
- Brand 5 is being investigated for false advertising with its claim that 'we have a more accurate calcium content than (brand 1)'. Explore this statement and **draw conclusions** about its accuracy.
- A spokesperson for Brand 6 has stated that 'the calcium content is more difficult to maintain as it is a more reactive metal than magnesium'. **Contrast** the magnesium and calcium content in brand 6. Does this explanation match the data presented in Figure 15.37?
- Identify** the general trend between the mass of magnesium and the mass of calcium in a brand's supplements.
- The 200 mg magnesium supplements are deemed to be falsely advertised if the content is found to be below 180 mg. **Compare** the data for the eight samples. Which of the brands have been falsely advertised?
- A magnesium content of over 220 mg would also be considered misleading advertising. Use the data to **justify** that no brand is providing misleading information in this regard.
- Brand 7 has released a new series of magnesium and calcium supplements containing 250 mg of magnesium or calcium. Use your response to Question 5 to **predict** whether the samples of these products would contain more magnesium or calcium.

# STEM activity: Creating composite materials

## Background information

Materials engineers develop and test new materials. 'Composite materials' are made by combining two or more materials, usually those with different properties. The materials do not blend with one another.



**Figure 15.38** Mud bricks are a composite of mud and straw. Mud is strong if you compress it, but breaks when you bend it. Straw is strong if you pull on it, but is easily crumpled. Mud bricks combine the two materials to create better building blocks that hold shape when squeezed or bent.

**Design brief:** Create a composite material for the purpose of building a specific product.

## Suggested materials

- web browser
- scissors
- ruler
- coins
- paper towels
- tape
- PVA glue
- ice block sticks
- paper
- cardboard
- elastic bands
- string or yarn
- other materials, where possible

## Research and feasibility

- 1 Research the two composite materials: glass fibre-reinforced concrete (GFRC) and steel-reinforced concrete. Copy and complete the table above and add other properties you believe are important.
  - a What are the differences and what are the benefits of one material over the other?
  - b How would the discovery of each material change the way we use concrete?

	Glass fibre-reinforced concrete (GFRC)	Steel-reinforced concrete
Strength		
Benefits compared to concrete		
Temperature variance		

- 2 As a group, decide on a purpose for creating a new material for manufacture. Research the important properties and features the new composite material will require.

## Design and sustainability

- 3 List the ratios of each component material used in the composite, and the method of manufacturing and testing your composite material.
- 4 Design the best possible method to create your new composite material.
- 5 Discuss the sustainability of your material, and its environmental impact. Your new material must have a positive environmental impact and be sustainable to manufacture.

## Create

- 6 Manufacture the composite material in the various ratios as set out in the design phase and allow it to set if required.
- 7 Test your material by applying forces to your material. Record the type of force.

## Evaluate and modify

- 8 Evaluate the original material capabilities compared to the new material. Discuss and explain the difference.
- 9 What are the maximum forces that could be applied to each ratio? Explain the effect of the ratios of the single materials when used as a composite material.
- 10 Suggest ways to improve the composite material. Should another material be added? Should the ratios of the component materials be altered?
- 11 Predict how the composite material might behave if it was constructed differently but with the same materials.

# Chapter 16

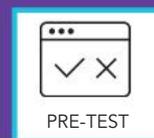
## Introduction to chemical reactions

### Inquiry questions

How do chemical equations show what is happening in a chemical reaction?

What happens to the energy in chemical reactions?

Why is life dependent on chemical reactions?

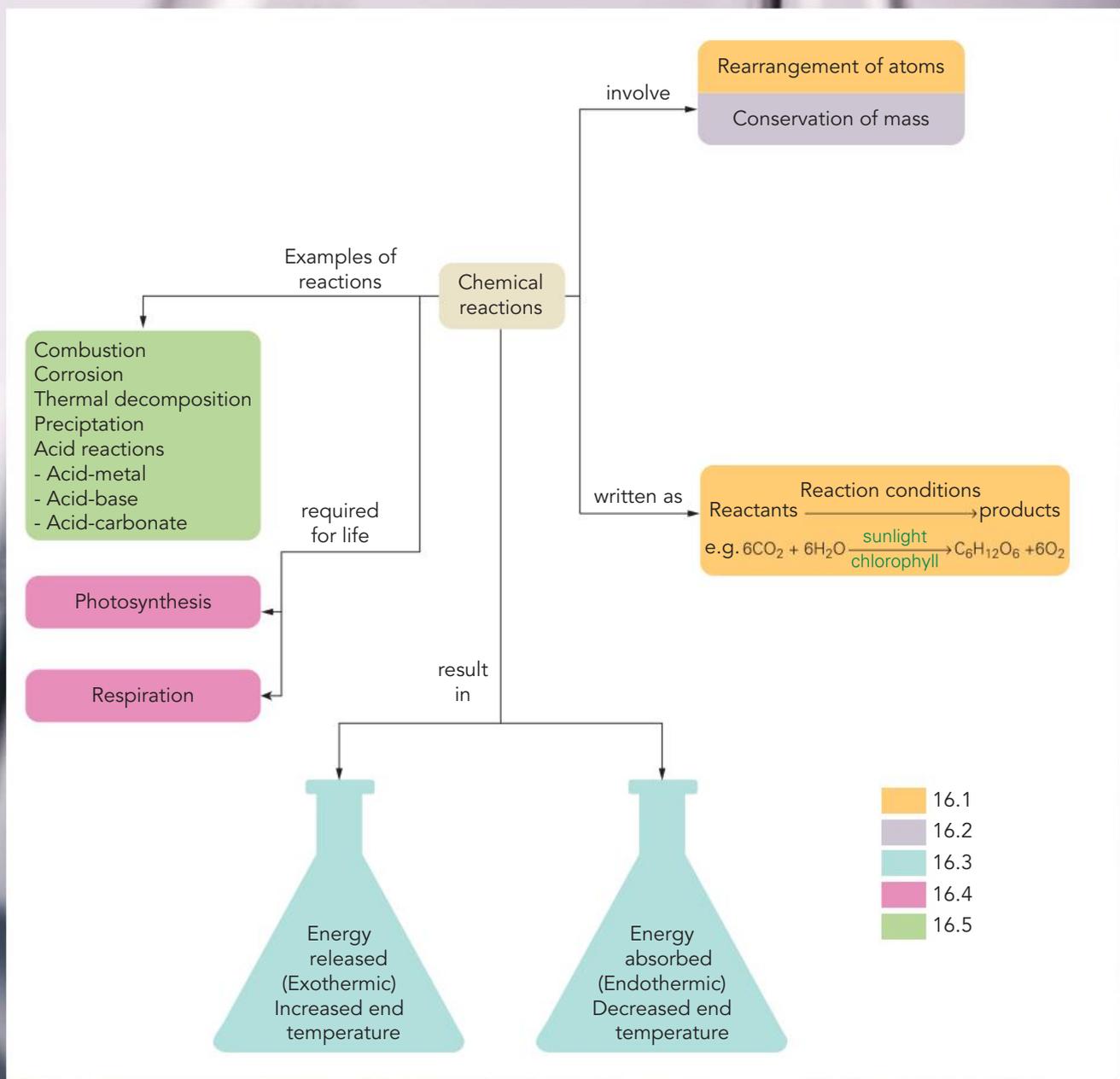


PRE-TEST

### Chapter introduction

This chapter is all about chemical reactions. You will learn what a chemical reaction is and the basics of how to write a chemical equation. You will investigate the law of conservation of mass and how this applies to chemical equations. You will also examine the role of energy in everyday chemical reactions. Finally, you will investigate and classify different types of chemical reactions.

# Chapter map



# 16.1 What is a chemical reaction?

## Learning goals

- 1 To deduce that in a chemical reaction, new substances are formed by rearranging atoms
- 2 To construct word equations
- 3 To identify and classify a range of compounds based on their characteristics and formulae



By now in your science lessons you will have carried out a number of experiments involving chemical reactions for different purposes. But did you know that almost everything around you has been created because of chemical reactions?



**Figure 16.1** All the ingredients in your sandwich, from bread to salt, were made by chemical reactions.

## Chemical reactions

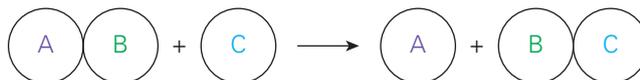
The simplest way to describe a chemical reaction is to say that starting substances are converted into new substances. But of course it is not as simple as that. During chemical reactions, the atoms in the starting substances are **rearranged** to make new substances. For this to happen, bonds holding the atoms together in the starting substances must be broken, and new bonds

**rearrange**  
move things into  
a different order

must form in different arrangements to make the new substances.

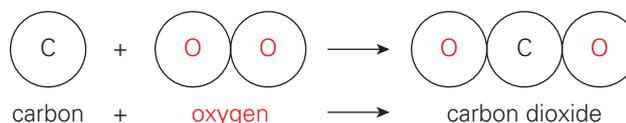
Figure 16.2 shows a chemical reaction in which compound AB is reacting with element C to make a new compound, BC, and element A. In this reaction, the bond between A and B in the compound AB is

broken and a new bond is formed between B and C to form compound BC – the atoms have been rearranged. The new substances are different from the starting substances; therefore, a chemical reaction has taken place. The arrow in a chemical reaction separates the starting substances that react together from the new substances produced by the reaction.



**Figure 16.2** Rearranging atoms in a chemical reaction

Let's look at a real-life example. Figure 16.3 shows the chemical reaction between carbon and oxygen. In this chemical reaction, the bonds between the two oxygen atoms are broken, the atoms are rearranged, and new bonds are formed between each oxygen atom and the carbon atom. The new substance formed has the name carbon dioxide.



**Figure 16.3** Formation of carbon dioxide is a chemical reaction.

The rearrangement of the atoms has a huge effect on the substances in this chemical reaction. Carbon is a solid at room temperature and oxygen is a gas. The compound formed in this reaction, carbon dioxide, is a gas at room temperature. The arrangement of the atoms within a compound determines the properties of a substance, which is why the properties of the compound formed in Figure 16.3 are so different from the starting substances.

### Quick check 16.1

- 1 Explain how new substances are formed during a chemical reaction.
- 2 Describe what is happening to the substances in the equation below.



### Advances in science 16.1

#### Living concrete that can repair itself

Concrete was first used in ancient times and is one of the world's most popular building materials. However, the problem with concrete is that over time it weakens, causing cracks to form. Water can enter these cracks, leading to the collapse of buildings or walls.

Henk Jonkers, of Delft University in the Netherlands, discovered a solution to this problem: concrete that contains bacteria and can repair itself. The bacteria selected for this process must be able to survive dormant for long periods of time without food or oxygen, and to withstand the alkaline conditions within the concrete.

*Bacillus pseudofirmus* and *Sporosarcina pasteurii* bacteria were chosen for the job, but these bacteria do not naturally produce the limestone needed to repair the concrete. Jonkers first used sugar to help the bacteria create limestone, but this made the concrete too weak. The solution was to use calcium lactate.

In 2009, Jonkers manufactured capsules made of biodegradable plastic containing calcium lactate and the bacteria. The capsules open when in contact with water; that is, when there is a crack in the concrete. The bacteria feed on the lactate, which causes a chemical reaction converting the calcium lactate into limestone, and the crack closes. Jonkers had made concrete that repairs itself!



Figure 16.4 The ageing and cracked concrete walls of Naples Island, California, are in danger of collapse, which could flood the homes located along the canals.



Figure 16.5 *Bacillus* bacteria under a microscope

## How is a chemical equation written?

### Reactants and products

In a chemical reaction, substances react with each other to form new substances. Until now, we have referred to the substances reacting together as starting substances. As these are the substances doing the reacting, they are called **reactants**. Reactants are

always written on the left-hand side of a chemical equation (written before the arrow). The new substances that are formed are called **products**. Products are always written on the right-hand side of an equation (written after the arrow).

**reactant**  
substance that is reacting in a chemical reaction

**product**  
substance formed in a chemical reaction

## Word equations

One way to represent a chemical reaction is with a word equation. **Word equations** are written with just the names of the reactants and products in the chemical equation. Below is the word equation for the reaction of two common chemicals you will have already used in your science lessons, an acid and an alkali. You should already be able to identify the reactants and products yourself.

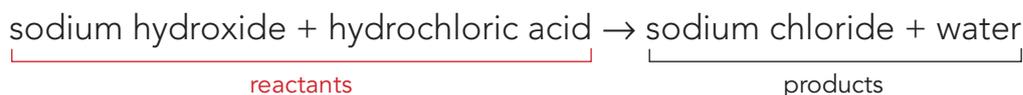
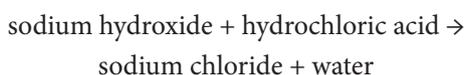


Figure 16.6 Chemical reaction between sodium hydroxide and hydrochloric acid

Notice that the reactants are on the left-hand side of the arrow and the products are on the right-hand side. It is very tempting, if you run out of paper, to write the same chemical reaction like the example below:



However, when possible, you should write the reactants on the left and the products on the right of the arrow.

If you run out of paper, set your word equation out like the one below, and you will not go wrong!

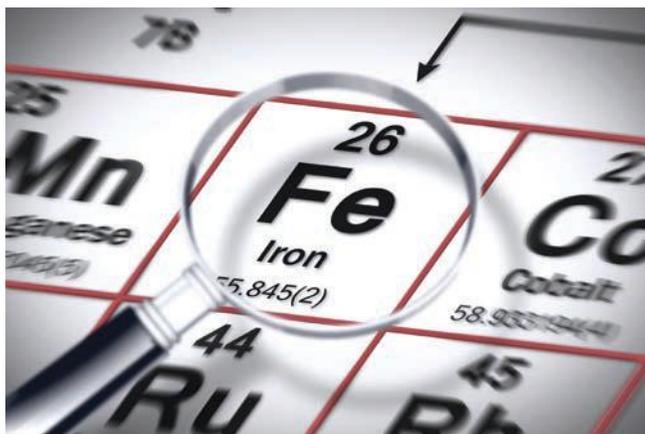
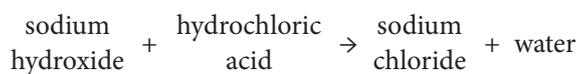


Figure 16.7 Iron is one of the elements with two letters in its chemical symbol. One is upper case (capital) the other is lower case. The symbol comes from the element's Latin name, ferrum.

## Chemical equations

One way of representing a chemical reaction is by using a **chemical formula** or equation. They are structured the same way as word equations but use chemical symbols instead of words to represent the substances in the reaction.

### word equation

a chemical equation written using just the words for reactants and products

### chemical formula

a chemical reaction written using the chemical symbols and formulas of the reactants and products involved

### monatomic

one atom, sometimes spelled 'monoatomic'

### diatomic

two atoms bonded together

You know from previous chapters that the symbols for chemical elements are listed on the periodic table. Remember that some elements have two letters in their chemical symbol. If this is the case, the first letter is upper case (capital) and the second letter is lower case. It is important to get into the habit of writing elemental symbols correctly.

All the metallic elements on the periodic table exist as individual atoms on their own and are described as being **monatomic**, meaning one atom. However, many non-metallic elements do not exist on their own. Instead, they tend to exist naturally as a gas or liquid with two atoms bonded together. These elements are known as **diatomic**, meaning two atoms. Table 16.1 lists the seven diatomic elements on the periodic table.

Element	Formula
Hydrogen	H <sub>2</sub>
Nitrogen	N <sub>2</sub>
Oxygen	O <sub>2</sub>
Fluorine	F <sub>2</sub>
Chlorine	Cl <sub>2</sub>
Bromine	Br <sub>2</sub>
Iodine	I <sub>2</sub>

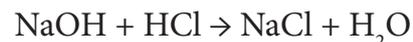
Table 16.1 The seven diatomic elements on the periodic table

The subscript (small and low) '2' shows that there are two atoms of these elements bonded together.

Working out the formulas of compounds, such as sodium carbonate, is more complicated than elements. So for now, you will need to look them up when formulating a symbol equation.

Let's take a look at the word equation in Figure 16.6 and see if we can turn it into a symbol equation. Using the

symbols for these compounds, you can create a chemical equation like the one below.



This chemical equation shows you what is happening when the compounds sodium hydroxide and hydrochloric acid react. The atoms are rearranged to form two new compounds – sodium chloride and water.

### Quick check 16.2

- 1 On which side of a chemical equation are the products written?
- 2 On which side of a chemical equation are the reactants written?
- 3 List three chemical elements which are diatomic.

### Explore! 16.1

#### The Haber process

The controversial German scientist Fritz Haber and his assistant Robert Le Rossignol developed the Haber process, which was later industrialised by Carl Bosch. Haber was awarded a Nobel Prize for his efforts in 1918. The Haber process enabled the production of ammonia ( $\text{NH}_3$ ) on a large scale by reacting nitrogen ( $\text{N}_2$ ) gas with hydrogen ( $\text{H}_2$ ) gas under optimum conditions. The largest ammonia plant in Australia is on the Burrup Peninsula in Western Australia; it produces around 330 000 tonnes each year. Ammonia is mainly used to make fertiliser.

- 1 Write a word equation for the production of ammonia in the Haber process.
- 2 The Haber process is actually a reversible reaction. How is this represented in the word and symbol equations?
- 3 Why is the large-scale production of ammonia so beneficial?



VIDEO  
The Haber  
process

### Practical 16.1

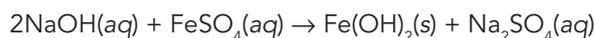
#### Comparing theoretical equations with experimental data

##### Aim

To consider the accuracy of experimental data compared with the theoretical outcome based on chemical equations.

##### Useful formulas

sodium hydroxide(aq) + iron(II) sulfate(aq) → iron(II) hydroxide(s) + sodium sulfate(aq)



calcium carbonate(s) + hydrochloric acid(aq) → calcium chloride(aq) + water(l) + carbon dioxide(g)



#### Be careful

Ensure appropriate personal protective equipment is used (safety glasses, disposable gloves, lab coat).

*continued...*

...continued

**Materials**

- 4 mL of 1 M iron(II) sulfate solution
- 5 mL of 1 M hydrochloric acid solution
- 8 mL of 1 M sodium hydroxide solution
- small piece of calcium carbonate
- 2 × 10 mL measuring cylinders
- 2 × 50 mL conical flasks
- test tube
- 2 rubber stoppers
- thread
- balance

**Planning**

Refer to the chemical reactions above, under 'Useful formulas'. For each reaction, predict whether the mass will change during the reaction. Justify your reasoning for this based on details from the theoretical equation.

**Procedure****Part 1: Prepare the results table**

- 1 Draw the table shown in the results section into your science journal.

**Part 2: Measure the mass of the reactants and products of the reaction between iron(II) sulfate and sodium hydroxide**

- 1 Record the level of uncertainty for the scales you are using in the table.
- 2 Using a measuring cylinder, measure 8 mL of sodium hydroxide solution.
- 3 Using a second measuring cylinder, measure 4 mL of iron(II) sulfate solution.
- 4 Place the conical flask on the scales and press 'tare' to zero.
- 5 Pour the contents of both measuring cylinders into the conical flask.
- 6 Record the mass of the combined mixture.
- 7 Observe the chemical reaction and record observations.
- 8 When it is finished, record the mass of the final products in the flask.

**Part 3: Measure the mass of the reactants and products of the reaction between calcium carbonate and hydrochloric acid**

- 1 Using a measuring cylinder, measure 8 mL of hydrochloric acid solution.
- 2 Place the conical flask on the scales and press 'tare' to zero.
- 3 Pour the hydrochloric acid into the conical flask. Add the calcium carbonate on the plate beside the flask.
- 4 Record the mass of the two reactants.
- 5 Add the calcium carbonate into the conical flask.
- 6 Observe the chemical reaction and record observations.
- 7 When it is finished, record the mass of the final products in the flask.

**Results**

- 1 Calculate the change in mass for each reaction and record it in the results table.
- 2 Calculate the range of uncertainty and record it in the table.
- 3 Calculate the relative uncertainty and record it in the table.

e.g. uncertainty =  $\pm 0.05$  g

$$\text{relative uncertainty} = \frac{(\text{uncertainty value})}{(\text{average value})} \times 100 = \frac{0.05 \text{ g}}{2.50 \text{ g}} \times 100 = 2\%$$

Independent variable	Dependent variable					
	Initial mass (g)	Final mass (g)	Change in mass (g)	Uncertainty ( $\pm$ ____)	Relative uncertainty	Other observations
Reaction 1						
Reaction 2						

continued...

...continued

### Discussion

- 1 Describe the change in mass for each of the reactions using the data you have gathered.
- 2 Discuss possible reasons for a change in mass in the two reactions.
- 3 Relate these results back to the law of conservation of mass and discuss any discrepancies.
- 4 Uncertainty is a measure of the variability in data. Describe the relative uncertainty for each of the groups.
- 5 Identify possible limitations of this method.
- 6 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

Discuss whether the experimental data supports the predicted outcome as shown in the chemical equations above.

## Explore! 16.2

### The Maillard reaction

The Maillard reaction is an important chemical reaction in many industries. An example of the Maillard reaction is the searing and browning of meat. Use the internet to research the following questions.

- 1 What is the Maillard reaction and how does it work?
- 2 What reaction conditions are required for the reaction?
- 3 Other than searing and browning meat, what is this reaction used for?



**Figure 16.8** Searing or browning of steak is an example of the Maillard reaction.

## Advances in science 16.2

### From tyres to biofuel

To make steel, coke (which is made from coal) is reacted in a blast furnace at very high temperatures with iron ore (an impure form of an iron compound).

The result of the reaction is molten steel, which can be set into moulds and used in many applications, primarily in the construction industry. The problem with this method is that coke is a non-renewable resource so supplies will eventually run out. There is an estimated 1.1 trillion tonnes of proven coal reserves worldwide. This means that there is only enough coal to last us around 150 years at current rates of production and usage.



**Figure 16.9** Burning coke in a blast furnace

continued...

continued...

Scientists at the University of New South Wales' Centre for Sustainable Materials Research and Technology (SMaRT@UNSW) have developed a solution to this problem. By investigating carbon reactions at high temperatures, researchers found that waste tyres and plastics could partially replace the non-renewable coke. In 2017, a stockpile of 15 000 tyres was found on a property near the Great Barrier Reef. The government only realised this after purchasing the \$7 million cattle station. These tyres were recycled by a company near Ipswich before being reprocessed and converted into fuel.

While it is more expensive to convert the tyres into other products compared to simply stockpiling them, it is less dangerous and far more environmentally friendly to recycle them. Tyres are highly combustible and once they start to burn, they are incredibly difficult to extinguish. One tyre fire in Wales burned continuously for 15 years! When tyres burn, high levels of chemical toxins such as cyanide, carbon monoxide, sulfur dioxide and heavy metals are released into the environment. Stockpiled tyres also provide a breeding ground for mosquitoes that can spread diseases such as dengue fever, Australian encephalitis, Ross River virus disease and Barmah Forest virus.



Figure 16.10 Stage 2 opening of the New Acland Coal Mine in Muldu, Queensland



Figure 16.11 The 15 000 used tyres dumped on a property in Springvale Station, north of Cairns, were converted into fuel.

## Reaction conditions

Not all chemical reactions happen immediately; that is, occur without us having to do anything to them.

**reaction conditions**  
conditions required for a  
chemical reaction to proceed

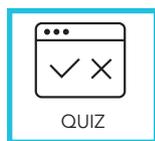
Some reactions require heat or light energy to get started, some require a high pressure, and some need a chemical called a catalyst to speed up the reaction. Some reactions start immediately, but

require a longer period of time. These factors are called **reaction conditions**. When special reaction conditions are required, they are written above the arrow in a chemical equation. This shows that these conditions are required for the reaction but do not get involved. Think about the reaction conditions required when baking a cake – you certainly cannot do this without time and an oven!

### Quick check 16.3

- 1 The molecular formula for glucose is  $C_6H_{12}O_6$ . What does this tell you about a glucose molecule?
- 2 Chlorine is a diatomic molecule. What does this mean?
- 3 Write a chemical equation with symbols for the reaction between iron (Fe) and chlorine ( $Cl_2$ ) to make iron chloride ( $FeCl_2$ ).

## Section 16.1 questions



## Remembering

- 1 **State** what  $\rightarrow$  means in a chemical reaction.
- 2 **Name** the reactants and products of the following reactions.
  - a sodium hydroxide + iron carbonate  $\rightarrow$  iron hydroxide + sodium carbonate
  - b propane + oxygen  $\rightarrow$  carbon dioxide + water
  - c hydrogen + oxygen  $\rightarrow$  water
  - d calcium carbonate  $\rightarrow$  calcium oxide + carbon dioxide
- 3 **Recall** the definitions of the following keywords by matching them to the correct definition.

Keyword	Definition
Reactants	The substances formed in a chemical reaction.
Products	The type of environment that the reaction needs for it to happen, e.g. temperature or pressure.
Reaction conditions	The substances that are reacting in a chemical reaction.

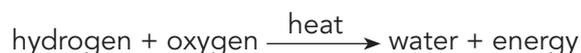
- 4 **Select** the diatomic molecules below.
  - H<sub>2</sub>O                      • CO<sub>2</sub>                      • N<sub>2</sub>                      • F<sub>2</sub>
- 5 When sodium is reacted with water containing universal indicator, the water will turn purple as sodium hydroxide (an alkali) is produced. Hydrogen gas is also made.
  - a **Name** the reactants in the reaction.
  - b **Name** the products in the reaction.
  - c **Write** a word equation to represent the reaction.

## Understanding

- 6 **Describe** the composition of copper sulfate (CuSO<sub>4</sub>) in terms of the number of each type of atom.
- 7 **Describe** what happens to the atoms in reactants during a chemical reaction.

## Applying

- 8 Nitrogen and oxygen gas exist in our atmosphere, but they do not react together. However, in the high temperatures and pressures of car engines they will react with each other. **Identify** the reaction conditions needed to cause nitrogen and oxygen to react with each other.
- 9 **Construct** a paragraph to explain what is happening in this reaction. Use the keywords: reactants, products, reaction condition.



## Analysing

- 10 **Categorise** the following examples as physical or chemical changes.
  - a Sugar dissolving in a cup of tea
  - b Steel nails rusting
  - c Ice melting to form water
  - d Frying an egg
  - e Toasting bread

## Evaluating

- 11 The following equation shows what happens during respiration in which glucose and oxygen (reactants) react together to make carbon dioxide and water (products). **Assess** whether the following word equation is suitable. If not, rewrite it so that it is.



- 12 **Propose** how social, ethical and environmental issues are considered during the development of new materials. You may use the example from Advances in science 16.2 in your answer.

## 16.2 Conservation of mass

### Learning goals

- 1 To recall the law of conservation of mass
- 2 To explain the importance of a closed system when measuring conservation of mass
- 3 To explain how this law is applied in chemical equations

#### conservation of mass

a law that states that matter can be neither created nor destroyed in chemical reactions

One of the fundamental laws of chemistry is the law of

**conservation of mass.** This law states that matter can be neither created nor destroyed in chemical reactions.



WORKSHEET



VIDEO  
Law of  
conservation

### Explore! 16.3

#### Mass and the universe

If the law of conservation of mass states that matter and energy can be neither created nor destroyed, how did the matter that is present now get here?

'We are made of star-stuff' is a famous statement by Carl Sagan, an American astronomer (although others had used the term 'star-stuff' before him). Use the internet to investigate how true the statement is and answer the following questions.

- 1 What happened at the start of the universe? How did this cause matter to form?
- 2 How were elements heavier than hydrogen formed at the start of the universe?
- 3 When heavier elements are formed in this way, a large amount of energy is released. This does not seem to support the law of conservation of mass. How does Einstein's equation (Energy = mass × speed of light<sup>2</sup> or  $E = mc^2$ ) explain this?
- 4 How were heavier elements in the universe (for example, iron) made?
- 5 Look up the composition of the human body on the internet. What are the six elements that make up nearly all of a human body? Among those, which one was not created by stars?

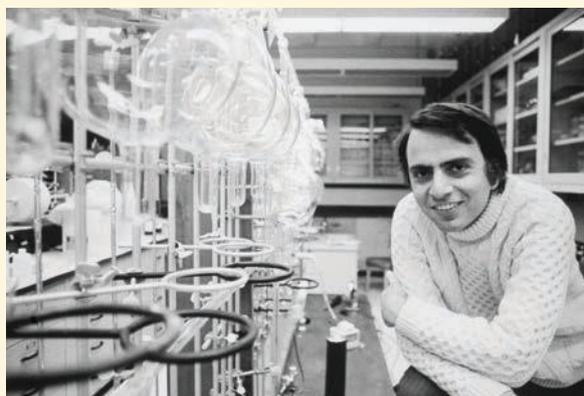


Figure 16.12 Carl Sagan said that 'we are made of star-stuff'.



LAVOISIER

Figure 16.13 Antoine Lavoisier proposed the law of conservation of mass.

#### Putting the law of conservation of mass into practice

The law of conservation of mass means that matter and energy can be neither created nor destroyed – but what does this mean?

A full glass of water left outside on a hot day will

become less full if you leave it for long enough. The glass of water will now have a smaller mass. You may conclude that this mass has been lost. But you know now that this is not the case. The water heats up, forming water vapour, which leaves the glass and goes into the air. Water vapour has mass. The water vapour has left the glass, which is why the mass of the glass decreases, but it is still present in the air somewhere. This example demonstrates why it is important to observe the conservation of mass in a closed system (one in which matter cannot escape). In an open system, reactions that produce gases will appear to lose mass.



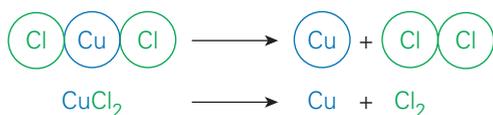
**Figure 16.14** Leave a glass of water outside on a hot day and it will appear to lose mass.

### Quick check 16.4

- 1 What is the definition of the law of conservation of mass?
- 2 If the mass of reactants is 30 g, what will the mass of products be?
- 3 Discuss why it is difficult to observe the law of conservation of mass in an open system.
- 4 Explain why the mass of a glass of water left out on a hot day decreases.

## How does the law of conservation of mass relate to chemical equations?

As a scientist, you need to factor in the law of conservation of mass when you write chemical equations. Consider the reaction in Figure 16.15. Here, copper chloride ( $\text{CuCl}_2$ ) is being broken down into its elements: copper ( $\text{Cu}$ ) and chlorine ( $\text{Cl}_2$ ).

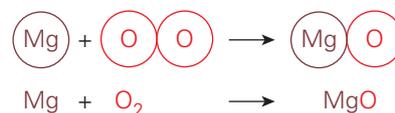


**Figure 16.15** The diagram and symbol equations showing the breaking down of copper chloride into its elements

For this reaction to obey the law of conservation of mass, there must be the same number of atoms of each element in the reactant and the products. In the reactant, there is one atom of copper and two atoms of chlorine. In the products, there is one atom of copper and two atoms of chlorine. Therefore, there is the same number of atoms on each side of the equation and therefore the same mass. The only difference is how the atoms are arranged.



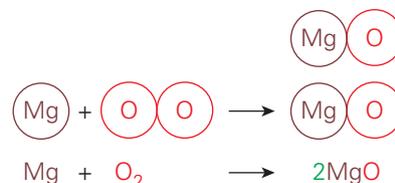
Figure 16.16 shows the diagram and symbol equations for the reaction between magnesium ( $\text{Mg}$ ) and oxygen ( $\text{O}_2$ ) to form magnesium oxide ( $\text{MgO}$ ).



**Figure 16.16** The reaction between magnesium and oxygen forms magnesium oxide.

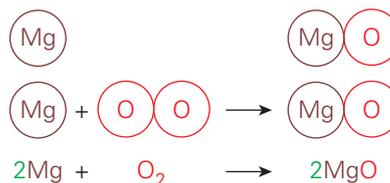
What do you notice about the number of each type of atom in the reactants compared to the product? The number of each type of atom in the reactants and the product is different. This means that the equation in Figure 16.16 is not obeying the law of conservation of mass. There is one magnesium atom on each side of the arrow, but the left-hand side of the equation has two oxygen atoms while the right-hand side has only one. This shows the product as having less mass than the reactants, which simply does not happen. Therefore the chemical equation must be altered to show that the law of conservation of mass is observed.

Figure 16.17 shows the equation adjusted so that it has two oxygen molecules on the right-hand side. This was done by adding another unit of magnesium oxide to the products. Notice that the symbol equation also now shows two magnesium oxide units in the products.



**Figure 16.17** This equation now has the correct number of oxygen atoms, but it is still not observing the law of conservation of mass.

However, adding the extra magnesium oxide unit to balance the oxygen atoms has also added another magnesium atom. The magnesium atoms are now unbalanced, with one on the left-hand side and two on the right-hand side of the equation. Adding one more magnesium atom to the left-hand side (reactants) will balance the equation (see Figure 16.18). Each side of the equation now has two magnesium atoms and two oxygen atoms. Again, notice that the symbol equation also reflects the addition of another magnesium atom.



**Figure 16.18** The correct balanced equation, which has the same number of each atom in the reactants and products and therefore observes the law of conservation of mass

### Quick check 16.5

- 1 Explain why it is necessary to balance equations.
- 2 Two students were doing an experiment in the laboratory. They measured the mass of reactants as 50 grams (g). After the reaction had completed, the mass of the products was 34 g. They noticed that a gas was given off during the reaction so they wanted to find out the mass of this gas. Explain to the students how they could calculate this.

### Practical 16.2

#### Observing the law of conservation of mass (1)

##### Aim

To observe the law of conservation of mass by reacting magnesium and oxygen.

##### Materials

- small piece of magnesium ribbon
- tongs
- crucible
- safety glasses
- matches
- Bunsen burner
- clay triangle
- tripod
- heatproof mat

##### Procedure

- 1 Copy the results table in the Results section.
- 2 Set up a Bunsen burner on a heatproof mat. Place the clay triangle on top of the tripod.
- 3 Weigh the crucible with its lid.
- 4 Place a piece of magnesium ribbon in the crucible and weigh it again with the lid on.
- 5 The mass of magnesium can be calculated by subtracting the mass of the empty crucible.
- 6 Heat the crucible using the Bunsen burner on the blue flame, carefully lifting the lid using the tongs to allow sufficient air into the crucible.
- 7 Continue heating until the magnesium has fully reacted.
- 8 When the crucible has cooled sufficiently, weigh it and its contents again. Calculate the mass of the new compound by subtracting the mass of the empty crucible.

##### Be careful

Do not stare directly at  
combusting magnesium.

*continued...*

...continued

### Results

Item	Mass (g)
Crucible + lid	
Crucible + lid + magnesium before heating	
Crucible + lid + compound after heating	
Magnesium	
Compound	

### Discussion

- 1 Describe your observations when the magnesium reacted in the crucible. How did you know that a chemical change had occurred?
- 2 Oxygen is  $O_2$ . Write a balanced symbol equation for this reaction.
- 3 Explain why this reaction is a difficult example for showing the law of conservation of mass.
- 4 Propose how you could have made it easier to demonstrate the law of conservation of mass.
- 5 Identify any potential sources of error in this experiment.
- 6 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

State if your results demonstrate the law of conservation of mass.

## Practical 16.3

### Observing the law of conservation of mass (2)

#### Aim

To observe the law of conservation of mass by reacting vinegar and baking soda.

#### Materials

- 10 millilitres (mL) of vinegar (acetic acid)
- 5 g of baking soda
- balance
- small measuring cylinder
- small conical flask
- resealable plastic bag (big enough to fit in the two cups, and with enough space for you to manipulate them)

#### Procedure

- 1 Copy the results table in the Results section.
- 2 Pour 10 mL of vinegar into the measuring cylinder.
- 3 Weigh out 5 g of baking soda into the conical flask.
- 4 Put the measuring cylinder and conical flask into the plastic bag. DO NOT spill any of the contents of the measuring cylinder or flask.
- 5 Measure the mass of the measuring cylinder, flask and plastic bag using the balance. Record this in your results table.
- 6 Seal the plastic bag again, being careful not to spill any of the contents.
- 7 Without opening the bag, pour the vinegar into the flask containing baking soda.
- 8 When you think the chemical reaction has finished, record the mass of the contents without opening the bag. Record this in your results table.
- 9 Calculate the change in mass using the initial mass and final mass results. Record these in your results table.

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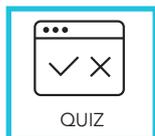
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**Results**

Initial mass (g)	Final mass (g)	Change in mass (g)

**Discussion**

- Describe your observations when the vinegar and baking soda reacted in the plastic bag. How did you know that a chemical change had occurred?
- The gas produced in the reaction is the same as one of the gases we exhale (breathe out). What is the name and formula of this gas?
- When vinegar (acetic acid) reacts with baking soda (sodium hydrogen carbonate), sodium acetate, water and carbon dioxide are produced.  
Write a word equation for this reaction.
- This experiment was carried out in a closed system. Deduce what you think this means.

**Section 16.2 questions****Remembering**

- Recall** the law of conservation of mass.

**Understanding**

- Explain** how the law of conservation of mass is shown in chemical equations.
- Emma carried out an experiment by reacting different amounts of magnesium with oxygen. Her results are shown in the results table. **Explain** how her results support the law of conservation of mass.

Mass of magnesium (g)	Mass of oxygen (g)	Mass of product (g)
5.90	1.74	7.64
2.34	1.83	4.17
6.39	2.36	8.75

- There are two reactants in a chemical equation, and one product. The mass of the product is 30 g. The mass of the first reactant is 17 g. **Show** that the mass of the second reactant must equal 13 g to observe the law of conservation of mass.

**Applying**

- Identify** the mass of the products in the following scenarios.
  - 35 g of reactants
  - 12 g of reactants
  - 2 g of one reactant added to 24 g of another reactant
  - 6 g of one reactant added to 3 g of another reactant

**Analysing**

- Analyse the following chemical equations to **determine** which of them observe the law of conservation of mass.
  - $C + O_2 \rightarrow CO_2$
  - $CaCO_3 \rightarrow CaO + CO_2$
  - $H_2 + O_2 \rightarrow H_2O$
  - $Na + Cl_2 \rightarrow NaCl$
  - $Ba + O_2 \rightarrow BaO$

- 7 **Distinguish** between an open and a closed system.
- 8 **Analyse** the following word equation and formula equation to answer the following:
- $$\begin{array}{ccccccc} \text{hydrochloric acid} & + & \text{magnesium} & \rightarrow & \text{magnesium chloride} & + & \text{hydrogen} \\ \text{HCl} & & \text{Mg} & \rightarrow & \text{MgCl}_2 & & \text{H}_2 \end{array}$$
- a **Identify** the reactants.
- b **Identify** the products.
- c **Decide** whether or not it observes the law of conservation of mass.
- d **Identify** the chemical formula of magnesium chloride.
- e **Determine** the chemical formula of the product.

### Evaluating

- 9 **Decide** whether an open or a closed system is better to observe the law of conservation of mass. **Justify** your choice.
- 10 In a chemical reaction, the mass of the reactants was 15 g. The mass of the products was 12 g. **Decide** whether this reaction followed the law of conservation of mass. **Justify** your choice.
- 11 Joy and Paul leave a glass of water on their balcony. When they realise it has been left there, the volume of water in the glass has reduced. Joy says that the mass of water molecules has been lost. Paul says there is less water and therefore less mass in the glass because the water has evaporated, and this mass has been added to the mass of the air.
- a **Decide** who you think is correct and justify your reasoning.
- b **Design** an experiment to prove who was correct.
- 12 A 20 g sample of reactants were reacted together. Only 18 g of product was made. **Assess** what may have happened to the remaining 2 g of mass.



## 16.3 Energy and chemical reactions

### Learning goals

- 1 To identify exothermic and endothermic reactions from experimental data
- 2 To describe the energy profiles of exothermic and endothermic reactions



### Exothermic and endothermic reactions

Because you cannot see atoms and molecules in a chemical reaction, it can be easy to think of them as stationary.

However, molecules and atoms are constantly moving, which means they have **kinetic energy** from movement. There is also **potential energy** stored within the chemical bonds between atoms in molecules and compounds.

**kinetic energy**  
the energy of moving matter

**potential energy**  
(chemical) the energy stored in the chemical bonds of a substance

**exothermic**  
heat is released from a reaction characterised by an increase in surrounding temperature

When the atoms rearrange in a chemical reaction, the potential energy stored in the bonds also changes. Sometimes energy from the reaction is lost into the surroundings, while sometimes the reaction requires energy from the

surroundings. These changes in energy correspond to a temperature change in the reaction surroundings, which can be measured during an experiment.

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). You can tell if a reaction is exothermic because you will measure a rise in temperature. Heat has left the reaction and gone into the immediate surroundings; it is the temperature of the surroundings that you will measure in an experiment.

**EXO** **THERMIC**  
External Heat

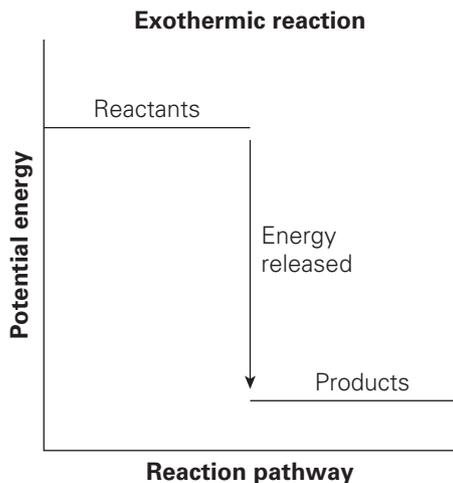
Figure 16.19 The word 'exothermic' means external heat.



Figure 16.20 Burning wood is an example of an exothermic reaction because heat is released.

In exothermic reactions the products have less energy than the reactants, which is why this extra energy is released into the surroundings. It is easier to see what is

happening in an exothermic reaction by looking at an energy level diagram, such as shown in Figure 16.21.



**Figure 16.21** An energy level diagram for an exothermic reaction

**endothermic**  
an absorption of heat in a chemical reaction characterised by a decrease in surrounding temperature

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 measure a decrease in temperature: heat has left the immediate surroundings and has gone into the



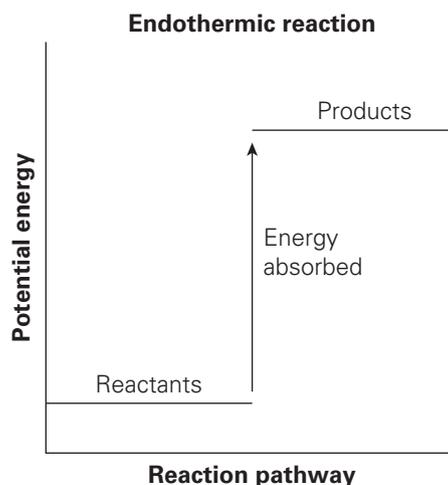
**Figure 16.22** Photosynthesis, in which plants use the Sun's light energy to make their own food, is an example of an endothermic reaction.

**ENDO** **THERMIC**  
Internal Heat

**Figure 16.23** The word 'endothermic' means internal heat.

reaction. As for exothermic reactions, in an experiment, you will measure the temperature of the surroundings.

In endothermic reactions, the products have more energy than the reactants, because extra energy is absorbed from the surroundings. It is easier to see what is happening in an endothermic reaction by looking at an energy level diagram, such as shown in Figure 16.24.



**Figure 16.24** An energy level diagram for an endothermic reaction

### Quick check 16.6

- 1 During a chemical reaction, the temperature of the solution decreases. Infer whether this reaction is endothermic or exothermic.
- 2 '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.

**Practical 16.4: Teacher demonstration****Endothermic and exothermic reactions (1)****Aim:**

To determine whether a reaction is endothermic or exothermic.

**Materials****Experiment 1**

- 1.4 g of potassium iodide
- 30% hydrogen peroxide
- food colouring
- washing-up liquid
- 100 mL plastic measuring cylinder
- plastic tray
- spatula

**Experiment 2**

- 10 g of ammonium chloride
- 32 g of barium hydroxide
- 250 mL measuring cylinder
- wooden block
- glass stirring rod
- 250 mL beaker

**Procedure**

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 washing-up liquid and a few drops of food colouring to the measuring cylinder.
- 3 Pour about 65 mL of 30% hydrogen peroxide into the measuring cylinder and mix it with the spatula.
- 4 Add the potassium iodide to the mixture, 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, 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		

**Discussion**

- 1 How did you know that a chemical reaction had taken place in both experiments?
- 2 Draw a potential energy level diagram for each experiment.
- 3 Determine why the reaction mixture shot out of the measuring cylinder in Experiment 1.

**Conclusion**

Draw a conclusion from this experiment regarding determining endothermic and exothermic reactions.

**Be careful**

Ensure that appropriate gloves are worn during this experiment.

## Practical 16.5

### Endothermic and exothermic reactions (2)

#### Aim

To determine whether reactions are endothermic or exothermic.

#### Materials

- 0.5 M hydrochloric acid
- 0.5 M sodium hydroxide
- 1 M copper sulfate solution
- 1 M sodium hydrogen carbonate
- 3 centimetre (cm) piece magnesium ribbon
- 1 spatula of zinc powder
- 1 spatula of citric acid
- 10 mL measuring cylinder
- thermometer
- polystyrene cup with lid

#### Procedure

- 1 Copy the results table, which gives the reactants to be used in four experiments.
- 2 Pour 10 mL of the first substance in Experiment 1 (i.e. hydrochloric acid) 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 (i.e. magnesium ribbon) 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 hydrochloric acid + 3 cm piece of magnesium ribbon				
2 10 mL hydrochloric acid + 10 mL sodium hydroxide				
3 10 mL copper sulfate solution + 1 spatula zinc powder				
4 10 mL sodium hydrogen carbonate + 1 spatula citric acid				

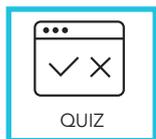
#### Discussion

- 1 Explain how you determined if each reaction was endothermic or exothermic.
- 2 Describe what happened to the energy in the reaction between sodium hydrogen carbonate and citric acid in Experiment 4.

#### Be careful

Ensure that appropriate gloves are worn during this experiment.

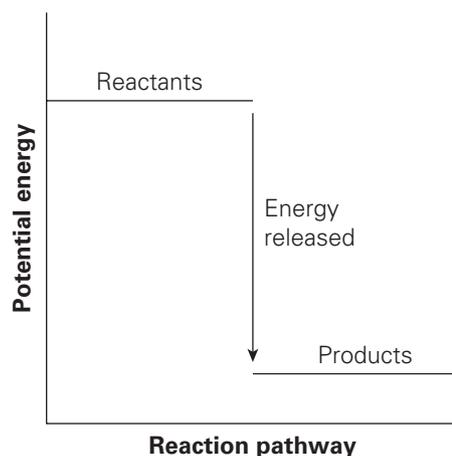
## Section 16.3 questions

**Remembering**

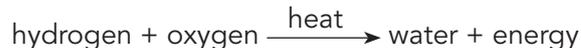
1 **Recall** one example of an endothermic reaction and one example of an exothermic reaction.

**Understanding**

2 **Explain** what is happening in this energy level diagram below for the reaction between copper sulfate and zinc in which the temperature of the reaction rose by 40°C.

**Applying**

3 **Construct** a paragraph to explain what is happening in this reaction. Use the keywords: reactants, products, reaction condition.

**Analysing**

- 4 **Contrast** exothermic and endothermic reactions.
- 5 **Classify** the following as exothermic or endothermic reactions.
- A reaction in which the temperature decreases
  - Releasing energy from food in respiration
  - Baking a cake
  - Combustion

**Evaluating**

- 6 The following reaction shows the thermal decomposition (breaking down) of calcium carbonate. It occurs at above 840 °C. **Deduce** whether it is an exothermic or an endothermic reaction. Justify your choice.  
 calcium carbonate → calcium oxide + carbon dioxide
- 7 Julia is observing a reaction and notices steam rising out of the test tube.
- Evaluate** whether the reaction is exothermic or endothermic.
  - Justify** your choice.

# 16.4 Chemical reactions in living things

## Learning goals

- 1 To construct word equations for respiration and photosynthesis
- 2 To describe the reaction conditions required for photosynthesis

### photosynthesis

the chemical reaction by which some organisms make their own food

### respiration

a chemical reaction which converts glucose and oxygen into carbon dioxide and water as well as energy

Life on Earth is dependent on two chemical reactions: **photosynthesis** and **respiration**. These are extremely important chemical reactions for life.



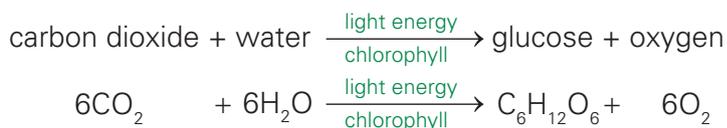
Photosynthesis is carried out mainly by plants and algae; respiration is carried out by all living organisms.

## Photosynthesis



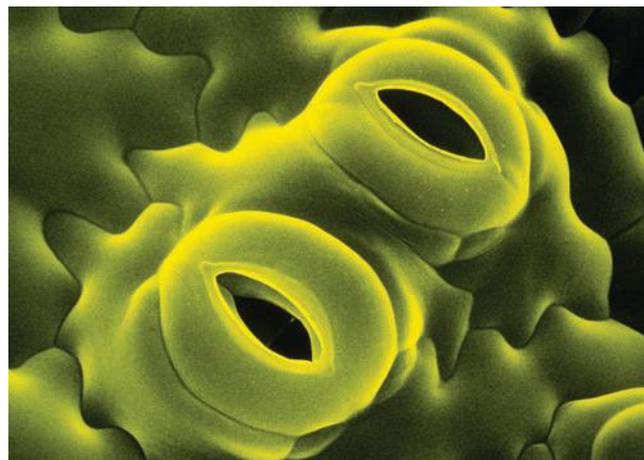
Photosynthesis is the process by which plants, algae and some bacteria make their own food in the form of glucose. It takes place in any part of the plant that is green and exposed to sunlight.

As leaves are exposed to the most sunlight, this is where most photosynthesis takes place. Leaves are green because they contain a green chemical called chlorophyll in tiny structures called chloroplasts. Photosynthesis is a series of biochemical reactions, which can be summarised by the word equation and balanced symbol equation shown in Figure 16.25.



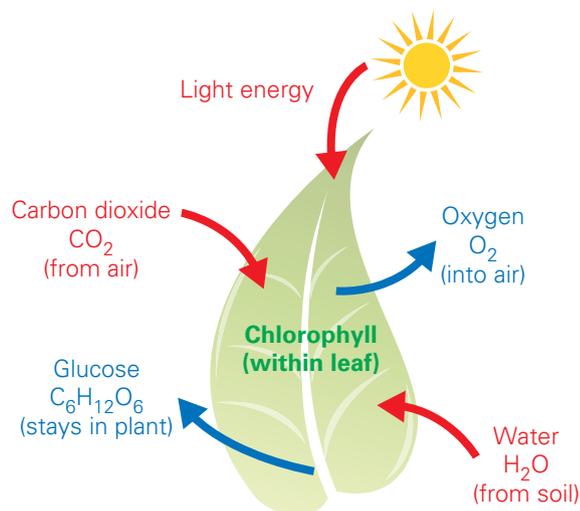
**Figure 16.25** The word and balanced symbol equations for photosynthesis

For photosynthesis to occur, plants and algae need to take carbon dioxide and water into chloroplasts. Carbon dioxide comes from the air and is absorbed into the leaf through tiny holes called stomata on the underside of the leaf (see Figure 16.26). Water in the soil is taken up into the plant by its roots.



**Figure 16.26** A scanning electron microscope image of leaf stomata (tiny holes found in the leaf). Carbon dioxide moves into the leaf through the stomata.

Once carbon dioxide and water are inside the plant, they will not react on their own. For this reaction to take place, energy from sunlight is required. Chlorophyll, the green chemical within the chloroplasts in leaves, is also required to convert the light energy into chemical energy. When carbon dioxide and water react in the presence of sunlight and chlorophyll, glucose and oxygen are formed.



**Figure 16.27** Photosynthesis: where the raw materials come from and what happens to the products

Table 16.2 summarises the chemicals and energy involved in photosynthesis.

Reactants	Reaction conditions	Products
Carbon dioxide	Light energy	Glucose
Water	Chlorophyll	Oxygen

**Table 16.2** Chemicals and energy involved in photosynthesis

## Practical 16.6

### Investigating factors that affect the rate of photosynthesis

#### Aim

To investigate how light intensity affects the rate of photosynthesis.

#### Materials

- water plant (e.g. *Elodea*)
- 250 mL conical flask
- 100 mL measuring cylinder
- electric lamp
- scissors
- metre ruler
- stop clock

#### Planning

- 1 Write a summary of the background information about the factors that affect the rate of photosynthesis.
- 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.

#### Procedure

- 1 Copy the results table.
- 2 Set up the lamp. Using the metre ruler, measure five distances (up to 1 metre [m]) away from the base of the lamp. These are the distances you will investigate. Record these distances in your results table.
- 3 Measure 100 mL of water using the 100 mL measuring cylinder and add it to the conical flask.
- 4 Place the conical flask the correct distance from the lamp.
- 5 Cut a 10 cm length strip of the water plant and add it to the conical flask. At the same time, start the stop clock.
- 6 Count the number of bubbles that are produced in 1 minute. Record this in your results table.
- 7 Repeat the investigation using the same procedure, but now choosing a different distance away from the lamp.
- 8 If you have time, repeat each distance and calculate the mean number of bubbles. Alternatively, you could share your results with the rest of your class so you have more data when calculating the mean.

#### Results

Distance from the lamp (m)	Number of bubbles produced in 1 minute

#### Data processing

Plot a scatter plot (with a trend line or a line of best fit) of your results.

*continued...*

...continued

### Discussion

- 1 Describe any patterns, trends or relationships in your results.
- 2 Explain any trends you have identified.
- 3 Identify any limitations in your investigation.
- 4 Propose how you could improve the investigation to make the results more:
  - a accurate
  - b reliable.
- 5 Design a similar experiment to investigate another factor that may affect the rate of photosynthesis.

### Conclusion

Draw a conclusion from this experiment regarding light intensity and the rate of photosynthesis, using data to support your statement.

### Quick check 16.7

- 1 Name the two reactants required for photosynthesis.
- 2 Name the two products produced during photosynthesis.
- 3 Explain why sunlight is needed for photosynthesis.
- 4 Write a word equation for photosynthesis.

## Respiration

Respiration is the process by which living organisms produce energy from glucose. Both plants and animals carry out a process called aerobic respiration, which means respiration requiring oxygen.



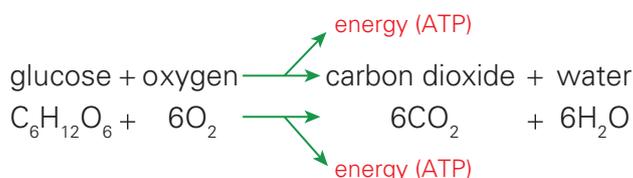
**Figure 16.28** When you exercise, more energy is required, so you breathe faster.

You know already that the glucose plants use in respiration is formed during photosynthesis. In contrast, animals get their glucose from the food they eat. Aerobic respiration takes place in the mitochondria. Alongside the useful product of respiration energy in the form of ATP other less useful products (carbon dioxide and water) are also produced.

### Try this 16.1

Limewater becomes cloudy in the presence of carbon dioxide. Get a test tube, a straw and some limewater. Blow into the limewater. What do you think will happen? How does this give us evidence for one product of aerobic respiration?

Aerobic respiration is a series of biochemical reactions that can be summarised by the word equation and balanced symbol equation below.



**Figure 16.29** The word and symbol equations for aerobic respiration

## Explore! 16.4

**Aerobic and anaerobic respiration**

Haile Gebrselassie and Usain Bolt are perhaps the most famous names in their sports. Usain Bolt ran the 100 m and 200 m, whereas Haile Gebrselassie ran long-distance races, including marathons. The energy requirements for these races differ dramatically and therefore so do the rate and type of respiration.

- 1 During a race, how would the breathing rates of the two runners differ?
- 2 During a 100 m race, Usain Bolt only carried out a type of respiration known as anaerobic respiration. Research the differences between aerobic and anaerobic respiration to explain why marathon runners and sprinters use different types of respiration.
- 3 In a marathon, runners pick up glucose drinks at various points during a race. Propose a reason for this.



**Figure 16.30** Haile Gebrselassie won the Berlin marathon in 2009.

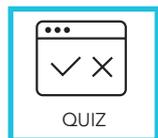


**Figure 16.31** Usain Bolt crossing the finish line. He is perhaps the greatest sprinter of all time.

## Quick check 16.8

- 1 Name the two reactants required for aerobic respiration.
- 2 Name the three products produced during aerobic respiration.
- 3 Identify where aerobic respiration takes place.

## Section 16.4 questions

**Remembering**

- 1 **Name** the molecules that are broken down in respiration.
- 2 **Name** the green pigment found in chloroplasts of plant cells that converts the Sun's light energy into chemical energy for photosynthesis.
- 3 **Name** the tiny holes that open to allow carbon dioxide to enter a plant during photosynthesis.
- 4 **Recall** the word equation for aerobic respiration.
- 5 **Identify** the missing words to complete the word equation for photosynthesis.  
carbon dioxide + \_\_\_\_\_ → glucose + \_\_\_\_\_

**Understanding**

- 6 **Explain** why condensation forms when you breathe out onto a cold window.
- 7 **Describe** ways in which a pot plant can increase its rate of photosynthesis.
- 8 **Compare** and contrast photosynthesis and respiration.
- 9 **Explain** why light energy is written above the arrow and chlorophyll is written below in the word equation for photosynthesis.
- 10 **Outline** the reason why leaves are often flattened and do not overlap.
- 11 **Explain** why plants compete with each other to be the tallest.

**Applying**

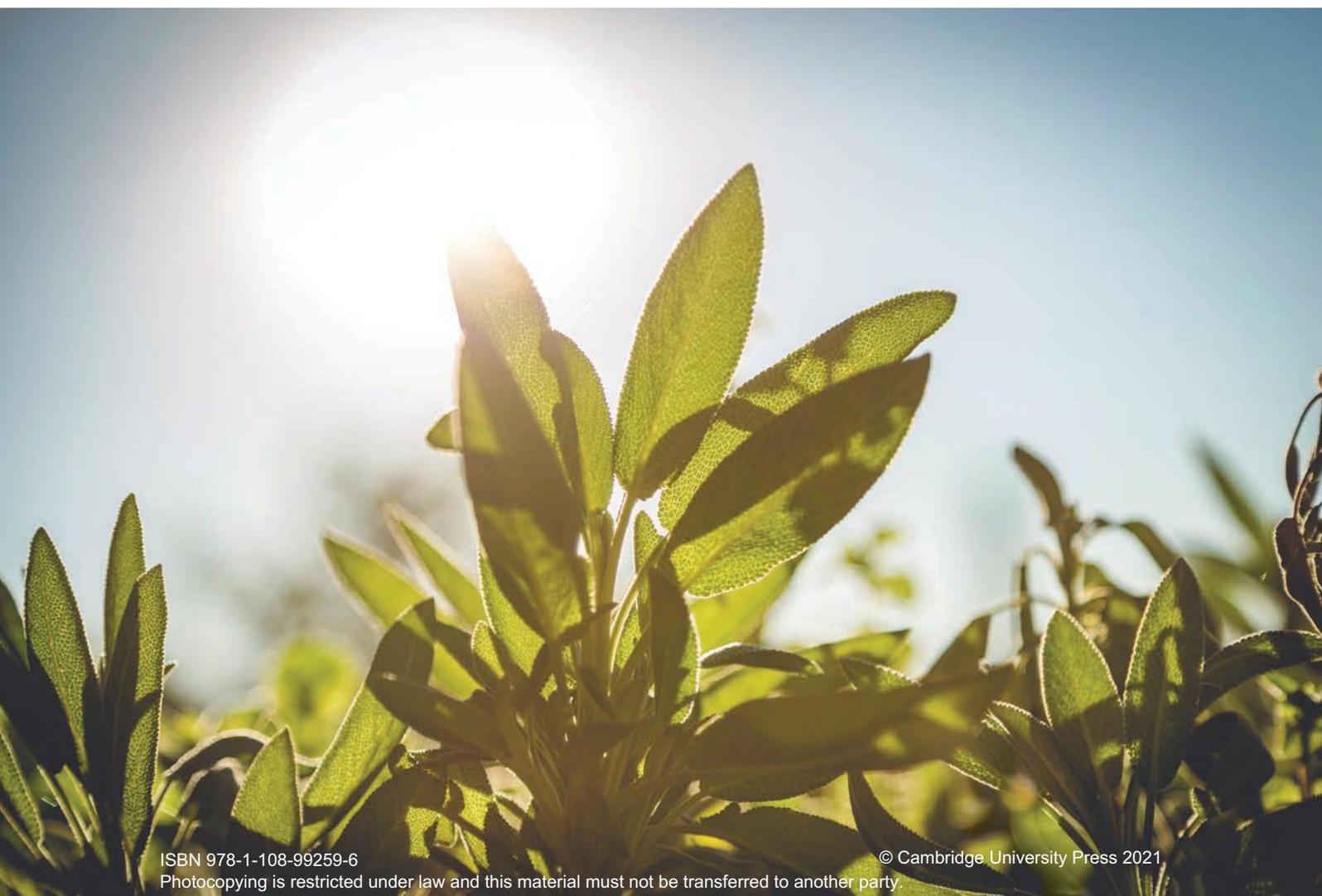
- 12 During anaerobic respiration in yeast, glucose is broken down into carbon dioxide and ethanol. **Construct** a word equation for this reaction.

**Analysing**

- 13 **Contrast** the ways that plants and animals get the raw materials required for aerobic respiration.
- 14 **Classify** respiration and photosynthesis as endothermic or exothermic reactions. **Explain** your decisions.
- 15 **List** some factors that can affect the rate of photosynthesis and **explain** why they affect the rate of the reaction.
- 16 **Make an inference** for why autumn leaves are orange or brown.

**Evaluating**

- 17 **Discuss** the reasons why plants can respire at any time of the day but only photosynthesise during daylight hours.
- 18 'Photosynthesis and respiration are the reverse reactions of one another.' **Decide** whether you agree or disagree with the statement and **justify** your response.
- 19 Biochemistry is the branch of science that involves study of chemical processes with living organisms (plants, animals, microorganisms). For example, a biochemist might research the chemical processes of cell growth, disease and enzymes involved in digestion, as well as how to manage what might go wrong in the processes. **Propose** how research and discoveries in this area might affect peoples lives.
- 



## 16.5 Chemical reactions in non-living systems

### Learning goals

- 1 To describe the features of combustion reactions and compare these to respiration
- 2 To construct word equations for the reactions of acids
- 3 To describe the features of different types of chemical reactions in non-living systems

### Combustion reactions

**combustion**  
the reaction of a fuel with oxygen, usually producing heat and light

**Combustion** reactions are specific examples of reactions that are exothermic in nature.

Combustion is the scientific term for burning; when fuels burn they release heat. For a fuel to burn, oxygen is required. Combustion reactions often take the format shown in Figure 16.32.



Figure 16.32 A typical combustion reaction

Fuels that contain hydrogen and carbon are called hydrocarbons. The equation in Figure 16.33 shows what happens when the simplest hydrocarbon, methane, is burned in oxygen.

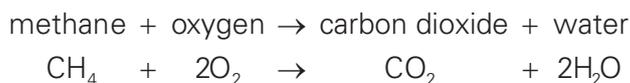


Figure 16.33 Complete combustion of methane

This is an example of complete combustion because enough oxygen is present to combine with all the hydrogen and carbon in the fuel to form water and carbon dioxide. However, if only a limited supply of oxygen is available, methane will undergo incomplete combustion, which will lead to the formation of carbon monoxide and carbon (soot), as shown in Figure 16.34.

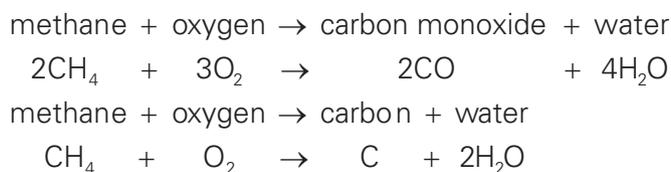


Figure 16.34 Incomplete combustion of methane has two possible outcomes.

Carbon monoxide is produced instead of carbon dioxide when the oxygen supply is reduced slightly. However, if there is very little oxygen available, only the hydrogen will combine with the oxygen, making water, and leaving carbon on its own (sometimes referred to as 'soot').

### Quick check 16.9

- 1 Explain why combustion reactions are described as exothermic reactions.
- 2 Identify the reactant gas required for all types of combustion reactions.
- 3 Carbon dioxide and water are released during the combustion of octane. Write a word equation to demonstrate this reaction.

Respiration (mentioned in Section 16.4) and combustion are similar chemical reactions. Both require a fuel and oxygen as reactants, both produce carbon dioxide and water as waste products and both are carried out to produce energy in the form of heat. However, combustion usually produces heat energy at a much faster rate than respiration.

## Explore! 16.5

**Controlled firestick farming**

For thousands of years, Aboriginal and Torres Strait Islander peoples have used fire to sustain Australian bushland and plant growth, in a practice known as firestick farming. Research the benefits of this practice and answer the following questions.

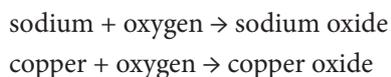
- 1 What is firestick farming?
- 2 At what time of year, in the *north* of Australia, is firestick farming most effective and why?
- 3 What are the products of combusting plant material in excess oxygen?
- 4 What are the effects of these products in the environment? Consider whether firestick farming enhances or reduces the magnitude of these effects.



Figure 16.35 A firestick is used to burn off dry grass in Arnhem Land, Northern Territory.

**Corrosion**

When metals react with oxygen in the air, they form metal oxides. This reaction is described as **corrosion**. It is also known as oxidation because the metals are combining with oxygen. Some metals such as sodium react quickly with oxygen, others like copper react more slowly. The word equations for these reactions are given below:



Gold and other unreactive metals do not oxidise in air.

**corrosion**  
the reaction of metals with oxygen from the air to form metal oxides

Rusting is a specific example of corrosion. It occurs when iron or any of its alloys, for example, steel, react with oxygen and water. The word equation below describes what happens in this reaction:

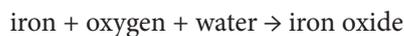




Figure 16.36 Rust results from iron corrosion.

### Quick check 16.10

- 1 Write a word equation for the corrosion of nickel.
- 2 Describe the difference between corrosion and rusting.

## Thermal decomposition

Some compounds break down when heated in a reaction known as **thermal decomposition**. As energy needs to be supplied to these reactions, we can also describe them as endothermic. When this happens, two products will form from one reactant.

**thermal decomposition**  
when a substance breaks down with heating, into two or more substances

**precipitate**  
a solid formed in a solution

This is how a thermal decomposition reaction can be recognised. Many metal carbonates take part in

thermal decomposition. The word equation below shows what happens when copper carbonate is heated:

copper carbonate → copper oxide + carbon dioxide

When this reaction occurs a colour change is observed. Copper carbonate is green and copper oxide is black.

### Quick check 16.11

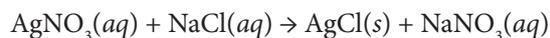
- 1 Describe how you would recognise a thermal decomposition reaction from the word equation alone.
- 2 Write a word equation for the thermal decomposition of calcium carbonate.

## Precipitation reactions

When substances in a solution are mixed and an insoluble product is made, this can be described as a precipitation reaction. A **precipitate** is a solid that is formed in a reaction mixture.

Below is an example of a precipitation reaction:

silver nitrate + sodium chloride → silver chloride + sodium nitrate



The small letters in brackets in chemical equations are state symbols. They tell us the state of the chemicals – whether solid, liquid or gas. The ‘aq’ next to the chemicals tells us that they are solutions dissolved in water: they are aqueous. A sugary cup of tea is an example of an aqueous solution because the sugar dissolves and distributes uniformly in the water.

The ‘s’ next to the silver chloride tells us that this substance is a solid. This is the precipitate in the product and therefore informs us that this reaction is a precipitation reaction.



Figure 16.37 The test tubes contain precipitates. The solid products do not dissolve in the reaction solutions. From left to right the precipitates are copper hydroxide (blue), iron(III) hydroxide (orange) and iron(II) hydroxide (green).

### Quick check 16.12

- 1 Recall the meaning of the term precipitate.
- 2 Describe how you would recognise a precipitation reaction from the word equation alone.

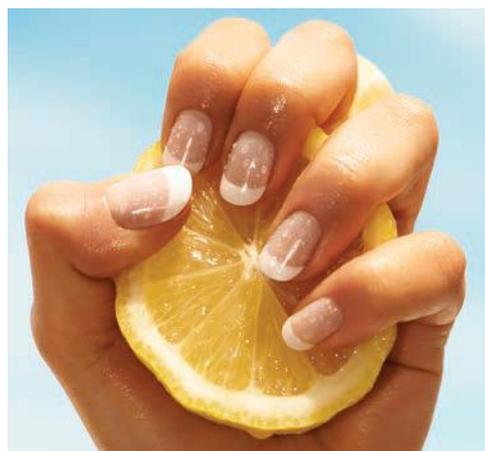
## Acid reactions

In this section, you will learn about three types of reactions involving **acids**: acid–metal, acid–**base** and acid–carbonate reactions. Before these reactions are discussed, you need to know what an acid is. A substance is classified as an acid when at 25°C it has a pH of less than 7: where pH stands for ‘potential hydrogen’ and is a measure of the concentration of hydrogen ions in a solution. The more hydrogen ions, the lower the pH. Acids are sour and can sting or burn the skin. You can find some common acids in your kitchen, for example, lemon juice and vinegar, while some common bases are baking soda and milk. The most common acids that you will come across in the science laboratory are hydrochloric, sulfuric and nitric acids. Hydrochloric acid released by the stomach helps the digestion of food.

In all the reactions that will be discussed, a **salt** will be one of the products formed. The table salt that you put on chips is sodium chloride. However, there are other types of salt. In chemistry, a salt is a substance that is formed when acids react with bases, metals or metal carbonates. Salts are made up of a metal and a non-metal. You need to be able to predict the name of the salt formed when acids react with metals, metal carbonates and bases. The type of acid used produces different products and affects the name of the salt. If hydrochloric acid is reacted, the salt will be a chloride; if nitric acid is used, the salt will be a nitrate; and if sulfuric acid is used, the salt will be a sulfate. Table 16.3 summarises the type of salt formed when different acids react.

Type of acid	Type of salt
Hydrochloric acid	Chloride
Nitric acid	Nitrate
Sulfuric acid	Sulfate

**Table 16.3** A summary of the type of salt formed when different acids react



**Figure 16.38** Lemon juice is a common household acid.

The other reactant in these acid reactions will be, or contain, a metal. For example, the base called sodium hydroxide contains the metal sodium, and the carbonate called calcium carbonate contains the metal calcium. The reactant other than the acid provides us with the first name of the salt. The type of acid provides the second name of the salt. Table 16.4 summarises how to predict the name of a salt produced in reactions that involve acids.

### acid

a substance that, when dissolved in water, has a pH of less than 7

### base

a substance that has a pH greater than 7 and that can react with an acid to form a salt and water; known as an alkali if it can dissolve in water

### salt

a product formed when an acid reacts with a metal, base or carbonate; made up of a metal and a non-metal

Reactant 1	Metal present	Reactant 2: type of acid	Type of salt	Name of salt
Magnesium (metal)	Magnesium	Hydrochloric acid	Chloride	Magnesium chloride
Calcium hydroxide (base)	Calcium	Nitric acid	Nitrate	Calcium nitrate
Sodium carbonate (carbonate)	Sodium	Sulfuric acid	Sulfate	Sodium sulfate

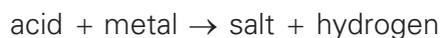
**Table 16.4** Examples of how to name the salt produced in the three types of acid reactions

**Quick check 16.13**

- 1 What is the pH of an acid?
- 2 Name a household acid and an acid used in your science laboratory.
- 3 Recall, what is a salt?
- 4 Name the salt produced when calcium carbonate reacts with sulfuric acid.
- 5 Describe the two rules for naming a salt.

**Acid–metal reactions**

When an acid–metal reaction occurs, an acid reacts with a metal to produce a salt and hydrogen gas ( $H_2$ ). The hydrogen gas produced in the reaction can be identified using a simple pop test. You can do this by capturing any gas produced and holding a lit match to it. If hydrogen is present, you will hear a ‘squeaky pop’. One general word equation for an acid reacting with a metal is shown in Figure 16.39.



**Figure 16.39** The word equation for any acid reacting with any metal

When hydrochloric acid reacts with magnesium, the salt magnesium chloride is formed, and the other product in

the reaction is hydrogen. Remember that the first part of the salt name comes from the metal and the second part comes from the type of acid used. Hydrogen is produced no matter what the acid or metal is.



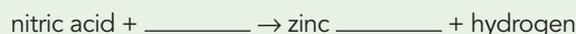
**Figure 16.40** The word equation for a specific acid–metal reaction

Some metals do not react with dilute acids to form a salt and hydrogen. Such metals include gold, copper, silver and platinum.

The reaction between acids and metals is a problem in everyday life. There is acid in rain and this can cause a large amount of damage to the many buildings and other structures made of metals.

**Quick check 16.14**

- 1 What is the general word equation for when any metal reacts with any acid?
- 2 List four metals that do not react with dilute acids.
- 3 Complete the word equation below.



**Figure 16.41** The orange toxic water produced here is due to the reaction of acid rain with the metal in this abandoned mine.

## Practical 16.7

### Reaction of acids with metals

#### Aim

To observe what happens when metals react with acids.

#### Be careful

Ensure appropriate personal protective equipment is worn.

#### Materials

- 1 M dilute hydrochloric acid
- 0.5 M dilute sulfuric acid
- small granules of copper, zinc, magnesium and iron
- 8 test tubes
- test-tube rack
- 4 rubber stoppers to fit the test tubes
- wooden splints
- Bunsen burner

#### Procedure

- 1 Copy the results table.
- 2 Place the 8 test tubes in the test-tube rack.
- 3 In 4 of the test tubes, add 2–3 cm depth of hydrochloric acid.
- 4 In the other 4 test tubes, add 2–3 cm depth of sulfuric acid.
- 5 To each of the hydrochloric acid test tubes, add a different type of metal. Place a rubber stopper loosely in the top of the test tube and note your observations. NOTE: ensure all metal samples have been cleaned before adding them to the acid.
- 6 After about 30 seconds, light a wooden splint, and for each test tube remove the stopper and hold the flame to the mouth of the test tube. Again, record your observations. NOTE: that the reaction between the acid and metals may be rather slow and not produce enough hydrogen gas to cause a pop.
- 7 Add the same types of metal to the test tubes containing sulfuric acid, place a rubber stopper in the top of the test tubes and note your observations.
- 8 After about 30 seconds, light a wooden splint, and for each test tube remove the stopper and hold the flame to the mouth of the test tube. Again, record your observations.

#### Results

Reactions with hydrochloric acid

Metal	Observations	Hydrogen produced?

Reactions with sulfuric acid

Metal	Observations	Hydrogen produced?

#### Discussion

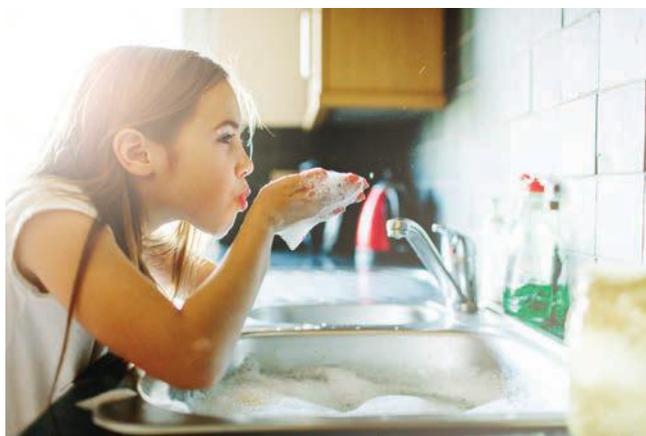
- 1 Discuss which of the metals reacted with the hydrochloric and sulfuric acids. How did you know?
- 2 Write word equations for each of the reactions you carried out in this practical.
- 3 State what happened to some of the reactions when the lit splint was put at the mouth of the test tube.
- 4 Explain what this experiment tells you about the reactivity of metals.
- 5 During this reaction, you may have felt the temperature of the reaction increase. Recall the name of this type of reaction.

## Acid–base reactions

Acid–base reactions occur when any acid reacts with any base to produce a salt and water. Notice that a salt is produced, just like in acid–metal reactions, but instead of hydrogen being the other product, water is made. A base is a substance that has a pH greater than 7 and that can react with an acid to form a salt and water. Bases that can dissolve in water (alkalis) tend to be bitter and feel soapy on the skin. Common bases that you may have in your house are hand soap and oven cleaner. Bases that you will

**neutralisation reaction**  
a reaction between an acid and a base, forming a solution that has a pH of 7

come across in your science laboratory include sodium hydroxide, calcium hydroxide and magnesium hydroxide.



**Figure 16.42** Washing-up liquid is an example of a household base.

The general word equation for any acid reacting with any base is shown in Figure 16.43.



**Figure 16.43** The word equation for any acid reacting with any base

When nitric acid reacts with sodium hydroxide, the salt sodium nitrate is formed. If you are unsure why this is the name of the salt, go back to the start of this section and remind yourself of the rules for naming salts.



**Figure 16.44** The word equation for a specific acid–base reaction

Acid–base reactions are also known as **neutralisation reactions**. This is because when acids and bases with the same volume and concentration react, they may result in a neutral solution (pH = 7). (Note that this does not always occur as it depends on the strength of the acid and base; you will learn this if you study chemistry in Stage 6.) Curing indigestion with an antacid and soothing a wasp sting with vinegar are examples of acids being neutralised with a base.



**Figure 16.45** The pain from a wasp sting can be soothed by vinegar because of a neutralisation reaction.

### Quick check 16.15

- 1 What is the general word equation for when any base reacts with any acid?
- 2 Identify the name for a reaction between an acid and a base.
- 3 Complete the word equation below.  
sulfuric acid + \_\_\_\_\_ → iron \_\_\_\_\_ + water

## Practical 16.8

### Reaction of acids with bases

#### Aim

To observe what happens when acids react with bases.

#### Materials

- 0.5 M hydrochloric acid
- 0.5 M sodium hydroxide
- 250 mL beaker
- 25 mL measuring cylinder
- dropping pipette
- stirring rod
- universal indicator paper for checking pH and colour chart (full range)
- spotting tile
- pH meter

#### Procedure

- 1 Copy the results table.
- 2 Using a 25 mL measuring cylinder, measure 25 mL of hydrochloric acid and add to the 250 mL beaker.
- 3 Add a small piece of universal indicator paper to each of the six hollows on the spotting tile.
- 4 Using the dropping pipette, add a drop of the acid onto one of the pieces of universal indicator paper on the spotting tile and record the pH in your table.
- 5 Measure the pH of the acid in the beaker using the pH meter and record it in your table.
- 6 Using the 25 mL measuring cylinder, measure 5 mL of sodium hydroxide and add this to the beaker containing the acid.
- 7 Repeat steps 4–5, recording your results in the results table.
- 8 Now add a further 5 mL of sodium hydroxide, and repeat steps 4–5. Record the result against the total volume of sodium hydroxide added. Continue these steps until the table is complete.

#### Results

Volume of sodium hydroxide (mL)	pH using universal indicator paper	pH using digital meter
0		
5		
10		
15		
20		
25		

#### Discussion

- 1 Describe what happened to the pH as you gradually added more and more base.
- 2 Identify the type of reaction that you carried out in this experiment.
- 3 Write a word equation for the reaction that you investigated.
- 4 Compare the differences in the readings from the universal indicator and the pH meter. Which one is more accurate and why?
- 5 To demonstrate this type of reaction, explain why it is important to use the same concentration and volume of the acid and base.

#### Be careful

Ensure appropriate personal protective equipment is worn.

### Acid–carbonate reactions

An acid–carbonate reaction occurs when any acid reacts with any metal carbonate to produce a salt, water and carbon dioxide. As with acid–metal and acid–base reactions, a salt is produced, but the other products are different. You can test for the presence of carbon dioxide produced in an acid–carbonate reaction by bubbling the gas through limewater. Limewater goes from colourless to milky in the presence of carbon dioxide (Try this 16.1).

The general word equation for any acid reacting with any carbonate is shown in Figure 16.46.



Figure 16.46 The word equation for any acid reacting with any carbonate

When sulfuric acid reacts with calcium carbonate, the salt calcium sulfate is formed. If you are unsure why this is the name of the salt, go back to the start of this section and remind yourself of the rules for naming salts.



Figure 16.47 The word equation for a specific acid–carbonate reaction

### Did you know? 16.1

#### Baking powder

A common type of carbonate that you may find in your home is baking powder. Baking powder is a mixture of an acid and a carbonate. In the presence of water or another liquid, the acid and carbonate react slowly in a cooking mixture, producing carbon dioxide and making your cakes light and fluffy.



Figure 16.48 An acid–carbonate reaction causes cakes to rise in the oven.

**Quick check 16.16**

- 1 What is the general word equation for when any metal carbonate reacts with any acid?
- 2 Describe the test that shows the presence of carbon dioxide.
- 3 Complete the word equation below.

hydrochloric acid + \_\_\_\_\_ → potassium \_\_\_\_\_ + water + carbon dioxide

**Practical 16.9****Reactions of acids with metal carbonates****Aim**

To observe what happens when acids react with metal carbonates.

**Materials**

- 1 M nitric acid
- calcium carbonate powder
- limewater
- 2 test tubes
- delivery tube
- test-tube rack
- spatula
- rubber stopper with hole

**Procedure**

- 1 Add about 2–3 cm depth of nitric acid into one of the test tubes.
- 2 Add about 2–3 cm depth of limewater into the other test tube and place both test tubes into the test-tube rack.
- 3 Add a heaped spatula of calcium carbonate into the test tube containing the nitric acid, and at the same time place the rubber stopper on top of this test tube and the delivery tube into the limewater (see Figure 16.49).

**Results**

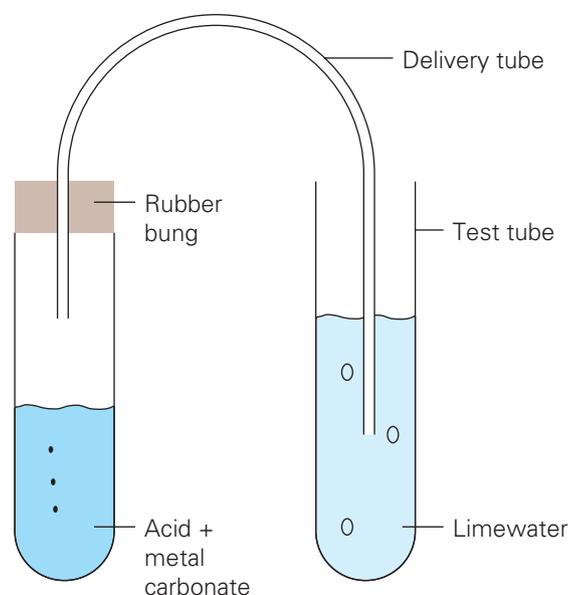
Record your observations.

**Discussion**

- 1 Write a word equation for the reaction you investigated.
- 2 Describe how your observations prove that carbon dioxide was present.
- 3 Research the reaction between carbon dioxide and limewater to explain your observations.

**Be careful**

Ensure appropriate personal protective equipment is worn.



**Figure 16.49** Testing for the presence of carbon dioxide using a delivery tube

## Explore! 16.6

## Weathering

Headstones are an important insight into what life used to be like and often hold huge sentimental value. The two pictures on the right show headstones of a similar age. The headstone in Figure 16.50 is made of limestone (calcium carbonate) and the one in Figure 16.51 is made of granite.



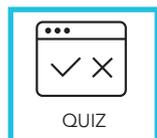
Figure 16.50 Limestone headstone



Figure 16.51 Granite headstone

- Describe the observations you can make about the quality of the headstones in each picture.
- Explain why it is more difficult to read the inscriptions on the limestone (calcium carbonate) headstone than on the granite headstone.
- Write a word equation to explain your ideas in question 2.
- Despite the obvious difference in quality, most of the headstones found in graveyards are made of limestone. Why do you think this is?
- How could you reduce the degradation of limestone headstones?

## Section 16.5 questions



QUIZ

## Remembering

- Identify the gases that are a product of complete combustion reactions involving carbon.
- Recall the products of the following reactions.
  - acid + metal  $\rightarrow$
  - acid + base  $\rightarrow$
  - acid + carbonate  $\rightarrow$
- State the pH range of an acid and a base.
- Recall the two rules when naming a salt.
- Recall the pH of a neutral solution.
- Identify the missing words to complete the table:

Acid	Type of salt
Hydrochloric acid	
	Sulfate
	Nitrate

- Complete the following word equation to show the corrosion of calcium metal.  
calcium + \_\_\_\_\_  $\rightarrow$  calcium \_\_\_\_\_

**Understanding**

- 8 **Explain** why thermal decomposition reactions can also be described as endothermic reactions.
- 9 **Explain** why fire blankets, when put over a fire, cause the fire to be put out.
- 10 **Compare** and **contrast** acid–base reactions with acid–metal reactions.
- 11 During an experiment to show that when acids and bases react, a neutral solution is formed, Martin used equal volumes of sodium hydroxide (base) with equal volumes of hydrochloric acid. However, the solution after mixing was not neutral. **Explain** how this could have happened.
- 12 **Predict** the products of the following reactions.
- Hydrochloric acid + copper carbonate
  - Nitric acid + potassium hydroxide
  - Sulfuric acid + iron
- 13 **Compare** respiration and combustion in terms of the rate of reaction and the energy that they release.

**Applying**

- 14 **Construct** a word equation for the complete combustion of butane (BBQ gas) to form carbon dioxide and water.
- 15 **Identify** which of the following are salts.
- Calcium oxide
  - Sodium chloride
  - Sodium carbonate
  - Copper chloride
  - Barium nitrate
- 16 **Construct** word equations for the following scenarios.
- Magnesium hydroxide is added to nitric acid in a neutralisation reaction to form magnesium nitrate and water.
  - Hydrochloric acid and calcium carbonate are mixed together.
  - The products formed in this reaction are copper chloride and hydrogen.

**Analysing**

- 17 **Distinguish** between complete and incomplete combustion.
- 18 **Categorise** the following as precipitation, thermal decomposition, combustion or corrosion.
- A reaction that starts with one reactant and finishes with two products
  - A solid forms in a solution
  - Carbon dioxide and water are waste products
  - Also known as oxidation
- 19 **Categorise** the following equations as acid–base, acid–carbonate or acid–metal reactions.
- Produces a salt and water as products
  - Produces a gas that can be identified by the squeaky pop test
  - Nitric acid + sodium  $\rightarrow$  sodium nitrate + hydrogen
  - Produces a gas that turns limewater milky
  - Is an example of a neutralisation reaction
  - Forms a salt

**Evaluating**

- 20 Is this statement true or false? 'Combustion is a chemical reaction.' **Justify** your choice.
- 21 Heartburn is caused by acid from the stomach entering the oesophagus. **Justify** the use of antacids to alleviate the pain caused by heartburn.

# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>16.1 I can classify compounds based on the word equations of chemical reactions.</b> e.g. Identify the reactant(s) in the following reaction: calcium carbonate → calcium oxide + carbon dioxide.	
<b>16.2 I can recall the concept of conservation of mass.</b> e.g. Describe what is meant by the term 'conservation of mass'.	
<b>16.2 I can deduce the new substances formed during some chemical reactions.</b> e.g. Predict the product of sulfuric acid + iron.	
<b>16.3 I can distinguish between endothermic and exothermic reactions.</b> e.g. Determine what type of reaction is occurring if the solution gets hotter when two reactants are added to each other.	
<b>16.4 I can describe photosynthesis and respiration.</b> e.g. Compare photosynthesis and respiration.	
<b>16.5 I can determine the products of different acid reactions.</b> e.g. Recall the products when a metal carbonate reacts with an acid.	



## Reflections

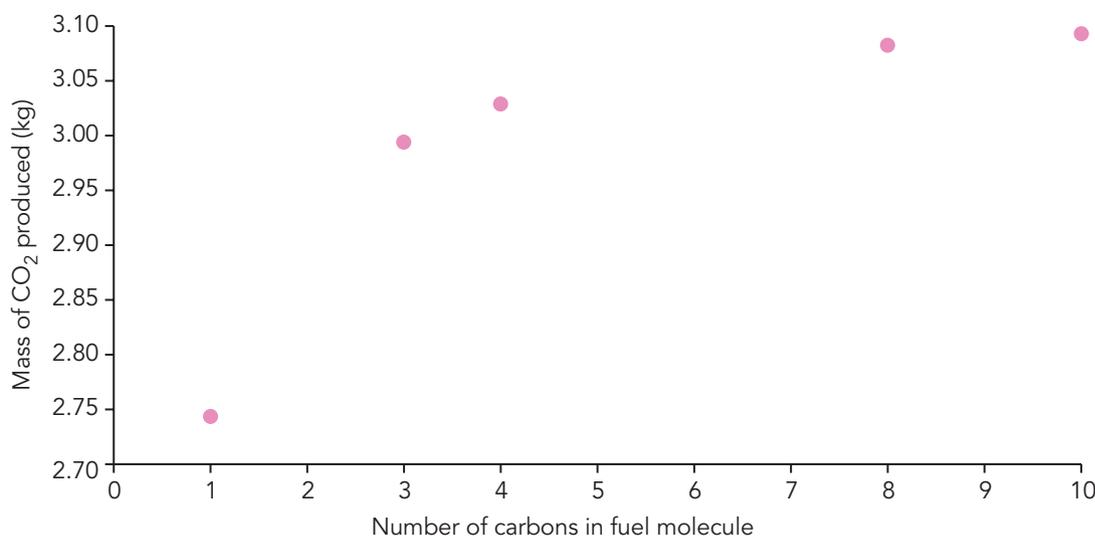
- 1 What **connections** come to mind when you think about chemical reactions and your everyday life?
- 2 What new concepts have **extended** your thinking about chemical reactions?
- 3 What information did you find **challenging** or confusing?

## Data questions

A variety of fuel sources is shown in Table 16.5, with the number of carbon atoms per fuel molecule and the mass of  $\text{CO}_2$  produced by burning 1 kilogram (kg) of each fuel.

	Number of reactant carbon atoms per molecule	Mass of $\text{CO}_2$ produced (kg)
Natural gas	1	2.74
LPG	3	2.99
Butane	4	3.03
Petrol 91	8	3.08
Petrol 98	8	3.08
Diesel	10	3.09
Coal	Varies	3.66

**Table 16.5** Number of carbon atoms per fuel molecule and the mass of  $\text{CO}_2$  produced by burning 1 kg of fuel.



**Figure 16.52** Number of carbon atoms per fuel molecule vs the mass of  $\text{CO}_2$  produced by burning 1 kg of fuel

- Identify** the fuel that produces the lowest mass of carbon dioxide per kilogram burned.
- A premium unleaded (petrol 98) brand has stated that their fuel produces less carbon dioxide emissions than a petrol 91 brand. **Determine** whether this statement is correct.
- A coal mining company has argued that the mass of carbon dioxide produced by burning 1 kg of their fuel is under 1 kg more than that produced from natural gas. **Determine** whether the evidence from Table 16.5 supports this claim.
- Identify** the trend between the number of carbon atoms per reactant molecule and the mass of carbon dioxide produced.
- At atmospheric temperature, generally fuel molecules with four carbons or less are gaseous fuels, while those with five or more carbons are liquid fuels. Coal is a solid fuel. **Classify** the fuels in Table 16.5 as gas, liquid or solid.
- A fuel company is producing a new biofuel made primarily from ethanol, which is a molecule with two carbon atoms. **Predict** the mass of carbon dioxide that would be produced by burning 1 kg of this fuel.
- Given the mass of carbon dioxide produced by burning coal, **deduce** the likely density of carbon atoms.
- Extrapolate** the data to predict the mass of carbon dioxide that would be produced by burning a fuel with a number of carbon atoms per molecule of 11.

## STEM activity: Baristas and the curdling milk problem

### Background information

Curdling is the process of coagulation that occurs when the protein components in the milk clump together. Certain blends of coffee can be quite acidic, and acid causes the proteins in milk to unravel and clump together, similar to what happens when an egg is boiled and the yolk solidifies. Soy milk is particularly susceptible to curdling.

As with many chemical reactions, temperature can affect the rate at which the reaction occurs. If you add lemon juice or vinegar to hot milk, the milk will curdle almost immediately due to the acidity (low pH), but adding it to cold milk will not produce a reaction for quite some time.

**Design brief:** Create an infographic for baristas, based on your experimentation results, for best practice with milk. Use images from your experimentation process.

### Activity instructions

You will propose the best pH, temperature and ratio of coffee to milk volume for a range of milk types in order to prevent curdling.

NOTE: an infographic is a visual representation of information, designed to make the data and information easy to understand at a glance.

#### Be careful

No food is to be consumed. Care is to be taken when handling boiling water.

### Suggested materials

- white vinegar or fresh lemon juice (both have a pH of approximately 2)
- instant coffee
- a range of different milks, including normal milk and soy milk
- water
- beakers, measuring cylinders, pipettes

- spoons or stirring rods
- kettle
- paper towels
- thermometer
- data-logging pH meter or alternative method for measuring pH

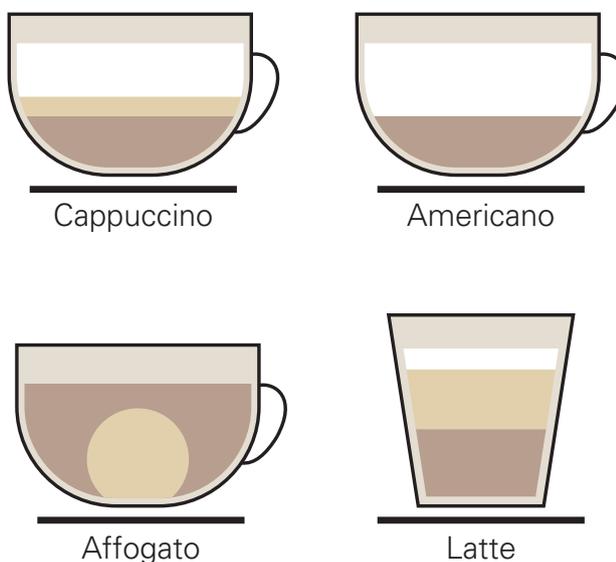


Figure 16.53 An infographic showing the various coffee, milk and froth ratios for different types of coffee drinks

### Research and feasibility

- 1 Research the process of how milk curdles and list all the factors.
- 2 Research and list the ingredients that are used in barista-made coffee, and the ratios involved. Take note of any temperatures and pH values of the ingredients. Make sure you include research on all the suggested materials.

### Design and sustainability

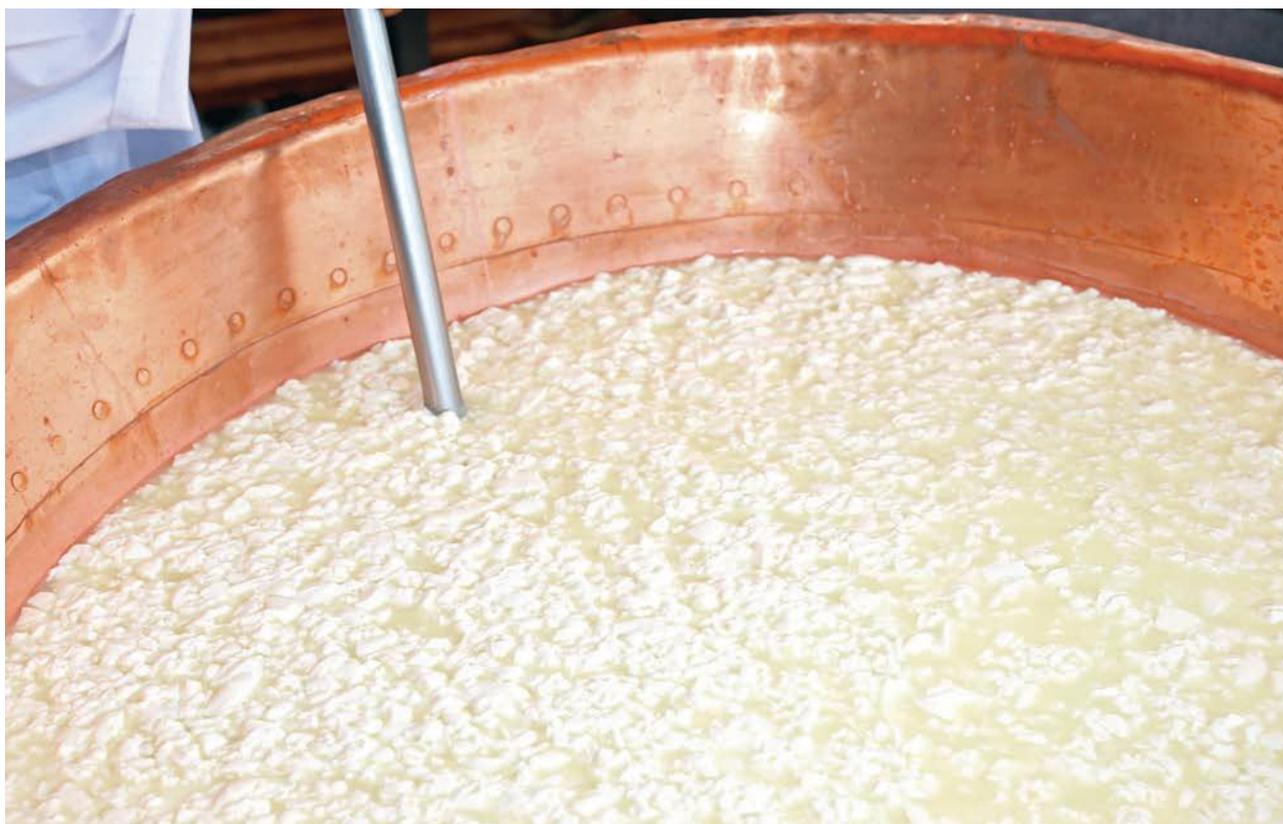
- 3 Design an experiment that demonstrates the conditions under which combining coffee and milk results in either curdling the milk or achieving a smooth texture. Think about how milk curdles and see if you can replicate this situation.

**Create**

- 4 Perform your experiment, ensuring you take photos and notes of all observations of the experiment along the way.
- 5 Create an A5 'cheat sheet' for baristas using infographics so they can easily identify the ratios possible for normal milk and soy milk with the most acidic coffee blends. You may do this by hand or search for free infographic design tools on the internet.

**Evaluate and modify**

- 6 Discuss your findings with your colleagues and present your infographic.
- 7 Propose the best ratio of coffee to milk for preventing the curdling of milk for acidic coffee blends with different milk products.
- 8 Identify possible sources of error in your testing procedure and suggest some ways to improve and modify your experiments in the future.
- 9 Predict how the temperature of the milk may have affected your findings.



**Figure 16.54** Australians drink nearly 4 billion cups of coffee each year, so it is important to know what situations cause milk to curdle in coffee.

# Chapter 17

## Rates of chemical reactions

### Inquiry questions

How can the rates of chemical reactions be monitored?

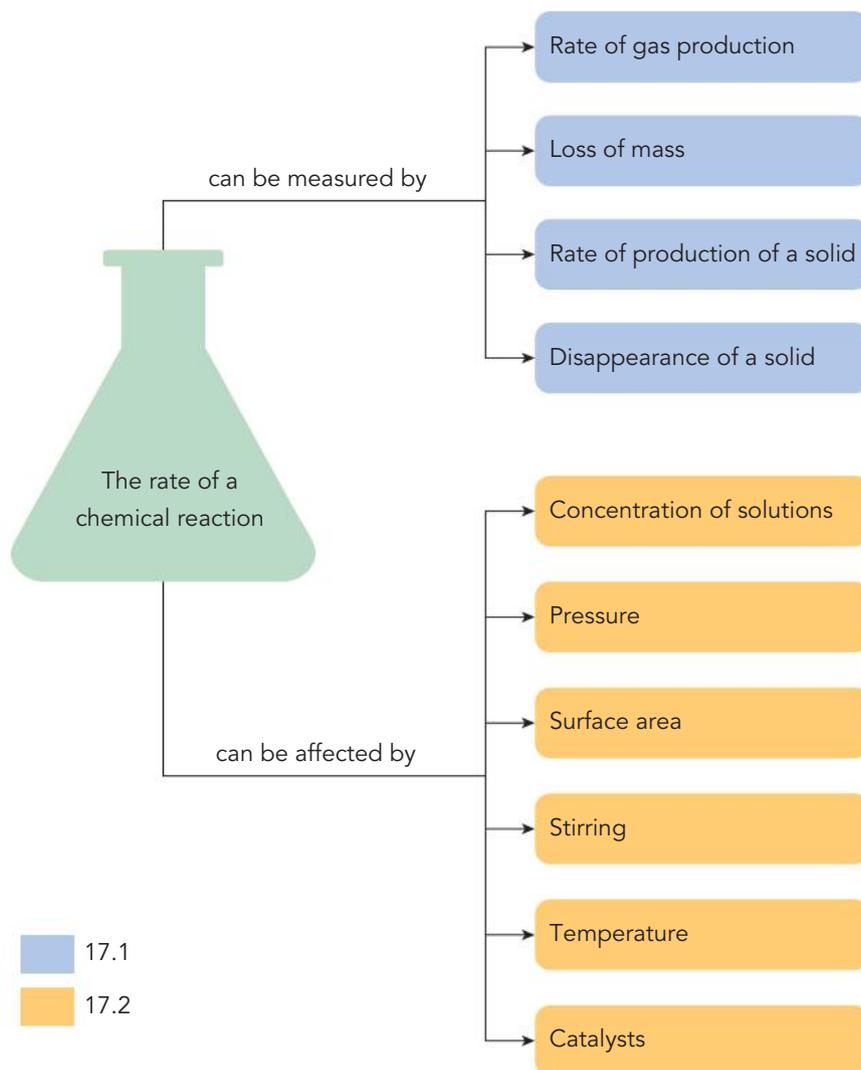
How do different factors affect the rate of chemical reactions?



### Chapter introduction

The chemical industry produces a large number of useful substances in vast quantities, many of which we could not do without. Monitoring chemical reactions is a crucial part of determining the optimum reaction conditions required for the fast and efficient production of these substances. In this chapter, you will investigate factors that can affect the rates of chemical reactions and how these rates can be monitored.

# Chapter map



# 17.1 Measuring reaction rates

## Learning goals

- 1 To recall how the rate of chemical reactions is measured
- 2 To describe how the rate of different chemical reactions can be monitored experimentally
- 3 To interpret the rate of chemical reactions graphically



The **reaction rate** of a chemical reaction can be found by measuring the quantity of a reactant used or the quantity of product formed over time.

$$\text{reaction rate} = \frac{\text{quantity of reactant used up}}{\text{time}}$$

$$\text{reaction rate} = \frac{\text{quantity of product formed}}{\text{time}}$$

### reaction rate

the quantity of reactant or product used up or made per unit time; how fast the reaction goes

The quantity of a reactant or product can be measured by its mass (in grams) or volume (in millilitres). Therefore, the

units for rate of reaction may be given as g/s ( $\text{g s}^{-1}$ ) or mL/s ( $\text{mL s}^{-1}$ ). The quicker a product forms or a reactant is used up, the faster the rate of reaction.

Various methods can be used to monitor the rate of a chemical reaction. It is important for you to be able to determine the method that would be most suitable for certain types of reactions.

## Measuring the rate of gas production

### Upturned measuring cylinder

An upturned measuring cylinder, filled with water and placed in a trough of water, can be used to measure the volume of gas produced in a reaction over a set period of time. In this technique, the volume of displaced water is measured, as this is the same as the volume of gas produced. Figure 17.1 shows the set-up for this method of measuring reaction rates.

In this example, the magnesium reacts with the acid to produce hydrogen gas, which travels through the delivery tube and collects in the measuring cylinder,

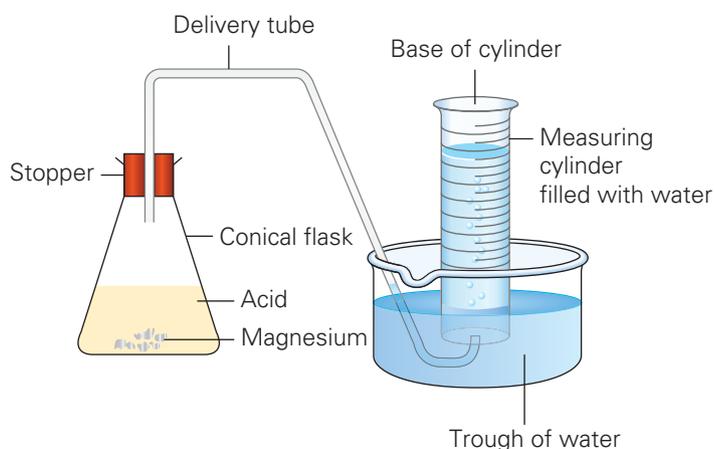


Figure 17.1 Diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

displacing the same volume of water. This lets you measure the total volume of gas produced over a certain time. As volume is the dependent variable, the unit of rate will be mL/s.

### Gas syringe

Gas syringes directly collect the volume of gas produced by a reaction. Figure 17.2 shows a gas syringe set-up. The increased pressure inside the syringe causes the plunger

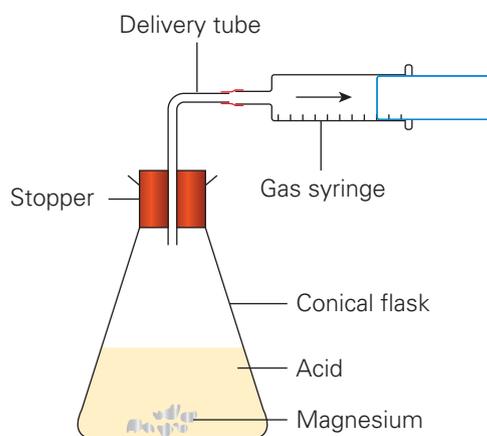


Figure 17.2 Diagram showing how to set up a gas syringe to monitor reaction rate

to move outwards. The volume of gas produced in a certain time can be recorded using the scale. Again, as volume is the dependent variable, the units of rate will

be mL/s. Gas syringes are more accurate than measuring cylinders, but they may not be as practical depending on the amount and rate of gas produced.

### Quick check 17.1

- Determine which of the following reactions can have their rate monitored using a gas syringe. Give reasons for your choice.
  - $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
  - $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $\text{Zn}(\text{s}) + \text{CuSO}_4(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{ZnSO}_4(\text{aq})$
  - $\text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{O}_2(\text{g})$
- Name one reason why a gas syringe might be used rather than an upturned measuring cylinder for measuring reaction rates.
- What are the units of rate when measuring the volume of gas produced?

## Measuring the rate of mass loss

In this method, the reaction vessel is placed on top of an electronic balance. As gas is lost into the atmosphere, the mass of the reaction vessel decreases. The mass can be recorded at regular periods of time to determine the reaction rate. As mass is the dependent variable, the unit of rate is g/s. This method relies on gas loss into the atmosphere, so it can only be used for reactions that produce a gas.

Note that hydrogen gas is an **asphyxiant** and can explosively ignite in the atmosphere, so the use of a fume hood is required (using or producing any hazardous

substance should always be done under a fume hood to reduce exposure).

#### asphyxiant

a gas capable of displacing the oxygen in the air; can lead to an interruption of breathing and unconsciousness

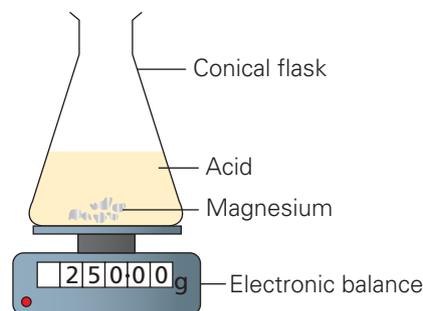


Figure 17.3 Diagram showing how reaction rate can be monitored by measuring loss of mass

### Quick check 17.2

- Determine which of the following reactions can have their rate monitored by measuring the loss of mass. Give reasons for your choice.
  - $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
  - $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $\text{Zn}(\text{s}) + \text{CuSO}_4(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{ZnSO}_4(\text{aq})$
  - $\text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{O}_2(\text{g})$
- Why might using an electronic balance be more accurate than using a gas syringe or upturned measuring cylinder?
- What are the units of rate when measuring the loss of mass in a reaction?

## Measuring the rate of solid production

The rate of the production of a solid in a reaction can be used as a way of monitoring the reaction rate. This can be done by collecting the precipitate (solid produced in a reaction) and weighing it, and thus producing a reaction rate in grams per second, g/s. However, in reality, it is not practical to collect a precipitate and weigh it as it is being formed because it forms in solution.

Another way for comparing relative reaction rates can be seen in the set-up in Figure 17.4. As the solid is produced, the cross beneath the conical flask will become more difficult to see. The time when the cross can no longer be seen is recorded and can be compared to the same reaction when variables are changed, such as concentration or temperature.

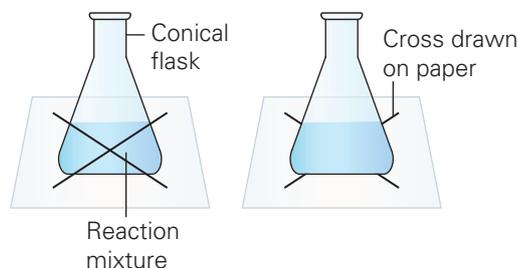


Figure 17.4 Diagram illustrating how to monitor the relative rate of a reaction in which a solid product is formed

### Quick check 17.3

- Determine which one or more of the following reactions can have their relative rate monitored using the time taken for a cross to disappear as shown in Figure 17.4. Give reasons for your choice.
  - $\text{Na}_2\text{CO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
  - $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $2\text{HCl}(\text{aq}) + \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) \rightarrow \text{S}(\text{s}) + \text{SO}_2(\text{g}) + 2\text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
  - $2\text{H}_2\text{O}_2(\text{l}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
- What are the units of rate when measuring the production of a solid in a reaction?

## Measuring rate of solid consumption

It is possible to record the time taken for a solid reactant to react with a liquid or solution. The weight of the solid is recorded at the start. Then the solid is placed into the liquid or solution. If the liquid is clear enough for the solid pieces to be observed, then the time taken for the solid to disappear can be recorded. The unit of rate for the consumption of solid is grams per second (g/s).

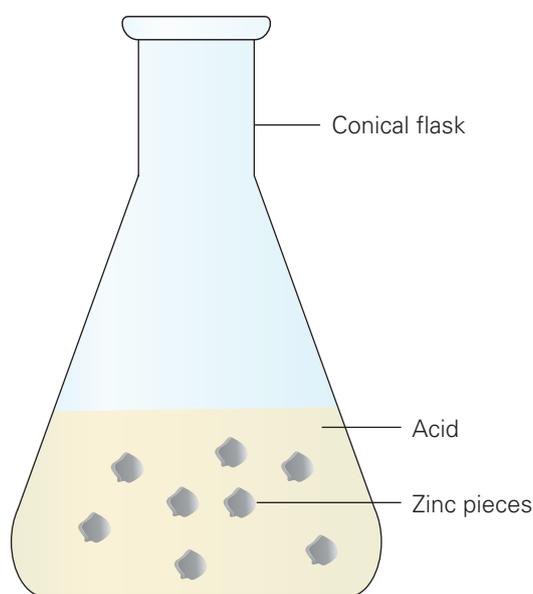


Figure 17.5 A reaction containing a solid and a liquid reactant can be monitored by eye if the solid pieces are large enough to be observed.

## Graphing experimental data

A number of measurements of mass or volume need to be collected at regular time intervals during the course of the reaction. After collecting data, graphs can be plotted to provide more information on the rate of a chemical reaction. The steeper the gradient on a graph, the faster the rate.

Consider the reaction between solid calcium carbonate and hydrochloric acid. The graph in Figure 17.6 shows that using powdered calcium carbonate produces a greater rate of reaction as it has a steeper gradient than when the calcium carbonate is in granule form. The reason for this is explained in Section 7.2.

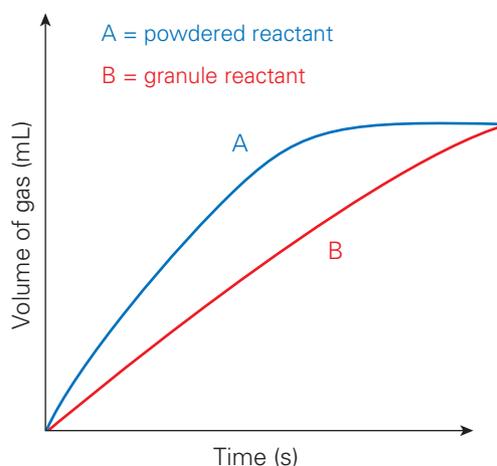


Figure 17.6 A graph showing the effect of surface area on the volume of gas produced over time

## Practical 17.1: Teacher demonstration

### Monitoring reaction rates

#### Aim

To determine how the surface area of zinc affects the rate of reaction with nitric acid, by using the upturned measuring cylinder technique.

#### Prior understanding

Although you are changing the mass of zinc in this experiment, you are actually changing the surface area of the metal. In this experiment, the nitric acid is in excess to each of the masses of zinc, so by increasing the mass, you are actually increasing the surface area. By measuring the volume of gas produced after one minute, the effect of increasing the surface area of the zinc on the reaction rate can be determined.

#### Materials

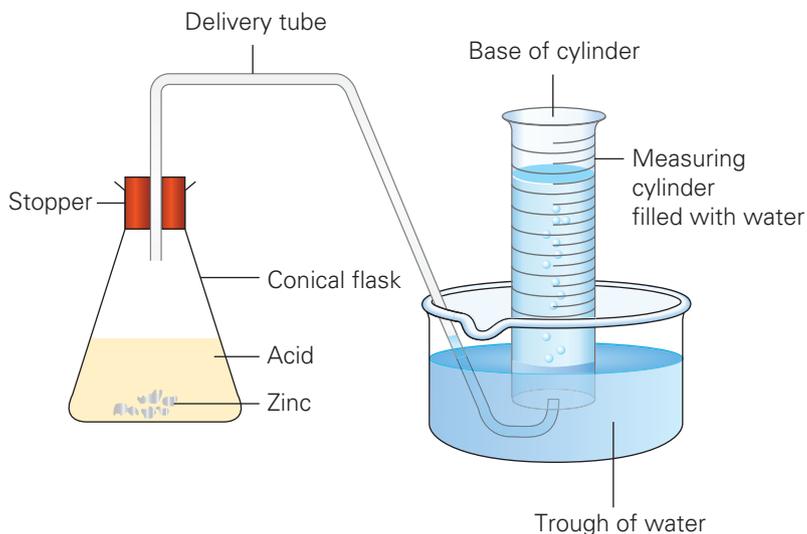
- zinc powder
- nitric acid (2 M)
- 25 mL measuring cylinder
- 50 mL measuring cylinder
- 250 mL conical flask
- large bowl
- 1 stopper and delivery tube
- weighing boat
- bosshead and clamp
- electronic balance
- stopwatch

#### Planning

- 1 Write a hypothesis for your investigation regarding the effect that the mass of zinc will have on the rate of the reaction.

#### Procedure

- 1 Draw the table shown in the results section into your science journal.
- 2 Half fill the large bowl with water.
- 3 Fill a 50 mL measuring cylinder with water and carefully invert it in the large bowl of water. Do not lose any water out of the measuring cylinder.
- 4 Clamp the measuring cylinder in place using a bosshead and clamp.
- 5 Using the 25 mL measuring cylinder, measure 20 mL of 2 M nitric acid and pour the acid into the conical flask.
- 6 Using the electronic balance, measure 0.5 g of zinc powder into a weighing boat.
- 7 Set up the delivery tube so the end without the stopper runs underneath and into the upturned measuring cylinder (see Figure 17.7 to help you).
- 8 Pour the zinc powder into the conical flask containing the acid. At the same time, put the stopper on top of the flask and start the stopwatch.



**Figure 17.7** Diagram showing how to set up an upturned measuring cylinder to monitor reaction rate

*continued...*

...continued

- 9 After one minute, record the volume of water displaced from the measuring cylinder. This is the same as the volume of gas produced.
- 10 Repeat once more with the same mass of zinc powder.
- 11 Repeat the steps 3–10 for the other masses of zinc powder.

### Results

Mass of zinc (g)	Volume of gas collected after 1 minute (mL)		
	1	2	Mean
0.50			
1.00			
1.50			
2.00			

### Discussion

- 1 Calculate the mean volume of gas released for each mass of zinc.
- 2 List the independent and dependent variables in this investigation.
- 3 Identify three controlled variables.
- 4 Plot a graph with mass on the  $x$ -axis and volume of gas on the  $y$ -axis.
- 5 What does your graph tell you about the relationship between the mass (that is, surface area) of zinc and reaction rate?
- 6 List other methods you could have used to monitor the rate of this reaction.

### Conclusion

- 1 Make a claim about the effect of the surface area of zinc on the rate of the reaction in this experiment.
- 2 Support your statement by using the data you gathered and include potential sources of measurement uncertainties or experimental faults.
- 3 Explain how the data supports your statement.

## Explore! 17.1

### Using colorimetry to monitor reaction rates

Research the process of using a colorimeter to monitor the rate of a chemical reaction, and then answer the following questions.

- 1 For what type of reactions would colorimetry be a suitable method to monitor the rate?
- 2 How does a colorimeter allow for reaction rates to be studied?
- 3 How does the concentration of the solution affect the amount of light absorbed by the sample?
- 4 In the following reaction, the solution of iodine in propanone starts off brown. As the iodine is used up the solution turns orange, then yellow and eventually colourless.
 

propanone + iodine  $\rightarrow$  iodopropanone + hydrogen iodide

  - a Describe what you would expect the readings from the colorimeter to look like as the reaction progresses.
  - b Sketch a graph of the results you would expect (concentration of iodine on the  $x$ -axis and absorbance on the  $y$ -axis).

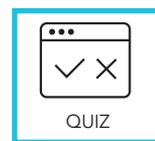


Figure 17.8 A scientist placing a sample for testing in a colorimeter

## Section 17.1 questions

## Remembering

- 1 **Name** two ways of monitoring the production of a gas from a chemical reaction.
- 2 **Identify** appropriate units of rate for the following methods of measuring reaction rates:
  - a loss of mass
  - b production of a solid
  - c gas syringe.
- 3 **Identify** the missing words to complete the following sentences:
  - a The greater the rate of reaction, the \_\_\_\_\_ the reactants are used up.
  - b The steeper the gradient on a volume versus time graph, the \_\_\_\_\_ the rate of reaction.

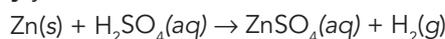


## Understanding

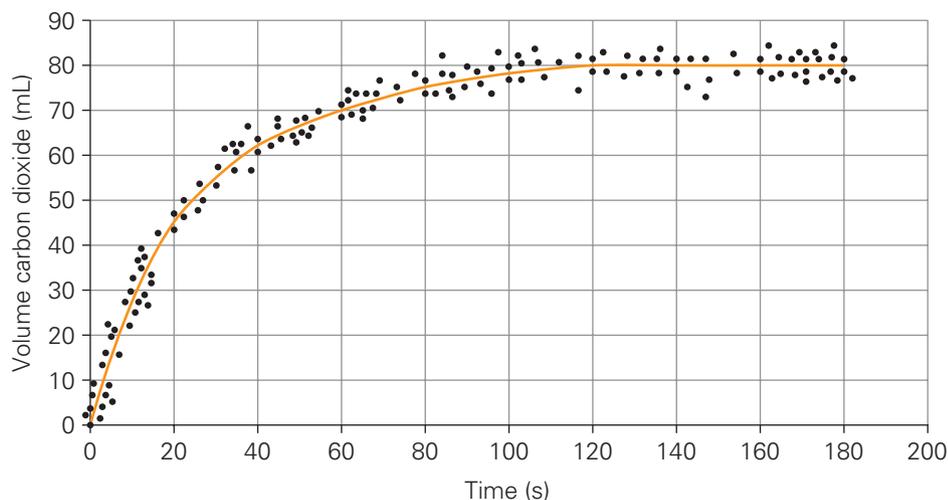
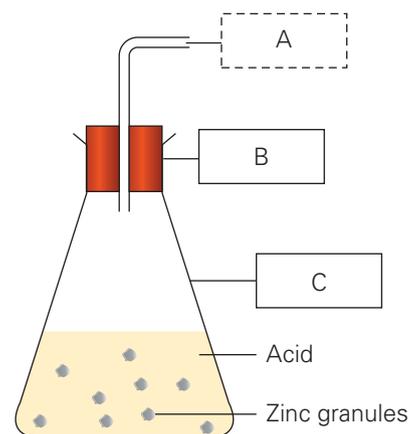
- 4 **Describe** what is meant by the term 'rate of reaction'.
- 5 **Explain** why the rate of reaction is greatest at the beginning.
- 6 **Demonstrate** by way of a labelled diagram how you could monitor the rate of a gas-producing chemical reaction using an upturned measuring cylinder.

## Applying

- 7 **Select** the most accurate technique to monitor the rate of this chemical reaction. **Justify** your choice.



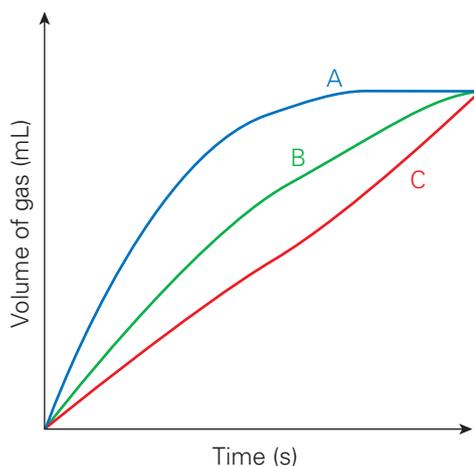
- 8 The diagram shows how a gas can be collected, and therefore, the rate of reaction measured. **Draw** or **determine** the missing component A and **identify** the label for B and C.
- 9 **Identify** the time period during this experiment shown in the graph which showed the fastest rate of reaction. **Justify** your choice.



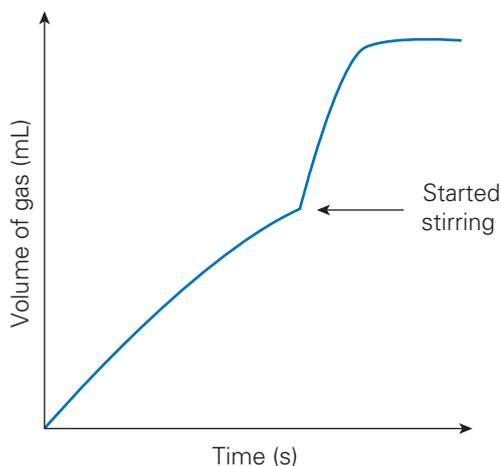
- 10 During an experiment, 45 mL of carbon dioxide was collected in 90 seconds. **Calculate** the rate of reaction and give appropriate units. Show your working.
- 11 **Construct** a word equation for a reaction that can be monitored by timing the disappearance of a solid.

**Analysing**

**12 Contrast** the rates of reaction for the three experiments shown in the following graph.



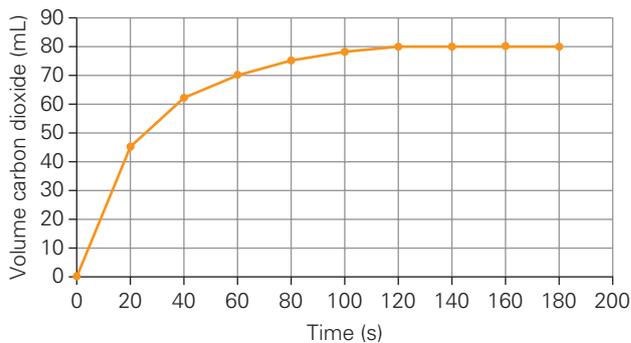
**13 Analyse** how stirring the reaction mixture affected the rate of this chemical reaction.



**14** On a rate graph, **determine** how the start and end of a reaction can be distinguished.

**Evaluating**

**15** Use the graph to answer the questions.



- Explain**, using your knowledge of chemical reactions, why between 120 and 180 seconds the volume of carbon dioxide stays the same in this experiment.
- Deduce** the value for the rate of the reaction during this time period.

## 17.2 Factors affecting reaction rates

### Learning goals

- 1 To recall factors that can affect the rate of a chemical reaction
- 2 To describe how some factors affect chemical reaction rates
- 3 To explain how and why factors such as temperature or a catalyst can affect reaction rates

It is important to know how the rate of a chemical reaction can be increased, particularly in industry, where producing the maximum amount of product with the greatest efficiency is crucial.

For a chemical reaction to occur, reactant particles must collide with one another to form the products. However, not all **collisions** are successful ones. This is because reactant particles must also collide with at least a certain level of energy, unique to each chemical reaction, called the **activation energy**. The activation

energy is the minimum energy required to break bonds in the reactants so they are able to form new bonds and make the products. If you can increase the frequency (number) of collisions and/or reduce the energy required for a successful collision (activation energy), you can increase the rate of reaction.



#### collisions

particles must collide for a chemical reaction to occur

#### activation energy

the minimum energy required for a successful collision and therefore to start a reaction

### Quick check 17.4

- 1 Give two requirements for a successful chemical reaction.
- 2 Give the definition of the term 'activation energy'.

**Figure 17.9** Industrial chemical plants rely on knowledge of reaction rates to produce maximum amounts of product in minimal amounts of time.



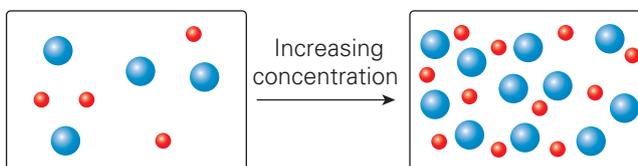
## Concentration

The **concentration** of a solution is a measure of the number of particles per unit volume. A solution which contains a large number of solute particles within a given volume of solvent is called a **concentrated solution**.

Likewise, a solution which contains a small number of solute particles within a given volume of solvent is called

a **dilute solution**. Increasing the concentration of a solution means that you are putting more particles into the same volume.

If the concentration of a solution is increased, the



**Figure 17.10** Increasing the concentration of a solution increases the number of particles within the same volume.

particles are more likely to collide, and therefore, the reaction rate will increase. It is a bit like cramming lots of people onto a bus – it gets a bit tricky to avoid bumping into each other!

Although increasing the concentration increases the frequency of collisions, it does not affect the activation energy. Particles still need to collide with the same activation energy for collisions to be successful.

### concentration

the amount of substance in a given volume

### concentrated solution

a solution which contains a large amount of solute compared to solvent

### dilute solution

a solution which contains a small amount of solute compared to solvent

## Quick check 17.5

Decide whether the following statements are true or false.

- A dilute solution contains a large number of reactant particles in a given volume.
- Increasing the concentration of a reactant only affects the frequency of collisions.

## Practical 17.2

### Concentration and reaction rate

#### Aim

To determine how changing the concentration of sodium thiosulfate affects the rate of reaction with hydrochloric acid.

#### Materials

- hydrochloric acid (2 M)
- sodium thiosulfate solution (0.15 M)
- 250 mL conical flask
- 10 mL measuring cylinder
- 50 mL measuring cylinder
- stirring rod
- 1 piece of white paper
- black marker pen
- stopwatch

#### Planning

Construct a hypothesis regarding how the sodium thiosulfate concentration will affect the reaction rate.

#### Procedure

- Draw the table shown in the results section into your science journal.
- Using the black marker, draw a large 'X' on the paper.

#### Be careful

Ensure appropriate personal protective equipment is worn. This experiment must be performed in a fumehood. Do not breathe in fumes when making observations.

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- Using a 50 mL measuring cylinder, measure 50 mL of sodium thiosulfate and pour it into the 250 mL conical flask. In the fumehood, centre the conical flask on the black cross (Figure 17.11).
- Using the 10 mL measuring cylinder, measure 5 mL of hydrochloric acid.
- Pour the acid into the conical flask, stir with a stirring rod and start the stopwatch.
- Stop timing when the cross is no longer visible and record the time in your results table.
- If available, dispose of the reaction mixture in a fume cupboard, otherwise pour it down the sink, rinsing with lots of cold water (taking care not to splash).
- Repeat the steps 3–7 for each concentration of sodium thiosulfate in the results table. The concentration of the sodium thiosulfate you add does not change (it is 0.15 M); however, adding water dilutes the solution.

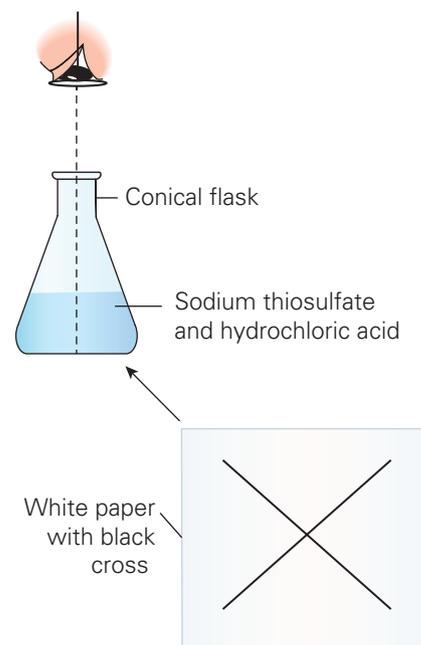


Figure 17.11 Diagram of centring the 'X' under the conical flask

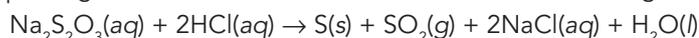
### Results

Concentration of sodium thiosulfate (M)	Volume of sodium thiosulfate (mL)	Volume of water (mL)	Time taken for cross to disappear (s)	Reaction rate (1/time) $\frac{1}{\text{time}}$ (/s)
0.15	50	0		
0.12	40	10		
0.09	30	20		
0.06	20	30		
0.03	10	40		

- Work out the relative rate of the reaction by calculating:  $\frac{1}{\text{reaction time}}$ .
- Plot a graph of concentration (x-axis) versus rate (y-axis).

### Discussion

- Using your graph, describe how increasing the concentration of sodium thiosulfate affects the rate of this chemical reaction.
- Explain why increasing the concentration of a reactant normally increases the rate of reaction.
- Explain why the disappearing cross method was suitable for this reaction, using the equation below:



### Conclusion

- State a conclusion regarding the concentration of sodium thiosulfate and the effect this has on the rate of reaction.
- Support your statement by using the data you gathered.

**pressure**

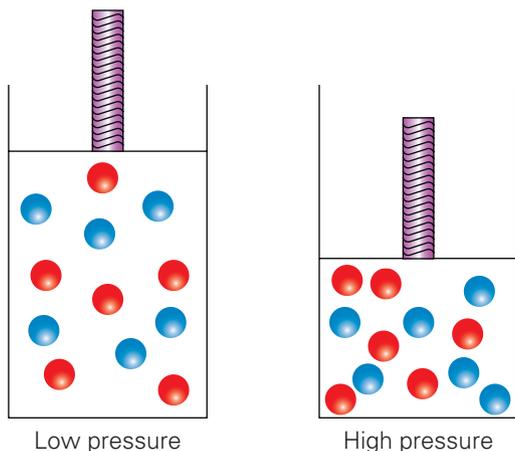
the force produced by collisions of gas particles per unit area of the container walls

**surface area**

the area of the outer part or surface of an object

**Pressure**

To increase the **pressure** of gaseous molecules, you can increase the number of particles and/or decrease the volume of the container.



**Figure 17.12** Reducing the volume of the container increases the pressure of gaseous molecules.

Gaseous particles under a high pressure are more likely to collide as there are more molecules within a smaller volume. Therefore, increasing the pressure increases the rate of reaction. This can only happen if one of the reactants is a gas, because solid and liquid particles are nearly impossible to compress. It is a bit like the comparison between a class of 30 students running around a sports hall with the same class running around in an English classroom. The smaller space increases the pressure, meaning you are more likely to collide. The energy with which you collide, however, is not affected.

**Quick check 17.6**

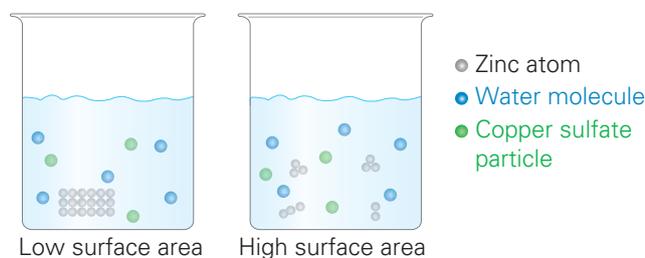
- 1 Why does increasing the pressure of solid and liquid reactants not affect reaction rate?
- 2 How can the pressure of a gas be increased?

**Surface area**

When solids react, it is only the particles on the surface, which are in contact with the other reactant, that react. If you can make the solid reactant smaller, by cutting it into pieces or grinding it into a powder, then the **surface area** is increased and more particles are exposed. Imagine a cake: when its surface area is increased by cutting into smaller pieces, there is a greater area of the cake exposed to the air, and therefore, it will dry out more quickly.



**Figure 17.13** Cutting a cake into pieces increases its surface area.



**Figure 17.14** To increase the surface area of a solid reactant, cut it into smaller pieces or grind it into a powder.

Increasing the surface area of a solid will cause the reaction rate to increase. This is because there are more particles exposed to the reaction, increasing the frequency of collisions. However, just like increasing the concentration, the energy with which the particles collide is not affected.

**Did you know? 17.1****Swallow, don't crush**

The pharmaceutical industry manufactures a wide variety of medicines through chemical reactions to produce a specific chemical to help an immune response or reduce pain. Often pharmaceutical medicines are sold in tablet form and are meant to be swallowed in that form – not crushed! The chemicals in the tablet can react with stomach acid to release the active ingredients into the bloodstream in a controlled fashion. However, if the tablet is crushed, the surface area of the reactant is increased and this reaction in the stomach becomes much faster and less controlled. Therefore, there is a possibility of overdosing, or other side effects may occur, as the medicine has been released into the body too quickly. Moreover, it might also render the medicine less effective. Pharmaceuticals in tablet form are designed not only to provide you relief from illness but also to provide the medicine over the right amount of time.



**Figure 17.15** If swallowing tablets is difficult, it may be worthwhile asking a pharmacist whether the medicine comes in other forms.

**Quick check 17.7**

- 1 Give two ways that the surface area of a solid can be increased.
- 2 A chemical reaction contains two different gaseous reactants. Can increasing their surface area increase reaction rate? Justify your answer.
- 3 Why does increasing the surface area of a solid reactant increase reaction rate?

**Try this 17.1**

Make three cups of hot weak tea (so you can still see the bottom of the cup), filled to the same height. Place a sugar cube in cup 1, a level teaspoon of granulated sugar in cup 2 and a level teaspoon of icing sugar in cup 3. Time how long it takes for the sugar in each cup to dissolve. After reading this section, you should be able to make a prediction about surface area and rate at which sugar dissolves.



**Figure 17.16** Sugar comes in various forms for various uses.

## Practical 17.3

### Surface area and reaction rate

#### Aim

To investigate how changing the surface area affects reaction rate.

#### Prior understanding

Rhubarb contains oxalic acid (toxic in large doses) which will react with pink-coloured acidified potassium permanganate to form colourless manganese(II) ions. This provides an ideal end point for measuring the rate of reaction.

#### Materials

- 2 x measuring cylinders (250 mL and 50 mL)
- 3 x 50 mL beakers
- 500 mL conical flask
- potassium permanganate crystals
- 1 M sulfuric acid
- white tile
- rhubarb stalks with leaves removed (Note: there is variation in the oxalic acid found in different stalks. Check if the stalks produce a result with the concentration of acidified potassium permanganate. Radish could be used as a replacement.)
- cutting tile
- knife
- 30 cm ruler
- stopwatch
- tweezers

#### Planning

- 1 Identify the independent variable from the clue in the aim, and describe the different groups that will be set up for the experiment.
- 2 Define the dependent variables and how they will be measured.
- 3 Identify and list the controlled variables to be monitored. For each variable, you must define the property that will be measured (numerically if possible) to ensure they are not changing throughout the experiment, e.g. temperature (to be maintained at 25°C).
- 4 Develop a hypothesis by predicting how a change in the independent variable will affect the dependent variable.
- 5 Write a risk assessment for this investigation.
- 6 Create a results table that will allow you to collect sufficient and relevant raw data, in addition to calculating the mean and uncertainty.

#### Procedure

##### Part 1: Prepare the potassium permanganate solution

- 1 Add two potassium permanganate crystals to 150 mL of 1 M sulfuric acid and stir well. Add another 150 mL of 1 M sulfuric acid to this solution, resulting in a light purple colour.

##### Part 2: Prepare the rhubarb

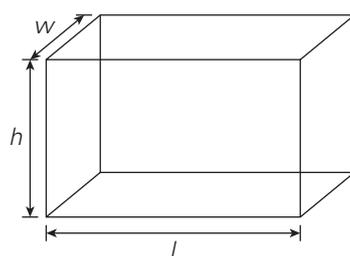
- 1 Cut nine identical lengths of rhubarb, ensuring they are as uniform as possible. You may need to use your knife to create straight edges and remove any excess.

#### Be careful

Risk of acid burns. Ensure appropriate personal protective equipment is worn. Wear safety glasses at all times. No food items are to be consumed.

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$$SA = 2lw + 2lh + 2wh$$

Figure 17.17 Calculating the surface area of a cube

- Take three of the lengths and calculate the approximate surface area of one of these lengths by using the calculation shown above. This will be your 'low' surface area rhubarb samples.
- Take another three of the lengths and cut them each in half. Calculate the total surface area for the two halves. This will be your 'medium' surface area rhubarb.
- Take another three of the lengths and cut them into four even pieces. Again, calculate the total surface area for the four quarters. This will be your 'high' surface area rhubarb and should be smallest in size compared to the other pieces from step 2 and 3.

### Part 3: Measure the reaction time

- Add 30 mL of acidified potassium permanganate to a beaker and place on a white tile. You may want to have a beaker of water next to the reaction beaker for a comparison.
- Using tweezers, add a piece of the low surface area rhubarb to the beaker. Be careful not to splash the acid.
- Immediately start the stopwatch. Stir the solution until the purple colour disappears, then stop the timer. Record the time it takes for the colour to disappear.
- Empty, wash and dry the reaction beaker.
- Complete **Part 3** steps 1–3 twice more with another piece of low surface area rhubarb.
- Repeat steps 1–4 with the other samples.

### Results

- Calculate the mean reaction rate for each rhubarb sample.
- Draw a scatter plot to analyse the relationship between the numerical independent variable and its dependent variable.
- Draw a graph and insert a copy below the results table into your science journal.

### Discussion

- Describe any trends, patterns or relationships that are found in your results.
- Use your graph to predict the value of the dependent variable if you were given rhubarb pieces that were halfway between the sizes of the medium and high surface area group.
- Extrapolate your data to predict the value of the dependent variable if you were given rhubarb pieces that had been cut into eight pieces.
- How much variation was observed between the measurements between different student groups within the class?
- Were other variables that could affect the validity of the results successfully controlled during the experiment?
- Suggest any other changes that could be made to the method to improve the validity of the results in future experiments.

### Conclusion

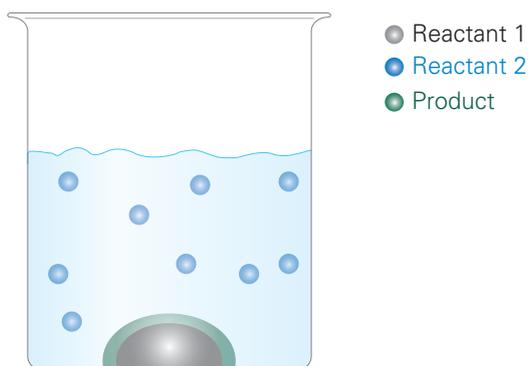
- Propose a conclusion regarding the type of relationship between the surface area of the rhubarb and reaction rate. Justify your answer with data.
- Use your own knowledge and scientific research to explain the theory behind your conclusion.

## Stirring (agitation)

**agitating**  
stirring or shaking a mixture

Stirring or **agitating** a chemical reaction increases

the reaction rate as it allows more of the reactant particles to collide with one another. When a chemical reaction is left undisturbed (like the one in Figure 17.18), the product forms on the surface of the solid reactant, creating a barrier for any further reaction. Like increasing concentration and surface area, stirring a chemical reaction only increases the frequency of collisions, not the activation energy.



**Figure 17.18** Stirring this reaction mixture would allow all of reactant 1 to come into contact with reactant 2.

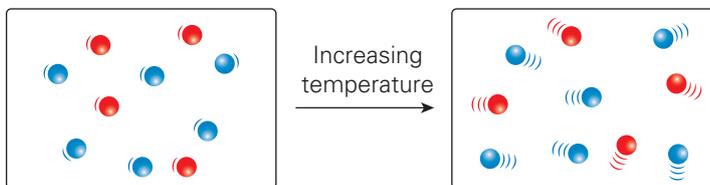
### Quick check 17.8

Why does stirring increase reaction rate?

## Temperature

When you increase the temperature of a reaction, the rate of reaction also increases. The thermal energy added to the reaction is converted into kinetic (movement) energy, so the particles move at greater speeds. Particles are therefore more likely to collide, and because they move at faster speeds, they are also more likely to collide at the reaction's activation energy.

Therefore, increasing the temperature of a reaction also increases the number of successful collisions. It is a bit like running in a corridor: if you are moving fast you are more likely to bump into someone *and* it is more likely to hurt!



**Figure 17.19** Increasing the temperature of a reaction increases kinetic (movement) energy of the reactant particles, increasing the number of successful collisions.

### Quick check 17.9

- 1 When heat is applied to a chemical reaction, what is the energy converted to at the particle level?
- 2 Why does increasing the temperature of a chemical reaction increase the frequency of successful collisions?

### Try this 17.2



**Figure 17.20** A chemical reaction causes glow sticks to release light.

Get three glasses and fill one with ice cold water, one with room temperature water and one with hot water. Crack three glow sticks and add one to each glass. Observe which one glows the brightest.

## Practical 17.4

### Temperature and reaction rate

#### Aim:

To determine the effect of temperature on reaction rate.

#### Materials

- 3 pieces of cleaned magnesium ribbon (3 cm in length)
- 2 M hydrochloric acid, initially at room temperature
- 10 mL measuring cylinder
- beaker
- 3 boiling tubes
- ice
- stopwatch
- thermometer
- Bunsen burner
- gauze
- tripod
- bench mat
- matches

Note that water baths or a hotplate may be used if available.

#### Planning

- 1 Create a research question that can be easily and safely investigated.
- 2 Write a hypothesis for your investigation regarding the effect of temperature on reaction rates.
- 3 Identify the independent and dependent variables in this investigation.
- 4 Give two controlled variables and why they needed to be controlled.

#### Procedure

- 1 Draw the table shown in the results section into your science journal.
- 2 Using the 10 mL measuring cylinder, measure 10 mL of the room temperature 2 M hydrochloric acid and pour it into the boiling tube.
- 3 Add one piece of magnesium ribbon to the acid and start timing immediately.
- 4 Time how long it takes for the magnesium to disappear and record this time into the results table.
- 5 Repeat another two times.
- 6 Using either a Bunsen burner, water bath or hotplate, heat a beaker of water to 40°C. This will be your water bath.
- 7 Once your water bath has reached 40°C, reduce the heat to maintain the temperature, but not allow it to increase.
- 8 Measure another 10 mL of 2 M hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your water bath and wait for it to reach the same temperature as the water. Switch off the hotplate or Bunsen.
- 9 Repeat steps 3–5.
- 10 Finally, create a cold ice bath by placing ice in a beaker of water.
- 11 Measure another 10 mL of 2 M hydrochloric acid and pour it into the boiling tube. Place this boiling tube in your cold ice bath and wait for it to reach the same temperature as the water.
- 12 Repeat steps 3–5.

#### Be careful

Hydrochloric acid is corrosive.

Heat the hydrochloric acid using a water bath only. Do not heat the acid directly with the Bunsen burner or hotplate.

Do not seal the boiling tube while reacting the acid and magnesium.

Wear safety glasses.

Work under a fume hood.

*continued...*

...continued

**Results**

Temperature (°C)	Time taken for magnesium to disappear (s)				Uncertainty
	Trial 1	Trial 2	Trial 3	Mean	

- 1 Calculate the mean time taken for the magnesium to disappear at each temperature.
- 2 Calculate the uncertainty for each set of trials at each temperature.
- 3 Plot a graph of your results, including a line of best fit.
- 4 Extrapolate your graph to predict the time it would take for the magnesium to disappear at 50°C and 60°C.

**Discussion**

- 1 Identify any patterns, trends or relationships in your results.
- 2 Write a word equation for the reaction of magnesium (Mg) with hydrochloric acid (HCl) to form magnesium chloride (MgCl<sub>2</sub>) and hydrogen gas (H<sub>2</sub>).

**Conclusion**

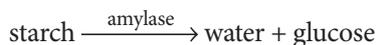
- 1 State a conclusion regarding the effect of temperature on reaction rate based on this experiment.
- 2 Support your statement by using the data you gathered.
- 3 Explain how the data support your statement.

**Catalysts**

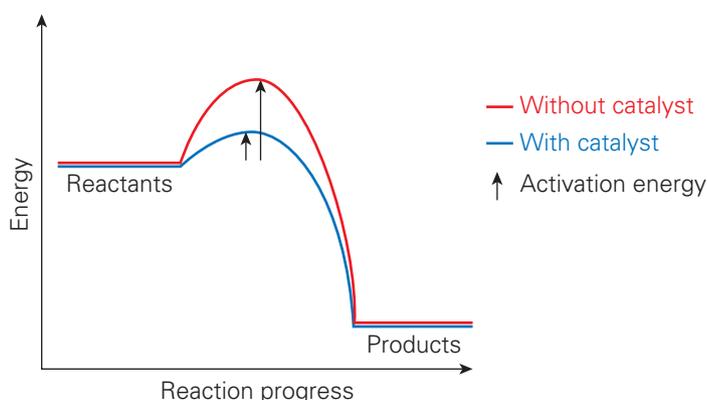
A **catalyst** is a substance that can be added to a chemical reaction to increase the reaction rate. During the reaction the catalyst is not used up and therefore it is not part of the reaction product. That is why the catalyst is not included in the chemical reaction, but it is often

**catalyst**  
speeds up a chemical reaction by lowering the activation energy; does not get used up in the process

written above the reaction arrow between the reactants and products as in the equation below.



When you eat carbohydrate-rich foods, the starch molecules are reacted with water and broken down into glucose. The enzyme amylase, which is found in your saliva, acts to catalyse (speed up) this reaction. Catalysts increase the reaction rate by providing an alternative route, which has a lower activation energy, for the reaction.



**Figure 17.21** Adding a catalyst to a chemical reaction decreases the activation energy and therefore increases the number of successful collisions and therefore reaction rate.

It is a bit like sheep jumping over a fence. The sheep are the reactant particles and the fence is the activation energy. If the fence (activation energy) is high, fewer sheep (particles) will reach the other side (there will be fewer successful collisions) On the other hand, if the fence is lowered by adding a catalyst, more sheep will be able to jump the fence (there will be a greater number of successful collisions).

## Quick check 17.10

- 1 What is a catalyst?
- 2 How does a catalyst speed up a chemical reaction?

## Practical 17.5

## Catalysts and reaction rate

## Aim

To determine the most effective catalyst to decompose hydrogen peroxide.

## Materials

- 0.5 g manganese(IV) oxide
- 0.5 g iron(III) oxide
- 50 vol hydrogen peroxide solution
- 1 cm<sup>3</sup> piece of potato
- 1 cm<sup>3</sup> piece of liver
- 1 cm<sup>3</sup> piece of celery
- dishwashing detergent
- 5 × 250 mL measuring cylinders
- 1 dropping pipette
- 25 mL measuring cylinder
- plastic tray

## Procedure

- 1 Draw the table shown in the results section into your science journal.
- 2 Line up the five measuring cylinders into the tray and add about 1 mL of dishwashing detergent to each measuring cylinder.
- 3 Add 25 mL of the 50 vol hydrogen peroxide to each measuring cylinder.
- 4 Add the manganese oxide to one of the measuring cylinders and start the stopwatch.
- 5 Measure the height of the foam when it stops rising and record this height in the results table.
- 6 Repeat in a clean measuring cylinder for two more trials.
- 7 Repeat for each of the catalysts.

## Results

Catalyst	Height of foam (cm)				Uncertainty of foam height $\frac{\text{max} - \text{min}}{2}$
	Trial 1	Trial 2	Trial 3	Mean	
Manganese oxide					
Iron oxide					
Potato					
Liver					
Celery					

*continued...*

## Be careful

Ensure appropriate personal protective equipment is worn.

...continued

**Processing data**

- 1 Calculate the mean height of foam for each catalyst.
- 2 Calculate the uncertainty in your results.

**Discussion**

- 1 Identify the catalyst that was the most effective at decomposing the hydrogen peroxide. How did you know?
- 2 Identify the catalyst that was the least effective at decomposing the hydrogen peroxide. How did you know?
- 3 One of the products produced relights a glowing splint. Identify this product.
- 4 Identify any limitations to your experiment.
- 5 Describe any improvements you could make that would improve the reliability of your results.

**Explore! 17.2****Catalytic converters**

Catalytic converters have been a key component of car exhaust systems in Australia since 1986. Their outer body is made of stainless steel and their inside comprises a honeycombed ceramic block containing transition metals such as platinum and palladium. The role of a catalytic converter is to speed up a chemical reaction which converts harmful emissions produced by burning petrol and diesel into less harmful emissions. Catalytic converters play such an important part in reducing harmful exhaust emissions that you can be given a heavy fine if your car does not have one.

- 1 Research and give the name of some harmful gases produced by burning petrol and diesel and describe how they could affect the environment.
- 2 Give the name of the gases produced by the catalytic converter and describe how they affect the environment.
- 3 Give the chemical equation for the conversion of nitrogen monoxide (NO) into nitrogen (N<sub>2</sub>) and oxygen (O<sub>2</sub>) which occurs in a catalytic converter.
- 4 Give the chemical equation for the oxidation of carbon monoxide (CO) into carbon dioxide (CO<sub>2</sub>) by reacting it with oxygen (O<sub>2</sub>) that occurs in a catalytic converter.
- 5 Explain the advantage of a catalytic converter having a honeycomb structure.
- 6 Explain why catalytic converters are less efficient when you start your car cold than when it has warmed up.



**Figure 17.22** A catalytic converter used in a car's exhaust system

**A summary of changing reaction rates**

Table 17.1 summarises how each factor discussed in this section influences the rate of a chemical reaction.

Factor affecting reaction rate	Effect on the frequency of collisions	Effect on the proportion of successful collisions	Effect on rate
Increasing concentration of reactants	Increases	Not affected	Increased
Increasing pressure of gaseous reactants			
Increasing agitation (stirring)			
Increasing surface area of solid reactants			
Increasing temperature	Not affected	Increased	
Adding a catalyst			

**Table 17.1** A summary of how each factor discussed affects reaction rate

## Section 17.2 questions

## Remembering

- Name** three factors that can affect the rate of a chemical reaction.
- Decide** whether the following statements are true or false.
  - Increasing the rate of stirring has no effect on the rate of reaction.
  - Changing the surface area of liquid reactants will increase the reaction rate.
  - Changing the pressure of a reaction mixture will only affect reactions containing gaseous reactants.
  - Increasing the temperature of a reaction increases the frequency and energy of collisions.
- Define** the term 'activation energy' in your own words.
- Identify** the name given to chemicals that are added to a chemical reaction to reduce the activation energy.
- Recall** one factor which speeds up the rate of a chemical reaction solely by affecting the number of collisions.

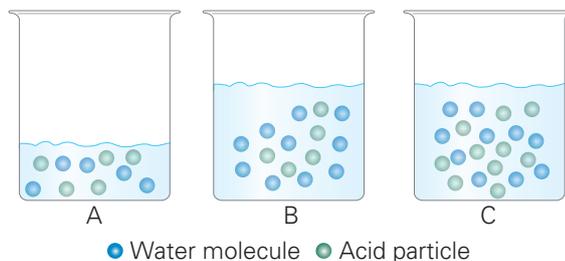


## Understanding

- Outline** the requirements for a chemical reaction.
- Summarise** the relationship between temperature and reaction rate.
- Custard powder can explode when launched into the air and ignited, but not when it is tightly packed in a container. **Explain** why.
- Describe** what is meant by the term 'successful collision'.

## Applying

- Children are advised to take fewer tablets than adults. **Determine** the factor affecting reaction rate that is influencing this advice.
- Your fire is not hot enough, so you add more fuel. **Identify** which factor you have changed to increase the reaction rate.
- The chemical reaction that occurs when you bake a cake mixture requires a large amount of heat for it to be successful. What can you **deduce** about the activation energy of this reaction?
- Use the following figure to answer the questions.
  - Determine** which solutions have the same concentration.
  - Is the solution in the other beaker more concentrated or more dilute? **Justify** your choice.
- Construct** a graph to show how surface area could affect reaction rate.

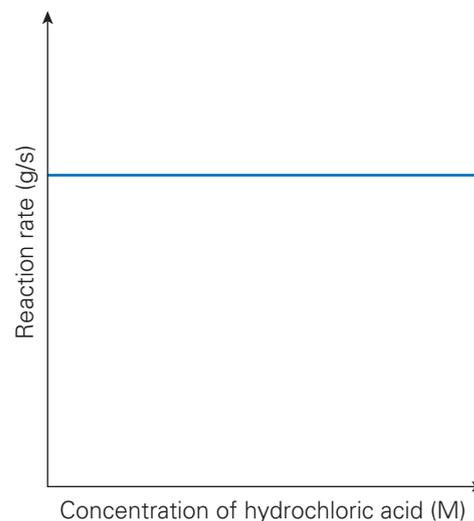


## Analysing

- Contrast** a dilute and concentrated solution.
- Describe** the relationship between surface area and reaction rate.

## Evaluating

- Scientists often use magnetic stirrers to stir chemical reactions. **Explain** why this continuous stirring increases the rate of reaction.
- A student conducted an experiment to determine how changing the concentration of hydrochloric acid affected the rate of reaction with sodium thiosulfate. They plotted a graph of their results, which can be seen on the right. What can you conclude about the effect of increasing the concentration of acid in this reaction? **Deduce** why this may be the case and provide reasoning.
- Your sugar cube is dissolving too slowly in your tea. **Propose** how you could make it dissolve faster and why.
- You have two beakers of the same solution. They are both of the same concentration. To increase the concentration of the solution, you pour them into the same beaker. **Decide** whether you have changed the concentration or not. **Justify** your choice.
- Discuss** the importance of our understanding of reaction rates on the chemical industry. How do advances in technology affect our lives? How may it generate new career opportunities?



# Chapter review

## Chapter checklist

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

Success criteria	Check
<b>17.1 I can determine the rate of reaction through experimental procedures and calculations.</b> e.g. Describe the method of using an upturned measuring cylinder to measure a rate of reaction.	
<b>17.2 I can name and explain the factors that affect rates of reaction.</b> e.g. Explain how increasing the temperature can increase the rate of a reaction.	



## Reflections

- 1 What **connections** come to mind when you think about reaction rates in your everyday life?
- 2 What new concepts have **extended** your thinking about chemical reaction rates?
- 3 What information did you find **challenging** or confusing?

## Data questions

A group of Chemistry students is measuring the rate of a reaction of magnesium metal and hydrochloric acid under different conditions. In three separate test tubes, the students added a strip of magnesium to 1 M HCl, powdered magnesium to 1 M HCl, and powdered magnesium in 2 M HCl, respectively (M is a unit of concentration; 2 M HCl is twice as concentrated a 1 M). The data points are presented in Figure 17.23. Note that the mass of magnesium used was the same for each reaction.

- 1 **Identify** the conditions in which the reaction went to completion fastest.
- 2 **Calculate** the rate of the reaction (in mL/s) for magnesium strip/1 M HCl from the time 0 to 40 seconds.
- 3 The rate of the reaction for the Mg powder/1 M HCl is 0.67 mL/s. Use this information and your answer to questions 1 and 2 to **determine** which reaction has the slowest reaction rate.
- 4 **Identify** the trend in the plot which is similar for all three experiments.
- 5 **Contrast** the effect of the magnesium surface area on the volume of gas produced and the rate of the reaction.
- 6 **Analyse** the data presented in Figure 17.23 for the three experiments. What would be the volume of gas collected for each experiment at 0 seconds (before reactants were mixed)?
- 7 A student has stated that when all magnesium and hydrochloric acid has reacted, the volume of gas produced will be 20 mL. **Justify** this conclusion with reference to the data in Figure 17.23.
- 8 **Extrapolate** the data for the Mg strip/1 M HCl experiment and estimate the volume of gas produced after 120 seconds.
- 9 The students would like to run another experiment with the same mass of magnesium powder and 5 M HCl. **Predict** (using Figure 17.23 as a template) how the data might be different in this experiment.

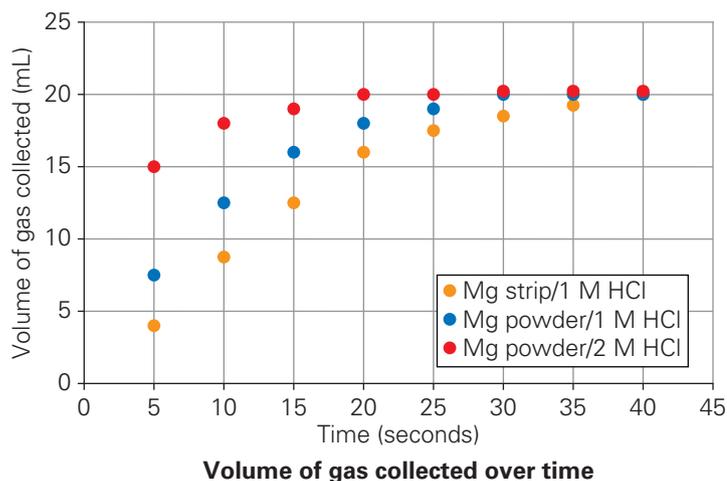


Figure 17.23 Volume of gas collected over time from reactions of magnesium metal and hydrochloric acid

# STEM activity: Designing airbags

## Background information

Airbags work on the principle of increasing the time of impact between two objects. In a car this could be the difference between life and death. A sensor is connected to an electrical circuit and once activated will send a signal that ignites the extremely toxic chemical sodium azide ( $\text{NaN}_3$ ), releasing nitrogen at high speed.

Airbags are not without risk and have failed, causing burns and injury due to the chemical reaction and projectile velocity of the bag itself, which can reach velocities up to 330 km/h. Sodium azide undergoes an initial reaction where it produces nitrogen gas and sodium metal. Sodium metal is highly reactive and if left would explode with the surrounding oxygen. Potassium nitrate is then used to react with the sodium, and after this reaction, silicon dioxide is used to produce the final product, a silicate, which is both harmless and stable.

**Design brief:** Design and create an airbag prototype that uses environmentally friendly chemicals and materials of manufacture. The airbag will need to create gas rapidly to work effectively.



Figure 17.24 An airbag that has been activated

## Suggested materials

- various types of acid (e.g. vinegar)
- various types of bases (e.g. baking soda)
- beakers of various size
- measuring cylinder
- rubber tubing
- thermometer
- plastic bags
- stopwatch
- balloons
- various materials

## Research and feasibility

- 1 Research how airbags work at present and how the chemicals are reacted in a safe way in the bag.
- 2 Research safe chemical reactions and different catalysts that could be used.
- 3 Discuss in your group the available materials you have and research the environmental concerns of the disposal of these materials.

## Design and sustainability

- 4 Decide as a group the chemical reaction you will use and how you will increase the rate of reaction of gas produced.
- 5 Design how your airbag will work, and sketch ideas before deciding on the final design. Remember, you will need to capture the gas. You may want to think about how you will test the effectiveness of your chemical reaction within the bag.
- 6 Complete a risk management table for the chemicals you are using. Make a note of any special disposal methods for the chemicals.

Material	Hazard	Risk management
e.g. 2 M hydrochloric acid	Burning skin/clothing	Use gloves and wear aprons, be careful when handling

## Create

- 7 Create your prototype airbag and test the effectiveness of your design.

## Evaluate and modify

- 8 Discuss the positives and negatives about your design. You may use a PNI (Positive, Negative, Interesting) table.
- 9 Evaluate the effectiveness of your chemical reaction at producing gas, reaction time for gas to be produced, the completion of the reaction, and how safe the chemical reaction was.
- 10 Recommend changes you would make in your design and the chemical reaction choice.

# Glossary

## Chapter 1

**absolute uncertainty** the size of the range of values in which the actual 'true value' of a measurement probably lies

**accuracy** how closely measures match the 'true' or accepted values

**confidentiality** participants' data and results must be kept private

**continuous data** quantitative (numerical) data that is measured and has a value within a range

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

**data logging** the process of using electronic equipment to collect data through sensors where information needs to be collected faster than a human can do independently, or where accuracy is essential

**dependent variable** the variable that is measured to see if the independent variable has had an effect

**discrete data** quantitative (numerical) data that is counted in whole numbers

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

**fieldwork** practical work conducted by a scientist in a natural environment, rather than in a laboratory

**independent variable** the variable that is systematically manipulated or changed in order to investigate its effect on the dependent variable

**informed consent** where possible, participants are informed about the risks and procedures involved in an experiment and they sign to say they agree to participate

**line of best fit** a line (or curve) that best represents the data set by going through, or is as close to, as many points as possible

**linear** a straight line plotted on a graph

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

**median** the middle value of the data set after all the values have been ranked (sorted in ascending order). There should be as many numbers below the median as there are above

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

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

**outlier** extreme data value that does not seem to fit the rest of the data

**parallax error** a measurement taken that is not the true value due to the position of the object along various lines of sight

**primary data** data that is collected or observed directly by a scientist

**qualitative data** data that is descriptive and non-numerical

**quantitative data** data values that are numerical

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

**range** the difference between the highest and lowest values in the data set

**reading error** a reading or measurement that is not the true value

**relative uncertainty** the ratio of the absolute uncertainty to the reported value, often expressed as a percentage

**reliability** how closely repeated measures agree with each other

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

**secondary data** data that has been previously collected for another purpose

**systematic error** error affecting accuracy that occurs through a poorly calibrated device (consistently high or consistently low)

**validity** the degree to which we accept the suitability of an experiment in addressing the research question, and whether it measures what it says it measures

**withdrawal rights** the right for a participant to leave a study at any time for any reason

**zero calibration error** a measuring instrument giving a non-zero reading when the true value should be zero

## Chapter 2

**absorb** to take up the energy of a wave (e.g. absorb light)

**amplitude** the distance (height) of a wave crest or the depth of a wave trough from the centre line of the wave

**angle of incidence** the angle between an incident light ray and the normal when the ray arrives at a surface

**angle of reflection** the angle between a reflected light ray and the normal, when the ray leaves a surface

**compression** the part of a longitudinal wave where the particles are squashed together

**concave** having an outline that is thinner in the middle, or a mirror that is curved inwards, like a cave

**conduction** transfer of thermal energy through collisions between vibrating or moving particles

**conductor (heat)** a substance that allows heat to pass through it easily

**convection** transfer of thermal energy due to the movement of particles in a liquid or gas

**convection current** circulation patterns resulting from the flow of liquids or gases due to a temperature or density difference in a substance

**convex** having an outline that is thicker in the middle, or a mirror that bulges outwards

**crest** the maximum displacement of a particle at the top of the wave

**cycle** one complete vibration or periodic movement of a particle through the crest and trough and back to its starting position; the length of a cycle is the wavelength

**displacement** the position of a particle when it has moved away from its rest position on the centre line of the wave

**echolocation** the location of objects using reflected sound (echo)

**electromagnetic radiation** transfer of energy by electromagnetic waves

**electromagnetic wave** a wave with electric and magnetic properties that can travel through matter or a vacuum

**free electron** an electron that is not attached to an atom

**frequency** the number of cycles of a wave per second

**gamma ray** high-energy ray with a very short wavelength produced when radioactive atoms decay

**heat** the transfer of thermal energy from hotter to colder objects or regions

**hertz** a unit for measuring the number of cycles that happen every second (frequency); abbreviation is Hz

**incident ray** a ray of light arriving at a surface

**infrared radiation** electromagnetic radiation that lies between microwaves and visible light; also known as heat radiation

**insulator (heat)** a substance or material that does not allow heat to pass through easily

**ionising radiation** higher frequency ultraviolet rays, X- and gamma rays which can turn atoms and molecules into ions; can potentially damage living cells

**kinetic energy** the energy of moving matter

**longitudinal wave** a wave with vibrations in the direction of travel instead of transversely; sound waves are an example

**mechanical wave** a disturbance in a medium that transfers energy through that medium

**medium** the matter through which a mechanical wave travels

**microwaves** electromagnetic radiation used for cooking, communications and Wi-Fi; lies between radio waves and infrared radiation

**normal** an imaginary line that is at right angles to a surface

**opaque** a substance that blocks the transmission of light completely

**optical density** an indicator of the refractive power of the substance, which is measured by comparing the amount of incident light to the amount of transmitted light

**oscillating** moving back and forth with periodic motion somewhat like vibration

**periodic motion** a movement of a particle or object that returns to its starting position and repeats in the same time interval, like a swing

**pitch** how high or low a sound seems to our ears on a music scale

**radiation** transfer of energy without the presence of particles

**radio waves** electromagnetic radiation that has the longest wavelength

**rarefaction** the part of a longitudinal wave where the particles are spread apart

**reflect** to throw back the energy of a wave (e.g. heat, light, sound) without absorbing it

**reflected ray** a ray of light that is reflected off a surface

**refraction** the bending of light as it passes from one medium to another

**refractive index** a measure of how much the speed of light changes as it passes from a vacuum into a particular substance

**seismic waves** waves that travel through the Earth and over its surface which when large enough cause earthquakes

**self-propagating** refers to a wave that (unlike mechanical waves) once started keeps going at a constant speed forever without needing the input of more energy



**SONAR** a mode of navigation used by ships to locate underwater objects using reflected sound

**temperature** a measure of the average kinetic energy of the particles in an object

**thermal energy** the internal energy present in an object or system due to its temperature

**translucent** allowing some light to pass through, but no clear image can be seen through them

**transparent** allowing light to pass through and a clear image can be seen through the substance

**transverse wave** a wave in which the particles vibrate or move at right angles (perpendicular) to the direction of energy transfer

**trough** the maximum displacement of a particle at the bottom of the wave

**ultraviolet light** radiation that lies between visible light and X-rays; is needed by our bodies to make vitamin D; short wavelength UV can cause sunburn and cancer

**vacuum** a space totally devoid of matter

**visible light** the part of the electromagnetic spectrum that we can see

**wave** carrier of energy from one place to another without any matter accompanying it

**wavelength** the distance from one wave crest to the next

**X-rays** short wavelength electromagnetic radiation that can pass through flesh to give images of bones; hazardous and can cause cancer

### Chapter 3

**acceleration** the change in velocity or direction of an object

**constant velocity** when an object is travelling at the same speed and direction, and is not accelerating or decelerating

**deceleration** when an object is slowing down, defined mathematically as negative acceleration

**displacement** how far you are from where you started and what direction you are from where you started

**distance** total distance travelled; measured in metres

**force** any interaction that, when unopposed, will change the motion of an object

**gradient** the gradient of a graph is the rise over the run

**inertia** a property of matter that keeps something in the same position or moving in the same direction unless acted upon by an external force

**instantaneous speed** the speed at any particular instant

**net force** the sum of all the forces acting on an object

**Newton's first law of motion** an object will remain at rest or in constant motion in the same direction unless acted upon by an external unbalanced force

**Newton's second law of motion** an object acted upon by a force experiences acceleration in the same direction proportional to the magnitude of the net force, and inversely proportional to the mass of the object

**Newton's third law of motion** for every action, there is an equal and opposite reaction

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

**speed** change in distance divided by time

**stationary** not moving

**vector** a quantity that has both size and direction

**velocity** change in displacement divided by change in time

### Chapter 4

**ammeter** a device for measuring electric current

**ampere** one coulomb per second

**battery** a portable source of power

**cell** a single electrical energy source that produces a current

**circuit** structure through which charges can move

**circuit breaker** carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

**component** part of a circuit

**conductor (electricity)** a material that allows electric current to flow easily

**coulomb** unit of electric charge; the amount of charge transferred in 1 second with a current of 1 amp

**current** the flow of electric charge, which may continue in a steady manner for a period of time

**earthed** having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

**electricity** a form of energy that results from either the accumulation of charge or the flow of charge

**electrocution** electric current passing through the body

**electrostatic charge** charge that stays on an object

**fuse** a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

**insulator** a material through which current cannot flow easily

**load** something that uses energy in a circuit

**mains electricity** the electricity that is supplied to homes

**ohm** the unit of resistance

**Ohm's law** the law that states there is a direct proportionality between the voltage applied across some conductors and the resultant electric current

**parallel circuit** a circuit in which each component is connected in a separate conducting path

**resistance** the degree to which a substance resists the flow of an electric current through it

**series circuit** a circuit in which the batteries and other components are all connected one after the other

**short circuit** when the current is allowed to flow from one conductor to another with little or no resistance

**static electricity** an imbalance of charge on objects

**voltage** a measurement of how much energy each charge carrier is given

**voltage drop** the difference in energy the charges carry before and after a load

**voltmeter** a device for measuring voltage between two points on an electric circuit

## Chapter 5

**efficiency** a measure of the ability to produce useful energy

**elastic potential energy** energy stored in an object due to its shape, usually resulting from the object either being compressed or stretched

**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

**energy transformation** the change in type or form of energy

**fossil fuel** a non-renewable energy source such as oil, coal or natural gas

**generator** a rotary mechanical device that converts rotational kinetic energy into electrical energy, i.e. the opposite of a motor

**geothermal energy** thermal energy that originates from inside the Earth

**gravitational potential energy** energy stored in an object due to its position above the surface of Earth

**hydroelectric power** a renewable source of energy harnessing the gravitational potential energy of water to generate electrical energy

**input energy** the energy that a machine or device uses as its source of energy

**joule** the unit of energy or work done

**kinetic energy** energy possessed by an object due to its motion

**law of conservation of energy** the law that explains how the total amount of energy in an isolated system is constant

**non-renewable** existing in limited quantities that cannot be replaced after they have all been used

**output energy** the energy that a machine or device provides or wastes

**potential energy** energy that is stored in an object due to its position and other factors, such as its mass, electric charge and internal stresses

**renewable** can be produced as quickly as it is used

**Sankey diagram** flow chart that represents the flow of energy through a system

**sustainable** causing little or no damage to the environment and therefore able to continue for a long time

**turbine** a device that converts the kinetic energy of a substance into useful work, for example a windmill

**useful energy** energy that can be used for a specific purpose

**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

## Chapter 6

**astronomical unit** the distance between Earth and the Sun

**baseline** a line between the two viewpoints used to calculate parallax angle (1 AU is the baseline used for calculating star parallax)

**black hole** the extremely dense remnant of a massive star; a region in space where gravity is so strong that nothing, not even light, can escape

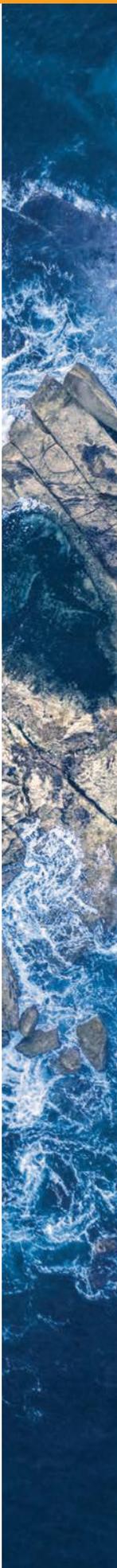
**blue shift** a spectrum shifted towards shorter wavelengths

**constellation** a group of stars as seen from Earth that appear to form a familiar shape

**cosmic microwave background radiation** electromagnetic radiation left over from the early stages of the universe

**dark energy** a theoretical force responsible for accelerating the expansion of the universe

**Doppler effect** a change in the frequency of sound or light waves emitted from an object when it moves towards or away from an observer



**galaxy** a gravitationally bound system of gas, dust and millions or billions of stars and solar systems

**geocentric** a model of the solar system with Earth at the centre

**H-R diagram** a graph where the star luminosity is plotted against spectral type/temperature (Hertzsprung–Russell diagram)

**heliocentric** a model of the solar system with the Sun at the centre

**Hubble's law** the further away a galaxy is, the faster it is moving away from Earth

**light year** the distance that light travels in one year (about 10 trillion km)

**luminosity** the intrinsic brightness of a celestial object; the rate at which a star produces energy

**optical telescope** a device that collects and focuses light from the visible spectrum to form an image

**parallax** the effect by which the position of an object seems to change when it is observed from different locations

**parsec** the distance at which a star appears to move one arcsecond in six months (equal to 3.26 light years or 30 trillion km)

**radio telescope** a device that receives radio waves emitted by stars and other celestial objects

**recessional velocity** the relative rate at which a star is moving away from Earth

**red shift** a spectrum shifted towards longer wavelengths

**retrograde motion** apparent backwards motion of a planet as seen from Earth

**singularity** a point at which infinitely dense matter occupies an infinitely small space

**spectral class** a group into which stars are classified based on their spectra/colour

## Chapter 7

**asthenosphere** the softer layer of rock under the lithosphere

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

**convection currents** movement of rocks within Earth's mantle due to temperature differences between the upper and lower layers

**core** the inner part of Earth's structure

**crust** the top layer of Earth which supports all life on Earth

**epicentre** the location on Earth's surface directly above the focus of an earthquake

**focus** the exact point under the surface of the Earth where the earthquake occurs

**geoid** a model of the Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

**hotspot** a pocket of magma that sits just underneath the crust

**lag time** the time between the arrival of the P and S waves

**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

**magma** hot liquid rock found just below the surface of the Earth

**mantle** the layer of the Earth underneath the crust which is made up of mostly solid rock and is where convection currents take place

**Pangaea** the supercontinent which has since broken into pieces and drifted apart

**plate boundaries** the edges where two tectonic plates meet

**plate tectonics** the theory that the Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

**seafloor spreading** a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

**seismic wave** 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

**subduction** when the denser oceanic plate sinks underneath less dense continental plate

**tectonic plates** Earth's lithosphere is split into gigantic slabs of rigid rock which float on the Earth's surface

## Chapter 8

**atmosphere** the mixture of gases above the surface of Earth

**biodiversity** the variety of species, ecosystems and genes that exist in a particular area

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

**carbon sinks** areas where carbon is stored (e.g. fossil fuels)

**carbon sources** processes or areas that release carbon

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

**enhanced greenhouse effect** the intensifying of the natural greenhouse effect due to human activity

**glacial period** a period in Earth's history when a reduction in global temperatures is sustained for a long period of time

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

**greenhouse gases** gases that contribute to the greenhouse effect

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

**interglacial period** a period in Earth's history when a warming in global temperatures is sustained for a long period of time

**lithosphere** the solid outer layer of Earth consisting of the crust and top layer of the upper mantle

**stratosphere** a layer of Earth's atmosphere above the troposphere containing the ozone layer

**sustainable ecosystem** a biological environment that is able to support itself without outside assistance

**troposphere** a layer of Earth's atmosphere which is closest to Earth's surface and where most of the weather occurs

## Chapter 9

**alveoli** (singular: alveolus) tiny air sacs found within the lungs, which are the site of gaseous exchange

**amino acid** an organic molecule that forms the basic building block of a protein

**antibiotic** a substance that inhibits the growth of bacteria inside the body

**antibody** also called immunoglobulin; a protective protein produced by the immune system in response to the presence of a foreign substance (called an antigen)

**antigen** a substance that induces an immune response in the body; can be foreign (nonself) or a self-antigen

**antiseptic** a substance that stops or slows down the growth of micro-organisms, used externally on skin

**bacteria** (singular: bacterium) microscopic, unicellular (single-celled) organisms

**binary fission** a form of asexual reproduction; the most common form of reproduction in prokaryotes, and occurs when a cell divides, giving rise to two identical cells

**budding** an asexual reproduction process where the new individual is a clone of the parent organism

**capillaries** (singular: capillary) the smallest vessels that contain oxygenated blood and enable red blood cells to deliver oxygen to the tissues on a cellular level

**carbohydrate** biological molecule made of carbon, hydrogen and oxygen, which can be broken down in the body with the release of energy

**cellular respiration** an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy

**effector** a muscle, gland or organ capable of responding to a response signal from the control centre

**enzyme** a biological catalyst that increases the rate of a chemical reaction without itself being changed by the reaction

**eukaryote** an organism with a nucleus and membrane-bound organelles

**fermentation** a chemical process by which energy is produced in the absence of oxygen

**fungus** (plural: fungi) single-celled or multicellular organisms which contain a nucleus and a cell wall made of chitin

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

**haemoglobin** an iron-containing protein which is responsible for oxygen transport within red blood cells

**homeostasis** the maintenance of a relatively stable internal body environment, despite changes in the external environment

**immune system** the system (cells and tissues) that enables the body to protect itself against disease

**immunise** the injection of a weakened or dead version of a pathogen to trigger the production of antibodies; provides protection against that pathogen in the future

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

**lipid** a chemical substance such as a fat or oil that can be used as an energy source

**lymphocyte** white blood cell that is involved with fighting disease; some produce antibodies

**memory cell** a type of white blood cell that is formed after exposure to a pathogen and remembers that pathogen in the future

**multicellular** composed of more than one cell



**nephron** the functional unit of the kidney, involved in filtering the blood to produce urine

**non-specific immunity** immunity provided by the branch of the immune system that does not depend on recognition of the pathogen; includes the first and second lines of defence such as physical barriers, inflammation and fever

**osmoregulation** the regulation of water levels in the blood/body

**pathogen** an infectious agent, such as a bacterium, virus, prion or parasite, that can cause disease

**phagocytosis** a cellular process where a white blood cell engulfs and ingests a cell or large particle to break it down using enzymes

**prokaryote** a single-celled organism with no membrane-bound organelles (such as a nucleus), e.g. a bacterial cell

**protein** a chemical substance composed of amino acids which has structural and regulatory functions; can also be used as an energy source

**receptor** a sense organ (or cell or group of cells) that detects a stimulus

**septic** describes a wound infected with a harmful pathogen

**specific immunity** immunity provided by the branch of the immune system that is specific to each particular pathogen; the third line of defence

**stimulus** (plural: stimuli) any object or event that elicits a sensory or behavioural response in an organism

**unicellular** composed of a single cell

**vaccine** a chemical substance composed of a dead or weakened version of a pathogen that is injected or ingested to make a person immune against that pathogen

**virus** an extremely small noncellular pathogen composed of infectious particles that are inactive outside a living host cell

## Chapter 10

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

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

**cerebral cortex** outer layer of the brain

**contralateral organisation** each hemisphere of the brain is responsible for the motor function and sensation in the opposite side of the body

**corpus callosum** a bundle of nerve fibres connecting the left and right hemispheres of the brain

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

**hemispheric specialisation** each hemisphere of the brain can exert greater control over specific functions

**homeostasis** the maintenance of a relatively stable internal body environment, despite changes in the external environment

**hormone** a chemical messenger that is secreted by endocrine glands and circulated in the bloodstream to act on a target cell

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

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

**nervous system** consists of the brain, spinal cord and peripheral nerves and receptors that communicate fast messages within the body

**neuron** an individual nerve cell

**neuroplasticity** the ability of the brain to change its neuron structure and function over time, in response to experiences; also known as neural plasticity

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

**pincer grip** a grasp that uses the pads then tips of the index finger and thumb to pick up and grasp objects

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

**reflex arc** the pathway that the signal travels during a reflex action

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

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

**stimulus–response model** the process of detecting and responding to a stimulus

**synapse** the junction between two neurons

**target cell** a cell affected by a specific hormone

## Chapter 11

**abiotic** non-living factors, such as temperature, pH, salinity, rocks and water

**apex predator** the highest level consumer in a food chain

**ATP** a molecule that provides useable energy in cells

**autotroph** also known as a producer; an organism capable of making its own food

**biome** a region of Earth's surface classified by the particular combination of climate, plants and animals that are found within it

**biotic** living factors, such as plants, animals and bacteria

**capture-mark-recapture method** a method for estimating animal population sizes that involves capturing, tagging, releasing and recapturing a sample of the population

**cellular respiration** an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy in the form of ATP

**chlorophyll** a group of green pigments found in the chloroplasts of plants and algae (as well as in the mesosomes of cyanobacteria) that are responsible for the absorption of light and subsequent production of glucose during photosynthesis

**chloroplasts** organelles found in plant cells (and some protists e.g. algae) that contain chlorophyll and, as such, conduct photosynthesis

**commensalism** a symbiotic relationship where one organism benefits and the other neither benefits nor is harmed

**community** all the populations of different species living in a particular area at a given time

**consumer** also known as a heterotroph; an organism that must eat or consume other plants or animals as a source of energy

**ecological niche** the role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment

**ecosystem** an ecological unit made up of living components, nonliving components and the interactions between them

**emigration** the movement of individuals out of the population

**eutrophication** when a body of water becomes too enriched with nutrients, causing an excessive growth of algae that may result in oxygen depletion of the water

**food chain** the flow of energy from organism to organism in an ecosystem

**food web** a series of interconnected food chains

**habitat** the environment an organism lives in

**heterotroph** also known as a consumer; an organism that must consume plants or animals as a source of energy

**immigration** the movement of individuals into the population

**interspecific competition** competition for food or resources between members of different species

**intraspecific competition** competition for food or resources between members of the same species

**invasive species** an organism that is outside its natural distribution and causes harm to an environment

**mutualism** a symbiotic relationship where both organisms benefit

**parasitism** a symbiotic relationship where a parasite benefits from living on or in a host (which is harmed)

**photosynthesis** the chemical reaction by which some organisms make their own food

**pollinator** an organism, such as an insect, that carries pollen from one plant, or part of a plant, to another

**population** members of one species living in a particular area at a given time

**predator** an animal that hunts other animals as its source of food

**productivity** the rate of generation of biomass in an ecosystem

**prey** a living animal that is captured and eaten by a predator

**primary consumer** the consumer who eats the producer in a food chain

**producer** also known as an autotroph; an organism capable of making its own food

**quadrat** a tool used to measure species abundance

**quaternary consumer** the consumer who eats the tertiary consumer

**random sampling** a sampling technique where each sample has an equal chance of being selected

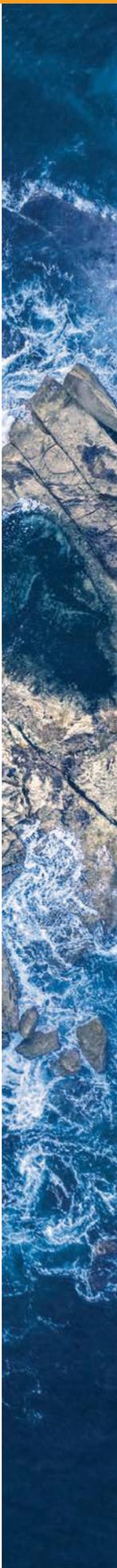
**secondary consumer** the consumer who eats the primary consumer

**symbiotic relationship** any type of close and long-term relationship between two types of living organism

**systematic sampling** a sampling technique where each sample is taken at fixed intervals that have been previously decided upon

**tertiary consumer** the consumer who eats the secondary consumer

**trophic level** the position an organism occupies in a food chain



## Chapter 12

**allele** two or more different forms of a gene

**aneuploidy** when an individual has an abnormal number of chromosomes

**autosomes** in humans, chromosome pairs 1 to 22

**base triplet** three DNA bases that code for an amino acid

**bioinformatics** an analysis tool that is able to sort biological data using computers

**carrier** an individual with a recessive allele for a disease, but who does not have the disease due to being heterozygous

**centromere** a structure that holds two sister chromatids together

**chromosome** a structure of tightly wound DNA

**chromosome mutation** a mutation involving large segments of DNA

**codominance** both alleles are expressed equally in the phenotype

**codon** three nucleotides (base triplet) on mRNA that code for an amino acid

**complementary pairing** adenine only binds with thymine and cytosine only binds with guanine

**deletion** a point mutation in which a nucleotide is deleted from the sequence

**diploid (2n)** a cell containing two sets of chromosomes

**DNA** genetic make-up that carries the instructions for life (deoxyribonucleic acid)

**dominant** a characteristic in which the allele responsible is expressed in the phenotype, even in those with heterozygous genotypes

**embryo** a zygote eventually becomes an embryo

**fertilisation** the fusing of an egg nucleus and sperm nucleus

**gametes** sex cells that combine to produce new offspring

**gene** a length of chromosome

**gene therapy** a process by which a copy of a functional gene is introduced into an organism

**genetic engineering** technology that allows genetic material to be manipulated and enables genes to be transferred between any two species

**genetic screening** genetic tests that are available for anyone in the population

**genetically modified organism** an organism that has had its genome altered by humans

**genetics** the study of inheritance

**genome** the full set of genes in an organism

**genotype** the combination of alleles for a gene inherited from our parents

**germline mutation** a mutation of DNA in gametes which can be inherited

**gonads** the sexual organs: testes in males and ovaries in females

**haploid (n)** a cell containing only one set of chromosomes

**heterozygous** having two different alleles at a locus

**homologous chromosomes** matching chromosomes

**homozygous** having two identical alleles at a locus

**hydrogen bonds** chemical bonds that hold the two DNA strands together

**incomplete dominance** a form of inheritance in which neither allele is dominant over the other, producing a third phenotype

**induced mutation** a mutation produced by environmental factors

**insertion** a point mutation in which an extra nucleotide (or more than one nucleotide) is inserted into the DNA

**inversion** a point mutation in which two nucleotides reverse their order

**karyotype** a pictorial representation of an organism's chromosomes

**locus** the location of a gene on a chromosome

**meiosis** the process by which the gonads make the haploid gametes

**mitosis** the process by which diploid somatic cells make identical diploid copies of themselves for growth and repair

**mutagenic** causing mutations in DNA

**mutation** a change in the genetic code of a cell

**non-disjunction** when the chromosomes failed to separate correctly in meiosis

**non-homologous chromosomes** non-matching chromosomes

**nucleotide** a subunit of DNA, consisting of a phosphate group bound to a deoxyribose sugar, which in turn is bound to a nitrogenous base

**ova** eggs

**pedigree** a chart formed to study patterns of inheritance over generations

**phenotype** the way an organism appears

**point mutation** a mutation in which a single nucleotide is changed

**polymer** a substance composed of large and/or complex molecules (macromolecules) which are made up of multiple smaller and/or simpler subunits (monomers)

**Punnett square** a specialised grid to show genetic crosses

**recessive** a characteristic in which the allele responsible is only expressed in the phenotype if there is no dominant allele present

**recombinant** produced by combining genetic material from different places

**reduction division** cell division in which there is a reduction in the genetic material between parent and daughter cells

**sex chromosomes** in humans, the 23rd pair of chromosomes that determines the sex of a person

**sexual reproduction** reproduction involving sex cells

**sister chromatids** two copies of the same chromosome, connected at a centromere

**somatic cells** the body cells of an organism

**somatic mutation** a mutation that occurs in somatic (body) cells which cannot be inherited

**spontaneous mutation** a naturally occurring mutation

**substitution** a type of point mutation in which one nucleotide is swapped for another

**transcription** the first stage of protein synthesis, where the base sequence of DNA is copied into mRNA

**transgenic organism** an organism that possesses a 'foreign' gene or segment of 'foreign' DNA in its genome as a result of human experimentation

**translation** the second stage of protein synthesis, where a sequence of mRNA is translated into a sequence of amino acids

**trisomy** when an organism has a third copy of a chromosome

**zygote** a fertilised egg produced by the fusion of male (sperm) and female (ovum or egg) gametes

## Chapter 13

**absolute dating** determining the actual age of a material

**adaptation** characteristic that contributes to a species' suitability for its environment

**analogous structure** structure that has a similar function but evolved separately

**artificial selection** intentional breeding of plants and animals to produce desirable traits

**biodiversity** the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur

**biogeography** the study of the geographical distribution of plants and animals

**biostratigraphy** a branch of stratigraphy focused on dating rock layers using the fossils found in them

**direct evidence** evidence that supports an assertion without intervening inferences

**DNA hybridisation** a technique that measures genetic similarity between two organisms

**endangered** a species that is in danger of becoming extinct

**evolution** the genetic changes in a population over a long period of time

**evolutionary tree** a diagram used to represent evolutionary relationships between organisms

**extinct** no longer existing

**fertile** able to reproduce

**fossil** the shape or impression of a bone, a shell, or a once living organism that has been preserved in rock for a very long period of time

**fossil record** the record of past life and evolution inferred from fossils

**fossilisation** the process of forming a fossil

**genetic diversity** the range of genetic traits within a species

**half-life** the length of time needed for the radioactivity of a radioactive substance to be reduced by half

**homologous structure** structure that is similar because it has evolved from the same ancestor

**index fossil** a fossil used as the base for dating the strata it occupied

**indirect evidence** evidence that requires inferences to be made

**megafauna** large animals with a body mass of over 45 kilograms

**natural selection** the process that results in the continued existence of only the organisms that are best suited to the conditions in which they live

**population (ecological)** a group of a particular species living in the same geographical area at the same time

**radioisotope** a version of a chemical element that has an unstable nucleus and emits radiation during its decay to a stable form

**relative dating** determining the order of past events without the specific age

**reproductively isolated** unable to breed successfully with related species due to genetic differences



**selection pressure** an external agent that affects an organism's chances of survival depending on their genotype (genetic variations)

**selective advantage** a characteristic that enables an organism to survive and reproduce better than other organisms in a population

**selective breeding** artificial selection

**speciation** the process by which new types (species) of living things are thought to develop from existing ones by evolution

**species** a set of animals or plants in which the members have similar characteristics to each other and can breed with each other

**species diversity** the number and abundance of different species in a given area

**stratigraphy** the branch of geology studying the rock layers

**trace fossil** a trace of an animal, such as footprint or imprint, that has become fossilised

**variation** genetic differences within a population

**viable** able to survive and reproduce

## Chapter 14

**alpha particle** a positively charged particle ejected spontaneously from the nuclei of some radioactive elements

**atom** the building block of matter

**atomic number** the number of protons in an atom of an element

**beta particle** a charged particle (electron) that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom

**electron** a subatomic particle with a negative charge found outside the nucleus in all atoms

**gamma ray** a high energy wave emitted from the nucleus of radioactive elements during radioactive decay

**ion** a charged version of an atom that has either gained or lost electrons

**isotopes** atoms of the same element with the same number of protons but a different number of neutrons

**mass number** the sum of the protons and neutrons in the nucleus of an atom

**molecule** a group of two or more atoms that are held together by chemical bonds

**neutron** a subatomic particle with a neutral charge found in the nucleus of an atom

**nucleus** (plural: nuclei) the central part of the atom containing its protons and neutrons

**proton** a subatomic particle with a positive charge found in the nucleus of an atom

**radioactive decay** when an unstable nucleus emits radiation (alpha and beta particles or gamma waves) and breaks down to form another element

**radioisotopes** unstable isotopes that are likely to break down or decay into other elements to try to achieve a stable nucleus

**relative atomic mass** the average mass of the different forms of each element

**subatomic particle** one of the particles that make up an atom

## Chapter 15

**alkali metals** group 1 metals that form an alkaline solution when they react with water

**anion** a negatively charged ion formed from the gain of electrons

**cation** a positively charged ion formed from the loss of electrons

**covalent bond** a strong bond, almost always between two non-metals which share electrons to form a molecule

**electron** smallest subatomic particle in an atom arranged around the nucleus in shells

**electron configuration** the arrangement of an atom's electrons in the shells around the nucleus

**electron shell** houses the electrons which orbit the nucleus of an atom

**element** substance made up of only one type of atom

**group** the vertical columns in the periodic table

**halogens** group 17 elements (e.g. chlorine and iodine)

**ion** a charged version of an atom, formed from the loss or gain of electrons

**ionic bond** a strong bond between an anion and a cation, formed via electron donation

**metalloids** elements in the periodic table that are situated close to the border between metals and non-metals; they share properties and appearance characteristics with both metals and non-metals

**noble gases** group 18 elements (e.g. neon and krypton)

**period** the horizontal rows in the periodic table

**transition metals** the block of metals containing the elements in groups 3 to 12 and in periods 4 to 7 in the periodic table

**valence electrons** the electrons in the outer shell of an element

## Chapter 16

**acid** a substance that, when dissolved in water, has a pH of less than 7

**base** a substance that has a pH greater than 7 and that can react with an acid to form a salt and water; known as an alkali if it can dissolve in water

**chemical formula** a chemical reaction written using the chemical symbols and formulas of the reactants and products involved

**combustion** the reaction of a fuel with oxygen, usually producing heat and light

**conservation of mass** a law that states that matter can be neither created nor destroyed in chemical reactions

**corrosion** the reaction of metals with oxygen from the air to form metal oxides

**diatomic** two atoms bonded together

**endothermic** an absorption of heat in a chemical reaction characterised by a decrease in surrounding temperature

**exothermic** heat is released from a reaction characterised by an increase in surrounding temperature

**kinetic energy** the energy of moving matter

**monatomic** one atom, sometimes spelled 'monoatomic'

**neutralisation reaction** a reaction between an acid and a base, forming a solution that has a pH of 7

**photosynthesis** the chemical reaction by which some organisms make their own food

**potential energy** (chemical) the energy stored in the chemical bonds of a substance

**precipitate** a solid formed in a solution

**product** substance formed in a chemical reaction

**reactant** substance that is reacting in a chemical reaction

**reaction conditions** conditions required for a chemical reaction to proceed

**rearrange** move things into a different order

**respiration** a chemical reaction which converts glucose and oxygen into carbon dioxide and water as well as energy

**salt** a product formed when an acid reacts with a metal, base or carbonate; made up of a metal and a non-metal

**thermal decomposition** when a substance breaks down with heating, into two or more substances

**word equation** a chemical equation written using just the words for reactants and products

## Chapter 17

**activation energy** the minimum energy required for a successful collision and therefore to start a reaction

**agitating** stirring or shaking a mixture

**asphyxiant** A gas capable of displacing the oxygen in the air; can lead to an interruption of breathing and unconsciousness.

**catalyst** speeds up a chemical reaction by lowering the activation energy; does not get used up in the process

**collisions** particles must collide for a chemical reaction to occur

**concentrated solution** a solution which contains a large amount of solute compared to solvent

**concentration** the amount of substance in a given volume

**dilute solution** a solution which contains a small amount of solute compared to solvent

**pressure** the force produced by collisions of gas particles per unit area of the container walls

**reaction rate** the quantity of reactant or product used up or made per unit time; how fast the reaction goes

**surface area** the area of the outer part or surface of an object



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