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for the Victorian Curriculum

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Welcome



Not all babies are healthy at birth; some, especially those born too early, need intensive care. Catheters, which are thin flexible tubes, are placed in sick babies' blood vessels to deliver fluids and medications. Sometimes these catheters don't reach the correct location, requiring multiple attempts from doctors to get it right.

To address this unmet clinical need, we developed neoNAV, an award-winning medical device that tracks where the catheter is during and after the procedure. The neoNAV addresses the weaknesses of current solutions, reducing the need for patient exposure to repeated X-ray radiation. It is also easier than using ultrasound, making care safer and less stressful for babies, and also improving clinical efficiency for busy clinical staff.

It's an exciting time to work in biomedical engineering as new medicines, treatments and medical devices are continuously being developed.

Shing Yue Sheung is co-founder and currently leading operations at Navi Medical Technologies. The collaborative team at Navi come from varied backgrounds such as medicine, biomedical engineering, finance, business consulting, management and programming. Navi has won a number of awards including selection into the TMCx Medical Device Accelerator, Grand Prize at the 5th Annual Pediatric Device Innovation Symposium Competition, First Prize – Startup Vic Healthtech Pitch Night among others.

Shing is on the Forbes 30 Under 30 Asia List and is a World Economic Forum Global Shaper. He completed a Bachelor of Commerce at The University of Melbourne, where he then earned a Master of Engineering, specialising in Bioengineering and Biomedical Engineering. He graduated with First Class Honours, was on the Dean's List and completed part of his studies at ETH Zurich, a major science and technology university in Europe. He was also awarded the 2018 MBS Alumni Leadership Award.

In his spare time, Shing enjoys playing tennis, guitar, exploring US culture and listening to podcasts.

Contents

	Authors and contributors	vi
	How to use this book	viii
	Acknowledgements	xi
1	Thinking like a scientist	
	1.1 Planning and conducting investigations	4
	1.2 Observations to conclusions	12
2	Homeostasis	
	2.1 The requirements for life	31
	2.2 Body systems working together	43
	2.3 Response to microorganisms	58
	STEM: Simulating the transmission of disease	78
3	Response and coordination	
	3.1 Keeping in control	83
	3.2 Neurons and the nervous system	88
	3.3 The spinal cord	97
	3.4 The brain	106
	STEM: Texting and reaction times – what do the numbers say?	122
4	Ecosystems	
	4.1 What is an ecosystem?	127
	4.2 Interactions between organisms and their environment	145
	4.3 Population dynamics within ecosystems	152
	STEM: Saving an endangered species!	166
5	Atoms	
	5.1 What are atoms, elements and compounds?	171
	5.2 The structure of the atom	175
	5.3 Atomic number and mass number	180
	5.4 Development of the atomic model	184
	5.5 Isotopes	192
	STEM: Designing and creating a product using bioplastics	200

6	Chemical reactions	
	6.1 Introduction to chemical reactions	205
	6.2 Conservation of mass	212
	6.3 Energy and chemical reactions	218
	6.4 Reactions of life	225
	6.5 Acid reactions	230
	STEM: Baristas and the curdling milk problem	242
7	Our changing Earth	
	7.1 Continent movement theories	247
	7.2 Plate tectonics and plate movement	257
	7.3 The effects of plate movement	270
	7.4 Technologies and natural disasters	279
	STEM: Earthquake-proof structures	286
8	Electricity	
	8.1 What is electricity?	291
	8.2 Simple circuits	299
	8.3 More circuits and their applications	313
	STEM: Can you see the renewables?	324
9	Electromagnetism	
	9.1 Magnets and electricity	329
	9.2 Generating movement	342
	9.3 Generating electricity	348
	STEM: The simplest maglev system	358
	Glossary	360
	Index	366

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Kerrie Ardley has taught a variety of Junior and VCE Sciences throughout her teaching career. Currently, she is the Head of Psychology at an independent school and also holds a position as a VCAA Assistant Chief Assessor. Kerrie enjoys teaching Junior Science, and seeing students learn through the connections between theory, practical work and the world around us.



Emma Bone

Emma Bone thrives on the dynamic and practical nature of science, which led her to a first class honours in Biomedical Science. Her desire to enable students to maximise their potential brought about a career as a Science teacher in Australia and in the UK, where she was also a Chemistry specialist teaching both GCSE and A level courses.



Dr. Eddy de Jong

Dr Eddy de Jong has been involved with science and physics education at the secondary and tertiary level for many years. He has taught science at all levels, Senior HSC/VCE Physics and university Physics. He was involved in the Victorian Gifted Students Physics Network, was a Physics Study Design writer with VCAA, and is currently chair of the VCE Physics Examinations Panel. He is a successful author of numerous science and physics texts. He is passionate about seeing young minds engaging with science and physics and aims to instil in students a sense of curiosity whilst developing their critical thinking skills.



Christopher Humphreys

Chris Humphreys is currently teaching Science and Physics at an independent school. He graduated from Nottingham University in the UK and completed his MSc in Physics at the University of Waikato in New Zealand. He has over thirty years' experience as a teacher in state and private schools in the UK, New Zealand and Australia.



Victoria Shaw

Victoria Shaw has been committed to sharing her love for science with Year 7–12 students for the past 18 years and previously studied pharmacology. She was Head of Science at an independent school for a few years and volunteers as an educator for Wildlife Victoria. She has also been an assessor for the VCAA and IBO and runs workshops in biology and psychology.



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Jonathan Blair graduated from the University of New South Wales with a Bachelor in Science, majoring in Pharmacology. He has worked in both research and commercial laboratories, specializing in cardiac regeneration and vaccine manufacturing, respectively. Jonathan is currently working as a laboratory technician for an independent school.



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Sarah Chuck teaches Science in Years 7–10. She completed a biomedical science degree at Monash University and Masters of Teaching Practice at RMIT. During her studies, Sarah worked in a genetics laboratory at the Australian Regenerative Medicine Institute modelling disease in organisms, such as the zebrafish. She hopes students will also find their experiences in science to be extremely interesting and rewarding.



Paulo da Silva

Paulo da Silva is a passionate STEM Educator with a varied background in ICT, Earth Sciences and STEM Curriculum Design. Paulo encourages students to use their curiosity and creativity to design, prototype, discover and innovate, in pursuit of the product developments and ideas of tomorrow. He also vocally campaigns for STEM Education opportunities for students from low socio-economic backgrounds.

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How to use this book

Overview of the print book

Short facts that contain interesting information

Did you know?

Quick checks for recalling facts and understanding content

Quick check

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

Explore!

Short activities to explore concepts that are currently being covered

Try this

Glossary

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



VIDEO

Videos are found in the Interactive Textbook.



WIDGET

Widgets are found in the Interactive Textbook.

Practical

Practical investigations consolidate student learning

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.

Science as a human endeavour

Section questions

Review questions to check students' understanding and application of the section content.

STEM activity: Texting and reaction times – what do the numbers say?

Background information

Many people might consider that reacting to a stimulus is an automatic process. However, that could not be further from the truth. Imagine that you are in a car driven by a friend, you are all having a great time and getting ready to enjoy your usual when suddenly, a dog runs in front of the car. The car starts to vibrate and the dog barks to escape unharmful.

The example above can be used to illustrate the powerful connection between brain activity in our bodies and the brain. First, light sensors (your eyes) recognize the sudden change in light conditions on the road, that information is sent for processing, then your brain can decide what has happened and if any action is required. Then, your brain compares the information coming from your light sensors to information contained in a vast collection of memory (memory) that brain finds a match and determines that something should under the car. It is only then the same thing that is coming in front of your car. Finally, the brain sends signals to the nervous system with the correct combination of contraction and expansion of very specific muscles; this is when your friend presses the brake pedal. In the meantime, your friend sends an instruction to the light sensors asking if they have feeding data while the whole process takes place. In some a different action is required.

This whole process described above takes place during 0.25 seconds on average. However, that value will constantly change, depending on your state of alertness! For example, imagine if your friend was texting while driving, do you think the outcome could have been different?

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

Activity instructions

In this activity you will use materials, a very elegant mathematical formula and your imagination to create an experiment that addresses:

- at least three sets of data
- at least three car graphs
- a conclusion that clearly answers the following question:
 - Victoria's Transport Accident Commission (TAC) is so worried about young people's reflexes while driving while driving that it hired your young startup company to conduct a sequence of experiments in the community to determine whether texting can slow down a person's reaction times.

Suggested materials

- 30cm ruler
- actions
- cardboard
- paper
- pen
- mobile phone to record amazing slow motion videos
- Microsoft PowerPoint for presentations
- video editing software for making short documentaries

Mathematical formula

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

where u = time, d = distance and $a = 0.80 \text{ cm/s}^2$ (acceleration due to gravity).

Evaluate and modify

- Imagine that you received a table with reaction time values (t) for a laboratory experiment. Knowing that all operational forces are almost constant and does not need to be worked out, how could you modify the equation above to estimate the distance value used in that experiment? In other words, how could you record the equation below to solve for distance instead of time?

$$d = \frac{1}{2}at^2$$
- Discuss with at least three of your colleagues the challenges you have encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.
- Reflection is an integral and vital aspect of any project and there is the real world. How could you use ICT tools (for example, apps, videos, slow motion cameras) to enhance this experiment?
- The results may change when a different type of ruler is used, such as metric, plastic or timber. Predict how the size or length of the ruler might have impacted on the results.
- Repeat this activity and compare your results when you use your dominant hand (the one you write with) and when you use your other hand. Is there any difference in reaction times between hands?

Consider adding other distracting sounds and lights during the activity, such as listening on a TV set or flicking a flashlight on and off. Do your responses slow with sensory responses agreed?

Create a PowerPoint presentation to relay your responses to the TAC.

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

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.

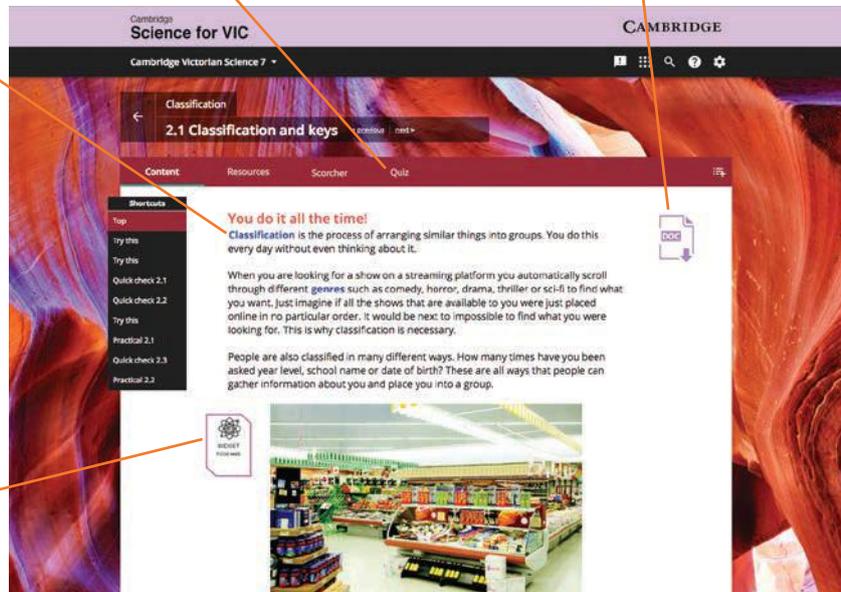
Definitions pop up for key terms in the text

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 1.1: Self-design

Aim

You will work in groups, allocating each person with at least one role covered in this chapter. Your group will act as a team of consultant engineers, working towards finding a solution to a problem by using the engineering design loop.

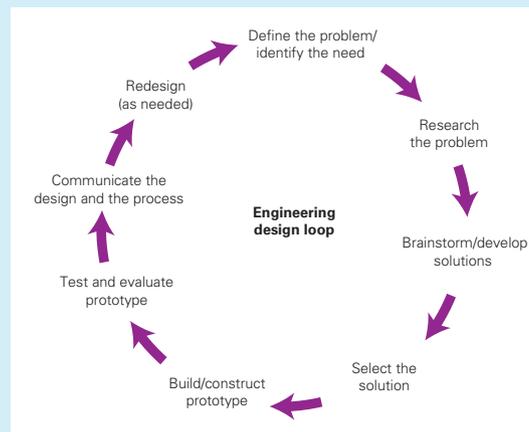
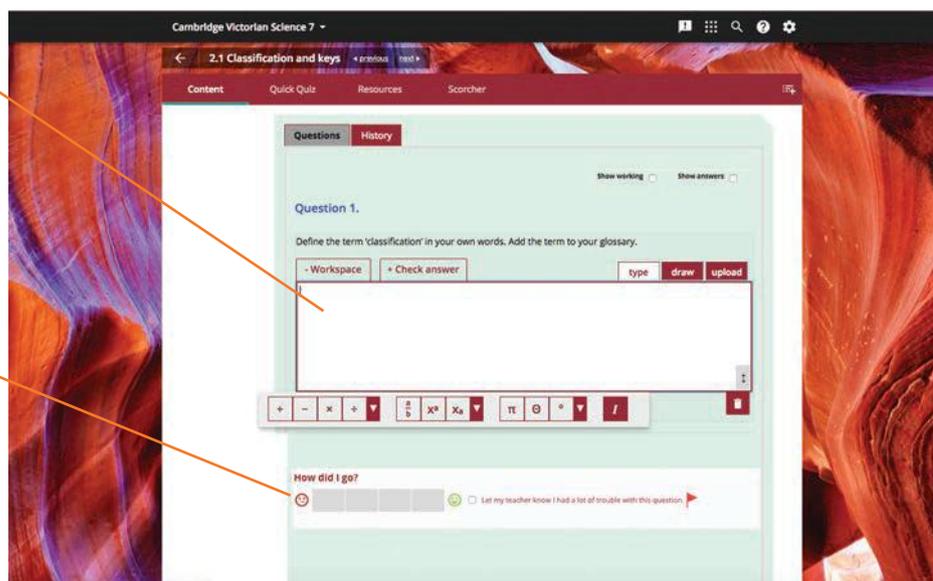


Figure 1.9 The engineering design loop

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.

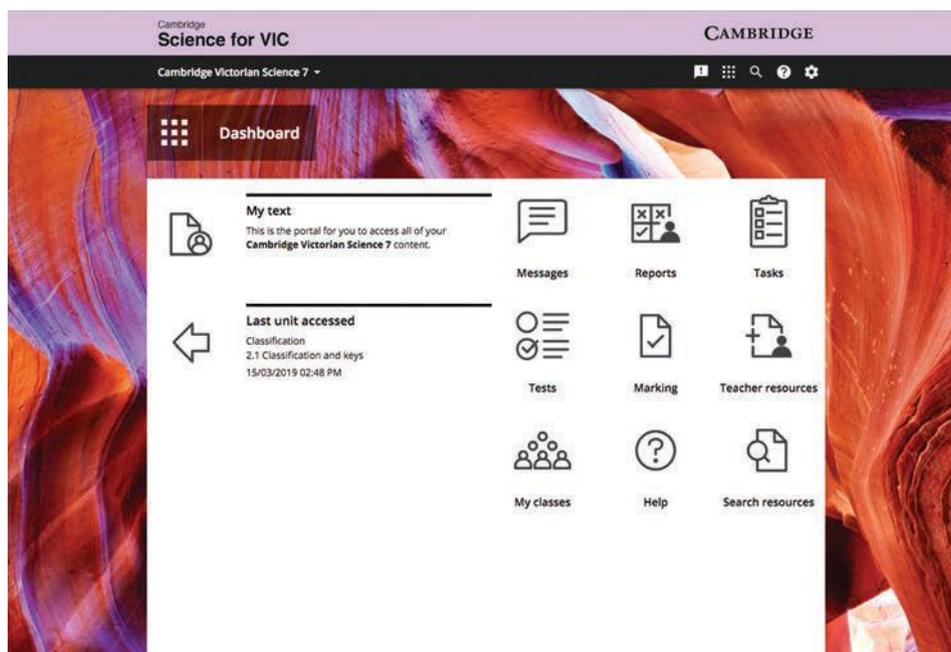
Self-assessment tools enable students to check answers, mark their own work and rate their confidence level in their work. This helps develop responsibility for learning and communicates progress and performance to the teacher. Student accounts can be linked to the learning management system used by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



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Chapter 1 **Thinking like a scientist**

Chapter introduction

Scientists work within many different and unique scientific domains, such as biology, chemistry, psychology, earth science and physics. In this chapter, students continue to explain relationships between variables and formulate hypotheses, and begin to think like a scientist. They build upon their understanding of the importance of science inquiry that involves identifying and posing questions, planning, conducting and reflecting on investigations, processing, analysing and interpreting data, and communicating findings.

Curriculum

Questioning and predicting: Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables (VCSIS134)	1.1
Planning and conducting: Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types (VCSIS135)	1.1
Recording and processing: Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students' own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data (VCSIS137)	1.2
Analysing and evaluating: Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence (VCSIS138)	1.2

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Glossary terms

continuous data

control condition

controlled variable

dependent variable

descriptive statistics

discrete data

experiment

experimental condition

extraneous variable

hypothesis

independent variable

inferential statistics

line graph

line of best fit (trend line)

mean

measure of variability

median

mode

objective data

observation

outlier

p -value

potable

primary data

qualitative

quantitative

range

reliability

secondary data

standard deviation

subjective data

trend

validity

variable





Planning and conducting investigations



Steps in the scientific method

If you can recall from earlier years, scientists and researchers use a series of orderly and systematic steps to plan, conduct, interpret

and report on any scientific investigation. The scientific inquiry process (often called the scientific method) can be summarised into eight steps, which scientists commonly use when conducting scientific research.

STEP 1: OBSERVE AND ASK QUESTIONS

A research question may be identified from an area of research interest.



STEP 2: DO BACKGROUND RESEARCH

A scientist who is interested in conducting an experiment on a certain topic of interest must first search relevant scientific literature.



STEP 3: CONSTRUCT A HYPOTHESIS

A hypothesis is a testable prediction about the relationship between two or more variables. It is usually formulated using the scientific knowledge obtained in the scientific literature – it is not just simply a haphazard guess without any prior knowledge – it is more of an educated guess.



STEP 4: TEST BY CONDUCTING AN EXPERIMENT

An experiment may include controlled laboratory experiments, natural observations, case studies, surveys, interviews and so on. Conducting the experiment requires a specific methodology. The method usually contains at least two sections:

- Materials (lists the scientific apparatus required to conduct the experiment)
- Method (a step-by-step procedure of how the experiment was conducted)

If human participants are used in the experiment, it also needs to include a section on participants and ethical dimensions. (This states how many people were used, gender, age ranges, how the participants were sampled and the research design used.)



STEP 5: GATHER 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, median and modes can be used to summarise the data.



STEP 6: ANALYSE THE DATA

The tables and charts of data then need to be examined. When analysing data, relationships, trends and patterns can be revealed. What each of the results indicate should be summarised.



STEP 7: EVALUATE THE HYPOTHESIS

This step involves drawing conclusions relating back to the hypothesis using the data to back up the conclusions. Inferential statistics are needed to infer from the data and to draw valid conclusions.



STEP 8: REPORT THE RESULTS

A scientific report is completed to document the research and share the finding with other scientists. Common methods used to report the research findings include practical reports, oral presentations, poster presentations.

While it is not a formal step in the scientific method, it is important for scientists to check whether the research that they conducted is reliable. The term 'reliable' is a technical term in Science. A reliable measurement or experiment will produce consistent results. It is similar to precision (repeated measurements are close together). Repeating measurements does not improve reliability but determines it. The average of repeated measurements will, however, have a reduced uncertainty. Once their research findings have been reported, it is important to replicate the results of the experiment to determine whether the results are consistent, and hence valid and reliable. Remember that a valid measurement is one that measures what it is intended to be measured.

The scientific method is an important part of any experiment. Within the field of science, an **experiment** is used to test a cause and effect relationship between two variables under controlled conditions. Although

causality only follows IF all extraneous variables are known and controlled. Once a research question has been posed, it is important to then construct a research **hypothesis** that forms the basis of the experiment.

experiment

a scientific procedure used to test a hypothesis or test a cause and effect relationship between two variables

hypothesis

a prediction or explanation for something that is based on known facts, but has not yet been proved

- 1 List the eight steps of the scientific method, as followed by scientists.
- 2 Discuss the importance of steps **4** and **5** in the scientific method.
- 3 What is the importance of conducting a scientific 'experiment'?

Quick check 1.1



Figure 1.1 The scientific method is used within any science laboratory.

Designing a sound experiment: From a research question to the method

Defining your experimental variables

Scientists use experiments to search for cause and effect relationships; for example, whether drinking coffee increases your heart rate. Cause and effect relationships help scientists to reliably estimate how changes in one thing might cause something else to vary in a predictable and repeatable way.

The things that are deliberately changed, or happen to change, during an experiment, are called **variables**. A variable is any factor, trait or condition that can exist in different types or amounts.

An experiment usually has three kinds of variables: the one you change, the one you measure the change in, and the ones you want to prevent from interfering with the results. These are known as independent, dependent and controlled variables.

variable

any factor that can change during an experiment

The **independent variable (IV)** in a scientific experiment is the variable which the scientist systematically manipulates or changes to measure what effect it has. A scientist has control over the IV. For example, this could be the amount of coffee the person consumes. Each different version of the independent variables (for example, one person drinks no coffee, one person drinks one cup, one person drinks two cups, one person drinks three cups) is a different **experimental condition**. The experimental condition where no intervention is made, or the independent variable is absent is called the **control condition**. In this experiment, the control condition would be the person who drinks no coffee. The control is very important as it gives the scientist a baseline to compare against, to measure if the IV has indeed had a substantial effect.

independent variable (IV)

the variable that is systematically manipulated or changed during an experiment

experimental condition

the different conditions where the independent variable changes

control condition

the condition where the independent variable is absent, used as a baseline to measure results against

The **dependent variable (DV)** in a scientific experiment is the variable that is observed, measured and recorded. It is the variable you predicted would be affected by the IV, and you are observing it to see if that is true, and to what degree. For the example

dependent variable (DV)

the variable that is measured during the experiment to see if the independent variable has had an effect



Figure 1.2 A good experiment is carefully controlled and tests only one variable at a time. This is called a fair test.

provided of testing the amount of coffee a person consumes, the DV could be measuring the person's heart rate.

Controlled variables

Experiments also have **controlled variables**. Controlled variables are quantities that remain constant. If they are not controlled, then they can interfere with the experiment and the changes you have observed in the dependent variable (results of the experiment) may be the result of these variables rather than a result of the independent variable. Basically, they cast doubt on the cause-and-effect relationship. Experiments can have more than one controlled variable.

controlled variable
any variables that may influence the outcome of an experiment, that are kept constant

You have all used the phrase, 'It's just not fair!' Fairness comes into play when conducting science experiments too. Once a research question has been posed, and an aim and hypothesis formulated, it is time to start designing a fair test using the acronym, 'cows moo softly'. The acronym (which is like a mnemonic or memory device, but which spells out a word or message) represents the terms, **C**hange, **M**easure, keep the **S**ame, which represent the independent, dependent and controlled variables.

The example experiment given earlier would not be a fair experiment if the person drinking three cups of coffee was also allowed to go for a run while the others sat still. Physical activity has not been controlled for, and now the increase in heart rate is impossible to attribute to one variable: was it the coffee or was it the exercise? Was it both? The scientists should have made physical activity a controlled variable; that is, made all the people from the different experimental conditions do the same amount of exercise. They would also need to control other variables, such as food and drink intake, as well as temperature and clothing.

Problem: You want to find out which brand of fertiliser makes a pea plant grow the tallest.

Try this 1.1

In this particular experiment, the variables to be considered will be:

- Change a variable (IV) – the brands of the fertiliser will be changed
- Measure a variable (DV) – the height of the pea plant will be measured
- Keep the same (controlled variables) – type of pea plant used, amount of light the plant is exposed to, type/quality of soil, the amount of water used to water the plant, the amount of fertiliser used and so on.

In pairs, brainstorm how you would go about testing which brand of fertiliser will make a pea plant grow the tallest, adding to the information above.

Constructing a research hypothesis

A good research hypothesis makes a testable prediction about the direction and extent of the effect that the IV will have on the DV. A hypothesis is best tested in an objective manner with all the variables in the experiment controlled, except for the independent variable. A well-written and testable hypothesis sets up the plan of how the data will be collected in the methodology.

A scientist will always include a clear direction of how they think the independent variable may impact upon the dependent variable in a hypothesis.

You can construct an appropriate research hypothesis by following a template like this:

'It is hypothesised that _____ will _____ the _____.'

↑
Insert IV here
↑
Insert predicted effect here, e.g. increase or decrease
↑
Insert DV here

For example,
'It is hypothesised that drinking coffee will increase a person's heart rate.'

Note how the scientist has incorporated the IV with the expected outcome of the

DV, showing a clear direction within the prediction. Due to scientific reports being quite formal in the write-up, you should never use the terms, 'I' or 'we' in your hypothesis. It is best started by using the phrase: 'It is hypothesised that....'

The following is an example of a research question for an experiment.

Research question: 'Does raising the temperature of water enable it to dissolve more sugar?'

Look at the table below and tick the appropriate box that each variable belongs to.

Try this 1.2

Experimental variables	Independent variable	Dependent variable	Controlled variable
Temperature of the water (in °C)			
Amount of water in the beaker to start with			
Amount of sugar that dissolves completely			

continued...

...continued

What would be a testable hypothesis for this experiment? In this case, a testable hypothesis could be: 'It is hypothesised that the higher the temperature (°C) of the water, the more sugar will be dissolved (grams).'

In this case, the scientist predicts that the higher the temperature, the more sugar will be dissolved, which includes the IV (temperature), DV (amount of sugar dissolved) and a clear direction for the prediction – higher water temperature will result in more of the sugar being dissolved. It is also important to note that correct units of measurement are included.

Extraneous variables

An **extraneous variable (EV)** is any unplanned (extra) variable, other than the IV, that can or may affect or cause a change in the results of the experiment (change the dependent variable). Therefore, it affects the results of the experiment in an unwanted way. You can think of them as controlled variables that have not been controlled for.

extraneous variable

any variable that may influence the outcome of an experiment that has been failed to be controlled for

validity

a valid experiment or procedure measures what is intended to be measured; when extraneous variables are not recognised and controlled this may not be the case.

Extraneous variables compromise an experiment (threaten the **validity** of data) because they make it difficult to determine if the change in the DV (results) 'causal relationship' is solely due to the IV and no other variable. This is why an experimenter must ensure that extraneous variables are eliminated. When eliminated, the variables are described as 'controlled variables' – as they are kept constant. For example, if the scientists conducting the coffee and heart rate example used on page 6 did not interview their participants first, they may have failed to control for the health of each participant's heart. If one of the participants actually did have a heart problem, such as tachycardia (a fast heart rate), this would be an extraneous variable and would affect the results.



Figure 1.3 Extraneous variables must be controlled for.

Data collection during experiments

Within an experiment, the data collected can be considered as either objective or subjective data. The preferred data used in scientific investigations is **objective data** as it is data that can be directly observed or measured. It is easy to compare different conditions and results within an experiment. Because objective data is measured in a planned, precise and systematic manner, it is not open for personal interpretation, so it is considered unbiased and unable to be altered.

Conversely, **subjective data** is data that relies on personal experience or responses. It may provide insight into the thoughts of the results of an

objective data

data that can be directly observed or measured, not open to interpretation

subjective data

data that relies on personal experiences, interpretation or responses

- 1 Why is it important to have controlled variables in an experiment?
- 2 Identify the IV and DVs in this research question: 'Does the salinity of water used influence pea plant growth?'
- 3 List two possible extraneous variables for this research question: 'Does the salinity of water used influence pea plant growth?'

Quick check 1.2

experiment, but it is very difficult to compare between participants. Because subjective data is based on personal interpretation of information, it is open to opinion, may be influenced by attitudes, values and beliefs, and subsequently may be biased and inaccurate.

primary data or **secondary data**. Table 1.1 summarises the key differences between the two. Most of the time in Science class, you will conduct experiments that produce primary data.

Different types of data

The data collected can also be subdivided into either qualitative or quantitative data. Figure 1.5 and Table 1.2 summarise the key differences between these two types of data.

primary data
data that is sourced for/
during the experiment

secondary data
data that is sourced from
someone else's research or
a database

Comparison of primary versus secondary data

Within the field of science, the data used for analysis can also be considered

Data	Description	Example	Advantages	Disadvantages
Primary	Data can be collected during the experiment within the laboratory or outside the laboratory in field work. Data can also be collected through completing questionnaires, rating scales, or interviews.	Carry out an experiment to collect first hand data; e.g. grow and then measure the length of a seedling (in cm) over a week.	<ul style="list-style-type: none"> Specific and detailed Can inform future research Current 	<ul style="list-style-type: none"> Time and cost involved Sample size restrictions
Secondary	Data that is taken and used from someone else's research results. It could be used as a basis to form a hypothesis, strengthen findings, explore trends and patterns and much more.	<ul style="list-style-type: none"> Census data Data obtained through another's research, e.g. in scientific journals 	<ul style="list-style-type: none"> Cheap and easy to obtain Large amounts of data Can be over long periods of time 	<ul style="list-style-type: none"> May not be up to date May not be specific enough

Table 1.1 Differences between primary and secondary data



Figure 1.4 Looking at data

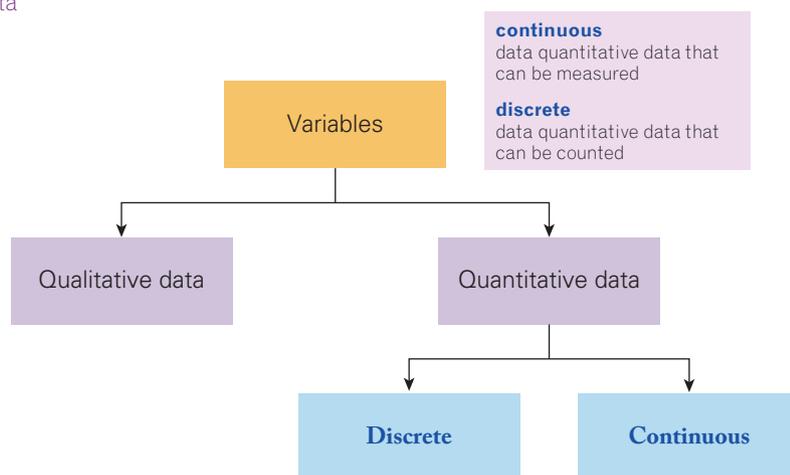


Figure 1.5 Different types of data

Quantitative data	Qualitative data
<p>Quantitative data: information about the <i>quantity</i> (how much)</p> <ul style="list-style-type: none"> • Uses numbers or categories • Can be statistically analysed • Easily measured and compared with other data • Similar to objective data as researchers can easily draw conclusions and allows for comparison with other data 	<p>Qualitative data: information about the <i>quality</i> (characteristics)</p> <ul style="list-style-type: none"> • Often expressed in words (letters) or pictures • Difficult to categorise/analyse: wide variety of forms and open to personal, observer or research biases • Similar to subjective data because both are opinion-based
<p>Discrete e.g. number of people who play a sport</p>	e.g. a description of the behaviour of children observed in the playground.
<p>Continuous e.g. weight of participants (75.2kg, 56.8kg)</p>	

Table 1.2 Key differences between quantitative and qualitative data

- 1 What is the difference between subjective data and objective data in an experiment?
- 2 Why is objective data the preferred data used in an experiment?
- 3 Look at the experimental results shown below and identify each as either qualitative or quantitative data collection techniques.

Quick check 1.3

Experimental results	Qualitative or quantitative data?	Reason
The plant appeared wilted and turned from light green in colour to brown.		
The height of the plant was 24cm.		
The leaf had jagged edges and was diamond in shape		
The diameter of the leaf was 7.6cm.		

Practical 1.1

How effectively can an elastic band knock over a tin can?

Background information

The energy stored in a rubber band is related to the distance the rubber band will fly after being released. This practical will investigate the difference between potential energy and kinetic energy. You and a partner will determine how effective different elastic bands can be in knocking over a tin can.

Be careful

Ensure safety glasses are worn at all times.



Figure 1.6 Experimental set-up

continued...

...continued

Aim

To investigate how effectively an elastic band can knock over a tin can.

Materials

- different elastic bands (range of thicknesses, length and width)
- empty tin can
- safety glasses

Method

- 1 Complete this table and use your answer to help you construct an appropriate hypothesis for this experiment.

Controlled variables – what you will keep the same	Independent variable – what you are changing to see its effect	Dependent variable – what will happen because of changing a variable

- 2 Collect different elastic bands and an empty tin can. You will need safety glasses to protect your eyes.
- 3 Do some preliminary investigations (a little bit of practice shooting the elastic bands) and establish the distance away from the tin can that you need to shoot from. Decide what the best method is for releasing the elastic band, as you need to use the same method every time.
- 4 Carry out the experiment using the different elastic bands from your chosen distance and using your chosen method.

Results

Construct a table to collect your results relating to the independent and dependent variables. You need to record and compare your results so you can support or refute your hypothesis.

Evaluation

- 1 What sort of elastic band was the most effective in knocking over the can? Which method of releasing the elastic band is most effective?
- 2 What type of energy is stored in a stretched elastic band?
- 3 What type of energy is demonstrated by a moving elastic band?
- 4 How could you reduce measurement uncertainties in this experiment?
- 5 What are two ways you could improve the experimental design in the future?



QUIZ

Section 1.1 questions

Remembering

- 1 What is step 1 of the scientific method?
- 2 Name the type of data sourced through someone else's research.
- 3 Why is the control condition within an experiment so important?

Understanding

- 4 How does the experimental condition differ from the control condition of an experiment?
- 5 Provide an example of objective data.
- 6 Why is it important to replicate the results of an experiment?

Applying

- 7 A student was testing the following research question: 'Do all brands of batteries have the same amount of battery life?' They tested this by putting batteries of different brands into a torch and leaving it on until the batteries ran out.
 - a Identify the IV and DV for this experiment.
 - b List one possible extraneous variable for the following research question: 'Do all brands of batteries have the same amount of battery life?'
 - c Explain why objective data would be gathered in this experiment.

Analysing

- 8 Discuss the importance of using primary data within an experiment and provide an example.
- 9 Construct a Venn diagram showing the similarities and differences between quantitative and qualitative data.
- 10 Suggest why qualitative data is similar to subjective data.

Evaluating

- 11 Investigate how scientists from the different fields of science observe data. Conduct some research and create a summary table.



1.2 Observations to conclusions



WORKSHEET

Observing and recording

I saw it, but what does that mean?

observational

the skill of closely watching an experiment, using all five senses or specialised tools to detect changes

Using our **observational** skills is essential when carrying out experiments in Science. One of the most important skills a scientist must have is the ability to write down what they observed using accuracy and succinct detail. There are many different forms

of observations that can occur and the trick is knowing which type to use during experiments.

Sometimes, our senses (including, hearing, sight, smell, touch and taste) may be the best option. However, within a scientific laboratory, it is never recommended to taste anything. This is due to the many different forms of chemicals used in the laboratory or left over residues

on equipment from experiments. There are also times when touch and smell may be dangerous (e.g. hot water, toxic gas). Other times, specialised equipment such as microscopes and data loggers will allow for precise and accurate observation that extends beyond our senses.

The ability to record accurate observations is also a key skill in science. Scientists are able to not only complete the experiment, but also be able to document what they observed. At times, qualitative data is used, other times quantitative data will be used. Sometimes a combination of both may be best.

Consider these observations taken by three students in the same laboratory group who completed the same experiment.

Try this 1.3

Joshua's observations	Sophie's observations	Laura's observations
The beaker with water in it took ages to heat up. Then when it did the white stuff just disappeared.	It took 12 minutes and 20 seconds for the 250 mL beaker of water to heat up enough and dissolve the 10 g of sugar that was added.	It took 13 minutes 11 sec to disappear.

- 1 Comment on whether the use of qualitative and/or quantitative data was used to record these observations above.
- 2 Who do you think has best documented their observation in this experiment?



Figure 1.7 It is important to accurately document your observations of chemical changes within experiments.

Practical 1.2

Utilising the art of observation

This practical has four short experiments for you to perform.

Aim

To practise careful experimentation and accurate recording of observations.

Be careful

Ensure proper protective equipment is worn.

Materials

- 0.5 M hydrochloric acid
- 0.5 M sodium hydroxide
- 0.5 M ferrous sulfate
- sodium carbonate
- potassium nitrate
- lithium chloride
- phenolphthalein indicator
- water
- 4 test tubes
- test-tube rack
- 2 rubber stoppers
- spatula

Method and results

For each experiment, carefully follow the instructions and record your observations in the results table below.

Experiment	Instructions	Observations
A	<ol style="list-style-type: none"> 1 Fill the test tube to a depth of about 5 cm with hydrochloric acid. 2 Add 1–2 drops of phenolphthalein indicator to the test tube. 3 Add an even spoonful of sodium carbonate to the test tube. 4 Gently swirl the test tube for 1 minute. 5 Document your observations. 	
B	<ol style="list-style-type: none"> 1 Fill the test tube to a depth of about 5 cm with sodium hydroxide. 2 Add one squirt of ferrous sulfate solution to the test tube and gently swirl. 3 Observe what occurs within the test tube after waiting approximately 2 minutes. 4 Document your observations. 	
C	<ol style="list-style-type: none"> 1 Fill the test tube to a depth of approximately 5 cm with water. 2 Add one spoonful of solid potassium nitrate. 3 Stopper the test tube and place your thumb over the stopper, gently shake the test tube. 4 Document your observations. 	
D	<ol style="list-style-type: none"> 1 Fill the test tube to a depth of approximately 5 cm with water. 2 Add one spoonful of lithium chloride. 3 Stopper the test tube and place your thumb over the stopper, gently shake the test tube. 4 Document your observations. 	

- 1 Which of the five senses would you not usually use in a laboratory experiment?
- 2 Why are observations important in any scientific experiment?
- 3 Do scientific observations include quantitative or qualitative data?

Quick check 1.4

How to record data using tables

Tables are quick and easy ways to record data in an organised manner, when conducting experiments. They allow accurate measurements of data to be presented. Generally, there are a few rules to follow when using tables to record data. Firstly, if you are drawing a table into your science log book or work book, you must always use a ruler.

Results are shown below:

Time after exercise (min)	Heart rate (bpm)
0	165
1	142
2	130
3	100
4	89
5	75
6	68

Comparing the tables above, it is clear that the one which accurately and succinctly sets out the data under column headings and also includes the unit symbol is the easier of the two to read relevant trends from.

Often the **reliability** of the results collected in an experiment can be

reliability
the consistency, stability or dependability of data or results

improved by repeating the experiment under the exact same conditions, using the exact same equipment, over a number of trials.

Secondly, the data is presented under column table headings so that trends can be easily seen.

For example, an investigation is conducted to determine the effects of heart rate having completed a 15 minute session of moderate level intensity exercise. The heart rate was taken immediately following exercise, for another 6 minutes.

Time after exercise	1 min	2 min	3 min	4 min	5 min	6 min	7 min
Heart rate	165 bpm	142 bpm	130 bpm	100 bpm	89 bpm	75 bpm	68 bpm

We can then calculate the average. Whilst this demonstrates the reliability of the results, it will not necessarily improve precision or the spread of data, but it will reduce the uncertainty of the mean value of measurements. This may reduce the random error.

Take for example an experiment that investigates the mass of a particular powder that dissolves in 200 mL of water at different temperatures. By repeating the investigation over three different trials, using the same conditions and equipment, it allows for the average mass of salt to be calculated. However, whilst this will reduce the random error, it will do nothing to reduce the systematic error.

temperature (°C)	mass of powder dissolved (g)			
	trial 1	trial 2	trial 3	average
10	22	22	21	21
20	38	40	39	39
30	43	46	46	45
40	72	76	74	74
50	96	95	94	96
60	118	117	110	115
70	124	130	130	128



Figure 1.8 Some of the equipment used in your science laboratory

- 1 500 mL sample of water taken from the Yarra River as it was heated for 15 minutes. They wanted to record the temperature every minute.

How would you advise the students to record their data using a table?

- 2 In another experiment, a number of identical seedlings were fed with different masses of fertiliser and their growth after one month was measured.

A sample of a student's graph is shown below.

3 grams	6 g	9 grams	0.012 kg	0.015 kilograms	18 g
5 cm	9 cm	0.020 cm	270 mm	21 cm	178 mm

In your workbook or laptop, carefully draw (use a ruler!) a results table as it should appear.

Quick check 1.5

Representing data on a graph

Data can also be presented using a graph.

It will visually show the **trends** in the results

trend

the overall pattern of movement in the data, e.g. increasing or decreasing

much more quickly than a table can. A trend is the overall pattern of movement in the

data. That is, does it usually tend to increase (an increasing trend) or does it usually tend to decrease (a decreasing trend).

The type of graph you choose will depend upon the type of data you need to display. For example, pie charts and bar charts can be used to display data when one of the variables is categorical, as in Figure 1.9.

Line graphs can be used to display data when both the independent and dependent variables are continuous (numerical) data (Figure 1.10). Line graphs allow you to plot points using two coordinates (a scatterplot) and then draw in a **line of best fit** (the trend line), which illustrates the underlying relationship between the two variables.

line of best fit

a line through a scatter plot of data points that best expresses the relationship between those points

line graph

a type of graph with x and y axes, used to display numerical data

In the real world, scientists tend to use **line graphs** more commonly than others.

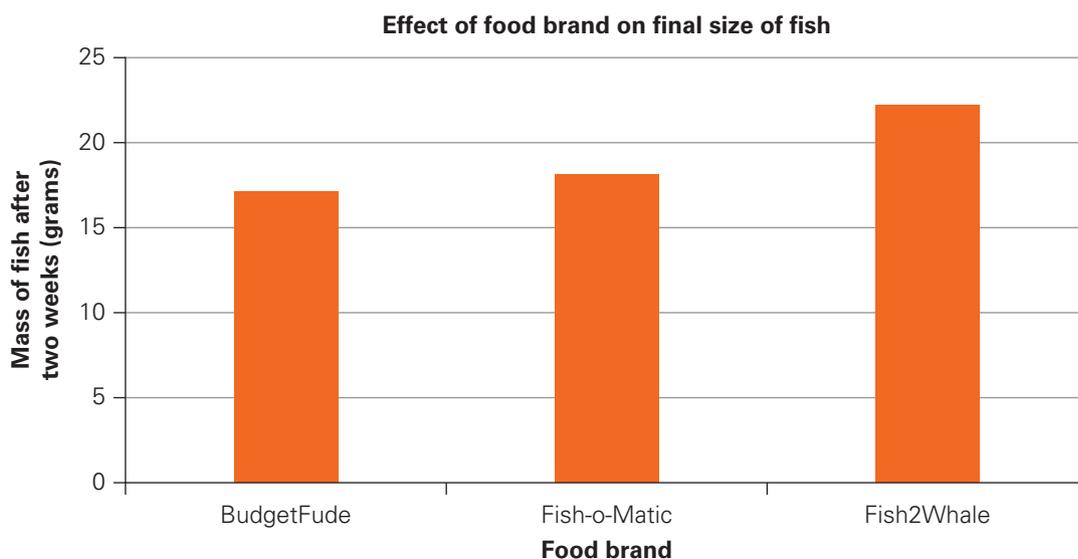


Figure 1.9 Example of a categorical bar chart

The line graphs you create should have the following features.

When drawing graphs, you must ensure that the independent variable is represented on the horizontal (x) axis and the dependent variable is represented on the vertical (y) axis.

Reading values from a graph

To find the value of one of the variables that corresponds to a given value of the other variable, you take a straight line to the intersection with the trend line. Try this 1.4 shows how you would estimate the time that it would take to boil a specified volume of water.

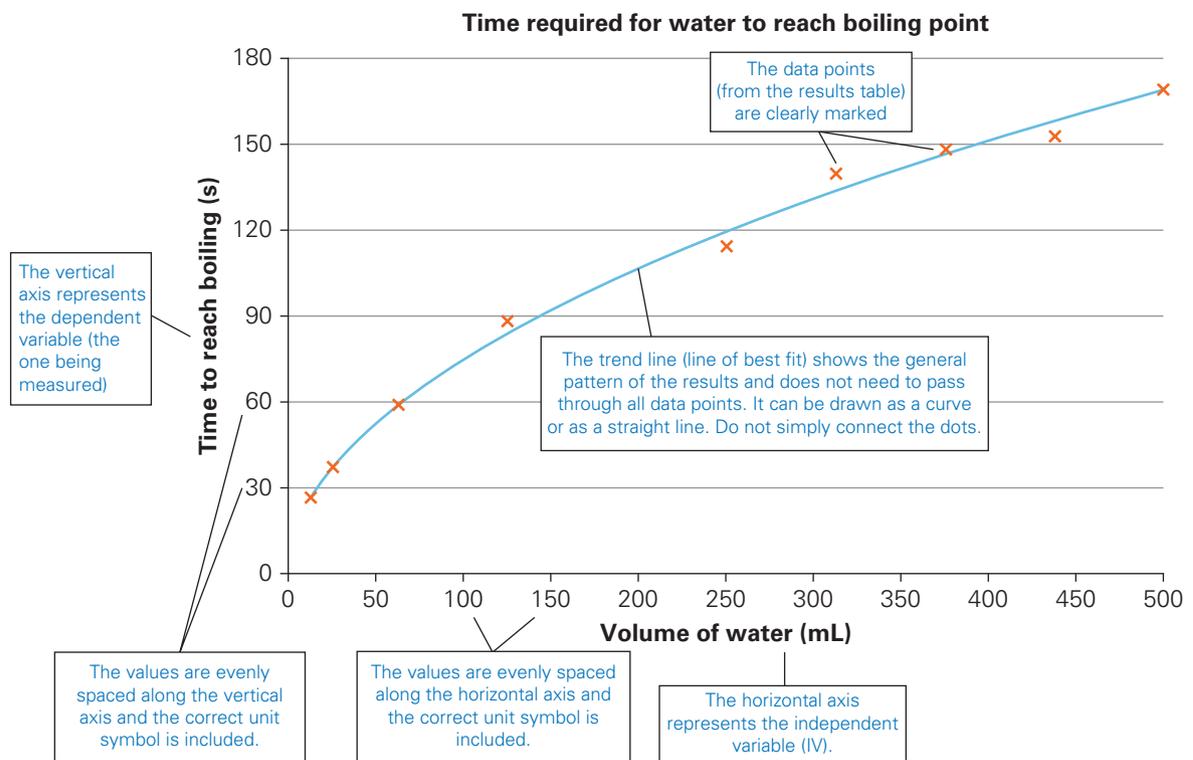
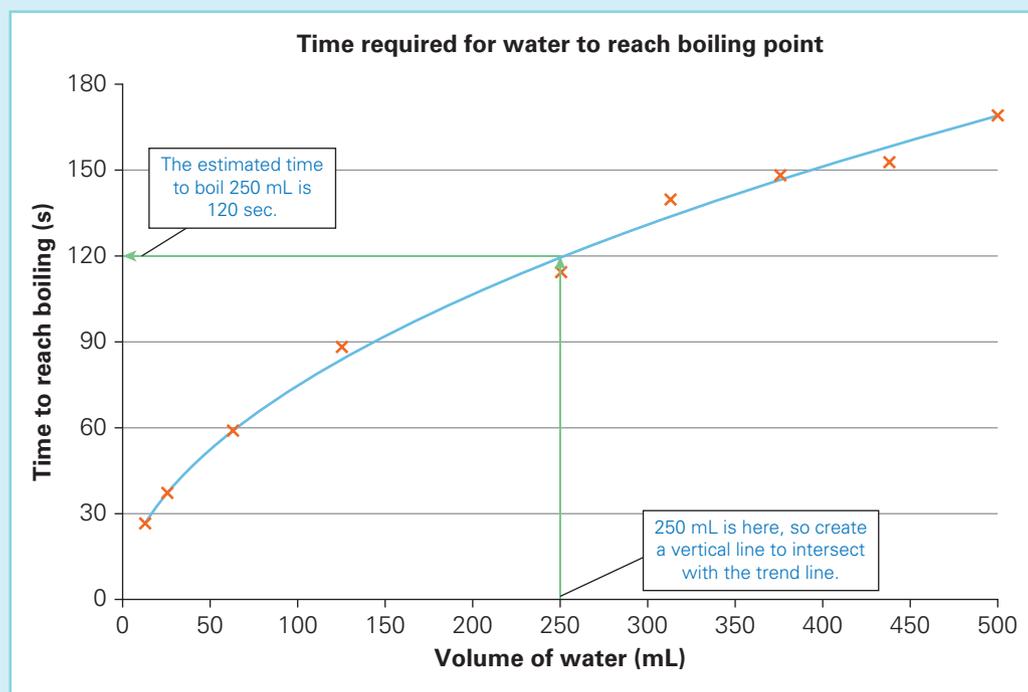


Figure 1.10 Example of a line graph

Reading values from a graph

Use the graph to complete the missing values in the table.

Try this 1.4



continued...

...continued

Volume of boiling water (mL)	Time taken to reach boiling point (s)
250	120
75	
	90
275	
	130

Analysing experimental data

Once you have collected your data in an experiment and presented the data in graph form you will need to interpret or analyse this data. This can be done using descriptive and inferential statistics.

When interpreting your graph, it is important to remember that the existence of a correlation (that is, the DV tends to show an increasing trend as the IV increases) does not necessarily mean it is a causal relationship. Not all experiments will show a correlation between the variables, but this is still an experimental finding!

Descriptive statistics versus inferential statistics

On their own, raw data are worthless. They have not been organised and are difficult to interpret, therefore, you need to organise the data in some way. This is referred to as descriptive statistics. **Descriptive statistics** are used to summarise, organise and describe data collected during research.

Examples of descriptive statistics include percentages, graphs, measures of central tendency (mean, median, mode), spread of scores (variability, range, standard deviation).

Descriptive statistics describe data but **do not** allow for drawing valid conclusions to whether there is a cause and effect relationship between the variables (IV and DV).

descriptive statistics

tools used to summarise and describe data sets, e.g. measures of centre and spread

extraneous variables; unless this is done it remains a correlation (even if it is a strong one) Inferential statistics allow researchers to make inferences (draw conclusions) and determine whether the results support or reject the hypothesis. In practice, inferential statistics involves comparing the experimental group and the control group and calculating whether the difference between them is statistically significant, or if the difference is likely to have been caused by chance.

Obviously, the average 'score' in the experimental group is quite likely to be different to the average 'score' in the control group. The question is, are they different enough to show that the IV has caused a significant change in the DV? Statistical significance refers to the significance of the difference between the two average scores.

Inferential statistics allow scientists to infer a cause and effect relationship between two variables – something that descriptive statistics (such as percentages and graphs) do not allow you to do with confidence.

What is the p-value?

A **p-value** is the level of probability that the difference between the control and experimental groups are due to chance factors and determines the statistical significance of the results.

inferential statistics

tool that allows scientists to establish cause and effect relationships between variables by analysing the changes in data sets

p-value

a statistic that gauges the level of probability that the difference between the control and experimental groups are due to chance factors, and determines the statistical significance of the results

It is typical to set the p -value at $p < 0.05$ (must be a lower-case p), which means that, for the results of a study to be deemed statistically significant, the probability that the results are due to chance factors must be less than 5% ($p < 0.01$ is used for medical studies).

If the results are deemed to be statistically significant ($p < 0.05$), then there is a less than 5% probability that the difference between the control and experimental groups is due to chance factors and a greater than 95% probability that the results are due to the independent variable. The hypothesis can be supported. Conclusions can be drawn.

What happens if $p > 0.05$? This means that there is greater than 5% probability that the difference between the control and experimental groups is due to chance factors and a less than 95% probability that the results are due to the independent variable. The hypothesis cannot be supported. Conclusions cannot be drawn.

Using measures of central tendency

The three most common ways of measuring the central tendency of a data set are the mean, median and mode. You may have heard this referred to as 'finding the average'.

mean
often referred to as the 'average', this measure of centre is found by adding all the values and then dividing this sum by the number of values

Mean: the exact average of all the data points, calculated by adding up all the data points and dividing that by the number of data points.

For example, consider this data set: 20, 25, 31, 28, 40, 66, 25

$$\begin{aligned} \text{Mean} &= \frac{\text{Total of all data points}}{\text{Number of data points}} \\ &= \frac{20 + 25 + 31 + 28 + 40 + 66 + 25}{7} \\ &= \frac{235}{7} \\ &= 33.57 \text{ (rounded to 2 decimal places)} \end{aligned}$$

Median: the middle score when the data points are arranged in order from lowest to highest. If the middle falls between two numbers, find the average (mean) of the two.

$$20 + 25 + 25 + \mathbf{28} + 31 + 40 + 66$$

The median for this set of data is 28.

Mode: the most frequently commonly occurring value in a data set.

$$20, \mathbf{25}, 31, 28, 40, 66, \mathbf{25}$$

The mode for this set of data is 25.

Using measures of variability

Measures of variability: how varied the data is or how widely the data is distributed or spread around the central point (mean). Common forms of this are the range and standard deviation. When analysing data, it is important to use both measures of central tendency and measures of variability.

Range: the difference between the lowest and highest values of the data.

For example, consider this data set: 20, 25, 31, 28, 40, 66, 25

$$\text{Range} = 66 - 20 = 46$$

Standard deviation: a measure of how spread out the data is around the mean. There is a mathematical formula for it, but any software that does data analysis should be able to do the calculation on how far the data 'deviates' from the mean of the data.

median
a measure of centre of a data set, found by ordering the values from smallest to largest and finding the middle point

mode
a measure of centre of a data set, found by identifying the most frequently occurring data value

measure of variability
the use of mathematical calculations that describes how spread the set of data or scores are from each other; for example, range or standard deviation

range
a measure of spread, found by subtracting the minimum value from the maximum value

standard deviation
a measure of spread that shows, on average, how far the scores differ from the mean

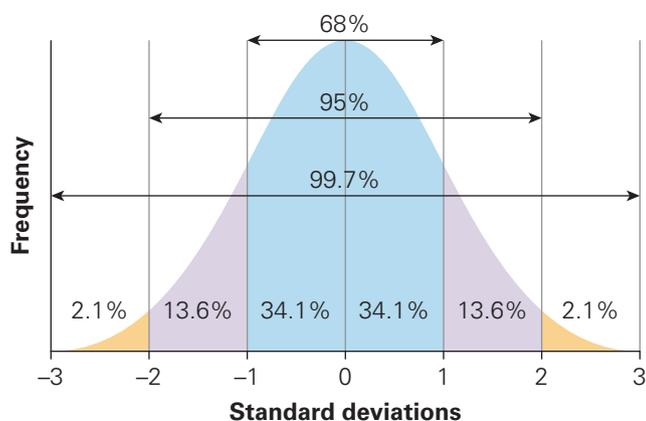


Figure 1.11 The normal distribution curve is a function where the data is arranged in a symmetrical bell-shaped curve. 68% of the data points occur within one standard deviation of the mean. 95% of data points occur within two standard deviations either side of the mean. Going three standard deviations out in both directions captures 99.7% of the data points.

Identifying experimental errors

When analysing experimental data, it is important to keep the possibility of experimental errors in mind. These can be due to human error, procedural errors or failures of the measurement tools and equipment. Does ‘human error’ mean ‘mistake’? You need to be clear about the differences between mistakes, systematic uncertainties (leading to systematic error) and random uncertainties (leading to random errors). Otherwise you could potentially assign everything to ‘human error’ and not analyse the underlying reasons. Some examples are:

- parallax error (misreading the level of liquid against a scale by not having the eye level). This will increase the likelihood that it is a systematic error.
- missing a step in the method. This will increase the systematic error too
- zero error (when a scale is not correctly adjusted to a weight of zero with the

container sitting on it, so the container contributes to the mass of whatever you are weighing). This will also increase the systematic error.

- malfunctioning equipment, such as faulty scales or data loggers. An experimental error might manifest as an extreme data point, known as an **outlier**. For example, consider the data from the caffeine and heart rate experiment discussed in section 1.1. Table 1.3 shows the results pre- and post-coffee consumption for the participants in the ‘1 cup’ experimental condition.

outlier
an extreme data point

The mean change in heart rate was

$$\frac{4 + 19 + 15 + 134}{4} = \frac{172}{4} = 46 \text{ beats per minute,}$$

if you include all four values. However, this does not sound right. The after-coffee heart rate for the fourth participant appears to be an outlier as it is located a long way away from the rest of the data. This could have been an experimental error, such as a malfunctioning heart rate monitor. Outliers are often excluded from the data analysis for this reason, however it is important to explore why they occurred and mention this in the discussion. The first response should be (if possible) to repeat the measurement before automatically ditching it. You cannot just exclude data points because they do not fit your hypothesis! If you exclude this

outlier, then the mean change in heart rate

$$\text{was } \frac{4 + 9 + 15}{3} = \frac{38}{3} = 12.7 \text{ beats per minute,}$$

which seems to be a much closer representation of the actual changes seen in the experiment.

Amount of coffee (cups)	Heart rate pre-coffee consumption (bpm)	Heart rate post-coffee consumption (bpm)	Change in heart rate (bpm)
1	70	74	4
1	62	81	19
1	55	70	15
1	61	195	134

Table 1.3 Results of coffee consumption

Drawing valid conclusions from research statistics

Analysis of scientific data allows researchers to draw meaningful conclusions regarding the objects or population being studied. If the scientific method has been rigorous, then the conclusions can be generalised, that is, applied to the wider population. This is especially useful for governments in forming policies and health providers in making treatment plans. If the results are to be generalised, then the following criteria must be met.

- The results must be valid.
- The procedure must be appropriate.
- The results must be statistically significant (this may be irrelevant of some scientific experiments e.g. determining a value for 'g'; here the concepts of uncertainty would be more relevant).
- There was valid experimental technique (including control of extraneous variables)

- Quick check 1.6**
- 1 What is the range and how do you calculate it?
 - 2 As part of a memory experiment, a psychologist conducts a test with 13 subjects and records the number of correct answers out of 30. The following scores are recorded: 12, 15, 17, 22, 18, 28, 27, 28, 16, 16, 15, 19, 16. Calculate the mean, median and mode from this set of data.
 - 3 What does a p -value of $p = 0.02$ mean?
 - 4 In a normal distribution, what percentage of data points are located within two standard deviations either side of the mean?

Australians purchased more than 726 million litres of water in 2015 at approximately \$2.75 per litre, amounting to almost \$2 billion. There are many different types of bottled water, such as artesian, mineral or fluoridated water, but there are also companies that sell groundwater that costs nearly nothing.

potable
clean and safe to drink

For areas with difficult or no access to **potable** water, bottled water may seem like a good solution. However, for areas that do have access to potable water, the environmental cost should be considered.

To produce bottled water, water needs to be pumped out of the ground, transported and chilled before again being transported to supermarkets and shops. The majority of the plastic bottles are not recycled and end up in landfill or waterways.

Did you know? 1.1



Your turn to think and act like a scientist!

Using a different class, create an experiment that tests the different brands of water for taste quality. Evaluate the cost per litre and taste-quality rating. Follow the eight steps of the scientific method and everything you have learnt in this chapter.

Try this 1.5

Section 1.2 questions



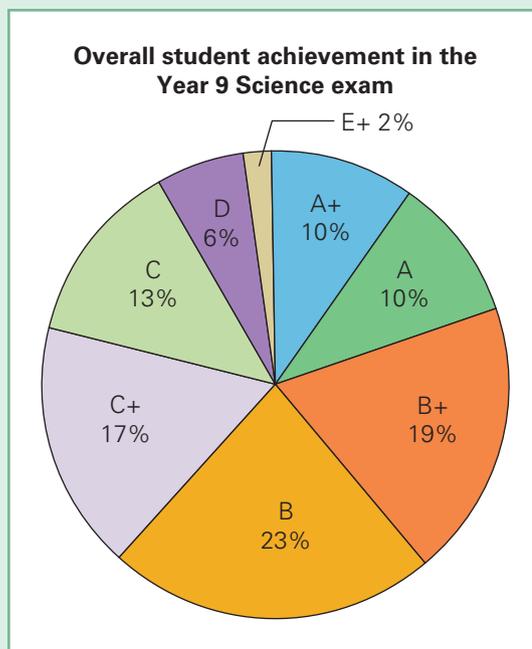
QUIZ

Remembering

- 1 Why are descriptive statistics useful when dealing with data?
- 2 Which experimental variable is placed on the x (horizontal) axis of a graph?
- 3 What is the name given to an extreme data point in a set of experimental data?

Understanding

- 4 The following pie chart shows you the proportion of grade achieved on the Year 9 Science exam in one class.



- a Why is this considered categorical data?
 - b Summarise the trends from this pie chart.
 - c Which other type of categorical graph might also be used?
- 5 If results from an experiment were to be generalised to the wider population, describe two features of the experimental process that must be followed.

Applying

- 6 Students were interested in conducting an investigation to determine how the length of a piece of wire impacted on its overall resistance. The results of their study are shown to the right.

- a Construct an appropriate graph, with all labelled axes, appropriate title, and plot the points from the data table.
- b Once the points are plotted, use a ruler to draw a straight line of best fit (trend line). The line should pass as close as possible to as many points as possible, however, it may not pass through every point.

Length of wire (cm)	Resistance (Ω)
10	0.28
20	0.50
45	1.12
90	2.55
160	3.95
200	4.89

continued...

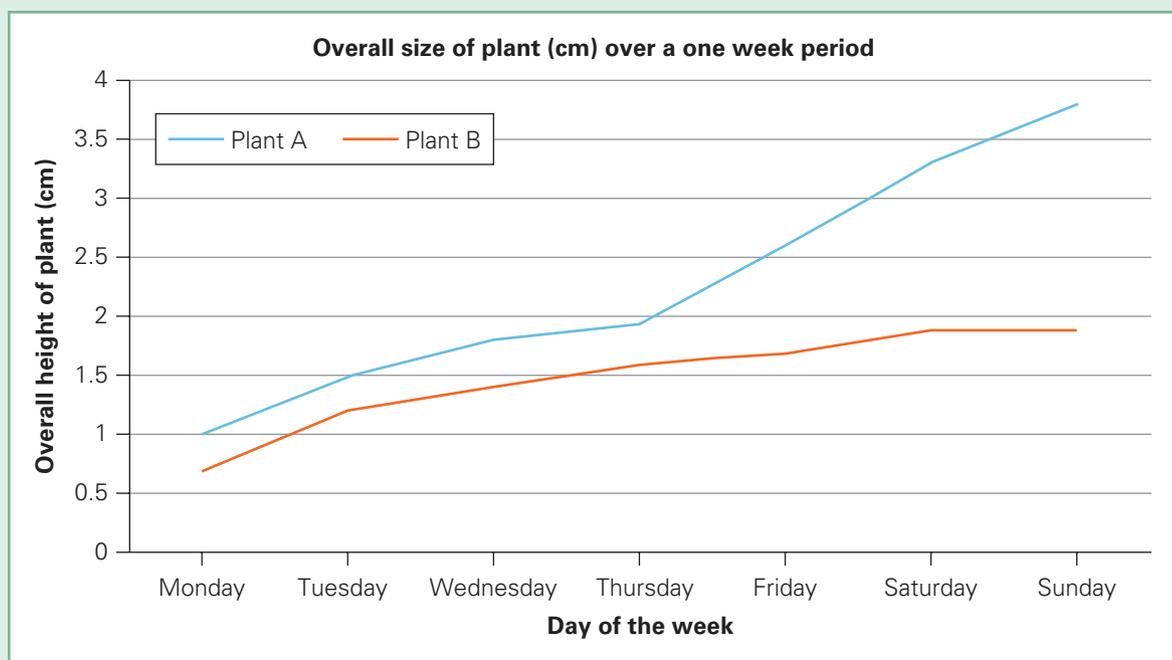
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- 7 Students were investigating the time (in seconds, s) taken for 200 g of sugar to dissolve in 500 mL of water at different temperatures (in degrees Celsius, °C). The results are shown at the right.
- Construct an appropriate graph with labelled axes and plot the points from the data table.
 - Choose whether you will sketch a line of best fit or a curve of best fit, depending on the shape of the data points plotted.

Temperature of water (°C)	Time taken to dissolve (s)
20.0	42
25.0	39
35.0	28
60.0	18
80.0	9
100.0	5

Analysing

- 8 Paul measured the change in overall height of two different pea plants over a weekly period. Both were watered daily, but Plant A was fertilised and Plant B was not. Refer to the graph below.



- How much difference in height was there between the two plants on the Monday?
- Why might starting on a different height impact the overall results of the data?
- Using the graph, determine the height difference between the two plants:
 - on Thursday
 - on Sunday.

Evaluating

- 9 Imagine you have been hired by a gaming company to help them investigate the effects playing video games regularly has on the adolescent brain. In particular, they want to know whether video games improve decision-making.
- Choose the variables that will be your control and independent variables and justify your choices.
 - Recommend how they might conduct the experiment, including the type of data they would be gathering, along with how the data should be processed and analysed.

Review questions

Remembering

- 1 Which variable is systematically manipulated or changed by the scientist during an experiment?
- 2 Which variable is measured during an experiment?
- 3 Completing your own experiment and recording the results yields what sort of data?



Understanding

- 4 Two mint bushes were planted in flower pots. One was planted in potting mix and one in sandy soil. They were left in a sunny position. Their change in height was measured in centimetres at regular intervals over a month. Identify the following factors.
 - a Independent variable
 - b Dependent variable
 - c Possible controlled variables
 - d Possible extraneous variables
- 5 A comprehension test was given to students after they had studied textbook material either in silence or with the television turned on. Identify the following factors.
 - a Independent variable
 - b Dependent variable
 - c Possible controlled variables
 - d Possible extraneous variables
- 6 Name one experimental mistake that could potentially cause an outlier in the experimental data.

Applying

The following p -values have been found after five different research procedures:

$$p = 0.02$$

$$p = 0.10 \quad p = 0.005$$

$$p = 0.05 \quad p = 0.01$$

- 7 Rank the p -values from lowest to highest. This shows the probability that the results of the experiment were due to chance.
- 8 Which p -values in question 7 indicate a statistically significant relationship between the independent and dependent variables?
- 9 Interpret a p -value of 0.20 ($p = 0.20$).
- 10 Graph the following data and draw a line of best fit. Ensure you appropriately label your axes, include a title and use an appropriate scale for both the x and y axes.

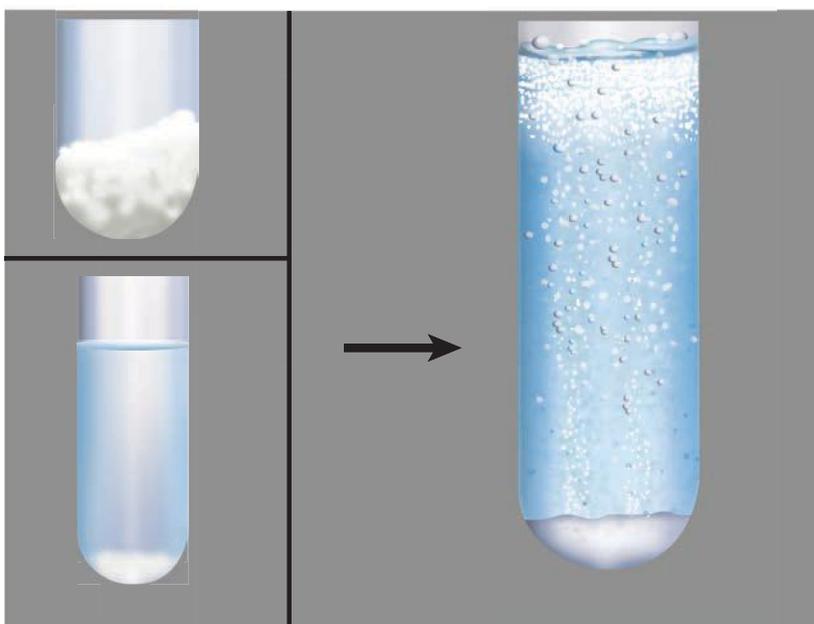
Day of experiment	Number of bacterial colonies on agar plate
0	1
1	2
2	5
3	12
4	22
5	28

Analysing

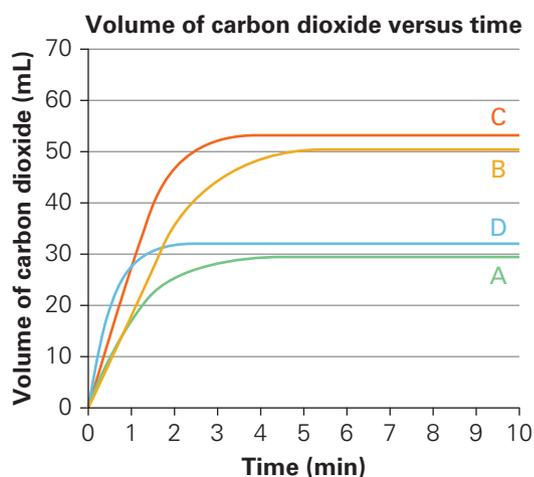
- 11 Four students set up an experiment looking at the neutralisation reaction between sodium carbonate (a white powder) and hydrochloric acid. Four test tubes were set up, each under slightly different conditions as shown in the table below.

Test tube	Volume of hydrochloric acid in test tube	Temperature of hydrochloric acid (°C)
A	50	22
B	80	22
C	100	22
D	50	60

The same amount of sodium carbonate was added to each test tube, and the volume of carbon dioxide produced was measured every minute.



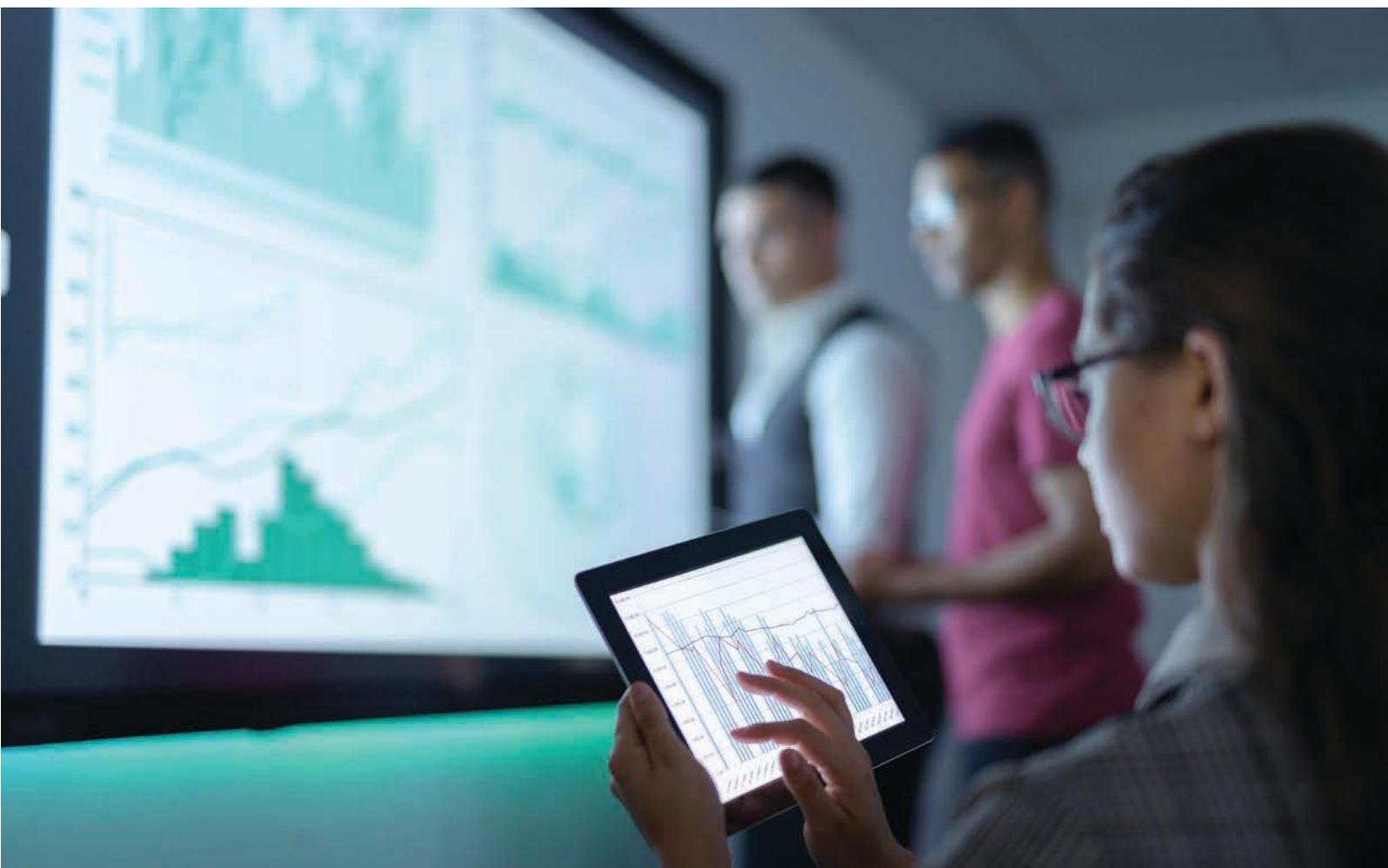
The following graph shows the amount of carbon dioxide produced by each test tube over time.



- a Which test tube produced the most carbon dioxide at 1 minute?
 - b Explain why test tubes A and D produced less carbon dioxide than test tubes B and C.
 - c One of the students wrote in his conclusion: 'The higher the temperature, the more carbon dioxide is produced.' Evaluate the accuracy of this statement.
 - d State one controlled variable in this experiment.
- 12 An evolutionary biologist was investigating the age (in months) when infants began to speak in sentences. She conducted a small observational study and collected the following data from 10 infants:
(Age in months): 30, 28, 22, 24, 25, 21, 28, 27, 31, 26
- a What was the mean age in months that infants began to talk in sentences, based on this study?
 - b What was the median age in months that infants began to talk in sentences, based on this study?
 - c What is the range in the ages of infants when they began to talk in sentences, based on this study?

Evaluating

- 13 One scientist told another: 'Your work is useless unless it is published in a peer-reviewed scientific journal.' Critically analyse this statement and make a judgement on its validity.
- 14 Justify why a scientist might choose to use secondary data from the Australian Bureau of Statistics rather than collect their own primary data.



Chapter 2 **Homeostasis**



Chapter introduction

The human body is a fascinating, yet complex, biological machine. Each body system works 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', and 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.

Curriculum

Multicellular organisms rely on coordinated and interdependent internal systems to respond to changes to their environment (VCSSU117)

• describing how the requirements for life (oxygen, nutrients, water and removal of waste) are provided through the coordinated function of body systems, for example, the respiratory, circulatory, digestive, nervous and excretory systems	2.1
• explaining (using models, flow diagrams or simulations) how body systems work together to maintain a functioning body	2.2
• investigating the response of the body to changes as a result of the presence of micro-organisms	2.3

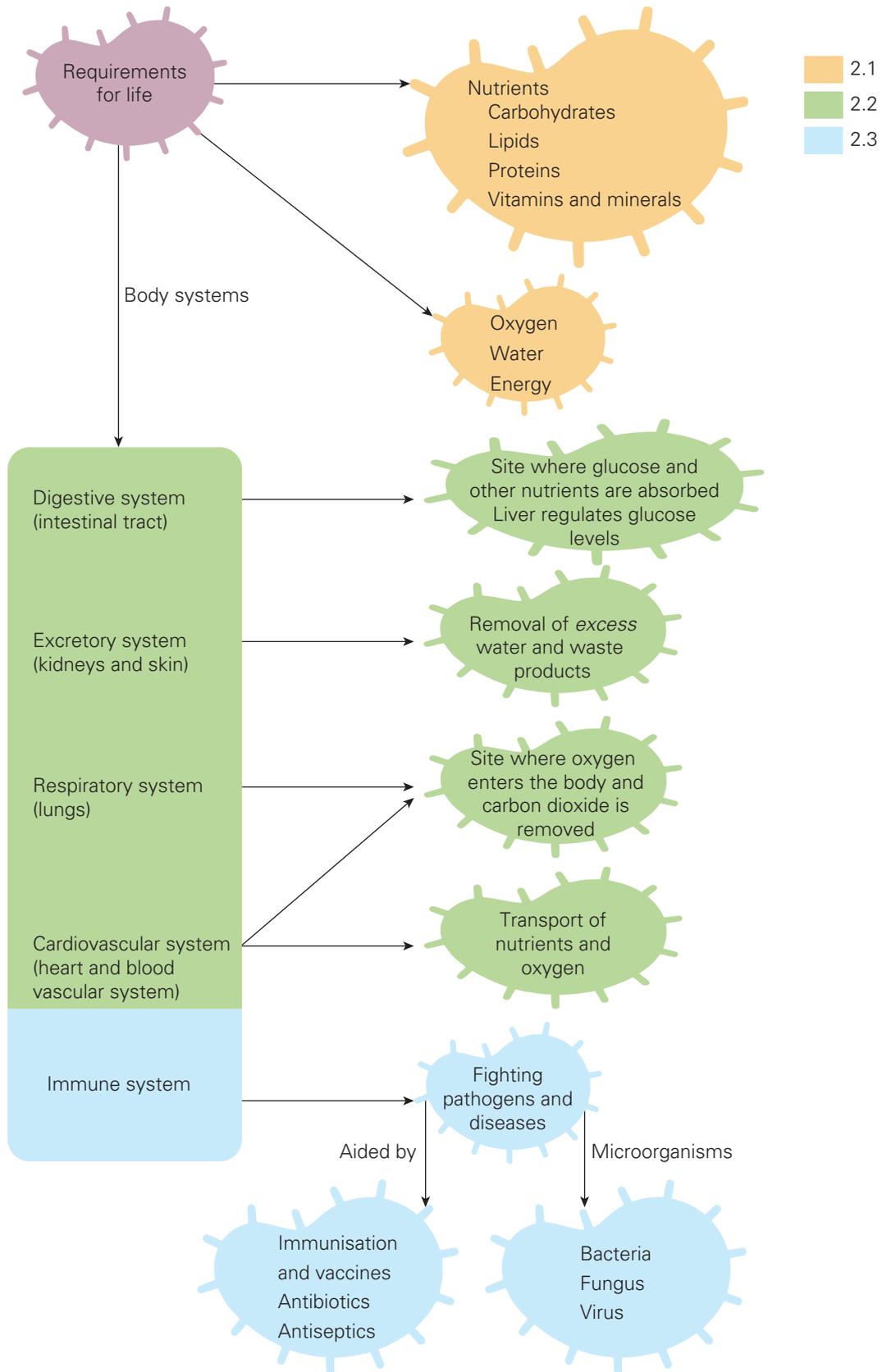
Victorian Curriculum F–10 © VCAA (2016)

Glossary terms

alveoli	enzyme	nephron
amino acid	fermentation	osmoregulation
antibiotic	fungus	pathogen
antibody	glucagon	phagocytosis
antigen	homeostasis	prokaryote
antiseptic	immune system	protein
bacteria	immunise	receptor
binary fission	insulin	septic
budding	lipid	stimulus
capillary	lymphocyte	unicellular
carbohydrate	memory cell	vaccine
effector	multicellular	virus



Concept map





2.1 The requirements for life

Multicellular versus unicellular organisms

Recall from your previous year's work that all living organisms consist of cells. Cells are commonly known as the 'building blocks of life' and are so small that you cannot see them without a microscope. Complex organisms, such as fish, mammals and humans, consist of many cells and are called multicellular organisms. For example, the human body is made up of trillions of cells. **Multicellular** organisms require specialised systems to carry out specific functions and consist of various levels of organisation within them. Individual

cells still perform specific functions, but they also work together for the good of the whole organism.

Simple organisms, such as bacteria, amoeba and paramecium,

may 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. However, this chapter will focus on multicellular organisms relying on highly organised and interdependent internal body systems needed to respond to changes in their environment.

multicellular

an organism that is composed of more than one cell

unicellular

a single-celled organism

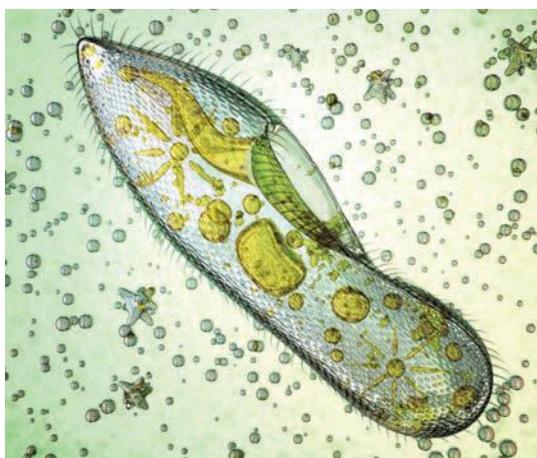


Figure 2.1 This shows the 3D structure of a unicellular organism known as *Paramecium caudatum*.



Figure 2.2 This jellyfish is an example of a multicellular organism as it contains specialised cells and systems to carry out specific functions.

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 rely upon both water and oxygen for survival and depend upon the food they eat to supply them with the energy required for purposes like breathing, digestion, movement and growth. Almost all the body's chemical reactions can only take place in water, which is also essential to maintaining the structure and shape of cells, tissues and organs. Also, many of the chemicals that maintain your body's proper functioning and balance (such as essential vitamins and minerals) must be obtained from the diet.

The molecule found in food that your body uses for fuel is glucose. During a process called cellular respiration, the energy stored in the chemical bonds of glucose is released as useable chemical energy. This process, which essentially involves a similar reaction to burning glucose, occurs in organelles of body cells called mitochondria. Cellular respiration provides cells with the energy required to conduct their specialised functions. The other reactant needed for cellular respiration is oxygen and you obtain



WORKSHEET



VIDEO
Components
of cellular
respiration.

this by breathing in the oxygen from the air. Look at the word equation for cellular respiration in Figure 2.3, and you will see the reactants on the left of the arrow and the products on the right.



Figure 2.3 Word equation for cellular respiration

Carbon dioxide and water are waste products in this process, though the water can be used in other processes instead of being excreted. Cellular respiration must occur non-stop for enough energy to be released for use within the cells.

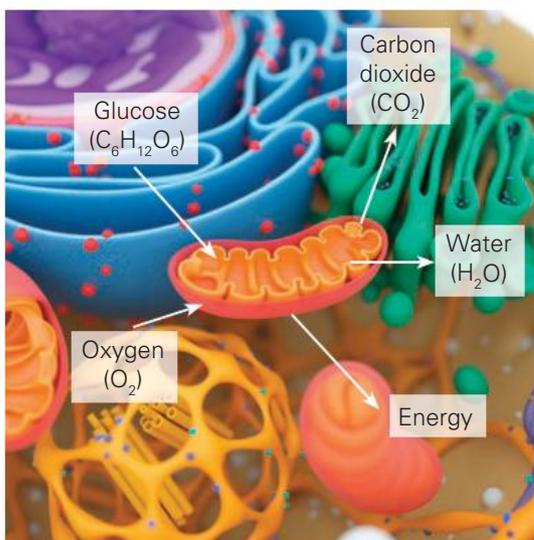


Figure 2.4 Cellular respiration occurs in the mitochondria of animal and plant cells to provide energy for cellular work.

- Quick check 2.1**
- 1 What is the main difference between a unicellular and a multicellular organism?
 - 2 What are the essential material requirements for life?
 - 3 List the reactants and products from the process of cellular respiration.
 - 4 Why is cellular respiration an essential requirement for life?



Figure 2.5 Water is an essential requirement and humans need about 2.5 litres of water per day to remain healthy. This includes the water obtained through food sources.

Nutrients

Nutrients are the chemicals that are obtained from a healthy diet and provide you with the energy and building blocks to allow your body's growth and repair.

The five main groups of nutrients that your body needs for optimum functioning are:

- 1 carbohydrates
- 2 lipids (fats/oils)
- 3 proteins
- 4 vitamins
- 5 minerals.

Carbohydrates

Carbohydrates are a vital energy source in the human diet. Just like a car needs fuel to run, the human body relies upon carbohydrates as its main source of energy.

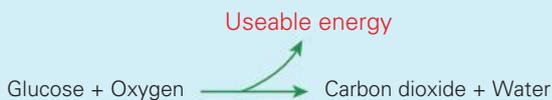
carbohydrate
biological molecules made of carbon, with hydrogen and oxygen in the same ratio as in water, and which can be broken down with the release of energy in the body

Carbohydrates provide the main fuel source for many vital organs, including the brain and kidneys. The digestive system breaks down

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 and also annotate the equation with where the substance comes from (reactants) and how it is removed from the body (products).

CELLULAR RESPIRATION REVISION POSTER



Try this 2.1

Types of carbohydrates	
Simple	Complex
Glucose and lactose, (also referred to as sugars)	Starch and cellulose (also referred to as polysaccharides)
	
Found in foods such as chocolate, honey (glucose) and milk (lactose)	Found in foods such as potatoes, rice, pasta, oatmeal, bread and vegetables

Table 2.1 Types of carbohydrates

carbohydrates into glucose so that cells can then use it in cellular respiration to make energy available. There are two main types of carbohydrates, as shown in Table 2.1.

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 of carbohydrate, but the energy stored in fats and oils cannot



Figure 2.6 Fats tend to be solid at room temperature (like butter). Oils tend to be liquids at room temperature (like olive oil). Their chemical properties determine their melting points.

be obtained as quickly as the energy in carbohydrates. The body uses fat for long-term energy storage.

Lipids have a big role in providing energy for the body. 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.

Proteins

Proteins are found in all living things and perform many functions, especially structural and regulatory ones.

- Some proteins are structural. For example, muscle, skin and hair are composed mainly of protein.
- Some proteins, called **enzymes**, are responsible for controlling the chemical reactions that take place in your body.
- Some proteins have specific roles, like haemoglobin, which carries oxygen around in the bloodstream.
- Some proteins are used to make **antibodies**, which enable your body to resist infectious diseases.
- Genes express their function by producing proteins that carry out the actual work.

lipid a chemical substance such as a fat or oil that can be used as an energy source
protein a chemical substance composed of amino acids, with structural and regulatory functions, and can also be used as an energy source. Food sources of protein include meat, legumes, dairy, eggs
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

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 absorbed (Figure 2.8). These can then be reassembled to make structural and functional proteins. Major dietary sources of

protein include meat, fish, dairy, legumes, nuts and seeds.

While amino acids from protein can be used as a source of energy, it is usually only when either there is a surplus or when there are no lipids or carbohydrates available. (For example, in the case of starvation.)



Figure 2.7 Protein is abundant in meat and fish, but there are many plant-based sources too.

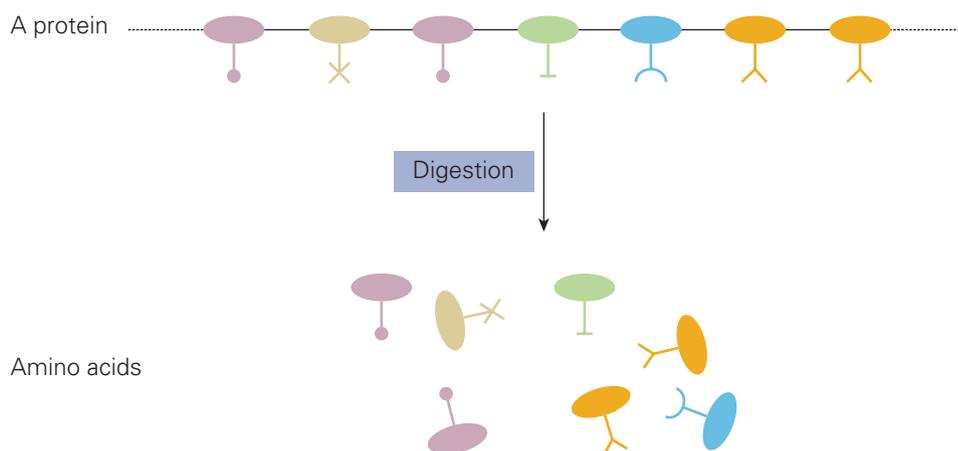


Figure 2.8 During digestion, proteins are broken down into individual amino acids. Your body cannot absorb protein, but amino acids can be absorbed and reassembled within the body to build new proteins.

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 assist in the breakdown of carbohydrates and

proteins. A deficiency of vitamins can lead to disease, such as scurvy or rickets. For the majority of people, all of the vitamins and minerals needed are available by eating a healthy varied diet and do not need routine supplements in tablet form. Some vitamins and minerals are toxic when taken in excess of the body's requirements.



Figure 2.9 This vitamin wheel shows some of the different vitamins your body needs and the foods they are found in.

Scurvy

Throughout the 13th to 16th 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.

Explore! 2.1

- 1 List the five main groups of nutrients that your body needs.

Quick check 2.2

- 2 Draw up a table summarising the function or purpose of each of the five nutrients in the body.

Practical 2.1

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)
- heat proof mat
- bottle cork with a needle inserted into the top
- thermometer
- tin can open at both ends (to act as a chimney)
- 25 mL measuring cylinder
- assorted food samples, e.g. Twisties (nuts should not be used)

Be careful

No food items are to be consumed.

continued...

continued...

Method

- 1 Place the tin can, Bunsen burner and cork on the heat proof mat. Ensure the room is well ventilated to avoid a build-up of smoke.
- 2 Use the measuring cylinder to pour 10 mL of water into the test tube.
- 3 Measure the starting temperature of the water and record it in the results table.
- 4 Measure the mass of the food sample and record it in the results table.
- 5 Place the food sample on the needle.
- 6 Have the test tube in its holder, ready to be placed over the flame.
- 7 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.
- 8 Measure the final temperature of the water as soon as the food sample is completely burnt out and record it in the results table (if it doesn't burn completely, relight it from the Bunsen and continue immediately).
- 9 Repeat with other food samples.
- 10 It is known that 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.

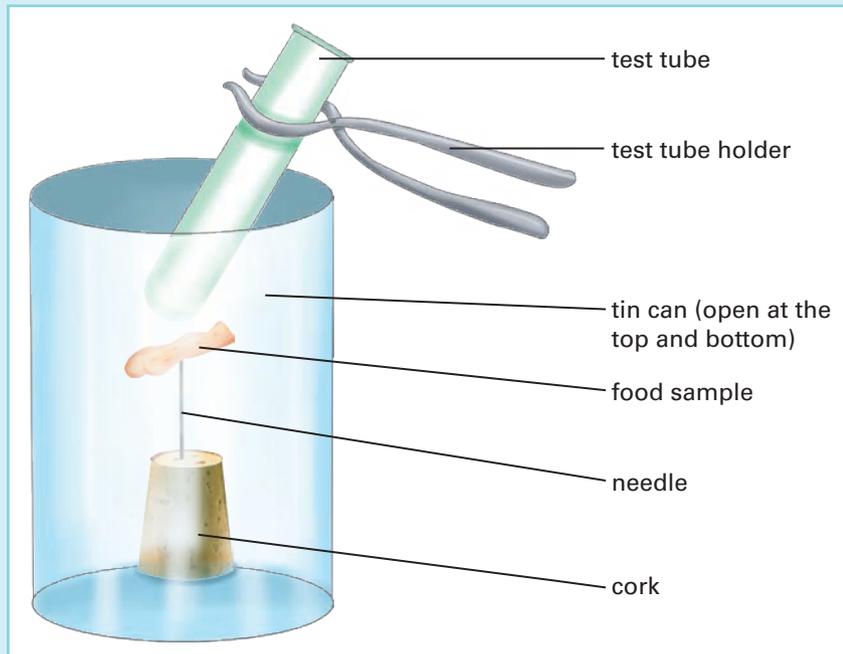


Figure 2.10 Experimental set-up

Results

Copy and complete the following table.

Type of food	Mass (g)	Starting temperature (°C)	Final temperature (°C)	Temperature change (final – starting temperature) (°C)	Energy content (temperature change × 42 joules) (J)

Evaluation

- 1 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?
- 2 Identify the foods that contained the most and least energy per gram. Was your hypothesis supported?
- 3 Identify two potential sources of error in this experiment.
- 4 Suggest two possible ways to improve the experimental design.

Conclusion

- 1 Make a claim from this experiment regarding foods and energy content.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Food, exercise and you

The body's source of energy is food. Carbohydrates are the body's preferred fuel; however, the body can draw upon the energy stored in proteins and lipids when carbohydrates levels are low. The internationally accepted unit for measuring the energy contained in food is kilojoules (kJ) and this is also used in Australia though labels sometimes show calories (Cal) as well. These labels are useful, because when you know the energy content of the food you eat, you can also calculate the amount of exercise required to 'burn off' this energy!

The average daily kilojoule (energy) requirement for a healthy adult is approximately 8700 kJ or 2079 Cal, and you will see this used as the average value on nutritional labels. However, people need to keep in mind that everyone's energy requirements are different, and they vary widely according to your age, gender, height and weight, and levels of physical activity. People with certain illnesses, or who are pregnant, will also have additional energy requirements. When you consume more kilojoules in a day than you burn, the excess energy is stored as fat. So it is not just high-fat diets that make you gain weight, but any excess kilojoules.

Bring in a food wrapper with the nutritional content supplied on it to analyse in class.

Try this 2.2

The following table summarises the energy content of the different components of food.

Food	Energy content
1 gram of protein	17 kJ
1 gram of fat	37 kJ
1 gram of carbohydrates	17 kJ

Calories are an old unit for measuring food energy, in science the kilojoule is used.

- 1 Calorie = 4.184 kJ

Using the tables of nutritional information for your chosen food source, copy and complete the table and calculate the following information.

	Food source	Partner's food source
Total calories per 100 g		
Protein (kJ) per 100 g		
Fat (kJ) per 100 g		
Carbohydrate (kJ) per 100 g		

- 1 Summarise the findings from the table above in a paragraph.
- 2 Rank the foods in order from highest calories to lowest calories.

Total Fat ▶
Generally choose foods with less than **10g per 100g**.
For milk, yogurt and icecream, choose less than **2g per 100g**.
For cheese, choose less than **15g per 100g**.

Saturated Fat ▶
Aim for the lowest, per 100g. **Less than 3g per 100g is best.**

Other names for ingredients high in saturated fat: Animal fat/oil, beef fat, butter, chocolate, milk solids, coconut, coconut oil/milk/cream, copha, cream, ghee, dripping, lard, suet, palm oil, sour cream, vegetable shortening.

Fibre ▶
Not all labels include fibre. Choose breads and cereals with **3g or more per serve**

Nutrition Information

Servings per package – 16
Serving size – 30g (2/3 cup)

	Per serve	Per 100g
Energy	432kJ	1441kJ
Protein	2.8g	9.3g
Fat		
Total	0.4g	1.2g
Saturated	0.1g	0.3g
Carbohydrate		
Total	18.9g	62.9g
Sugars	3.5g	11.8g
Fibre	6.4g	21.2g
Sodium	65mg	215mg

Ingredients: Cereals (76%) (wheat, oatbran, barley), psyllium husk (11%), sugar, rice, malt extract, honey, salt, vitamins.

Ingredients ▲
Listed from greatest to smallest by weight. Use this to check the first three ingredients for items high in saturated fat, sodium (salt) or added sugar.

◀ 100g Column and Serving Size
If comparing nutrients in similar food products **use the per 100g column**. If calculating how much of a nutrient, or how many kilojoules you will actually eat, use the per serve column. But check whether your portion size is the same as the serve size.

Energy
Check how many kJ per serve to decide how much is a serve of a 'discretionary' food, which has 600kJ per serve.

Sugars
Avoiding sugar completely is not necessary, but try to avoid larger amounts of added sugars. If sugar content per 100g is more than 15g, check that sugar (or alternative names for added sugar) is not listed high on the ingredient list.

Other names for added sugar: Dextrose, fructose, glucose, golden syrup, honey, maple syrup, sucrose, malt, maltose, lactose, brown sugar, caster sugar, maple syrup, raw sugar, sucrose.

◀ Sodium (Salt)
Choose lower sodium options among similar foods. **Food with less than 400mg per 100g are good, and less than 120mg per 100g is best.**

Other names for high salt ingredients: Baking powder, celery salt, garlic salt, meat/yeast extract, monosodium glutamate, (MSG), onion salt, rock salt, sea salt, sodium, sodium ascorbate, sodium bicarbonate, sodium nitrate/nitrite, stock cubes, vegetable salt.

Figure 2.11 Nutrition labels shown on food packages provide the nutritional facts of the food.

How do you lose weight?

Explore! 2.2

When we lose weight, where does it go?*The Age**By Ruben Meerman & Andrew Brown*

14 March 2018 — 9.24 pm

The world is obsessed with fad diets and weight loss, yet few of us know how a kilogram of fat vanishes off the scales. Even the 150 doctors, dietitians and personal trainers we surveyed shared this surprising gap in their health literacy. The most common misconception by far, was that fat is converted to energy. The problem with this theory is that it violates the law of conservation of matter, which all chemical reactions obey.

Some respondents thought fat turns into muscle, which is impossible, and others assumed it escapes via the colon. Only three of our respondents gave the right answer, which means 98 per cent of the health professionals in our survey could not explain how weight loss works. So if not energy, muscles or the loo, where does fat go?

The correct answer is that fat is converted to carbon dioxide and water. You exhale the carbon dioxide and the water mixes into your circulation until it's lost as urine or sweat. If you lose 10 kg of fat, precisely 8.4 kg comes out through your lungs and the remaining 1.6 kg turns into water. In other words, nearly all the weight we lose is exhaled.

The 415 grams of carbohydrates, fats, and protein most Australians eat every day will produce exactly 740 grams of carbon dioxide plus 280 grams of water (about one cup) and about 35 grams of urea and other solids excreted as urine.

The good news is that you exhale 200 grams of carbon dioxide while you're fast asleep every night, so you've already breathed out a quarter of your daily target before you even step out of bed. So if fat turns into carbon dioxide, could simply breathing more make you lose weight?

Unfortunately not. Huffing and puffing more than you need to is called hyperventilation and will only make you dizzy, or possibly faint. The only way you can consciously increase the amount of carbon dioxide your body is producing is by moving your muscles.

But here's some more good news. Simply standing up and getting dressed more than doubles your metabolic rate. In other words, if you simply tried on all your outfits for 24 hours, you'd exhale more than 1200 grams of carbon dioxide. More realistically, going for a walk triples your metabolic rate, and so will cooking, vacuuming and sweeping. Metabolising 100 grams of fat consumes 290 grams of oxygen and produces 280 grams of carbon dioxide plus 110 grams of water. The food you eat can't change these figures.

Therefore, to lose 100 grams of fat, you have to exhale 280 grams of carbon dioxide on top of what you'll produce by vaporising all your food, no matter what it is. Any diet that supplies less "fuel" than you burn will do the trick, but with so many misconceptions about how weight loss works, few of us know why.

continued...

...continued

- 1 '415 grams of carbohydrates ... will produce exactly 740 grams of carbon dioxide plus 280 grams of water'. The input and output does not look balanced. What else do you require as an input for metabolism?
- 2 According to this article, when you lose weight, where does it go?

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, your body temperature and for many other day-to-day functions. It is recommended you consume 2 litres 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 fluid intake to match the loss, or your body will become dehydrated. Physiologically, this 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 who play Australian Rules football can expect to lose, on average, approximately 1 litre of fluid per hour, and in hot, humid weather 2–3 litres 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 are a contributor to childhood obesity (as teenagers are drinking them when not engaging in sports) and tooth decay in elite footballers.

Science as a human endeavour 2.1



Figure 2.12 Even very small amounts of dehydration will reduce an athlete's performance in individual or team sports, including football.

Losing water

During a race, Formula One drivers are subjected to both high temperatures and high *g*-forces (the force felt as a result of acceleration, including the lateral acceleration of cornering). A driver can typically experience *g*-forces in excess of '4.5 times the *g*-force', which means the force is four and a half times their weight! A driver can lose up to 3 litres of water during a race, and they must counter this loss by consuming plenty of fluids before the race, otherwise their coordination and concentration may become impaired—not ideal when you're doing over 300 km/h! If a driver were to stand on a scale at the end of the race, the water lost means their weight might be 3 kilograms less than before the race, but this is readily gained back as they replenish their bodies with fluids and food.

Did you know? 2.1



Figure 2.13 It is not only footballers who lose water while competing.

Practical 2.2

How much sugar do different types of soft drink contain?

Aim

To determine how much sugar is in different soft drinks.

Because we cannot extract the sugar from the drinks and weigh it, we must use a different method. The more sugar that is dissolved in water, the denser it will be (i.e. the same volume will weigh more). We will graph the density of different concentrations of sugar in water – this will be our reference graph. Then we will measure the density of the soft drinks and estimate the concentration of sugar they contain from our reference graph. This assumes that it is only the sugar content of the soft drinks, and no other dissolved substance, that affects the density.

Materials

3 different types of regular (not diet) soft drink, e.g. cola, lemonade, ginger beer. These should be poured out into jugs or large containers, labelled just with the type and brand of soft drink, but no other information. The containers should be left unsealed for a few hours until they are no longer fizzy (i.e. there are no bubbles in the liquid).

- sugar
- water
- 500 mL measuring cylinder
- 3 × 250 mL beakers
- scale
- stirrer

Method

Pre-testing

- 1 Formulate a hypothesis. From the different types of soft drinks, which one do you think contains the most sugar? Or the least?

Sugar solution reference graph

- 1 Record the mass of the empty measuring cylinder in column A of the results table, for rows 1–3.
- 2 Add 20 g of sugar to the measuring cylinder.
- 3 Carefully add water to the measuring cylinder up to the 200 mL mark, so you now have 200 mL of sugar solution. Stir to dissolve the sugar.
- 4 Record the mass of the measuring cylinder and sugar solution in column B of the results table.
- 5 Subtract the mass of the measuring cylinder (column A) from its mass with the sugar solution (column B). Record this measurement in column C. It is the mass of 200 mL of the sugar solution.
- 6 Empty the measuring cylinder, rinse and shake to remove drops of water from it.
- 7 Add 40 g of sugar to the measuring cylinder, and repeat steps 3–6, recording the results in row 2 of the table.
- 8 Add 60 g of sugar to the measuring cylinder, and repeat steps 3–6, recording the results in row 2 of the table.
- 9 Calculate the density of the sugar solutions for rows 1–3 of the results table by dividing mass in column C by volume of the solution (200 mL) and record the results in column D.

$$\text{density} = \frac{\text{mass of the sugar solution (C)}}{\text{volume of the sugar solution (200 mL)}}$$

Be careful

No food items are to be consumed.



Figure 2.14 Regular soft drinks contain a lot of sugar, mainly sucrose (table sugar) or fructose, both a type of carbohydrate.

continued...

...continued

- 10 Draw a line graph showing the density of the sugar solution (y-axis, g/mL) versus the mass of sugar it contains per 200 mL (x-axis, g). This is the reference graph.

Mass of sugar in 200 mL sugar sol.	A Mass of measuring cylinder (g)	B Mass of measuring cylinder + sugar solution (g)	C (= B – A) Mass of sugar sol. alone (g)	D (= C / 200) Density of sugar sol. (g/mL)
1) 20 g sugar				
2) 40 g sugar				
3) 60 g sugar				

Soft drink

- Label three 250 mL beakers 4 to 6.
- Record the mass of each beaker in column A of the results table below.
- Using the measuring cylinder, add 200 mL of flat soft drink to beaker 4, and record the name of the soft drink in the first column of the table below.
- Weigh the beaker with the soft drink and record in column B of the results table.
- Subtract the mass of the beaker (column A) from the mass of the same beaker and the soft drink (column B). Record this measurement in column C. It is the mass of the soft drink alone.
- Repeat steps 2–5 for beakers 5 and 6 using different soft drinks.
- Calculate the density of each soft drink by dividing the mass of the soft drink in column C by the 200 mL volume. Record it in column D of the table.

Beaker + name of the drink	A Mass of the beaker (g)	B Mass of beaker and soft drink (g)	C (= B – A) Mass of soft drink alone (g)	D (= C / 200) Density of soft drink (g/mL)
4)				
5)				
6)				

Sugar content of soft drink

- On the y-axis of the reference graph, mark and label the density of the soft drink in beaker 4. With a ruler, draw a horizontal line from this mark across the graph. At the point where it intersects the graph line, draw a vertical line to the x-axis. At the point where the vertical line intersects the x-axis, record the value. This is the mass of sugar in 200 mL of the soft drink. Divide the mass by 2. This is the mass of sugar in 100 mL of the soft drink. Record this result.
- Repeat for beakers 5 and 6

Evaluation

- Compare and summarise the results obtained, using the mass of sugar in 100 mL of soft drink.
- Formulate a conclusion based on your original predictions about which soft drink had the most sugar by supporting or not supporting the hypothesis.
- Identify two possible sources of error in this experiment.
- Identify two ways the experimental design might be improved.

Conclusion

- Make a claim from this experiment regarding sugar content in soft drinks.
- Support the statement by using your observations (include potential sources of error).
- Explain how your observations support your claim.



QUIZ

- 1 What unit is food energy measured in?
- 2 Write down the approximate daily energy requirements for a healthy adult.
- 3 The kilojoules you burn up exercising depend on your weight, the length of time you exercise for and the intensity. Do some research online to see if you can find out how much 30 minutes of some different exercises/activities will burn in kilojoules for one weight range. Summarise what you find out in a table.
- 4 Whatever your age, gender, height or activity level, to maintain your body weight, energy in must equal energy out. Explain what this means.
- 5 Define the term 'dehydration' and explain why it is so important to keep hydrated.

Quick check 2.3**Section 2.1 questions****Remembering**

- 1 What is 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 Name 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.
- 9 Calculate the energy from the following food types: (Remember that kilojoules are similar to calories: 1 calorie = 4.184 kJ.)
 - a Peppermint crisp chocolate bar contains 172 calories energy per bar
 - b One bottle of Powerade sports drink contains 185 calories
 - c Four Weetbix contain 107 calories
 - d One red apple, raw, skin on contains approximately 60 calories

Analysing

- 10 An athlete is contemplating going on a diet to lose some weight and decides to minimise their carbohydrate intake. What are some potential consequences or considerations for the athlete?
- 11 On the whole, females tend to need less energy overall in their daily recommended energy intake (kJ) compared to men. Discuss possible reasons for this.
- 12 Fats provide more energy than carbohydrates. Why don't athletes eat lots of fatty food just before they compete?

Evaluating

- 13 Predict if any health issues would arise if a person was drinking sports drinks when they were not physically required to do so.
- 14 According to the Australian Institute of Health and Welfare, 1 in 4 Australian children were overweight or obese in 2014–2015. Decide whether childhood obesity is a problem in Australia or not. Recommend several strategies on how childhood obesity rates might be reduced.
- 15 If the Victorian Government banned all sugary foods and drinks in all schools, would this solve obesity in children? Discuss the pros and cons of this rule.



2.2 Body systems working together

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 are made up of organs with highly specific functions. These systems are:

- | | |
|----------------|------------------------------------|
| 1 Circulatory | 7 Nervous |
| 2 Endocrine | 8 Muscle |
| 3 Skeletal | 9 Immune |
| 4 Reproductive | 10 Skin and outer
body covering |
| 5 Digestive | 11 Respiratory |
| 6 Excretory | |

All multicellular organisms depend upon body systems to work 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 environment, such as an increase in temperature, an adjustment must be made so that the internal environment of the body and cells remains stable. It is a bit like a set of scales that need to be kept in constant balance, or the job of a heating/cooling system in a house.



homeostasis
the maintenance of a relatively stable internal body environment, despite changes in the external environment

The nervous system plays the primary role in control and coordination over most actions of the human body and works hand-in-hand with the endocrine system that produces particular hormones that are released into the blood stream in response to external or internal changes. Together they form a team:

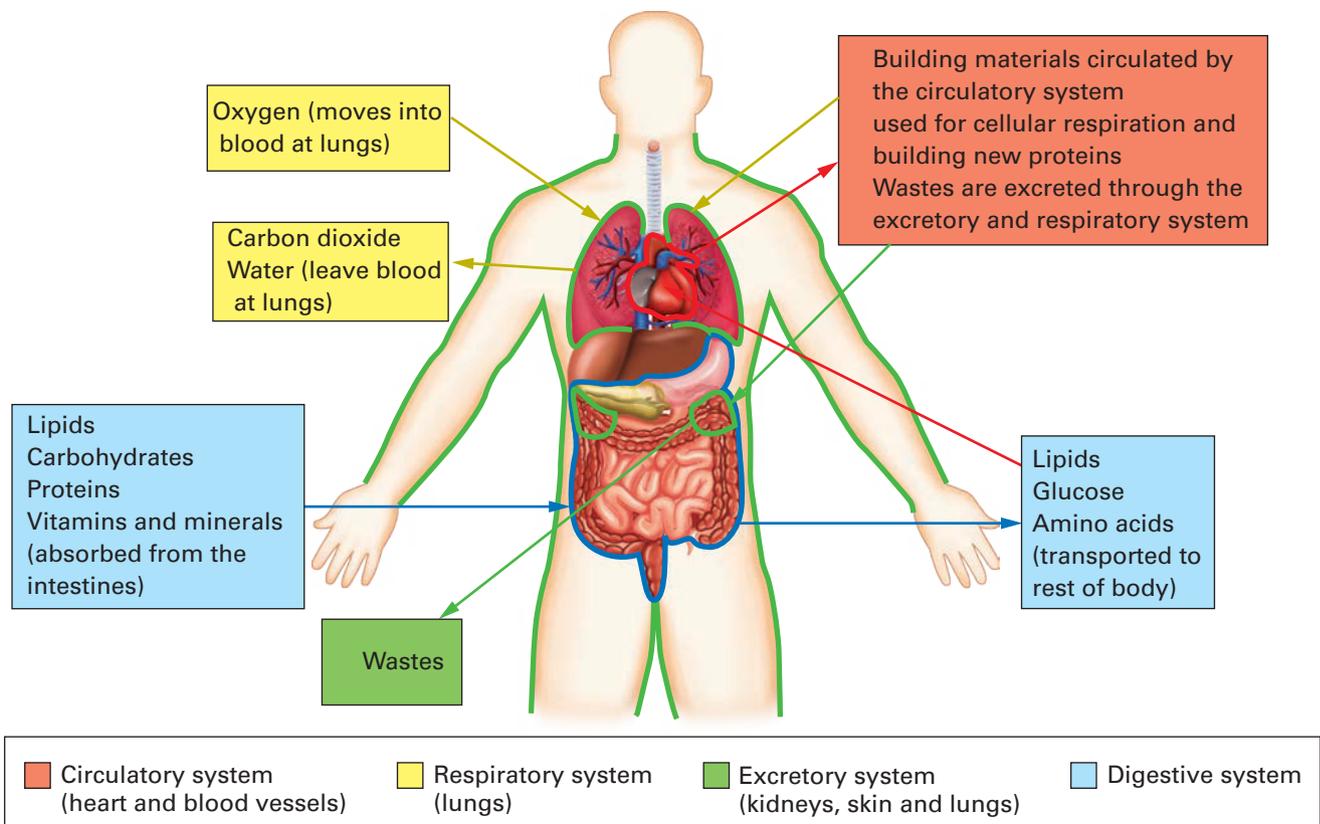


Figure 2.15 An example of how 4 of the 11 body systems work together with other systems



VIDEO

Describe how negative feedback works.

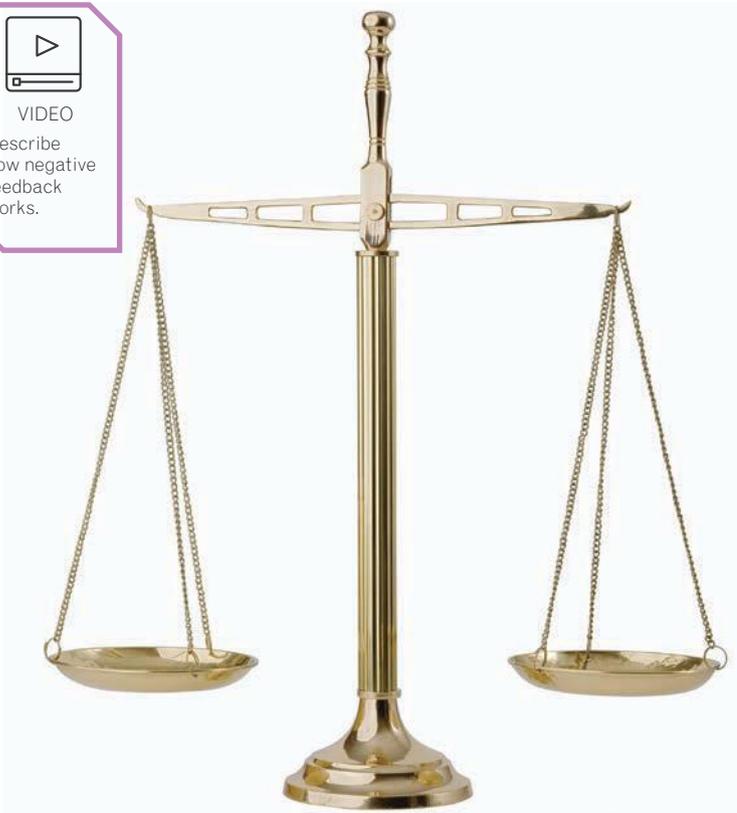


Figure 2.16 Homeostasis is like a scale: the body will automatically balance out the excess, lack of specific substances or the level of physical parameters (such as temperature) to keep the body working at its optimum level.

the nervous system provides fast-acting, short-lasting effects and the endocrine system triggers slower-acting, long-lasting effects.

Stimulus–response model

To achieve homeostasis, the body needs to respond to changes within the body's internal and external environment. These are 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 5-step stimulus–response model, shown in Figure 2.17 and Table 2.2.

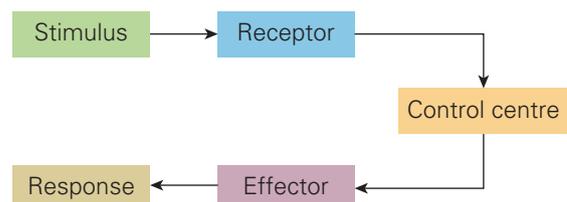


Figure 2.17 A flow chart outlining the stimulus–response model

stimulus

any object or event that elicits a sensory or behavioural response in an organism

receptor

a sense organ (or cell/group of cells) that detects stimulus

effector

a muscle, gland or organ capable of responding to a response signal from the control centre

Stage of the flow chart	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 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
Effector	The muscles or organs that are signalled to cause the response	Muscles begin to contract and relax quickly (shivering) to generate heat
Response	Returns the body back to a state of balance so the receptors are no longer active	Body core temperature is raised back up to within normal range

Table 2.2 A summary of the stages of the stimulus–response model

- Quick check 2.4**
- 1 Define the term 'homeostasis'.
 - 2 Explain why homeostasis is so important to your survival.
 - 3 What part/s of the body are involved in maintaining homeostasis?
 - 4 Draw the stimulus–response model into your notes or on A4 paper and annotate it with information about each of the five parts, similar to Figure 2.17.

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 allows 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 carbohydrates down into sugars. This partially digested food then progresses down the digestive system and continues to be broken down both physically (by the teeth) and chemically (by enzymes and stomach acid). The smaller chemical units, 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.

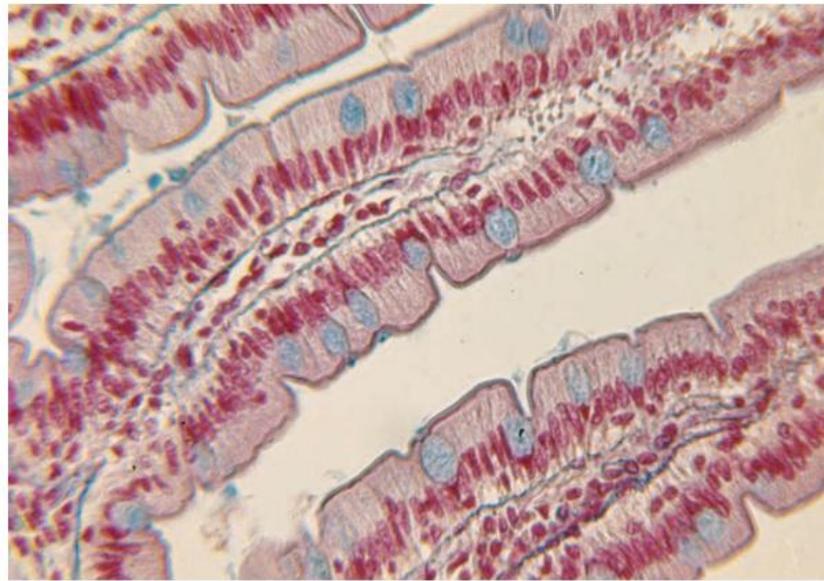


Figure 2.18 Specialised cells in the intestines have a high surface area to aid absorption of nutrients into the bloodstream.

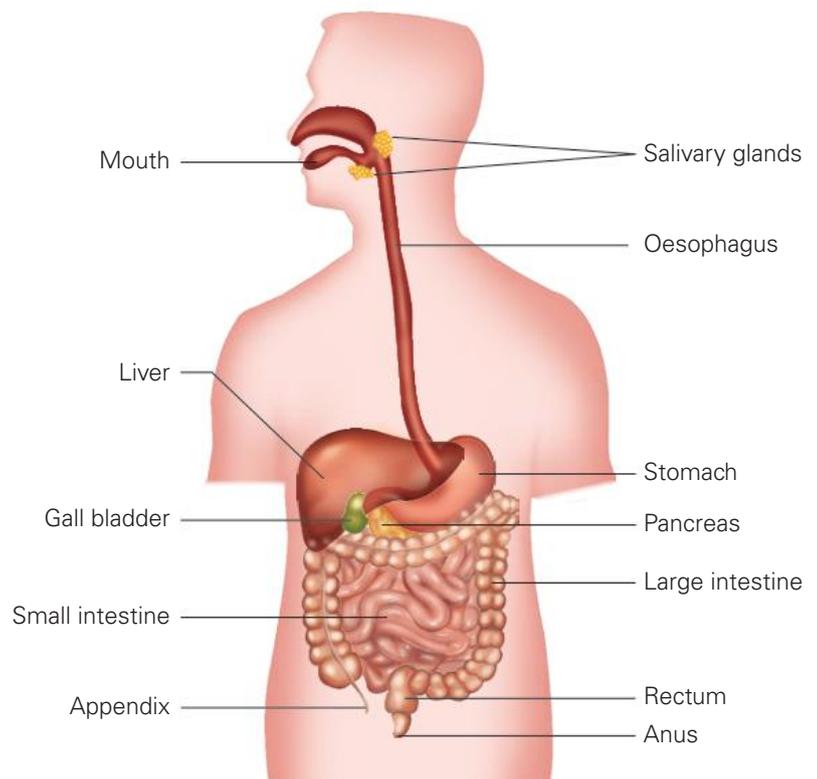


Figure 2.19 The human digestive system

No stomach**Did you know? 2.2**

The platypus and echidna, both egg-laying mammals or 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 to conserve energy.



Figure 2.20 Both the platypus and echidna do not have a stomach.

Diffusion is 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 in and out of them. When glucose-rich blood flows near active cells (using glucose), glucose will diffuse from the blood into nearby cells.

Practical 2.3**Modelling water diffusion with gummy bears****Aim**

To explore the diffusion of water in gummy bears.

Materials

- gummy bears (3 per group)
- 200 mL beaker
- water
- scale
- ruler

Method

- 1 Construct a hypothesis for this experiment: What do you imagine will happen to the gummy bear upon soaking?
- 2 Using your ruler, measure the length and width of your gummy bear and record this in a table of values.
- 3 Weigh your gummy bear and record its mass in the table of values.
- 4 Label a beaker with your group names and half fill it with water.
- 5 Place your gummy bear in the beaker and leave it for 2–3 hours.
- 6 Gently remove your gummy bear from the water and pat it dry. Be careful as it will be very fragile.
- 7 Remeasure the length and width of the gummy bear, record its new mass and record any descriptive observations of the lolly.

Results

- 1 Calculate the percentage change in the length, width and mass of the gummy bear.

$$\text{Percentage change} = \frac{\text{After measurement} - \text{Before measurement}}{\text{Before measurement}} \times 100$$

- 2 Record the changes in a bar graph.

continued...

Be careful

No food items are to be consumed.

...continued

Evaluation

- 1 Account for the change in length, width and mass of the gummy bear.
- 2 Given your results, what conclusions can you make regarding the concentration of water in the gummy bear?
- 3 Predict what might have happened if you had soaked the gummy bear in a solution of concentrated sugar.
- 4 Name two potential sources of error for this experiment.
- 5 Suggest a way the experimental design might be improved.

Conclusion

- 1 Make a claim from this experiment regarding water diffusion and the glucose content of gummy bears.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Regulating blood glucose levels

Body cells function best when conditions are stable within narrow physical and chemical ranges, and one of the substances that needs to be highly regulated is the concentration of glucose in 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 donuts 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.

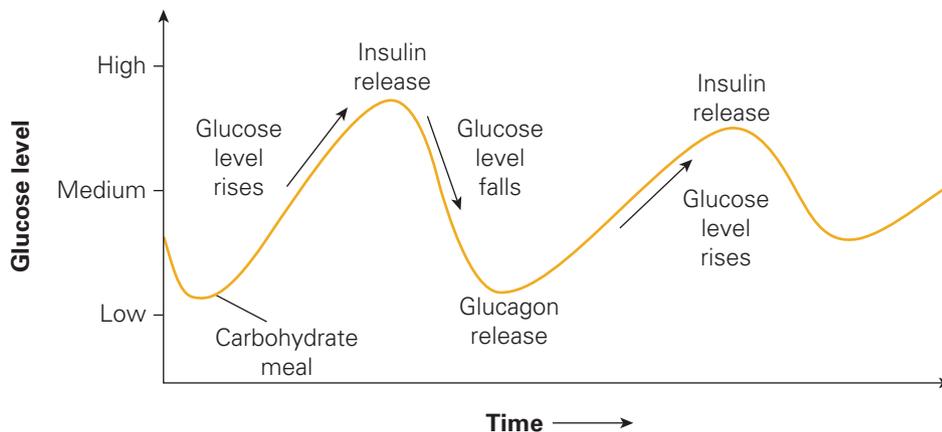
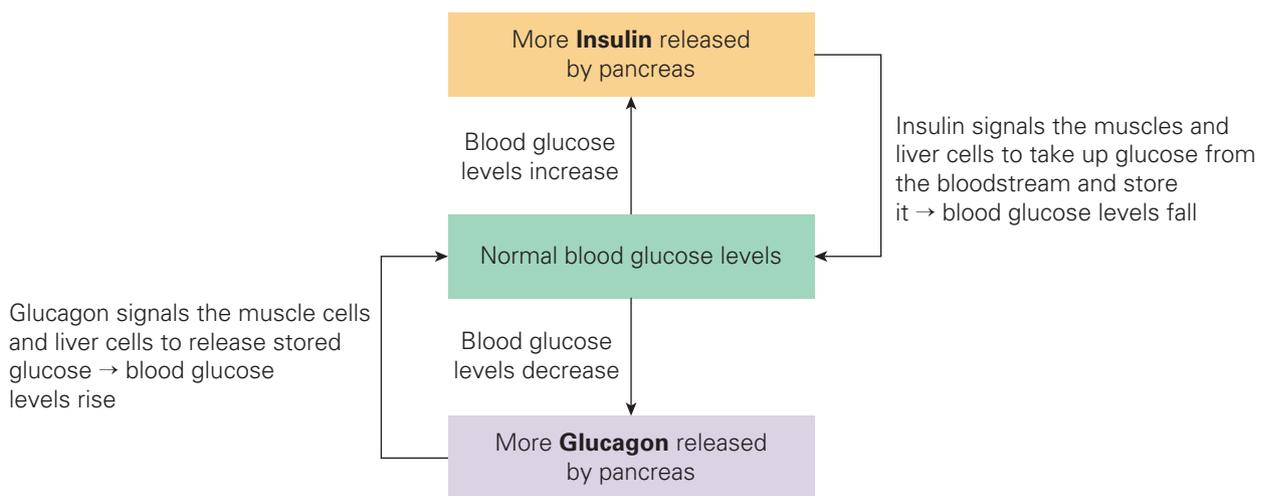


Figure 2.21 After a carbohydrate-rich meal, insulin levels in the bloodstream increase as the body needs to decrease the blood glucose levels.

insulin

a hormone secreted by the pancreas that triggers the liver and muscle cells to take up glucose from the bloodstream, lowering the blood glucose levels

Homeostasis of blood glucose levels is controlled by two hormones, which are both secreted by the pancreas: **insulin** and **glucagon**. Both hormones are slow-acting products of your endocrine system

and they act upon effectors to bring about opposite changes. They are released in different amounts, according to your blood glucose levels.

glucagon

a hormone secreted by the pancreas that triggers the liver and muscle cells to release glucose into the bloodstream, raising the blood glucose levels

Using the information provided in this chapter, construct a flow chart showing the stimulus-response model in action for control of blood glucose levels. You may choose either scenario: blood sugar levels are too high or too low. Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector and response.

Try this 2.3

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

Diabetes**Explore! 2.3**

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 2.22 Artificial insulin is injected into the body by a diabetes sufferer.

- 1 What is the primary role of the human digestive system?
- 2 What role do digestive enzymes play in providing energy to your cells?
- 3 After a meal rich in simple carbohydrates, your blood glucose levels rise sharply. Which hormone would be released by the pancreas to decrease the levels?

Quick check 2.5

The excretory system

The digestive system works very closely with the excretory system whose main responsibility is the removal of wastes (called excretion) 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 all have roles to play in excretion of certain substances. These are summarised in the Table 2.3.

Organ	Role in excretion
Kidneys	Filter the blood and form urine which allows removal of urea, excess salts and water
Large intestine	Stores and transmits useless waste material after digestion to outside of the body
Liver	Breaks down alcohol, toxins and the excess amino acids (from proteins) that are in the bloodstream
Lungs	Exhale water vapour and carbon dioxide
Skin	Secretes fluid waste (sweat) for temperature control

Table 2.3 Organs that assist with excreting wastes

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 one million **nephrons** – tiny microscopic structures that are known as the functional unit of the kidney. This means they do all the hard work and to do this, they have an amazingly complex structure that enables them to work super efficiently. So how do they do it? 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, 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. 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

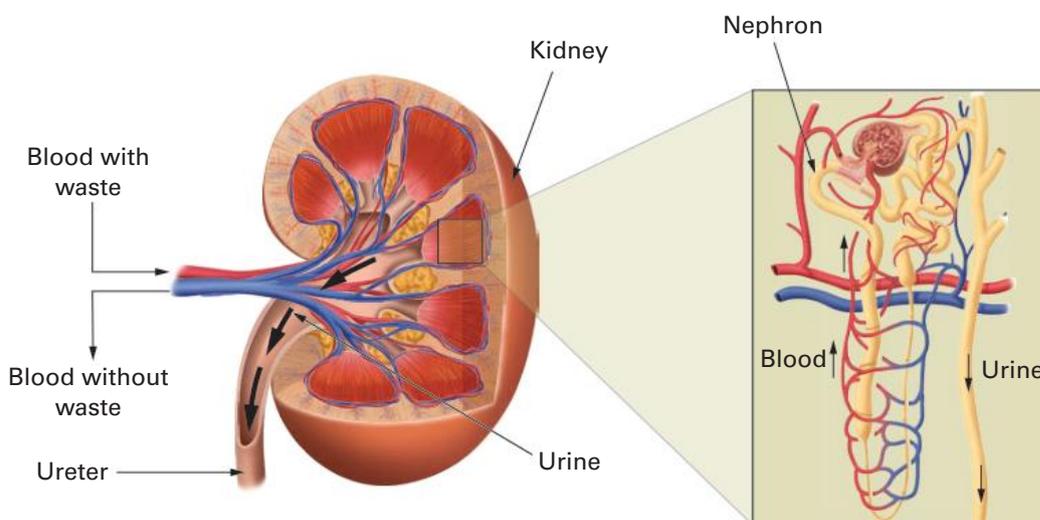


Figure 2.23 The structure of the kidney and one nephron: the functional unit of the kidney

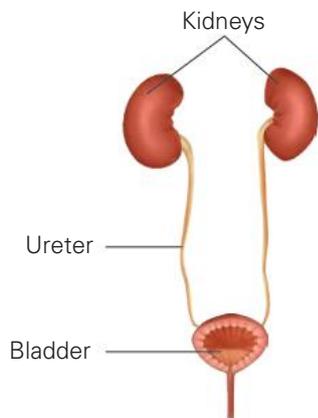


Figure 2.24 A simple overview of the organs involved in urine production, storage and excretion

Regulating water levels

The regulation of the amount of water in the blood is a very important example of homeostasis. It is often referred to as **osmoregulation**, where ‘osmo’ refers the concentration of dissolved substances like salt and sugars. The amount of water in the blood is measured continuously by a group of osmoreceptors in the hypothalamus of the brain. They can detect if there are low levels of water in the blood (the blood is very concentrated) or high levels of water in the blood (the blood is very dilute).

osmoregulation
the regulation of water levels in the blood/body

These are the important steps in osmoregulation and how the different body systems are involved.

- ADH is produced by the hypothalamus but is stored in the pituitary gland.
- The pituitary gland in the brain (part of the central nervous system) controls blood water concentration by releasing the antidiuretic hormone (ADH) when water levels are low (endocrine system).
- ADH is released and is carried by the blood (cardiovascular system) to the kidneys (excretory system) when there is not enough water in the blood. ADH increases the ability of the kidney tubules to absorb water and return it to the blood.

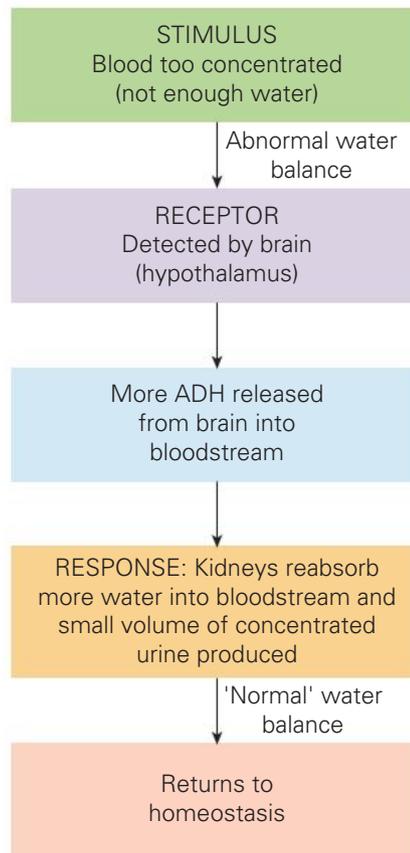


Figure 2.25 The stimulus–response flow chart for when water levels are low

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.

Try this 2.4

Diuretics

A diuretic is a drug that increases water excretion in the urine. These might be taken by athletes for two reasons.

- They cause rapid weight loss (due to loss of water). This strategy might be used by boxers or jockeys who need to maintain a certain weight.
- They can mask other illegal drugs as they flush it out of the athlete's system.

Athletes have been suspended for taking diuretics to mask banned drugs.

continued...

Did you know? 2.3

...continued



Figure 2.26 Athletes may be banned for taking diuretics.

The respiratory and cardiovascular systems

The respiratory system and the cardiovascular system work together to keep up a constant supply of oxygen to the cells of the body. Both 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 depends upon the exchange of gas inside the lungs. To breathe in, a large muscle called the diaphragm contracts and draws air into your lungs. The air (which is approximately 21% oxygen) travels in the nose and mouth, down the trachea (windpipe) and to branching tubes called bronchi and bronchioles into the left and right lungs. These tubes terminate in microscopic air sacs called **alveoli** (singular:

alveoli
(singular: alveolus) tiny air sacs found within the lungs, which are the site of gaseous exchange

- Quick check 2.6**
- 1 What are the names of some organs that are involved in excretion of wastes?
 - 2 List two functions of the excretory system.
 - 3 Which part of the kidney is responsible for filtering blood? Outline its role.
 - 4 What does the hormone ADH stand for and what is its role in osmoregulation?
 - 5 Which part of the brain monitors blood water concentration?

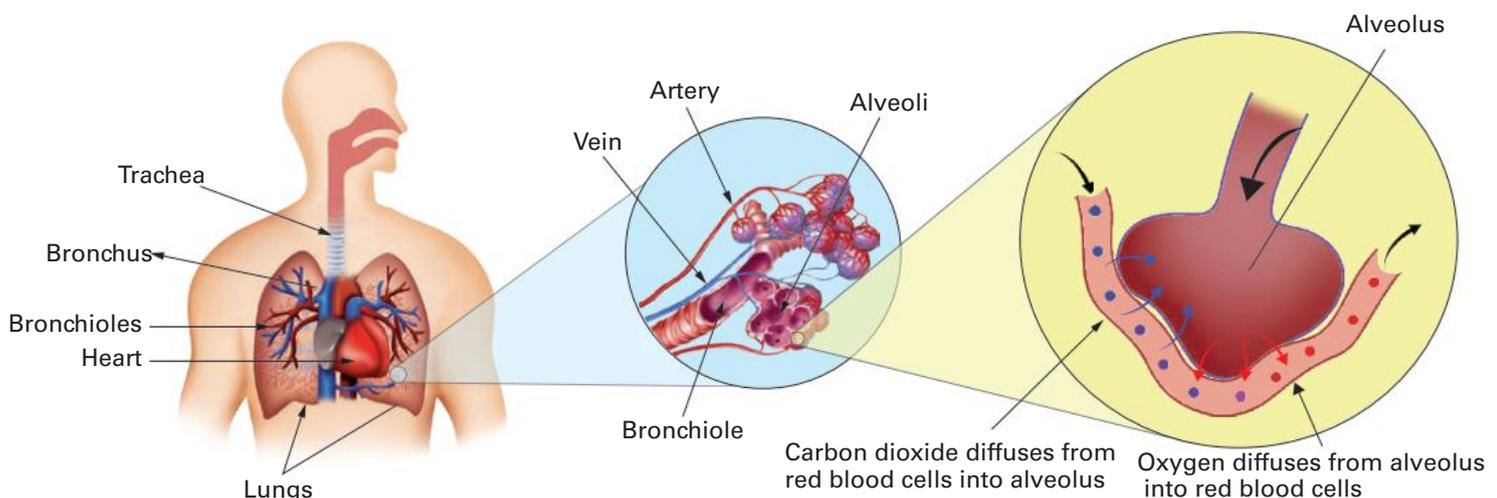


Figure 2.27 Zooming in on the respiratory system: breathing for the purpose of gas exchange

alveolus). There are approximately 300 million alveoli in the lungs, and if you could somehow lie them out flat, they would cover more area than a tennis court!

capillary

the smallest vessels which contain oxygenated blood and enable red blood cells to deliver oxygen to the tissues on a cellular level

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 a process called 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 and this needs to be disposed of. Carbon dioxide diffuses out of the body cells and moves into the bloodstream, and then travels to the lungs where it diffuses from the capillaries into the alveoli of the lungs and is breathed out (exhalation).

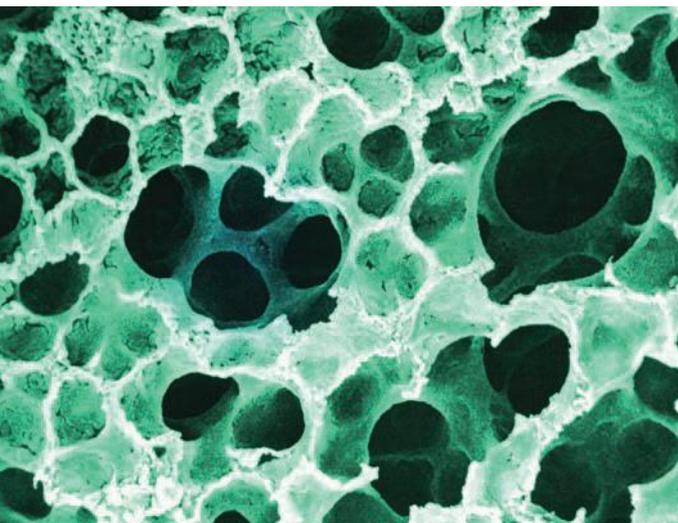


Figure 2.28 Alveoli in the lungs

The cardiovascular system

The circulatory system is the transport system of the body. It has four main functions.

- 1 It transports nutrients, oxygen and water in the blood to all cells in the body, so they can carry out cellular respiration to make energy available and the building blocks necessary to repair, grow and produce new cells.
 - 2 It transports wastes products to the kidneys or lungs to be excreted.
 - 3 It also carries other materials such as hormones, energy from cell respiration and antibodies around the body.
 - 4 It helps to maintain body temperature.
- You may recall from Year 8 that 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.

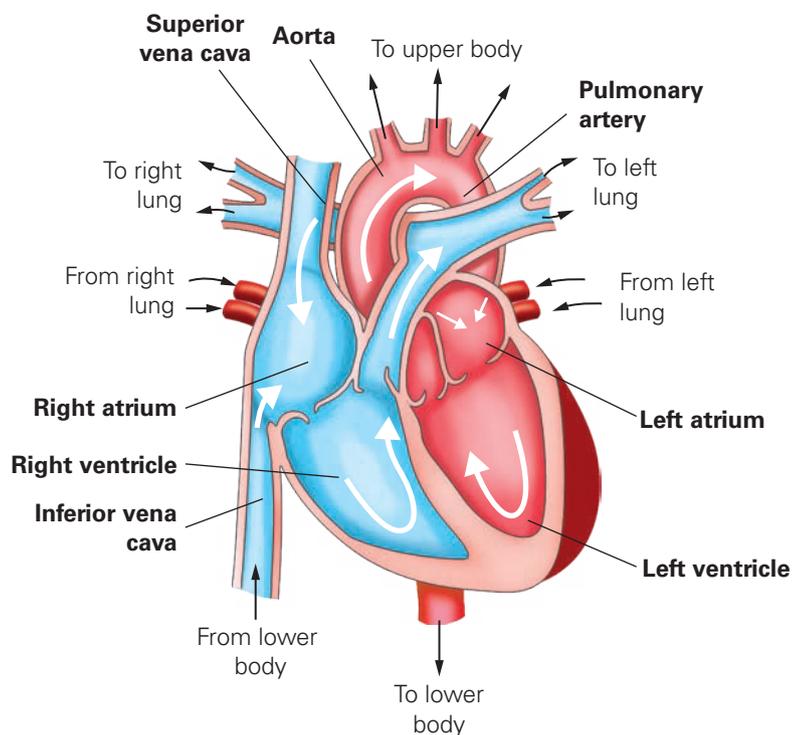


Figure 2.29 Human heart anatomy diagram showing blood flow with main parts

Construct a flow chart detailing the movements of an oxygen molecule and a carbon dioxide molecule. Ensure you cover the entire cycle – starting with inhaling (breathing in) and finishing with exhaling (breathing out).

Try this 2.5

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 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). Measure your own pulse for 15 seconds and then multiply this by 4: this is your heart rate in beats per minute (bpm). These days, many sports watches such as Fitbits can take a continuous reading of your pulse in bpm.



Figure 2.30 Modern sports watches allow you to continuously monitor your heart rate over the course of a day.

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.

Try this 2.6

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 the blood pressure is too low, it can result in a loss of 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 you know, the kidneys regulate the amount of water in the blood. In doing so, they also play a role in regulating blood pressure as well. 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 brainstem sends signals to the heart to slow down and to the blood vessels to dilate, thus lowering blood pressure.

Using the information provided in this chapter, construct a flow chart showing the stimulus–response model in action for control of blood pressure. You may choose either scenario: blood pressure is too high or too low. Ensure your flow chart features all the stages: stimulus, receptor, control centre, effector and response.

Try this 2.7

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

- 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 Where are the receptor sites that detect changes in blood pressure?
- 4 Other than the heart, which organ is involved in maintaining blood pressure?

Quick check 2.7**Practical 2.4****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, therefore less oxygen needs to be consumed. However, your respiratory and circulatory systems must work together to meet your increased energy needs during exercise.

As you exercise, your large muscle groups are contracting harder and more frequently and this requires energy! The cells require more oxygen because it is a necessary reactant of cellular respiration (the burning of glucose to release energy). This increased oxygen demand is achieved by:

- increasing your respiration 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: pump the oxygen faster to the cells

Aim

To investigate the effect of low- and high-intensity exercise on heart rate and breathing rate.

Hypothesis

Construct a hypothesis predicting what the results will be. Be specific in your predictions; for example, if it increases, by how much do you imagine?

Materials

- stopwatch
- calculator
- Optional: sporting watch/device that may record pulse in bpm or pulse oximeter

Method

- 1 Measure your partner's 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.)
- 2 Get your partner to count how many times they exhaled in this 15-second period.
- 3 Multiply both numbers by 4 to get beats per minute and breathing rate per minute. Record these in the table.
- 4 Instruct your partner to walk at their usual pace outside for a 2-minute period (low-intensity) and when time is up, immediately then measure their heart rate and get them to count how many times they take a breath in a 15 second period.
- 5 Multiply both values by 4 and record in table.
- 6 Measure the heart rate and breathing rate at 1-minute intervals another two times.
- 7 Instruct your partner to run around outside and use the stopwatch to time them for a 2-minute period (high-intensity) and when time is up, immediately then measure their heart rate and get them to count how many times they take a breath in a 15-second period.
- 8 Multiply both values by 4 and record these in the table.
- 9 Measure the heart rate and breathing rate at 1-minute intervals two more times.

continued...

...continued

Results

- 1 Complete the results table.

Time	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 minutes after exercise				
1 minute after exercise				
2 minutes after exercise				
High-intensity exercise (2-minute run)				
0 minutes (immediately after exercise)				
1 minute after exercise				
2 minutes after exercise				

- 2 Using Excel, or graph paper, construct a graph showing the change in breathing rate and heart rate per minute when performing both low intensity and high intensity exercise.

Evaluation

- 1 Explain your results (both heart rate and breathing rate) with reference to the homeostatic mechanisms occurring in the body.
- 2 Compare how long it took for the heart rate and breathing rate to return to rest following low-intensity and high-intensity exercise.
- 3 Discuss at least potential sources of error from this experiment.
- 4 Propose at least two suggestions on how this experiment could be improved.

Conclusion

- 1 Make a claim from this experiment regarding the circulatory and respiratory systems.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Extension

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

Science as a human endeavour 2.2

Bioprinting and the creation of organs

People can live longer and healthier lives these days with thanks to many technological advances, particularly in the field of medicine. Statistics provided by the Australian Institute of Health and Welfare speculate that a boy born in Australia between 2013–2015 can expect to live to the average age of 80.4 years and a girl would be expected to live to an average age of 84.5 years, in comparison to 47.2 years for males and 50.8 years for females, born between 1881–1890.

Approximately 1500 people in Australia alone are on the organ transplant list at any one time. Yet surprisingly, only 60% of families give consent for organ and tissue donations to proceed if organ donation is a possibility for members of their family who pass away. Luckily, advances in the field of 3D bioprinting will enable the possibility for many more organs to be created and therefore donated to those who need them, in the future. Stem cells are a special type of cell that have not matured into a particular cell type yet (for example, a skin cell, lung cells, liver cell). By harvesting these stem cells, they can be sent to a lab and chemically induced to differentiate into the type of cell needed, for example, a liver cell. These cells then replicate and can grow a whole fully functioning organ that can be transplanted without the fear of rejection! This technology would allow scientists to custom-build organs and tissues that match the patient's own cells, reducing the time spent waiting for a compatible organ donor.

This is a relatively new field. In fact, it was only in 2016 that researchers developed the first functioning 3D-printed liver tissue. Other such organs like skin, cartilage, bones and glands, have also been bioprinted. The technology was originally developed for rapid fabrication of industrial parts, but now it has been recognised for its biological applications, it is necessary to ensure sterile and tightly controlled conditions. However, there are many challenges that lie ahead for the developers of this technology due to the technical requirements that are involved with the bioprinting of organs. Yet hope remains that this technology might be a critical step towards meeting the need for donor organs.

Bioprinting

Research the 3D Print Exchange site, which is organised by the National Institute of Health (NIH) in the United States of America. It provides an open and interactive platform where users can browse, download, and share biomedical 3D print files, modelling tutorials and educational materials.

- 1 Propose why you think the NIH has made this information widely available.
- 2 Discuss the positive and negative ethical viewpoints of 3D bioprinting.

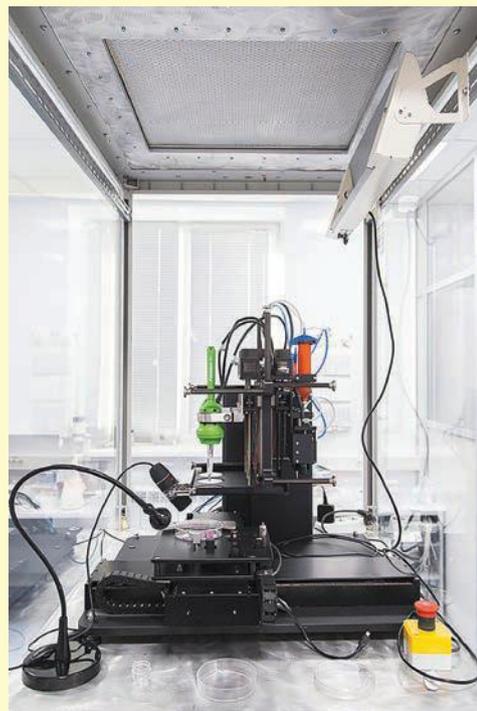
Explore! 2.4

Figure 2.31 This 3D bioprinter developed by the Russian company 3D Bioprinting Solutions is capable of printing live organs.

Section 2.2 questions



QUIZ

Remembering

- 1 Homeostasis is the maintenance of a relatively stable internal environment. Name four things that are tightly regulated within the human body.
- 2 The functioning or functional unit of the kidney is called a _____.
- 3 Gas exchange occurs between which two structures in the lung?
- 4 What hormones are secreted by the pancreas and what effect do 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 During long and frequent periods of exercise an athlete is likely to reduce muscle mass. Explain why.
- 8 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

- 9 Discuss why both the lungs and kidneys are considered to be organs involved in excretion.
- 10 Construct a Venn diagram showing the digestive, circulatory and respiratory systems. In their overlapping zones, summarise in dot points the way the systems interact.

Evaluating

- 11 The graph below shows the results of a glucose tolerance test for two patients, A and B. Justify which patient has diabetes using data from the graph.





2.3 Response to microorganisms



pathogen

a small organism, such as a bacterium, virus, prion or parasite that can cause disease

bacteria

(singular: bacterium) microscopic, unicellular (single-celled) organisms

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 2.4 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		AIDS
Anthrax		Mumps

Table 2.4 Some common diseases caused by different pathogens

Bacteria

Bacteria (singular: bacterium) are simple unicellular organisms called **prokaryotes**, that have a cell wall but no distinct organelles inside (see Figure 2.32). Individual bacteria cannot be seen with the naked eye, but a bacterial colony (group of millions of bacteria) will be visible if it contains a sufficient number of bacteria. Scientists therefore need a microscope to

study individual bacteria. The best light microscopes at school can magnify about 1000 times. Electron microscopes are used by scientists as they allow magnification of cells up to 500 000 times.

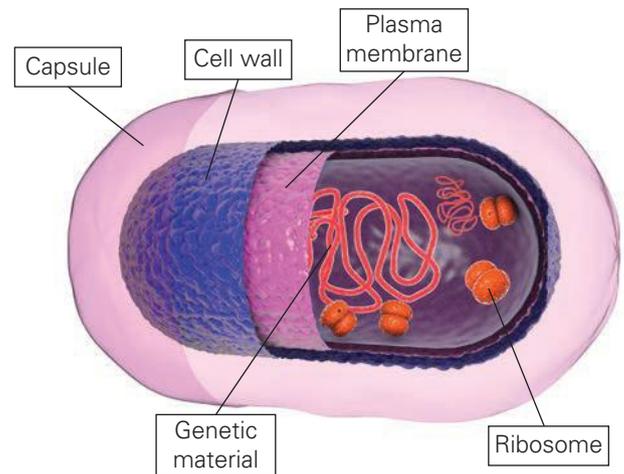


Figure 2.32 General structure of a bacterial cell

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. So, if you start with only one bacterium, after 20 minutes, you will have 2 bacteria, then following another 20 minutes, 4 bacteria, and so on, until after just 3 hours, you have had 9 cell divisions, equating to a growth from 1 through 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.

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, such as bacteria, and occurs when the cell divides, giving rise to two identical cells



Figure 2.33 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.

Quick check 2.8

- 1 Define the term 'pathogen'.
- 2 Why are bacteria considered as prokaryotes? Describe their structure.
- 3 How do bacteria reproduce, and why is this a problem if a pathogenic strain infects a person?
- 4 List the different names and shapes of bacteria.

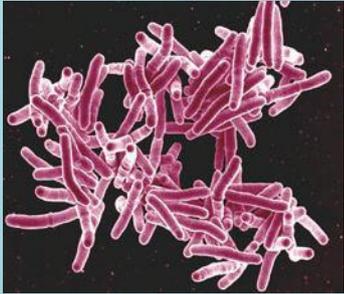
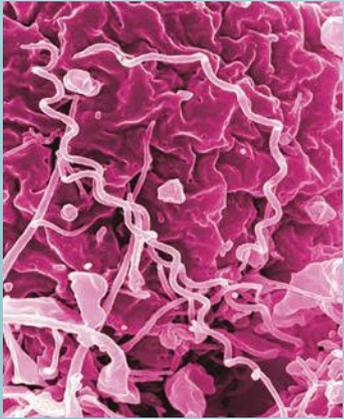
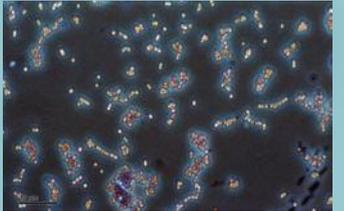
Shape	Biological name	Diseases	Magnified image
Rod	bacillus (plural: bacilli)	Typhoid Tuberculosis	
Spiral	spirillum (plural: spirilli)	Syphilis	
Spherical	coccus (plural: cocci)	Streptococcus (causes tonsillitis)	

Table 2.5 Common types of disease-causing bacteria

Practical 2.5: Teacher demonstration

Observing bacteria under a microscope

At least three different microscopes have been set up to show some different types of bacteria that have been stained for you to see under a magnification of 1000.

Aim

To observe different types of bacteria under the microscope.

Materials

Microscope, slides of different types of bacteria: for example, cocci, bacilli, spirilli

Method

- 1 Using the microscopes, observe the bacteria under a magnification of 1000.
- 2 Using a pencil, sketch each type and provide a title for each sketch.

Results

Sketch what you can see under the magnification of $\times 1000$.

Evaluation and conclusion

Were you able to differentiate between the three different types of bacteria? Write a few sentences to describe how you did.

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, 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.

Did you know? 2.4



Figure 2.34 Scientists used to use the eye of an ox for growing bacteria. Nowadays, a nutrient agar dish is used. This one contains bacterial colonies.

Practical 2.6

Using nutrient agar plates to grow bacteria

Be careful

Ensure gloves are worn when handling nutrient agar plates.

Do not sneeze or expose the agar to any pathogenic organisms.

Hands are to be washed with soap immediately after handling nutrient agar plates.

Sealed agar plates are not to be opened. Once plates have been observed they will be collected and destroyed.

All working surfaces are to be wiped down with disinfectant after all nutrient agar plates are collected.

continued...

...continued

Aim

To grow bacteria on nutrient agar plates.

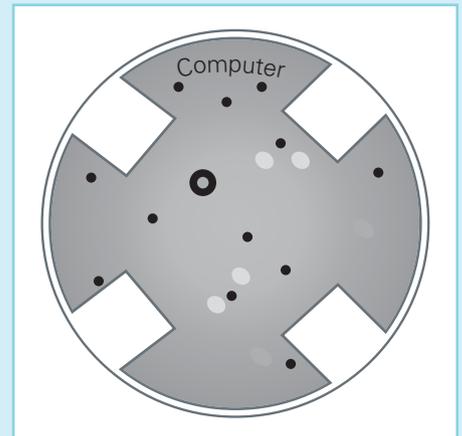
Materials

- Petri dish containing sterile nutrient agar
- cotton buds
- marker pen
- masking tape
- disposable gloves
- disinfectant
- handwash (soap)

Method

- 1 Using a cotton bud, wipe over an object of choice, such as a phone screen, computer keyboard, mouse or door handle.
- 2 Open the Petri dish and swab the cotton bud over the nutrient agar.
- 3 Secure the lid and label the plate with the masking tape and pen.
- 4 Wipe down all work surfaces with disinfectant after all the nutrient agar plates have been collected.
- 5 The plates will be stored upside down (with the agar at the top) in an incubator for 1–2 days.
- 6 Remove the plates from the incubator, place in a clear zip-lock bag and observe the colonies of bacteria that have grown.

Warning: Microbes can produce harmful toxins, so it is very important to seal them in airtight containers. 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).



Results

- 1 Sketch the colonies that you can see on your agar plate. Try and distinguish between the bacterial colonies that have a smoother surface, compared to the colonies of mould that tend to have a furry appearance.
- 2 Count the number of colonies and record the type of colonies you have observed.
- 3 Record every group's results in a class tally of number of bacterial colonies and number of mould colonies. Using the class results, construct a column graph highlighting the proportion of each type of colony.

Evaluation

- 1 Choose another student's agar plate and comment on the similarities and differences as compared to your agar plate. Explain why this may be the case.
- 2 Rank the objects or places from the class results in order from least to most bacterial growth on the agar dishes. Explain why these differences exist by looking at the original location of the sample.
- 3 Suggest two potential sources of error for this experiment.
- 4 Propose two ways in which this experiment could be improved.

Conclusion

- 1 Make a claim from this experiment regarding the growth of bacterial and mould colonies on agar.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Fungus

Fungi can be single-celled or multicellular organisms, that contain a nucleus and a cell wall made of chitin. They also have membrane-wrapped organelles, including mitochondria, which means they are eukaryotic organisms like plants, animals and you! Familiar fungi include yeasts, moulds, and mushrooms. Unlike plants, fungi cannot photosynthesise to make their own food. Instead they use their long, fibrous cells to penetrate plants

fungus

(plural: fungi) single-celled or multicellular organisms which contain a nucleus and a cell wall made of chitin

and animals, breaking them down and extracting nutrients. You may have seen a furry growth on 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.



Figure 2.35 The pink area between this person's toes is a localised tinea infection (commonly known as 'athlete's foot').



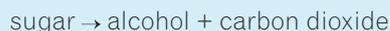
Figure 2.36 The green-black areas are mould growing on pieces of bread.

Practical 2.7

Fermentation

Yeast is a type of fungus, one that is very useful in 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. Fermentation is a specialised process that allows sugar to be broken down by yeast in the absence of oxygen to produce alcohol and carbon dioxide.



Some alcoholic beverages (like champagne) are fizzy, if the carbon dioxide is contained and not allowed to escape. A similar reaction is what 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
- sugar
- yeast
- measuring cup for 10 mL

continued...

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

...continued

- 200 mL beakers
- balloon
- limewater
- delivery tube with stopper
- teaspoon
- marker pen

Method

- 1 Collect five test tubes. Place the first four in a rack and label them A, B, C and D (as shown in Figure 2.37).
- 2 Label test tubes A–D and fill each test tube 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.

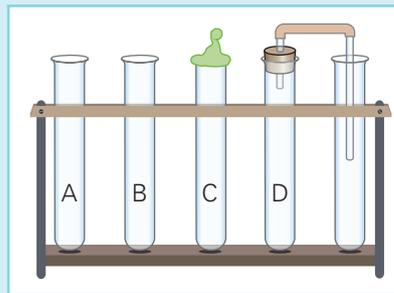


Figure 2.37 Experimental set-up

Results

Tabulate the results of the experiment by recording your observations, including smell.

Evaluation

- 1 Why was it important to use warm water and not to use water that is too hot?
- 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 Name two potential sources of error in this experiment.
- 4 Suggest two improvements you could make to the experimental design.

Conclusion

- 1 Make a claim from this experiment regarding the fermentation process.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Viruses

Viruses are tiny pathogens. They cannot be seen with the light microscope but can be seen with the 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 spring into action, and they take over the cell turning it into a virus factory (see Figure 2.38 on page 64).

virus

an extremely small non-cellular pathogen comprised of infectious particles that are inactive outside a living host cell

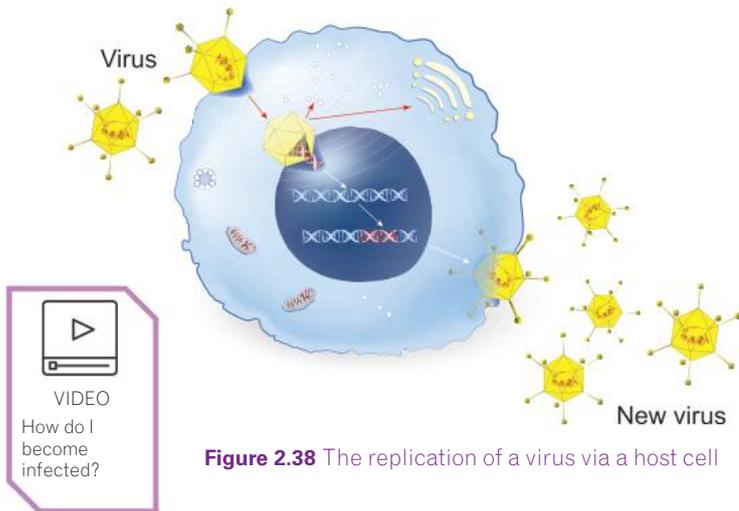


Figure 2.38 The replication of a virus via a host cell

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 invading cell to replicate and survive viruses are not considered to be non-living. Regardless, viruses are an important part of all ecosystems, including the human body. In your body, viruses are known not only to infect your own cells, but they can also infect the other pathogens that live inside you.

Disease transmission

From the Black Plague outbreaks in history to more recent cases of animal-borne strains of influenza, 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. Figure 2.39 and Table 2.6 outline the main modes of transmission.

- 1** List three common types of fungi. **Quick check 2.9**
- 2** Outline 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 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 PNG 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	Spread by contaminated blood or other body fluids.	HIV can be transmitted through shared needles from tattooing, piercings or medical procedures.

Table 2.6 Modes of infectious disease transmission

Prior to the invention of the microscope, little was known about the causes of disease. The conceptions of disease and disease-causing agents has evolved over time, refined by the scientific community and improvements in technology.

In ancient times, diseases were believed to be caused by the gods or demons, and practices such as bloodletting and trepanning (drilling holes in the skull) were used to release the 'evil spirits'.

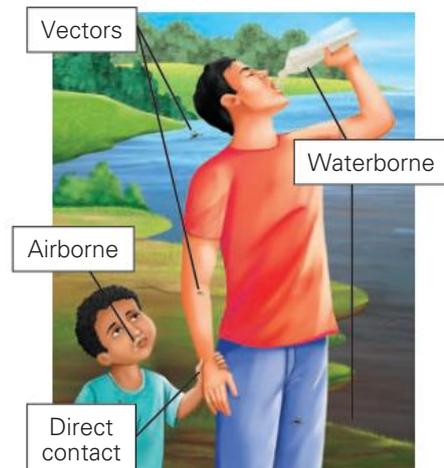


Figure 2.39 Modes of disease transmission Cambridge University Press

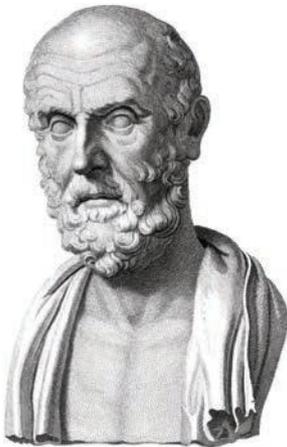
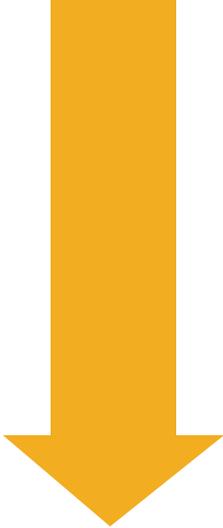
<p>Hippocrates (460–377 BCE)</p> 	 <p>Hippocrates</p>	<p>The Ancient Greeks, led by the work of Hippocrates, believed that disease was caused by an imbalance in body ‘humors’ (blood, yellow bile, black bile and phlegm), which mirrored their understanding that all matter was composed of a combination of fire, earth, air and water. Hippocrates developed the idea that certain medical conditions were associated with seasonal changes when the air might become contaminated with poisonous vapours.</p>
<p>Fracastoro (1478–1553)</p> 	 <p>Girolamo Fracastoro</p>	<p>Girolamo Fracastoro, an Italian poet, physician and mathematician, observed the epidemics of syphilis, plague and tuberculosis and developed the theory that diseases were spread by invisible particles. He proposed some were transferred by touch, while others could be spread by touching an infected person’s clothing or breathing the same air as them. This work laid the foundation for the modern-day germ theory, later confirmed by the work of Louis Pasteur and Robert Koch.</p>
<p>Pasteur (1822–1895)</p> 	 <p>Louis Pasteur</p>	<p>Louis Pasteur experimented with microorganisms and disproved the theory of ‘spontaneous generation’ that earlier scientists had subscribed to: the notion that disease could arise from non-living matter. His work proved that microorganisms were all around us.</p> <p>His name is commemorated in the term pasteurisation which is the process used to kill bacteria in milk and wine to prevent them from ‘going off’.</p>

Figure 2.40 Timeline of development of germ theory

continued...

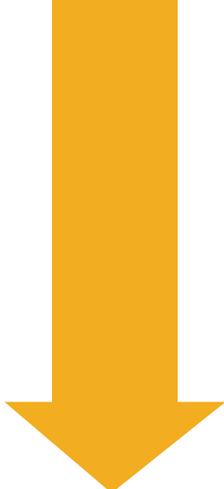
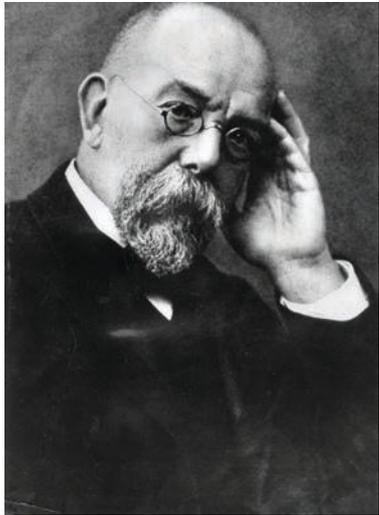
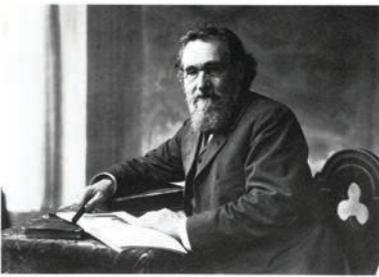
<p>Koch (1843–1910)</p>  <p>Metchnikoff (1845–1916)</p> 	 <p>Robert Koch</p>  <p>Elie Metchnikoff</p>	<p>Robert Koch developed a set of rules called ‘Koch’s postulates’, which lay out four criteria that must be met before a microbe can be said to cause a disease. Combined with Elie Metchnikoff’s discovery of antibacterial white blood cells, the modern germ theory of disease was born.</p>
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Figure 2.40 *continued...*

Microbiology

Microbiology is a specialty field that investigates microscopic organisms. Choose one of the following famous microbiologists and research in detail what they studied, the contributions of their discoveries and the impact they had on the field of biology and medicine.

Choose from Edward Jenner, Louis Pasteur, Joseph Lister, Alexander Fleming and Howard Florey.

Explore! 2.5



Figure 2.41 A microbiologist in the 1920s using test tubes and microscopes for observation

The lines of defence in the immune system

immune system

the system (cells and tissues) that enables the body to protect itself against disease

phagocytosis

a cellular process where a white cell wraps around and ingests a cell or large particle to break it down using enzymes

The body's **immune system** is its defence against infectious diseases. The immune system has three lines of defence that fall into two different categories of response when a pathogen enters the body (see Table 2.7).

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 (protect external boundaries) and mucous membranes (protect internal boundaries, such as in the gut, mouth and nose). It 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 which restrict the growth of pathogens on their surfaces and prevent the entry of pathogens into the body; for example, sweat, tears, ear wax, mucus and stomach acid.

Second line of defence

The second line of defence against infection is another non-specific response that responds in the same way against different types of pathogen. Specialised white blood cells called macrophages and neutrophils are constantly circulating in your blood stream, on a search-and-destroy mission. Their role is to change the shape of their membrane, surround and then ingest dead cells and pathogens: This process is called **phagocytosis**. These specialised cells can also activate the inflammatory response, resulting in the damaged area becoming swollen, red, hot and painful. A

fever can also occur in the second line of defence, which increases the body temperature to activate heat-shock proteins and suppress pathogen growth. You have probably experienced this unpleasant side effect when you have suffered from a cold or flu, but it is good to know it serves a purpose!

Macrophages and neutrophils are just two of the many different types of white blood cells that are formed in the bone marrow. White blood cells have a life span ranging from two hours to several years.

STRUCTURE OF THE SKIN

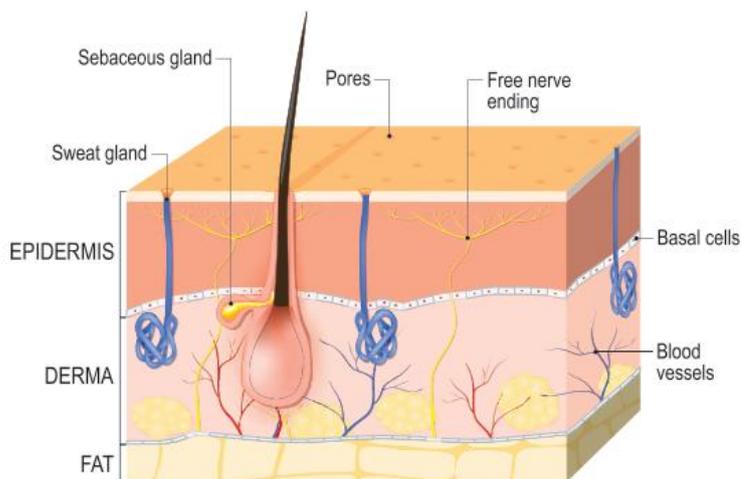


Figure 2.42 The skin's surface acts as one of the first lines of defence, but only if it is intact.

Non-specific immunity	Specific immunity
First and second line 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

Table 2.7 Immune system lines of defence

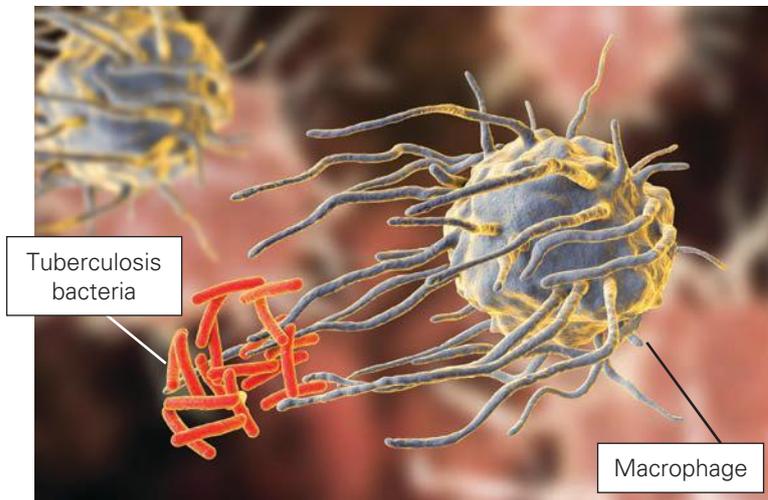


Figure 2.43 Macrophage engulfing tuberculosis bacteria

Third line of defence

The third line of defence includes two main groups of specialised white blood cells known as **lymphocytes** – the B cells and the T cells. These also develop in the bone marrow and their letter indicates where they mature (B = bone marrow and T = thymus gland).

lymphocyte

white blood cell that is involved with fighting disease. Some produce antibodies

There are 25 million to a billion different T cells in your body. T cells are made in the bone marrow, but they mature in the thymus. Interestingly, most T cells are produced during younger years, so children will have a bigger thymus than adults. T cells are a type of white blood cell involved in the immune response.

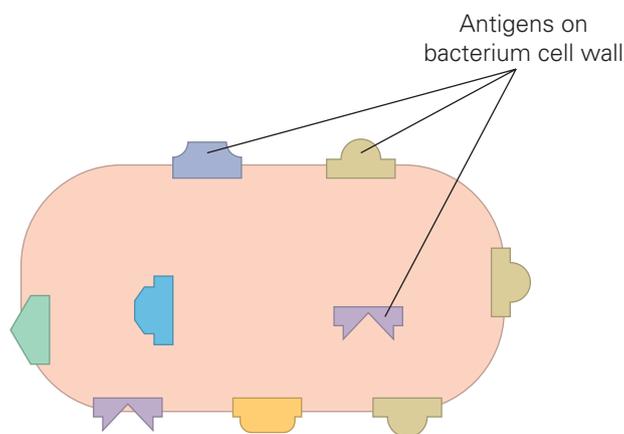


Figure 2.44 Antibodies bind to the antigens on a pathogenic bacterium. This bacterium does not have long to live!

There are two types of T cells in your body: killer T cells and helper T cells.

Killer T cells need to differentiate between infected or foreign ('non-self') cells and non-infected 'self' cells. To do this, they identify a special molecule called an **antigen**. Each cell has a unique T cell receptor that can only bind with one kind of antigen, like a lock that can fit with a specific size and shape of a key. Healthy cells have 'self-antigens' on the surface of their membranes that the T cells can identify as being beneficial. However, if a cell is infected with a virus, the cell will contain virus antigens on its surface that will signal the killer T cell to identify it as foreign, so it must be destroyed.

antigen

a substance that induces an immune response in the body, can be foreign or a self-antigen

The other type of T cell is the helper T cell. These cells act like team leaders and provide specific chemical instructions to other cells.

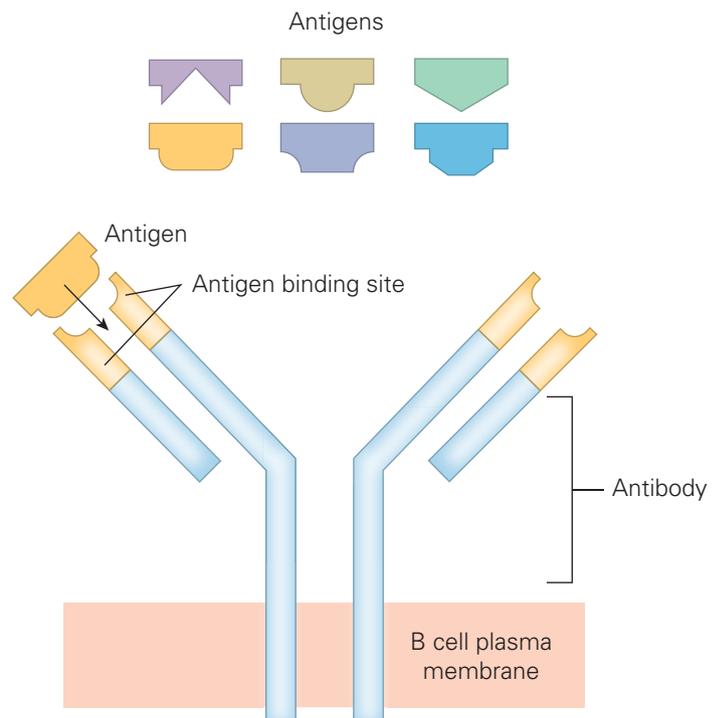


Figure 2.45 Like a lock-and-key, antibodies are designed with specific binding sites that can only attach to certain antigens that have the right shape and size to the binding site on the antibody. Above, only the yellow antigen would be attached to the antibody as it contains the same shape and size as the antibody's binding site. The other colours are different shapes.

These chemical instructions help both killer T cells and B cells to replicate and make a lot more of themselves so that they can fight an infection and make sure the fight stays under control.

Antibodies cause pathogens to clump together, and they attract the white blood cells to come and perform phagocytosis and kill the pathogen. The lymphocytes also can

memory cell

a type of white blood cell that is formed after exposure to a pathogen, and remembers that pathogen in the future

form **memory cells**, meaning that if the body encounters that specific pathogen again, the immune response will

be much faster and stronger. Sometimes, the second and subsequent responses are so effective, you might not even feel unwell or know you have been infected!

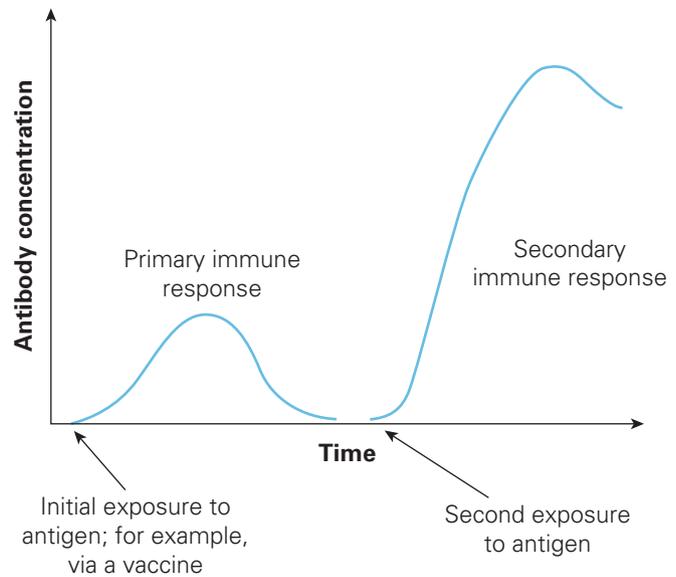


Figure 2.46 The second immune response to an antigen on the surface of a pathogen is faster and larger if it has been exposed before.

- 1 Define non-specific and specific immunity.

Quick check 2.10

- 2 Copy and complete the following table, listing what is involved in each line of defence.

Non-specific immunity		Specific immunity
First line of defence	Second line of defence	Third line of defence

Immunisation and vaccines

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

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

weakened pathogen (complete with all its identifying antigen flags) into your body. This **immunises** you against the disease caused by that pathogen. The altered version of the pathogen cannot cause an infection, but the immune system still recognises it as a

HPV

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 and is responsible for the death of one woman every two minutes, globally. Research published by the International Papillomavirus Society, led by doctors in Melbourne, has shown the rates of HPV infection in Australia have declined from 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!

Did you know? 2.5



Figure 2.47 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.

threat (because of the antigens) and produces antibodies in response. After the threat has passed, many of the antibodies will break down, but the memory cells remain in the body if you encounter that pathogen again. Immunisation acts like a first exposure to a pathogen, but without the risk of actually getting sick!

- 1 Define the term 'vaccine'.
- 2 In what ways is vaccination similar to, and different from, infection with an actual pathogen?

Quick check 2.11

What are antibiotics?

Antibiotics are chemical substances produced by a living organism (usually a mould) that can stop the growth of bacteria.

antibiotic
inhibits the growth of bacteria inside the body

antiseptic
a substance that stops or slows down the growth of microorganisms, used externally on skin

Doctors must know about the properties of the antibiotics available and know which ones to prescribe to treat specific bacterial infections.

Antibiotics can be effective against certain types of bacteria but may have

little effect against other types. Current research is focused on the discovery of new antibiotics and testing to determine on which bacteria they are most effective.

Antibiotic resistance

Antibiotics have been used in medicine since the 1930s as the traditional method of fighting bacterial infections in the human body. However, scientists are becoming increasingly concerned about drug-resistant bacteria, because infections often last longer, cause more severe illnesses, require more doctor visits or longer hospital stays, and



Figure 2.48 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.

may even cause death. Antibiotic resistance occurs when the sensitive bacteria are killed when a person takes antibiotics, but some resistant ones may be left to grow and multiply. The antibiotic is now ineffective for that colony of bacteria and the resistant bacteria can be passed on to other people!

Unnecessary antibiotics

Did you know? 2.6

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 it is actually a viral infection and antibiotics will be useless.

Antimicrobial resistance (AMR)

Antimicrobial resistance (AMR) can occur when pathogens such as bacteria, viruses, parasites and fungi, develop resistance against medicines that were once previously able to destroy them. Pathogens that develop antimicrobial resistance are sometimes referred to as 'superbugs'.

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.



Figure 2.49 Antiseptic gels and hand sanitisers act to kill pathogens.

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.

septic
describes a wound infected with bacteria

Practical 2.8

Effectiveness of antiseptics against soil bacteria

Aim

To determine the effectiveness of different antiseptics against soil bacteria.

Materials

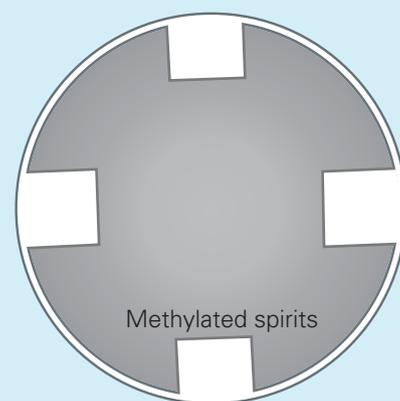
- soil sample
- 5 test tubes
- 200 mL beaker
- test-tube rack
- 4 different antiseptics: methylated spirits, iodine, QAC, Dettol, and a control; distilled water
(*Note:* QAC stands for quaternary ammonium compounds, a class of chemicals or disinfectants used alone or added to cleaning products.)
- nutrient agar plate
- marker pens
- disposable gloves
- disinfectant
- handwash (soap)

Method

- 1 Construct a hypothesis for this experiment. In which test tubes do you anticipate that you will observe a growth of microbes?
- 2 Add a heaped teaspoon of soil to a beaker filled with 100 mL of water.
- 3 Put about 5 drops of this soil/water mixture into each of 5 test tubes. Label them A–E.
- 4 Add to each of the test tubes about 5 drops of a different antiseptic:
Test tube A: Methylated spirits
B: Iodine (handle with care)
C: QAC
D: Dettol
E: Distilled water (as a control)
- 5 Label five areas A–E on the bottom of an agar plate as in the diagram. (*Hint:* If you write the letters backwards, they will appear the correct way when later viewed from above.)
- 6 Using a cotton bud, smear a tiny amount of the contents of test tube A onto the agar in the area you have marked 'A'. Keep the agar plate covered as much as possible while you do this to prevent microbes in the air settling on the agar.
- 7 Using a fresh cotton bud each time, repeat with the contents of the other test tubes.
- 8 Seal the lid with sticky tape.

Be careful

- Ensure gloves are worn when handling nutrient agar plates.
- Do not sneeze 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.



continued...

...continued

- 9 Wipe down all work surfaces with disinfectant after all nutrient agar plates have been collected.
- 10 The plates will be stored upside down (with the agar at the top) in an incubator for 1–2 days.
- 11 After incubation, examine the agar plates. Take photos and discuss the types of microbes that are growing on your plates. Complete table below.

Results

Antiseptic	Photo	Description of microbes
Methylated spirits		
Iodine		
QAC		
Dettol		
Distilled water (control)		

Evaluation

- 1 How does the pattern of microbial growth reveal the effectiveness of the antiseptic? What effect has the antiseptic had?
- 2 Do all the antiseptics tested have some effectiveness? How do you know?
- 3 Identify two potential sources of error in this experiment.
- 4 Suggest two ways the experimental design could be improved.

Conclusion

- 1 Make a claim from this experiment regarding the effectiveness of different antiseptics.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

- 1 What is the difference between an antibiotic and an antiseptic?
- 2 A patient in a hospital ward is isolated due to infection with a 'superbug'. What is a superbug? Why is the patient isolated?

Quick check 2.12**Section 2.3 questions****Remembering**

- 1 What is a pathogen? Provide two examples.
- 2 Are bacteria classified as a prokaryote or eukaryote? Why?
- 3 A lymphocyte is a special type of white blood cell. What are the two different types of lymphocytes called?

Understanding

- 4 Describe one difference between a bacterial cell and eukaryotic cell (for example, plant or animal cell).
- 5 Outline how immunisations can help fight disease.
- 6 Explain why a virus is considered to be non-living.
- 7 Compare and contrast the role of antibiotics and antiseptics.
- 8 Outline the difference between non-specific immunity and specific immunity.

Applying

- 9 Identify reasons why viruses cannot be treated with antibiotics.
- 10 The body's immune system may sometimes start to recognise 'self' antigens as foreign and 'non-self'. Propose what might happen in this case.

Analysing

- 11 '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.
- 12 Briefly describe how vaccines work.

Evaluating

- 13 Create a Venn diagram that contrasts the first, second and third lines of defence.
- 14 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.



QUIZ



Review questions

Remembering

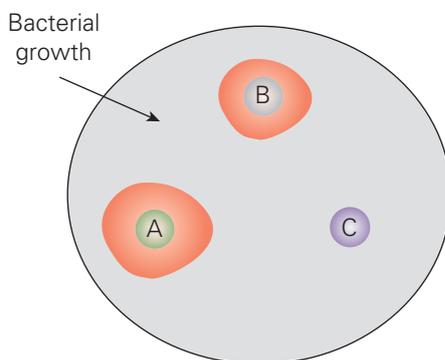
- 1 Recall what a disease-causing agent is called.
- 2 Name three diseases caused by viruses.
- 3 List the five categories of essential nutrients required for life.
- 4 Define the term 'homeostasis'.

Understanding

- 5 Compare and contrast bacteria and viruses.
- 6 Explain how yeast, a fungus that causes the condition known as thrush, reproduces.

Questions 7 and 8 refer to the following information.

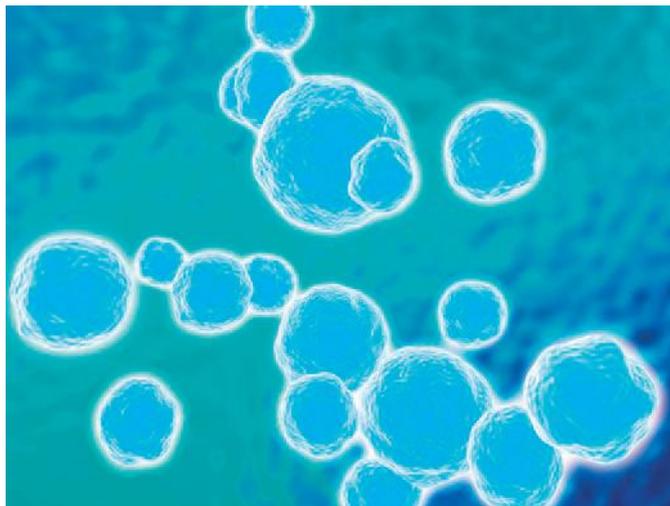
Antimicrobial substances A, B and C were tested for their effectiveness against a strain of bacteria growing on agar. Interpret the results shown below by answering the following questions.



- 7 Of the antimicrobial substances tested, which was the most effective? Explain your reasoning.
- 8 Of the antimicrobial substances tested, which was the least effective? Explain your reasoning.
- 9 Summarise how the digestive, circulatory and respiratory systems interact with each other.
- 10 Explain why a highly active person who eats a low-kilojoule diet might lose weight.

Applying

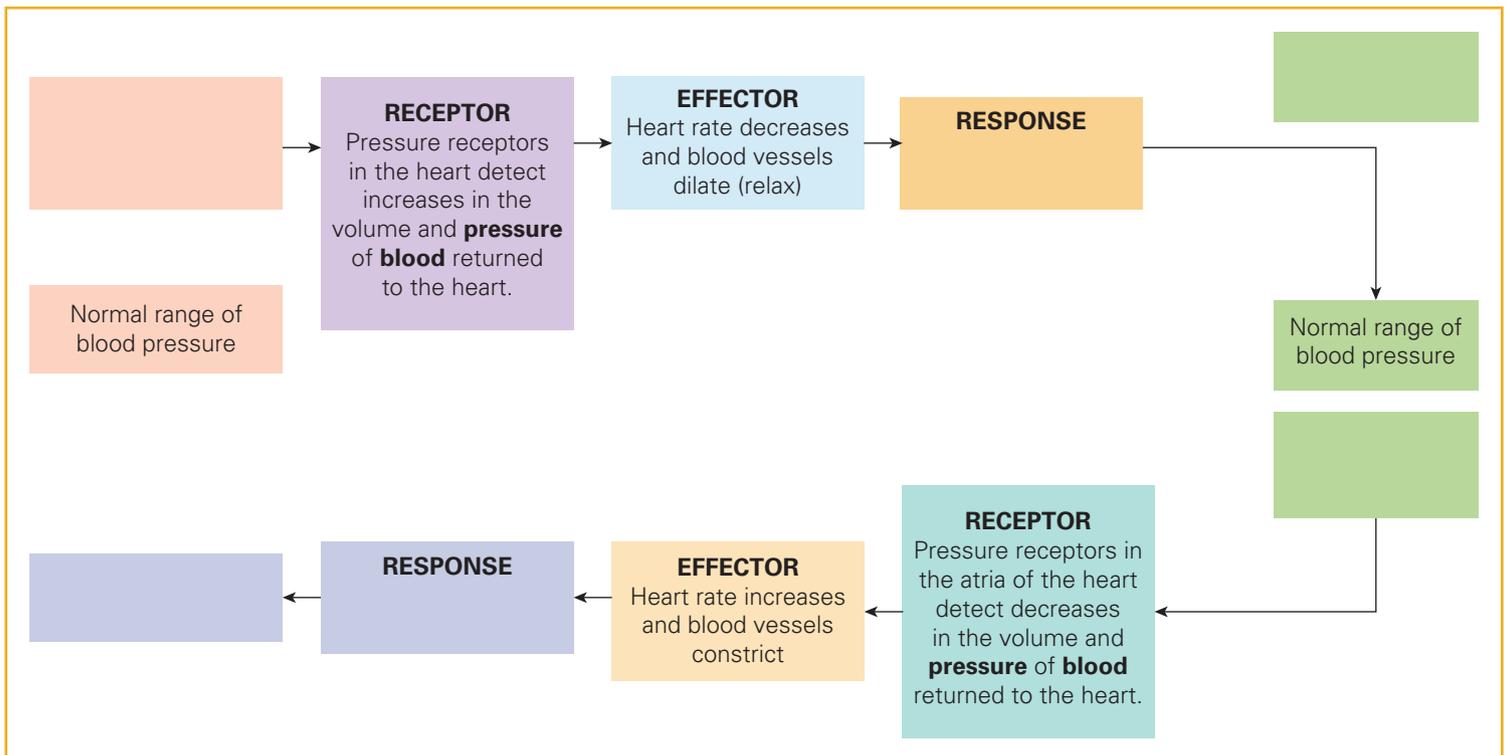
- 11 Describe how vaccination can prevent individuals from being infected by a disease.
- 12 The image below shows MRSA bacteria that have developed resistance towards antibiotics. When they reproduce, the resistance is passed on to the resulting organisms.



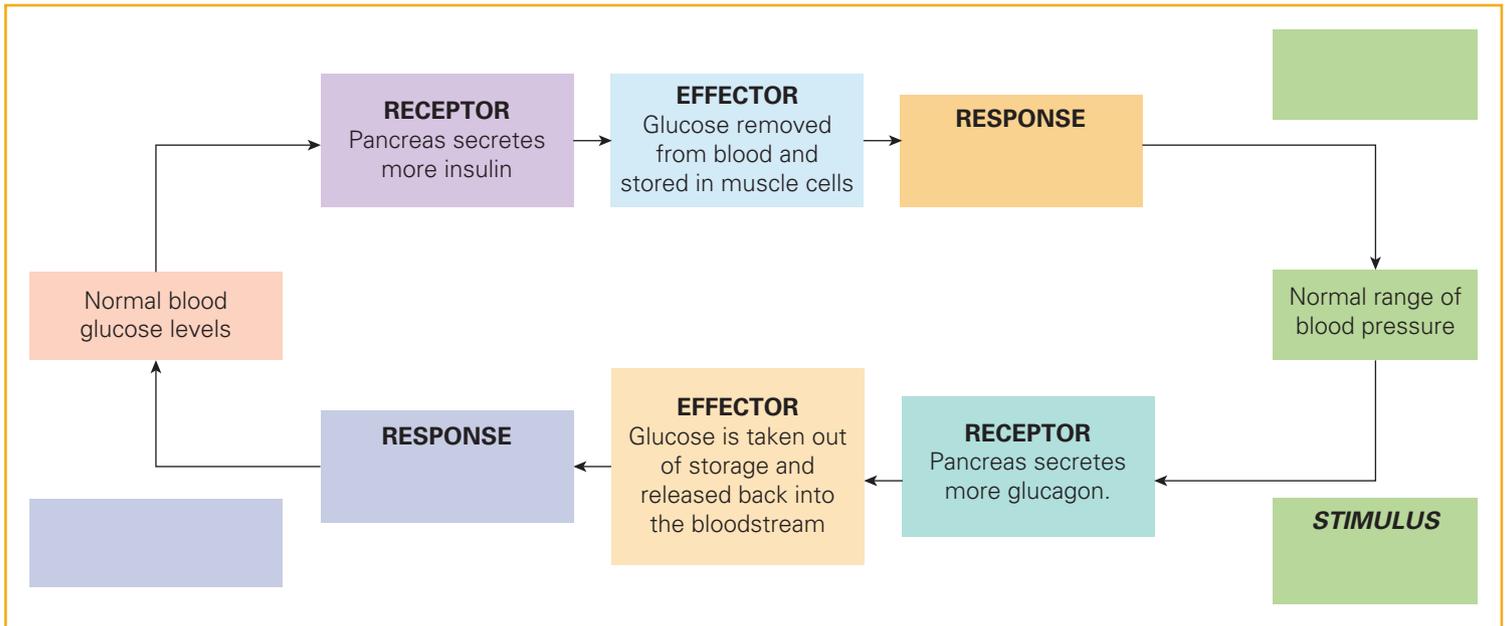
- a Bacteria come in a variety of shapes, each with a specific name. Suggest the scientific name for this type of bacteria.
- b What name is given to the process of bacterial reproduction?
- c The MRSA bacteria can survive on a healthy person's skin or lungs without causing any symptoms or ill effects, 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

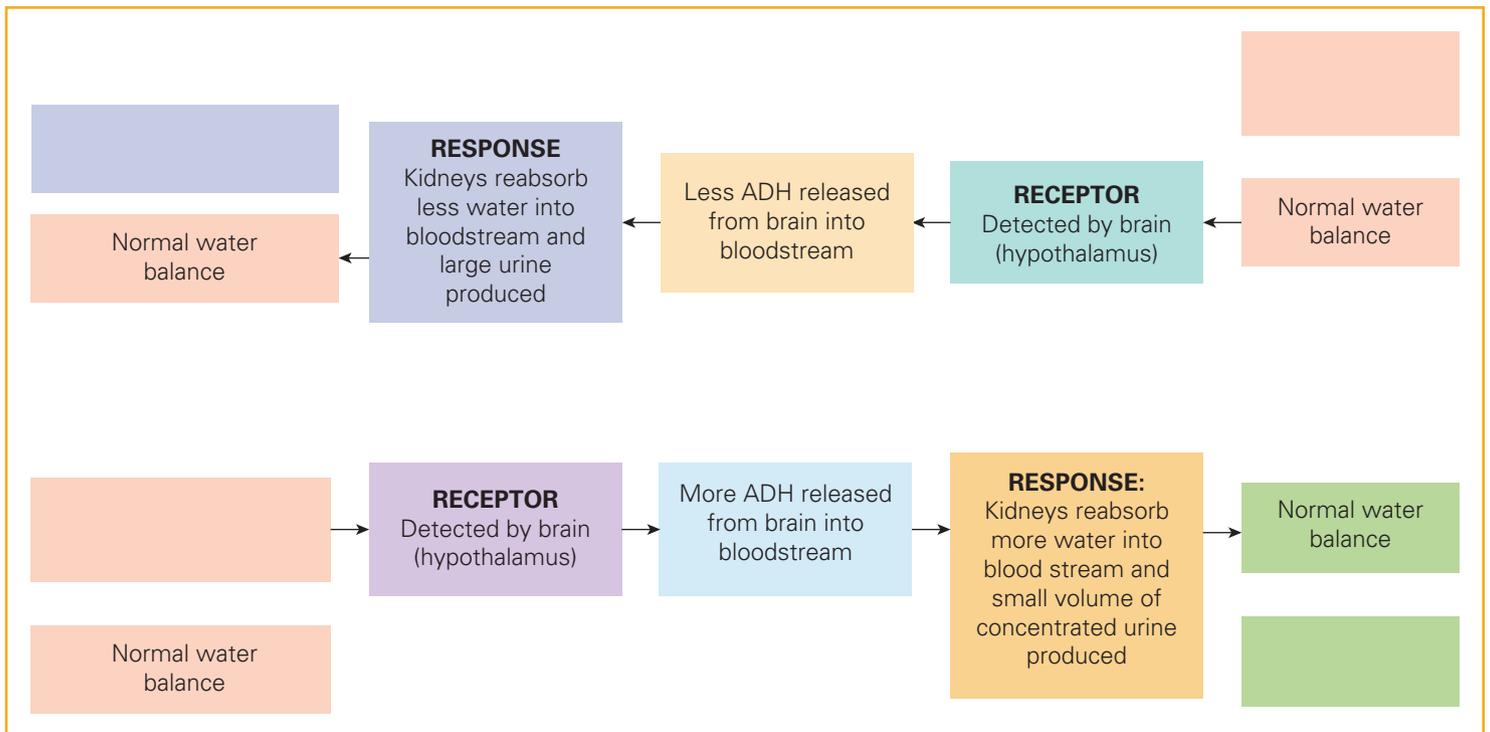
- 13 Categorise the following organs as receptors or effectors.
 - a Hypothalamus
 - b Baroreceptors
 - c Liver
 - d Kidney tubules
 - e Pancreas
 - f Skeletal muscles
- 14 Complete this flow chart to compare the ways in which the body responds to each of the following scenarios.
 - a High blood pressure versus low blood pressure



b High blood glucose levels versus low blood glucose levels



c High levels of water in the blood versus low levels of water (dehydration)



Evaluating

15 A professional hockey player has an important match tomorrow.

- What nutrient is the body's preferred source of fuel? Suggest a meal that would be suitable for his dinner the night before the game.
- What nutrients might this player draw upon if this preferred source is depleted?

- c Glucose is burned to provide useable energy. What is the name and worded equation for this reaction?
 - d The player loses several litres of water during the game. Detail two homeostatic responses his body would use to retain water and maintain his blood pressure.
 - e Upon checking his heart rate monitor, the player sees his heart rate peaked at 185 bpm during the game. Explain why this occurred with reference to the body's energy requirements.
- 16 People with type 1 diabetes inject insulin to control their blood glucose level. A pancreas transplant is another treatment for type 1 diabetes. One risk of a pancreas transplant is organ rejection, because the body recognises the transplanted organ as 'non-self'.
- a What structure (on the transplanted organ) has the body detected as 'non-self'?

Scientists have developed an artificial pancreas to treat type 1 diabetes, however it is still at early stages of commercial use. The flow chart below shows how an artificial pancreas works.

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



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



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

A woman with type 1 diabetes has an artificial pancreas. The woman eats a meal that causes her blood glucose level to rise sharply.

- b Suggest the main nutrient present in the meal she has consumed. Outline the steps of what happens to return the blood glucose levels to normal.
- c Assess some problems that might occur in using the artificial pancreas system above and decide whether it is a viable solution for individuals with type 1 diabetes.

STEM activity: Simulating the transmission of disease

Background information

You may have heard of Zika if you have been travelling overseas. It is a virus that is closely related to Dengue fever and is spread through the bite of an infected *Aedes* species of mosquito. Generally, infection by the Zika virus does not produce severe symptoms. However, it may affect fetuses in pregnant women, increasing the chances of abnormalities and other syndromes.

The Zika virus first spread outside of Africa and Asia in 2007 to Yap Island, Federated States of Micronesia. There were also outbreaks in the Pacific Islands between 2013 and 2015 before it spread to countries in South and Central America and the Caribbean. Cases have also been reported in Thailand and Indonesia. While the *Aedes aegypti* mosquito can be found in some parts of Queensland, and *Aedes albopictus* can be found in the Torres Strait Islands, all cases of the Zika virus diagnosed in Australia were caught overseas. Therefore in most parts of Australia, there is no risk of Zika transmission via mosquitoes.

Consequently, the way an infectious disease spreads through a population has caused scientists and public health officials a lot of concern, as the mechanism of spread and its containment are not always well understood. When an outbreak of a serious disease occurs, scientists must track down the disease and determine its origin before they can manage the spread and prevent further infection.

In science and engineering, simulations of real systems are used to test hypotheses,

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understand the nature of particular problems, and generate effective solutions. For example, biomolecular engineers use computers to model how particular molecules can contribute to disease; while biomedical engineers simulate outcomes like the transmission of diseases, and software engineers use graphs to represent connections and data organisation. Engineers therefore, have a significant role in modelling and predicting the spread of infectious disease.

Design brief: Evaluate the effectiveness of disease transmission simulation.

Activity instructions

As a class, you are going to simulate the exchange of body fluids and, consequently, demonstrate the spread of an imaginary 'Zika-like' infectious disease in a community. You will then determine the origin of the infection and, taking on the role of biomedical engineers, you will analyse the data and predict future infection levels. Your final task will be to evaluate the role of simulations in modelling the transmission of disease and suggest improvements to this activity (teachers, see the teacher guide for this activity in the Online Teaching Suite for a sample method).



Figure 2.50 The spread of infectious diseases around the world can be fast and needs identification, analysis and containment, and then prevention as soon as possible.

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.

Evaluate and modify

- 1 Understanding models. This activity represents one kind of model used by engineers – a simulation of how an infectious agent spreads through a community. List some other examples of models used in science. Why do people use models? Simulations like today's activity are also models. This simulation of the exchange of bodily fluids, demonstrates how an infectious disease can spread quickly from person to person without his or her knowledge. If sodium hydroxide (NaOH) represents the infectious agent, what do the other parts of the simulation represent?
 - 2 Tracing the source of infection. Take on the role of epidemiologists and, as a class, try to determine the source of the infection in your community – who was the original carrier?
- You may like to begin by removing those uninfected from your list, but what will you do next?
- 3 Making future predictions. One of the purposes of simulations is to allow for trends to be established. Work out your predictions for the number of infected on 'Day 4' and 'Day 5', and then graph (using Excel or Desmos) the total infected number versus time (days).
 - 4 Evaluating the model. When creating models, engineers must assume certain things. 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.
 - 5 Writing 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 3 **Response and coordination**

Chapter introduction

The brain is the master organ that controls the actions of nerves within the nervous system and is also involved in the regulation of hormones within the endocrine system. Any thought, feeling or behaviour that you undertake on a daily basis is ultimately controlled by the brain. The brain continually reorganises itself by making new neural connections throughout life and this marvellous concept, known as neuroplasticity, is explored later in this chapter. You will begin by looking at how the brain provides a critical link between the nervous and endocrine systems, and then look in depth at the structure and function of the human nervous system.

Curriculum

An animal's response to a stimulus is coordinated by its central nervous system (brain and spinal cord); neurons transmit electrical impulses and are connected by synapses (VCSSU118)

• identifying functions for different areas of the brain	3.4
• modelling the 'knee jerk' reaction and explaining why it is a reflex action	3.3
• identifying responses involving the nervous and endocrine systems	3.1, 3.2, 3.3
• researching the causes and effects of spinal cord damage	3.3

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Glossary terms

action potential

cerebral cortex

contralateral organisation

corpus callosum

endocrine system

hemispheric specialisation

homeostasis

homunculus

hormone

interneuron

motor neuron

nervous system

neuron

neurotransmitter

plasticity

reflex action

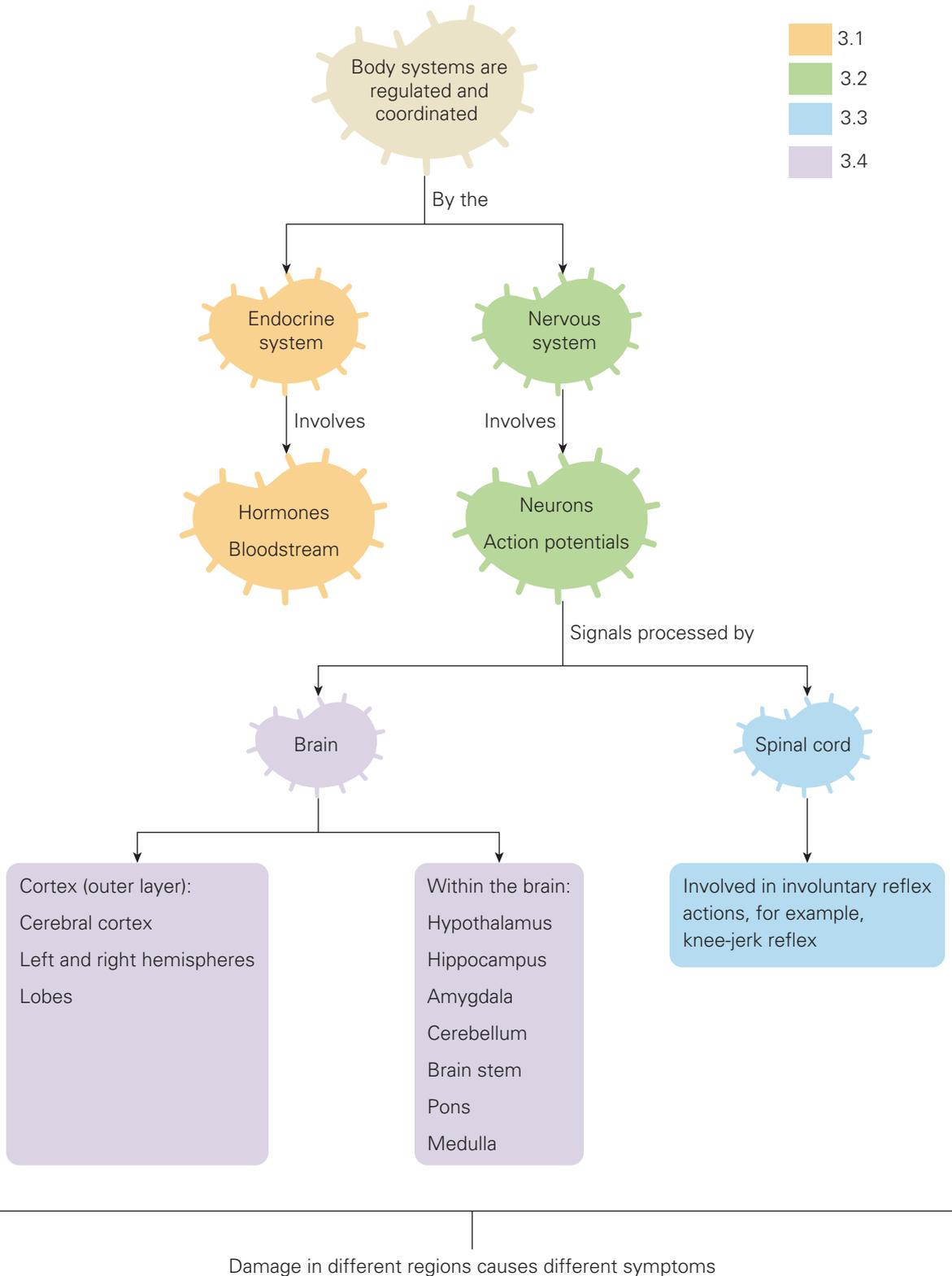
sensory neuron

synapse

target cell



Concept map





3.1 Keeping in control

The brain controls all bodily functions by communicating with different parts of the body every second of every day. It does this in two ways: by sending electrical signals and neurotransmitters via the nervous system and by communicating using chemical messengers (hormones) via the endocrine system.

The nervous system

The basic building blocks of the nervous system are our neurons. A **neuron** is

neuron
a specialised nerve cell

nervous system
consists of the brain, spinal cord and peripheral nerves and receptors that communicate fast messages within the body

essentially an individual nerve cell. It is the network of these neurons that allow signals to move between the brain and body. These organised networks, composed of up to

one trillion neurons, 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



Figure 3.1 The neuron is the basic building block of the human nervous system.

(PNS), which is all of the neurons and nerve networks throughout the body that lie outside of the CNS. The PNS has multiple roles including controlling voluntary muscle movements and the self-regulating bodily functions that you have no conscious control over. Figure 3.2 shows the key components of the human nervous system.



WORKSHEET



VIDEO

What do hormones do?



VIDEO

Parts of the nervous system.

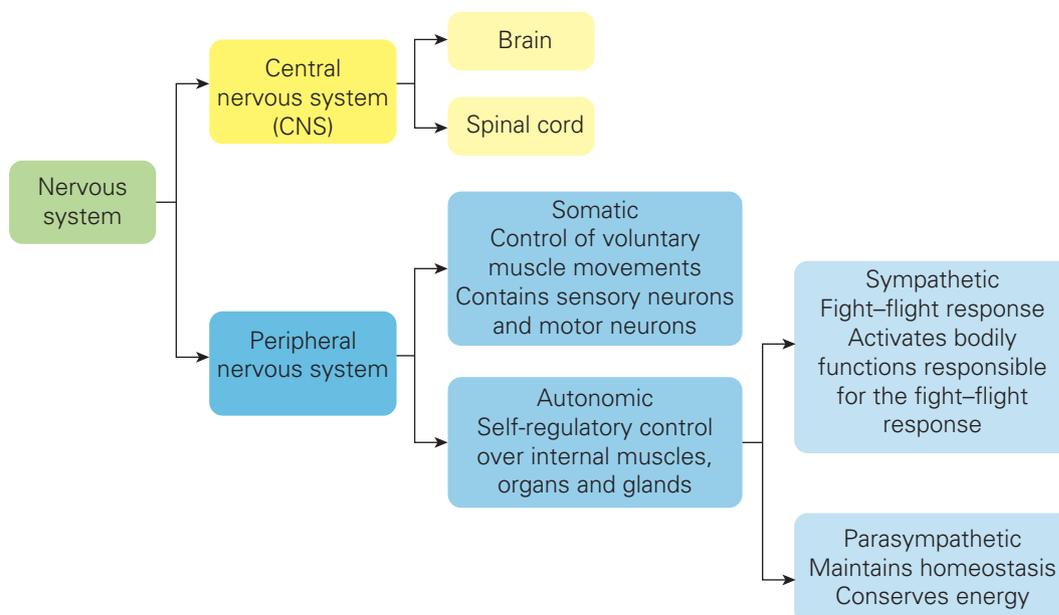


Figure 3.2 The components of the human nervous system

- 1 What is another name for an individual nerve cell?
- 2 Which components make up the CNS (central nervous system)? And the PNS (peripheral nervous system)?
- 3 What role does the somatic nervous system play? Give an example that illustrates the somatic nervous system in action.

Quick check 3.1



VIDEO

Identify parts of the endocrine system.

The endocrine system

The nervous system does not work in isolation, but works with the body's sense organs and the **endocrine system**. The endocrine system utilises 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 and include the pineal gland, the hypothalamus and the pituitary gland.

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

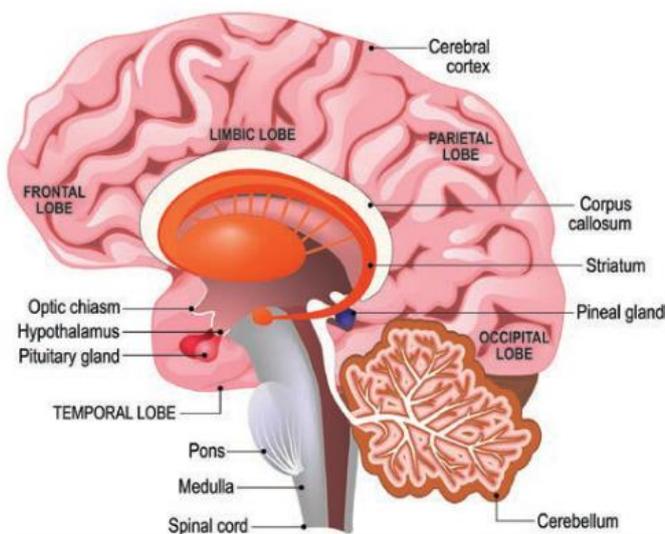


Figure 3.3 A cross-sectional view of the brain showing the location of the pineal gland, pituitary gland and the hypothalamus

Located at the base of the forebrain is a tiny collection of neurons known as the

hypothalamus. The hypothalamus links the nervous system and endocrine systems. It is responsible for regulating an astonishing number of behaviours, such as sleep, hunger, thirst, managing sexual behaviour, and emotional and stress responses. The hypothalamus also controls the pituitary gland for the release of several different hormones.

Other important glands found throughout the body include the thyroid, thymus, adrenal glands, pancreas, ovaries and testes. These glands are involved in regulating our metabolism, fight-or-flight responses and reproductive processes.

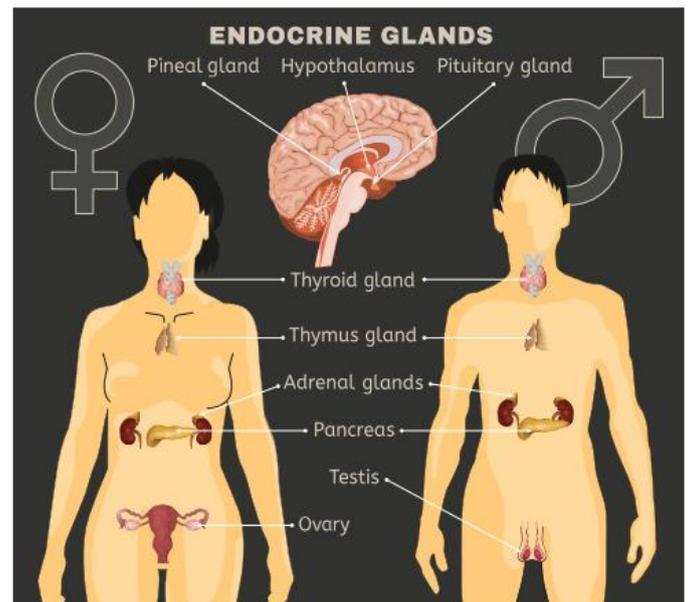


Figure 3.4 Female and male endocrine glands throughout the body

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 bloodstream. The blood carries the hormones around the body so in this way, hormones are transported and can effect change 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 just small amounts of these chemicals can have major effects. Table 3.1 shows where hormones are produced in the human body.

Organ	Hormone	Action of hormone
Pancreas	Insulin	Decreases blood glucose levels by increasing the uptake of glucose by the liver and muscle cells
	Glucagon	Increases blood glucose levels by stimulating the liver to release glucose 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–flight–freeze process
Kidneys	Erythropoietin	Promotes the production of red blood cells by the bone marrow
Pituitary gland	Growth hormone (GH) and others	GH Stimulates cell division, growth and repair of the body
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, operating via the pituitary gland (the 'master gland') as well as via nerves to other glands
Testes	Testosterone	Promotes growth of bone, the 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 3.1 Endocrine glands, their hormones and actions

Endocrine disrupting chemicals in plastics

Explore! 3.1

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 bodily functions. The scientific research behind this hypothesis has come from mainly 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, but 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 BPA (bisphenol A) in?
- 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.

Melatonin and sleep

An adolescent typically requires 9.25 hours of sleep per night. However, an adolescent's body clock is shifted forward 1–2 hours each day, which may cause a delay in feeling 'sleepy'. Due to melatonin not being released in adolescents until 1–2 hours later on average than a child or an adult, they may not feel sleepy until 1–2 hours later at night. This can be further exacerbated by social media and work, school or sporting commitments. As a result, adolescents have irregular sleep patterns, an accumulation of sleep debt and have difficulty waking up in the morning.

Did you know? 3.1



The pineal gland is highlighted and secretes the hormone melatonin, which controls the body's biological clock.

Step 1. Each morning, record the amount of sleep you have for a 7-day period.

Step 2. The recommended number of hours of sleep for an adolescent is 9.25×7 days = 64.75 hours. Express the amount of sleep you got as a percentage by following this formula:

$$\text{Percentage of required sleep} = \frac{\text{your hours}}{64.75} \times 100$$

If the percentage is greater than 100, you are getting a sufficient amount of sleep. If it is below, you are suffering from sleep debt. The lower the percentage, the greater the sleep debt. For example, if you get 8 hours of sleep each night for 7 days, then $8 \times 7 = 56$ so, $\frac{56}{64.75} \times 100 = 86.48\%$. This means you are only getting 86.48% of required sleep for a week and are suffering a 13.52% sleep debt.

Step 3. Collect the results of the whole class and find the average sleep debt of one of your classmates.

Try this 3.1

- 1 Which part of the brain 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 Which hormone is responsible for regulating sleep patterns and induces sleep?
- 4 Define target cells.
- 5 Discuss the effects of oestrogen and testosterone.

Quick check 3.2

Homeostasis is maintained through the endocrine and nervous systems working together. It involves the use of chemical messengers to signal to cells, however the speed of message transmission and the length of the effects differ between the two systems.

The key differences between the actions of the endocrine and nervous systems are shown in Table 3.2.

Two systems working together

homeostasis

the maintenance of a relatively stable internal body environment, despite changes in the external environment

While the body does adapt to external events, it also maintains a relatively constant internal environment through a process called **homeostasis**.

As discussed in Chapter 2, 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.

Feature	Nervous system	Endocrine system
Signals	Electrochemical messengers (via electrical impulses and neurotransmitters)	Chemical messengers (hormones)
Pathway	Transmission by neurons	Transported in bloodstream
Speed of information	Fast	Slow
Duration of effect	Short lived	Typically, longer lasting
Type of action and response	Voluntary or involuntary	Involuntary
Target cells	Localised cells	Often distant (many cells may be affected)
Example of action	Your friend throws a ball at you. Your sensory receptors detect the visual stimulus and the message is transmitted via nerves to your brain. Further messages are then sent down the spinal cord and via motor neurones and your skeletal muscle is 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 3.2 A comparison of the nervous and endocrine systems

Section 3.1 questions



QUIZ

Remembering

- 1 What is the basic building block of the human nervous system called?
- 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 Construct a Venn diagram that shows the similarities and differences between the nervous and endocrine system.

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	c Pulling your hand away from a flame
b Walking	d Contractions of intestine to move food along.

Evaluating

- 8 The contraceptive pill contains a chemical which acts like the hormone oestrogen, and it must be taken daily by women. 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.



Neurons and the nervous system



Types of neurons

The brain and nervous system are made of approximately 100 billion specialised nerve cells, known as neurons. Neurons transmit neural information to, from and within the central nervous system. There are three types of neurons:

1 **Sensory neurons** transmit neural information from sensory receptor sites in the PNS to the CNS. The sensory information being transmitted could be from any of your five senses.

2 **Interneurons** transmit neural information within the spinal cord and brain. Interneurons connect the sensory and motor neurons and can only be found in the CNS.

3 **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 muscles, organs or glands.

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

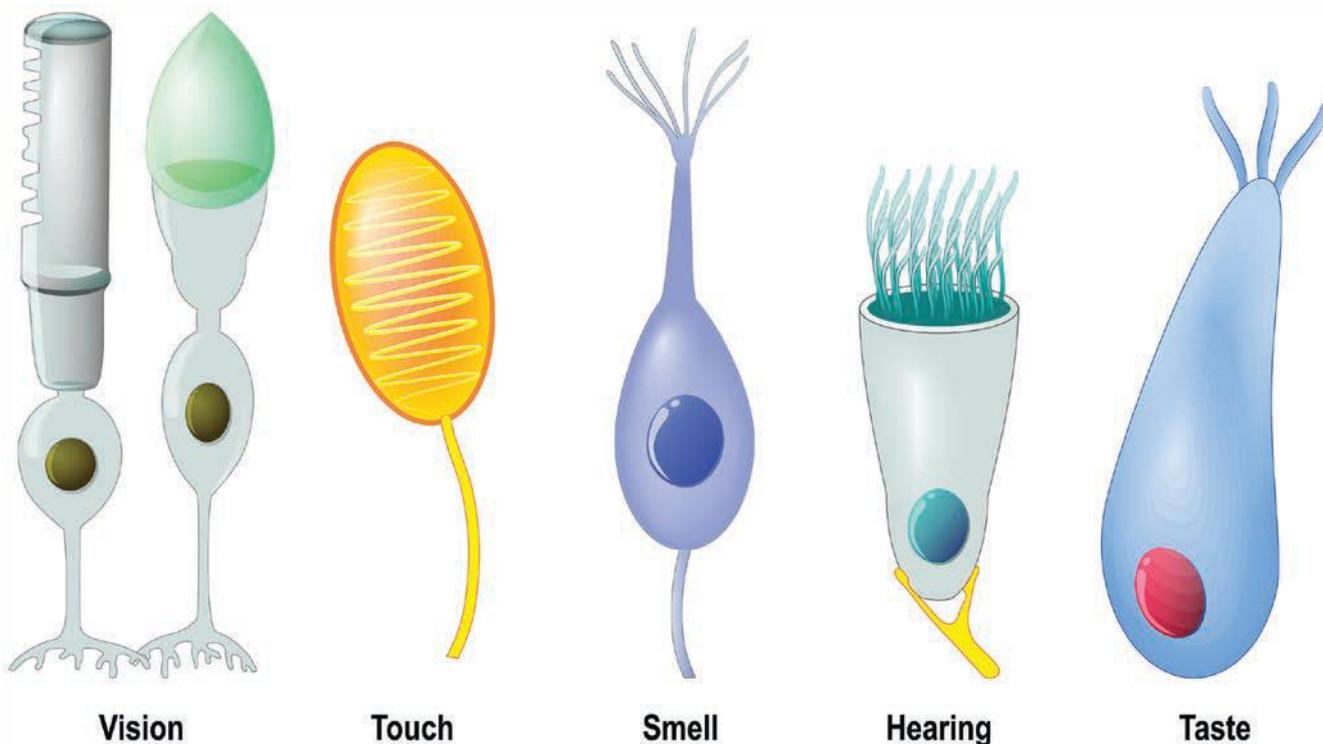


Figure 3.5 The different sensory neuron receptors associated with your five senses. Their shape is closely associated with their specialised functions.

To help remember the three types of neurons, think of a SIM (Sensory, Inter, Motor) card that is stored in mobile phones in order for it to work.

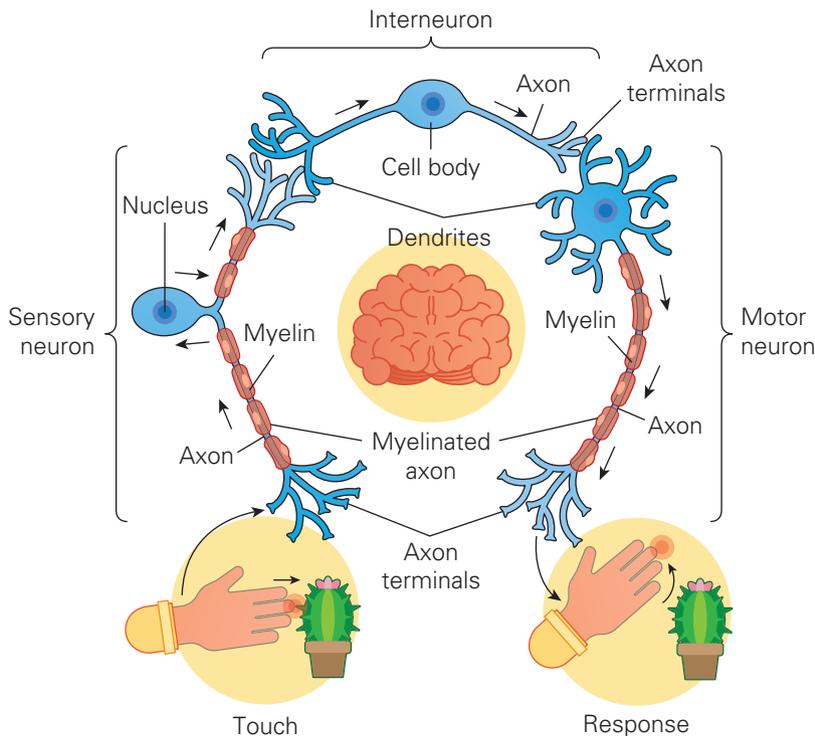


Figure 3.6 The three types of neuron (sensory, inter and motor) form an arc. Note how the sensory neuron has receptors to detect a stimulus and the motor neuron causes your response.

Structures of a neuron

The key structures of the neuron include the dendrites, cell body, axon, myelin sheath, axon terminal and the synapse. Although the synapse is not a true structure, it is the small gap that exists between neurons, where the neurotransmitters pass the information from one neuron to the next or to an effector.

Structure of neuron	Function
Dendrite	Contains receptor sites that receive neurotransmitters from neighbouring neurons
Cell body	Contains most of the cell's organelles including the nucleus
Nucleus	The 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 all grouped together in a bundle
Axon terminal	Found at the end of the axon and contains neurotransmitters that are held in vesicles. Neurotransmitters that are released once an electrical impulse is received
Myelin sheath	An insulating layer 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 each other. There is a small gap between the neurons called a synapse . When an electrical impulse is received, the signal diffuses/travels across this gap but as chemical signals called neurotransmitters . The neurotransmitters then bind to the receptors on the dendrites of the neighbouring neurons.

synapse
the gap between two neurons

neurotransmitter
the chemical messenger that is released from one neuron and travels across the synapse to bind to the next neuron

Table 3.3 Structure of the neuron

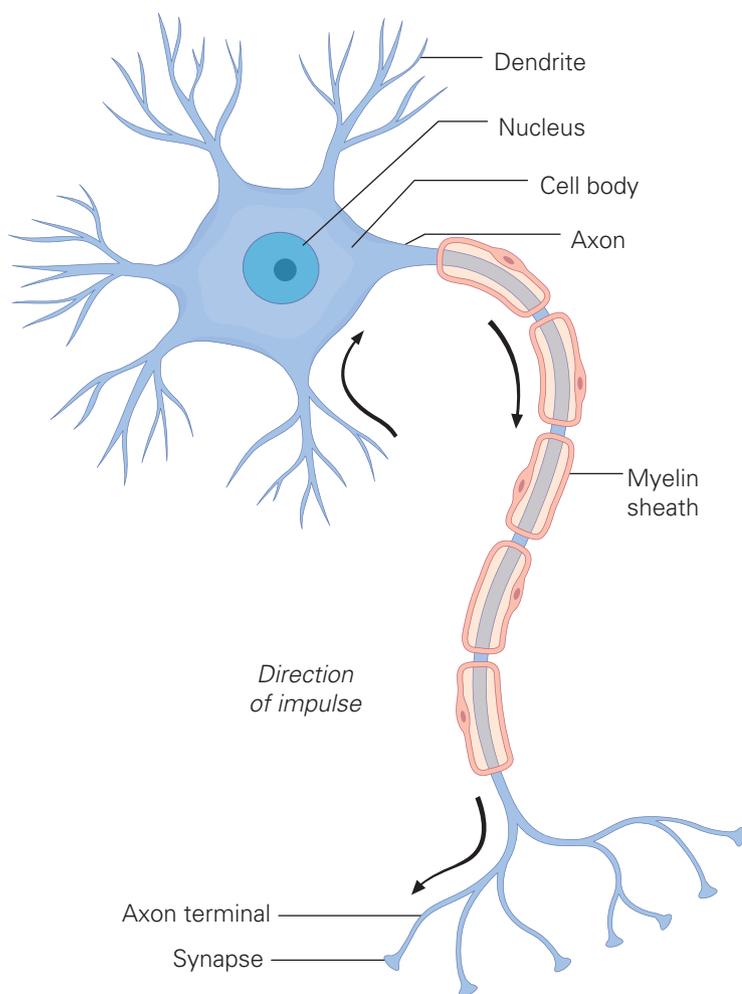


Figure 3.7 The key structures of a neuron showing the neural impulse travelling in one direction only along the neuron, from the dendrites to the axon terminal.

Making model neurons

Try this 3.2

Create a poster showing models of two neurons, their structure and function. Make sure your poster has the following features: a title, a model of two adjacent neurons, labels for every structure on one of the neurons (along with a dot point explaining their function) and a label for the synapse.

You will need a piece of A3 paper and your teacher will provide you with a selection of materials to make the model neurons. Some suggestions include: pipe cleaners, aluminium foil, pom-poms, straws, modelling clay/plasticine or similar.

Suggested method:

- 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 another pipe cleaner around the soma just at the end of it, so you have a long piece coming down.
- 3 Around the axon there 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 cm long each and thread them onto your axon with gaps between the lengths of straw. You should have a bit of string left at the end.
- 4 Put the end of the pipe cleaner near the bottom of the last myelin and twist to make a hoop and cut 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 Label the parts of the neuron with a dot point explaining the function of each structure (including the synapse).
- 7 Stick the neuron onto the sheet of paper, and hang 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!

- 1 Name the three different types of neurons.

Quick check 3.3

- 2 Where are interneurons found in the body?
- 3 Interneurons are sometimes called connector neurons. Explain why you think that is an appropriate name.
- 4 What is the function of the myelin sheath that covers the axon?
- 5 A fly lands on someone's face and they brush it off. List the three types of neurons in the order they would be activated when the stimulus is detected.

Communication within and between neurons

Communication within: action potential

An **action potential** is another name for the electrical impulse or 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

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

on a chemical messenger to pass the action potential on to the next neuron.

When a neuron is not sending a neural impulse along its axon, it is considered to be 'at rest'. Each neuron requires a minimal level of stimulation – called the neuron's threshold – to be activated and an action potential to begin. When enough chemical

messengers (neurotransmitters) arrive from other neurons, and the threshold is reached, an action potential can begin and will move along the axon, like a wave. If the threshold is not reached, no action potential can start. This is known as the 'all or none' principle. Once an action potential has been triggered, it is self-sustaining, meaning that it will continue to the end of the axon without further stimulation.

The speed of an action potential moving along an axon can vary between neurons. The fastest travel over 100 m/s, with the slowest traveling at about 1 m/s. The speed depends upon two factors: the larger the diameter (width) of the axon, the faster the impulse and if the axon has a myelin sheath it travels faster than unmyelinated axons.

MULTIPLE SCLEROSIS

Healthy Neuron

Damaged Neuron

Affected Areas

Multiple sclerosis **Explore! 3.2**

Multiple sclerosis is a degenerative neurological condition, characterised by the development of *scleroses* (Greek for 'scars') forming on neurons of the central nervous system. These scars result in damage to the myelin sheaths, which insulate the neurons, meaning they 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 Which of the following neurons can be affected: interneurons in the brain, motor neurons, interneurons in spinal cord, sensory neurons?
- 2 Outline treatments that exist for multiple sclerosis.

Figure 3.8 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 the vesicles (tiny sacs of neurohormone) within the axon terminal. This side of the synapse

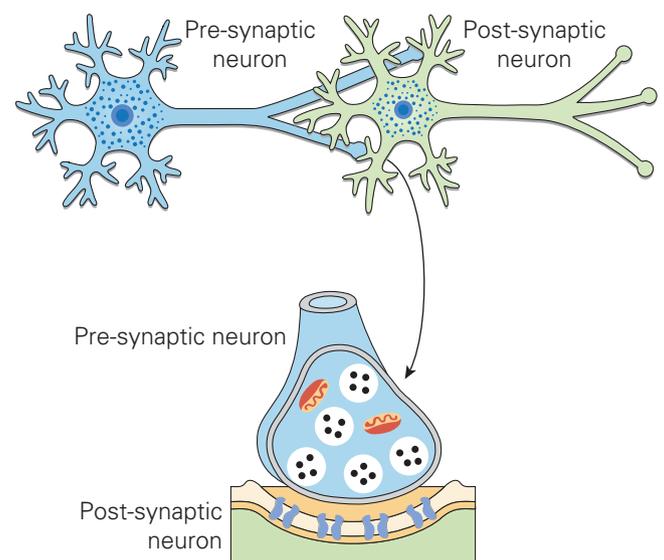
is known as the pre-synaptic neuron. These specialised chemical messengers then move across the gap between neurons (called the synaptic gap). Scientists have managed to identify over 100 different neurotransmitters in the human brain alone, but evidence suggests there are significantly more than this number.

Neurotransmitter	Role	What can go wrong?
Dopamine	Acts within the brain on pathways associated with motor functions (movement) and emotional arousal and motivation	A lack of dopamine-producing cells in the brain can cause Parkinson's disease, a neurological condition characterised by tremors, stiffness and uncoordinated movements.
Acetylcholine	Transmits the message from the axon terminals of a motor neuron to a skeletal muscle	Curare is a plant-based toxin that was used by South American Indigenous people to paint onto the arrows of blow-darts. When shot at a victim, this toxin prevented acetylcholine from binding to the post-synaptic neuron, causing paralysis.
Serotonin	Produced in the intestine and central nervous system; it regulates appetite, mood, memory and behaviour	Some scientists theorise that low levels of serotonin are linked to depression.
Glutamate	Major excitatory neurotransmitter in the CNS; involved with memory and learning	High glutamate levels are involved with depression, anxiety and DHD-like symptoms such as the inability to concentrate. Low levels of glutamate are linked to insomnia, lack of concentration and low energy levels.

Table 3.4 Some common neurotransmitters and their roles

Once the neurotransmitters cross the synaptic gap, they bind to special receptor sites on the dendrite of the next neuron – also called the post-synaptic neuron. The receptor sites convert the information 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 Figures 3.9 and 3.10.

Figure 3.9 Communication between neurons involves the action potential triggering the release of neurotransmitters from their vesicles in the pre-synaptic neuron, moving across the gap and binding to receptors on the post-synaptic neuron.



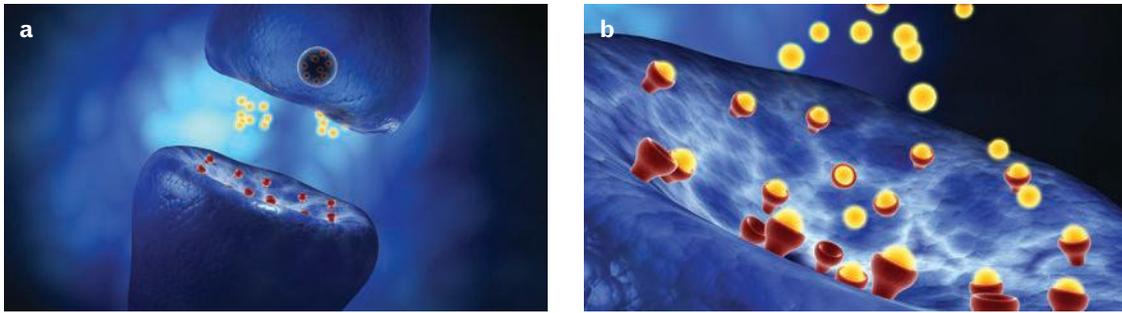


Figure 3.10 (a) A vesicle in the axon terminal storing neurotransmitters and the neurotransmitters (yellow) crossing the synapse to be received by the receptor sites (red) on the neighbouring neuron's dendrite. (b) Neurotransmitters (yellow) being released across the synapse and being received by the receptor sites (red) of the dendrite if they share the same distinct size and shape as each other.

The longest neuron

Did you know? 3.2

The sciatic nerve contains the longest neuron in the human body. It extends from the spine to the tip of the toe and can be up to 1 m in length.

Calculate the time it would take for an action potential to travel from your brain to your toes using the fastest and slowest speeds to obtain a range. Use a calculator and rounded approximate values to make the calculation easier.

Try this 3.3

- 1 Is an action potential a signal between two neurons or along a neuron?
- 2 What does the 'all or none' principle mean?
- 3 What is a neurotransmitter?
- 4 What is the role of the post-synaptic neuron?
- 5 List three common neurotransmitters and describe their function.
- 6 Rewrite these stages of the flow chart in the correct order, showing how an action potential passes from one neuron to another.

Quick check 3.4

Action potential stimulates vesicles to release neurotransmitters

Action potential initiated once threshold is reached

Neurotransmitters released into synaptic gap

Action potential travels along axon

Neurotransmitters bind to receptor sites on post-synaptic neuron's dendrites

You know that 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, as Figure 3.11 shows.

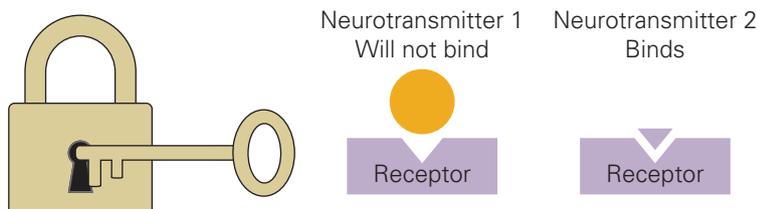


Figure 3.11 A specific neurotransmitter will bind only to its corresponding receptor, and in this way ensures it only causes the desired response.

Neurotransmitter messages can be categorised as either excitatory or inhibitory. An excitatory neurotransmitter increases the likelihood of the action potential being sent along the next neuron, whereas an inhibitory neurotransmitter

decreases the likelihood of the action potential being sent along the next neuron. They are both considered important, as they can initiate a response or to stop something from happening at the effector site.

Neurotransmission at the synapse

Try this 3.4

Using the 'Stop motion' App, create a short animation that clearly represents how neurotransmission occurs between neurons. Alternatively, you could construct a comic book style outline or poster.

You must label:

- pre-synaptic neuron (axon terminal)
- vesicles
- neurotransmitters
- post-synaptic neuron (dendrites)
- receptor sites
- synapse
- action potential.

Your animation should show the movement of vesicles binding with the cell membrane and releasing neurotransmitters to the next neuron, with reference to the lock-and-key theory.

Drugs

Did you know? 3.2

Drugs are substances that have an effect on the brain. They can change the way neurons send, receive and process information. Some drugs, such as marijuana and heroin, mimic naturally occurring neurotransmitters to activate neurons. Other drugs, such as cocaine and amphetamines, induce neurons to release greater amounts of naturally occurring neurotransmitters, greatly amplifying signals, preventing recycling of the chemicals and disrupting communication channels.

Parkinson's disease

Science as a human endeavour 3.1

Neurodegenerative disease is an umbrella term for a range of conditions that primarily affect the neurons in the human brain. Neurons are cells that do not reproduce or replace themselves, so when they become damaged or die they cannot be replaced by the body. 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-type symptoms, such as tremours and rigidity.

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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 is dependent upon technological advances in brain imaging. For example, in 2015, scientists developed new wearable sensor networks and mobile phone applications that have the potential to monitor and manage patients with Parkinson's disease. They hope that the use of low-cost wearable sensors means that the symptoms of the patient can be continuously detected and quantified. The information can then be sent to hospital to generate a daily report that will alert the doctor if there is any unusual data.

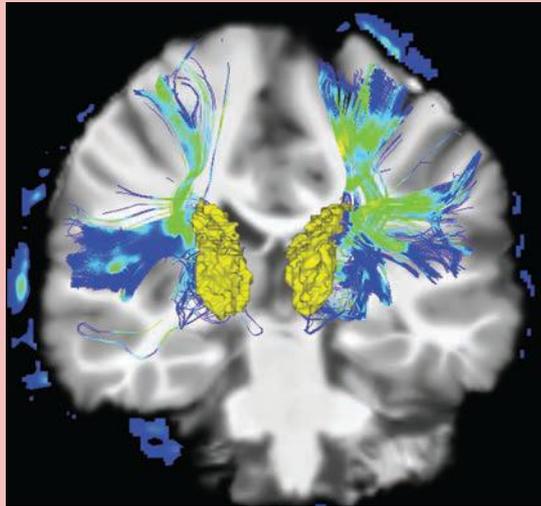


Figure 3.12 This enhanced scan of the brain of a patient with Parkinson's disease uses yellow to highlight the area near the substantia nigra and blue and green to highlight the fibres of the motor system. Compare the left and right sides. (Active areas would be shown in red or orange.)

Parkinson's disease

Explore! 3.3

Research into either one of the following topics. Summarise your findings by explaining how technologies have improved knowledge and understanding of Parkinson's disease, or have helped Parkinson's sufferers 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 sufferers of Parkinson's disease have 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 3.2 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 What is the function of dendrites?

Understanding

- 4 Describe how an action potential is triggered and transmitted from one neuron to the next.
- 5 How does the function of the motor neuron and sensory neuron differ?
- 6 Describe the synapse.

continued...



QUIZ

...continued

Applying

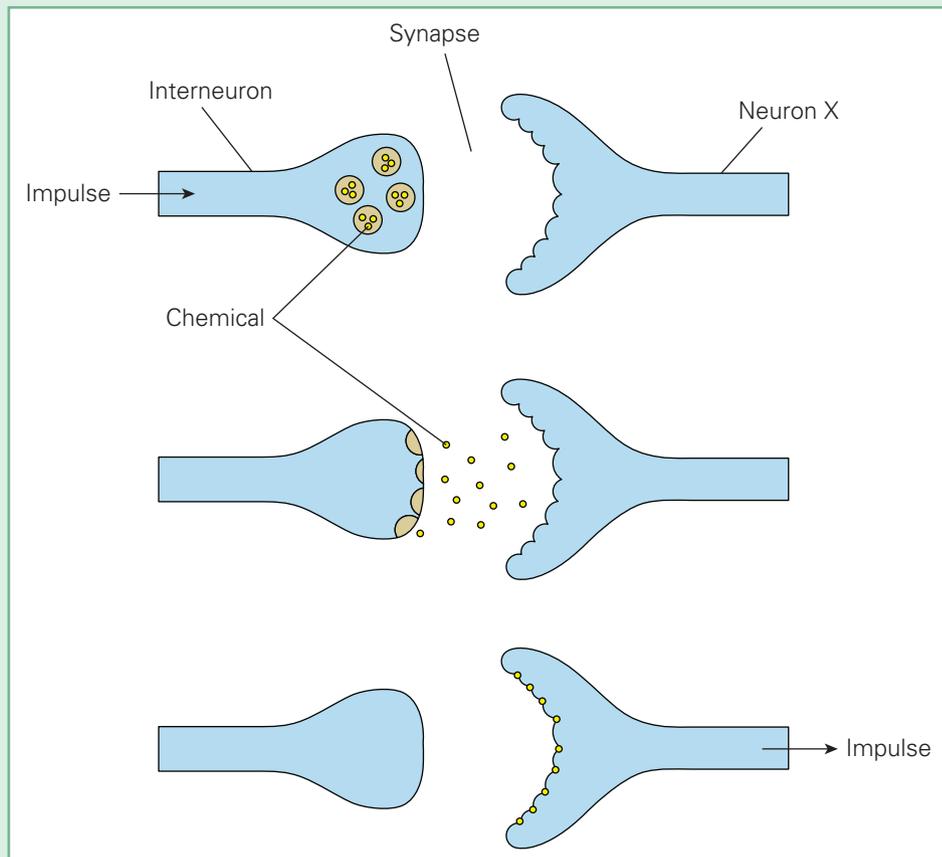
- 7 Using the stimulus–response model, construct a flow chart showing the steps involved in the following scenario. Be sure to include these terms on your flow chart: stimulus, motor neuron, muscle, interneuron, sensory neuron, receptor.

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 Using the 'lock-and-key' analogy, explain how neurotransmitters work across the synapse.
9 If a drug blocks the receptor sites, explain the effect it could have on neurotransmission across the synapse.

Analysing

- 10 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.
11 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.
12 The figure below shows how an impulse moving along an interneuron causes an impulse to be sent along another type of neuron, neuron X.



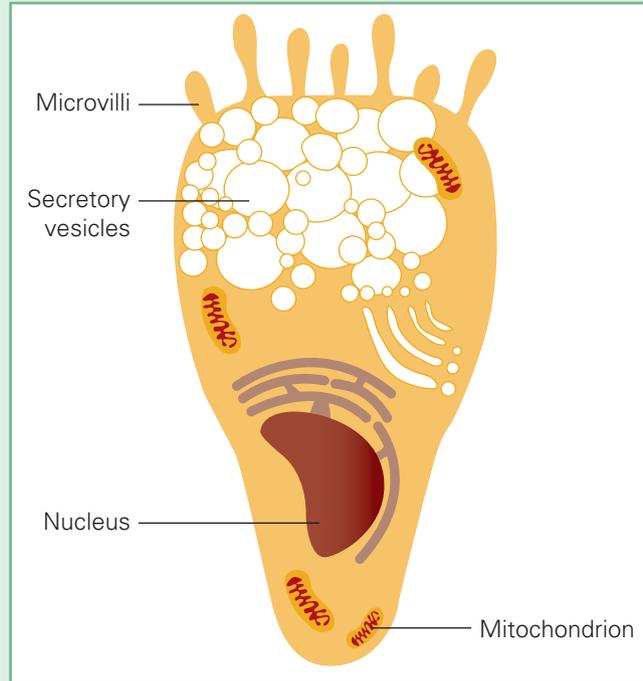
- a What type of neuron is neuron X?
b Describe how information passes from the interneuron to neuron X.
Use the diagram to help you.

continued...

...continued

Evaluating

- 13 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?



- 14 Compare the role of two important neurotransmitters found within the brain – serotonin and dopamine.



The spinal cord

Reflex actions

A **reflex action** or spinal reflex is a quick automatic involuntary action that protects the body from danger. Sometimes it is necessary for the body to react very fast, without waiting for instructions from the brain. It is therefore the spinal cord that is primarily involved in responding to the stimulus and initiating

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

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 signals travel to the spinal cord and back to the muscle which contracts quickly. This can also be called a reflex arc. Figure 3.13 shows an example of a reflex arc.

You may have noticed terms from Chapter 2 such as ‘stimulus’ and ‘response’ also appear



in this chapter. This is because Chapter 2 looked at homeostasis and the nervous system as a key player in regulating our body systems in response to change.

When the brain is involved in detecting and responding to a stimulus, the process is called the stimulus–response model.

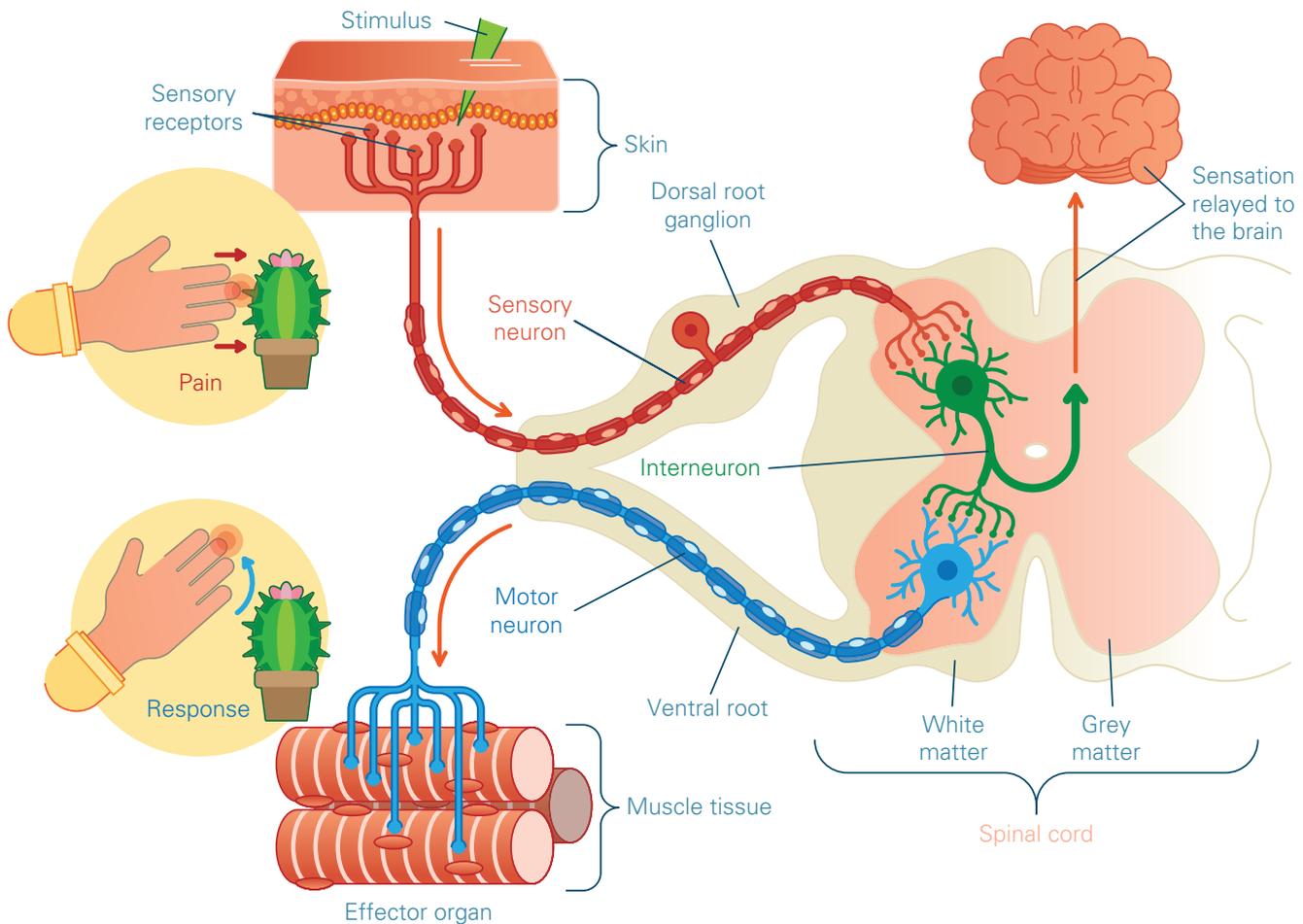


Figure 3.13 An example of a reflex arc. You touch a pointy cactus with your finger, a receptor in a sensory neuron detects the pain and initiates an action potential. The impulse is carried to the spinal cord where the sensory neuron connects to an interneuron. The interneuron then connects to a motor neuron that sends an action potential through to the muscle tissue. Your muscles contract and you move your hand away from the sharp cactus.

Copy and complete the table below, with reference to the following scenario.

Try this 3.5

A person sees a can of soft drink sitting on the bench. They feel quite thirsty, so they reach out and pick up the can to have a drink.

Part of the stimulus–response model	Definition of this part	Use example scenario to complete this column
Stimulus	Change in the environment	
Receptors	Detect the stimulus and stimulate the sensory neuron	
Sensory neurons	Transmit an action potential (nerve impulse) to the integration area (the CNS – central nervous system)	

continued...

...continued

Part of the stimulus–response model	Definition of this part	Use example scenario to complete this column
CNS	Brain coordinates an appropriate response by sending nerve impulse along interneurons which connect to motor neurons	
Motor neurons	Transmits an action potential (nerve impulse) to the effector organ (muscle or gland)	
Effectors	Act to cause the response	
Response	Body's reaction to the stimulus	

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. The tap of the hammer causes a slight stretch within the quadriceps muscle (front of your thigh) which is connected to the tendon. This stretch is detected by stretch receptors in the muscle and communicated via a sensory neuron to the spinal cord. There, interneurons will connect the sensory to a motor neuron that will send an impulse right back to

the quadriceps, triggering the muscle to contract which then makes you kick. This kick is the product of a lightning-fast knee-jerk reflex arc. A kick only indicates that a particular section of the spinal cord and the associated nerves are working properly. A series of different reflex tests are required for a more precise health indicator of the whole nervous system.

A 'knee-jerk' reflex can be represented with a reflex arc. It is important to note that there is no brain involvement. The CNS integration takes place in the spinal cord.

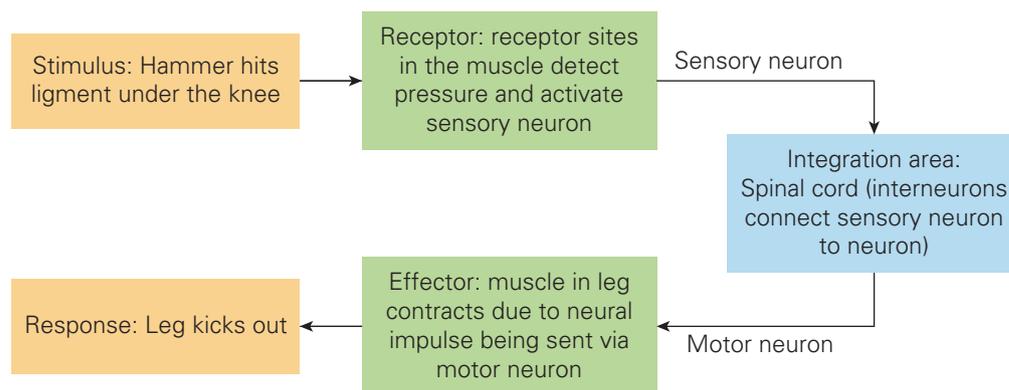


Figure 3.14 A reflex arc of the knee-jerk reflex

Practical 3.1

Testing your reflexes and response times

Aim

To explore the speed of some of your automatic reflexes and response times.

Materials

- stopwatch
- ruler
- well-lit room

Method

Part 1: Testing your pupillary reflex

- 1 Look closely at the eyes of your partner, estimating the diameter of their pupils in millimetres.
- 2 Ask them to close their eyes for 60 seconds and tilt their head down towards the floor. Record this on the stopwatch.
- 3 Observe closely as you ask them to tilt their head up towards a light before opening their eyes. Record your observations of how their pupils react.

Part 2: Testing your knee-jerk reflex

- 1 Have your partner sit on a chair with one leg crossed over the other.
- 2 Using your hand or a ruler, gently strike the patellar tendon just below the kneecap and observe what happens. *Note:* You may need to repeat this experiment several times to get a response.

Part 3: Ruler drop

- 1 Have your partner lean their forearm on a bench with their hand extending over the edge. Ask them to make a pincer grip with their thumb and index finger with a gap of about 2 cm between them.
- 2 Dangle the ruler 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. Release it without warning.
- 4 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.
- 5 Repeat the experiment several times for each person and average their results.

Results

Tabulate your results as follows.

	My results	My partner's results
Part 1: Pupillary reflex	<i>Describe</i>	<i>Describe</i>
Part 2: Knee-jerk reflex	<i>Describe</i>	<i>Describe</i>
Part 3: Ruler drop	_____ cm dropped through on average	_____ cm dropped through on average

Evaluation

Part 1

- 1 Explain what you observed when your partner opened their eyes, noting the stimulus and the response.
- 2 How might this reflex assist us in everyday life?
- 3 Is pupil size under voluntary or involuntary control?

Part 2

- 1 Draw a reflex arc for the knee jerk reflex, showing the stimulus and response.
- 2 Label the neurons that are involved.

continued...

...continued

Part 3

- 1 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.
- 2 What did you notice with repeated trials? Did people improve? Give one reason why this may be the case.
- 3 Suggest two ways the experimental design could be improved (for any of the three parts).
- 4 Suggest one potential source of error in this experiment (any of the three parts).

Conclusion

- 1 Make a claim from this experiment regarding reflexes and response times.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Conscious and unconscious responses

A reflex action is an unconscious process as the brain is not initially involved in activating a response. This is different from a conscious process where the brain is involved in activating a response. The differences are shown in the table below.

Did you know? 3.3



Conscious response to stimuli	Unconscious response to stimuli
<ul style="list-style-type: none"> • Reaction involves the brain and a level of awareness • Paid attention to stimulus • Voluntary or intentional reaction • Often goal directed or purposeful • Can be a more complex response • Tend to vary • Can be learned • Can control it 	<ul style="list-style-type: none"> • Reaction does not involve a level of awareness by the brain • Do not have to pay attention for it to happen • Involuntary or unintentional • Reflexive or automatic, increasing chances of survival • Most are simple responses • Tend to occur in the same way each time • Do not require learning • May not be able to control it

- 1 True or false? **Quick check 3.5**
The brain is not immediately involved in a reflex arc.
- 2 Draw a reflex arc for a person touching a flame.
- 3 Compare a reflex arc and the stimulus response models of the nervous system. In what ways are they similar and different?

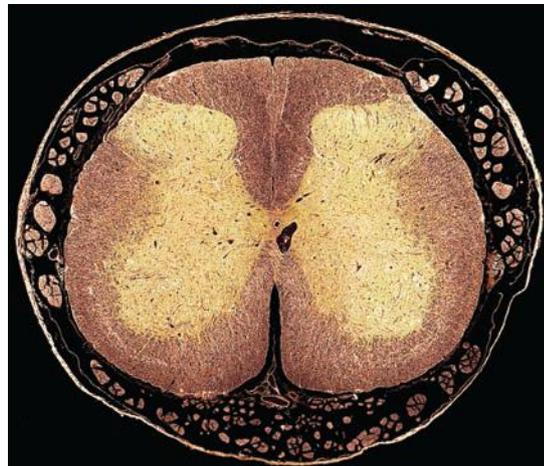


Figure 3.15 Light micrograph (LM) of a cross-section through the human spinal cord in the lumbar region. The spinal cord consists of a butterfly-shaped core (yellow) known as grey matter, which consists of nerve cells. Surrounding the grey matter is a larger region of white matter, made up of myelinated nerve fibre bundles or tracts.

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 3.15.

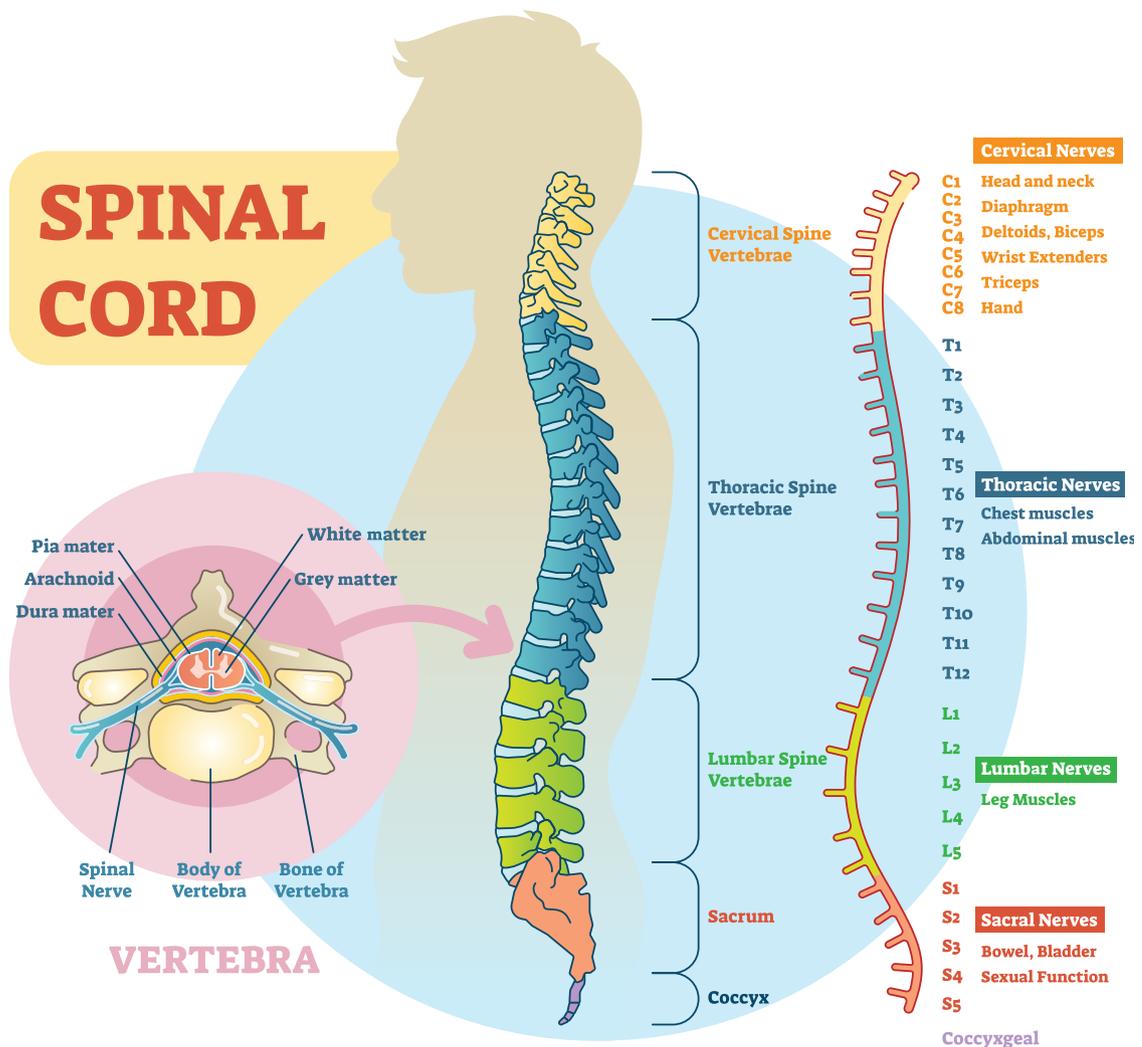


Figure 3.16 Spinal cord showing all sections – cervical spine, thoracic spine, lumbar spine, sacrum and coccyx, along with a diagram of the vertebrae

The spine consists of 33 vertebrae:

- 7 cervical (neck)
- 12 thoracic (upper back)
- 5 lumbar (lower back)
- 5 sacral (sacrum – located within the pelvis)
- 4 coccygeal (coccyx – located within the pelvis).

By adulthood, the five sacral vertebrae fuse to form one bone, and the four coccygeal vertebrae fuse to form one bone.

The level where the injury occurs determines the effects that the person suffers (see Figure 3.17). Spinal cord damage is classified according to the person's type of loss of motor and sensory function. Table 3.5 lists the main types of classification.

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 ('para' means two)	Two limbs affected (left and right legs) by impaired sensation and movement
Triplesia ('tri' means three)	Rare incomplete spinal cord injury leads to three limbs (one arm, two legs) affected by impaired sensation and movement

Table 3.5 Classification of spinal cord injuries

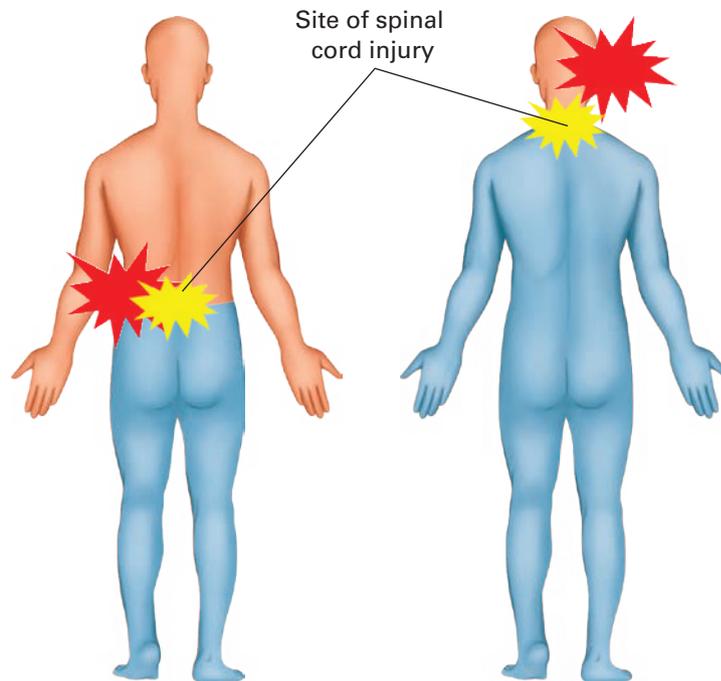


Figure 3.17 The effects the person suffers depend upon the location and severity of the injury – the higher up the spine, the more severe the effects.

The types of symptoms experienced by a person with spinal cord injury depend upon the location and severity of the injury. They may include:

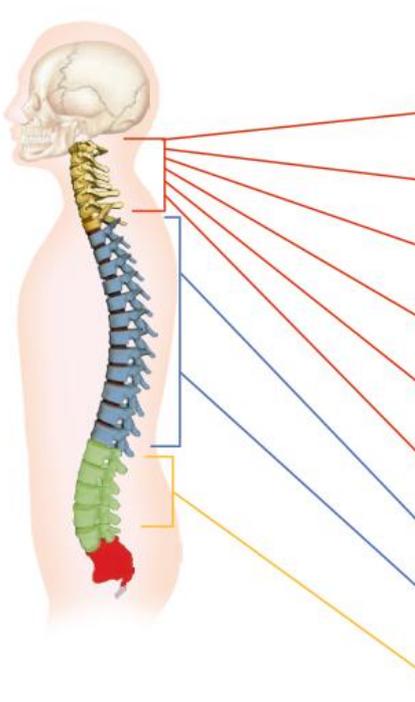
- muscle weakness or paralysis (including difficulty breathing if the diaphragm muscle is affected)
- sensory dysfunction such as loss of sensation or pins and needles
- sexual dysfunction
- digestive problems
- problems regulating their heart rate and blood pressure
- loss of control over bowel and bladder function.

Prognosis of spinal cord injuries

The level that the spinal cord injury occurs at will determine the extent of symptoms and the prognosis for rehabilitation. Figure 3.19 shows the levels of spinal cord injury and the rehabilitation potential.



Figure 3.18 Paralympic Winter Games 2018; paraplegic competitors in the Men's 7.5 km Sitting Classic



Level of injury	Possible impairment	Rehabilitation potential
C2 - C3	Unable to breathe, potentially fatal	Dependant for care
C4	Quadriplegia and breathing difficulty	Dependant for 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. 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 3.19 Spinal cord injury and potential for rehabilitation

- 1 What are the names of the different regions of the spine?
- 2 Define the terms 'quadriplegia' and 'paraplegia'.
- 3 List three ways a spinal cord injury might occur and name three symptoms that might result from that injury.

Quick check 3.6

Spinal cord injury

There is currently no cure for spinal cord injuries, however, stem cells have presented some possibilities for treatment. Research the following questions to discover how harnessing these unspecialised cells might assist in the recovery from a spinal cord injury.

- 1 What are stem cells?
- 2 How have they showed promise for use in spinal cord injuries?
- 3 What are some of the positives and negatives of using stem cells in treatment of spinal cord injuries?

Explore! 3.4

Practical 3.2

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



Figure 3.20 A catch of silver garfish

continued...

...continued

- scalpel
- probe
- newspaper
- dissection microscope
- dissection board
- disposable gloves

Method

- 1 Working in pairs, place garfish on a clean board.
- 2 Using forceps and scalpel carefully make an incision down the underbelly from pectoral fins to anus.
- 3 You may need to remove the guts.
- 4 Remove as much flesh as possible surrounding the backbone so it is 'clean'.
- 5 Place spine/backbone onto a Petri dish.
- 6 Discard flesh (wrap in newspaper before placing in bin).
- 7 Using the microscope, sketch the backbone 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.
- Extreme care is required when handling the scalpel.
- Proper cutting technique should be demonstrated before student use.
- Never use the scalpel by cutting towards any part of your body.
- Use forceps – not your fingers – to cut towards and away from.
- User discretion is advised.

Separating the spinal cord from the spine

- 9 You are now to carefully try and separate the vertebrae from each other 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 it is still attached) under the microscope and sketch. Include a title, labels and magnification.

Results

Record your observations and include your two sketches.

Evaluation

- 1 Comment on the appearance of the garfish's spine. Decide whether or not there was sufficient protection to 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 land creatures.

Conclusion

- 1 Make a claim from this experiment regarding the spinal cord of garfish.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Section 3.3 questions

Remembering

- 1 A person suffers a spinal cord injury whilst surfing and loses motor control and sensation in their legs. How would this spinal cord injury be classified?
- 2 Define what is meant by reflex action. Include its role in defending the body against damage.
- 3 Provide an example of a reflex action.

continued...



QUIZ

...continued

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 Distinguish between the stimulus and the response in the knee jerk reflex.
- 6 What are two differences between conscious and unconscious responses?

Applying

- 7 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.
- 8 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

- 9 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.
- 10 Luke has damage to his spinal cord at L3. Classify his injury as paraplegia or quadriplegia.

Evaluating

- 11 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.

Unconscious responses to stimuli are often the most complex actions.

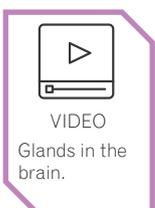
A spinal cord injury in the cervical region is likely to result in paraplegia.
- 12 A person picks up a very hot cup of coffee and immediately drops it, breaking the mug. Draw a flow chart, beginning at stimulus and ending in response and highlight the section of the flow chart that demonstrates whether this is a reflex, or a response that is coordinated by the brain.



The brain



WORKSHEET



VIDEO
Glands in the brain.

Cerebral cortex

The cerebrum is the largest part of the human brain. Its outer layer of the brain is called the **cerebral cortex**. It is only 2–3 mm thick, yet it contains three-quarters of the brain's neurons. It 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 contain four lobes. The left and right hemispheres are connected by a thick band of nerve fibres called the **corpus callosum**.

cerebral cortex
outer layer of the brain

corpus callosum
a bundle of nerve fibres connecting the left and right hemispheres of the brain

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

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

hemisphere is also involved in specific functions; for example, the left side specialises in your ability to formulate and understand language. Each hemisphere can specialise or exert greater control 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 scientific approaches to studying hemispheric specialisation include:

- studying people with brain damage
- studying people who have had a 'split-brain' operation
- studying people with intact, undamaged brains.



Figure 3.21 Both the left hemisphere and the right hemisphere of the brain are responsible for specialised functions.

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 and they are called the frontal lobe, the parietal lobe, the occipital lobe and the temporal lobe. They each have their own specialised functions.

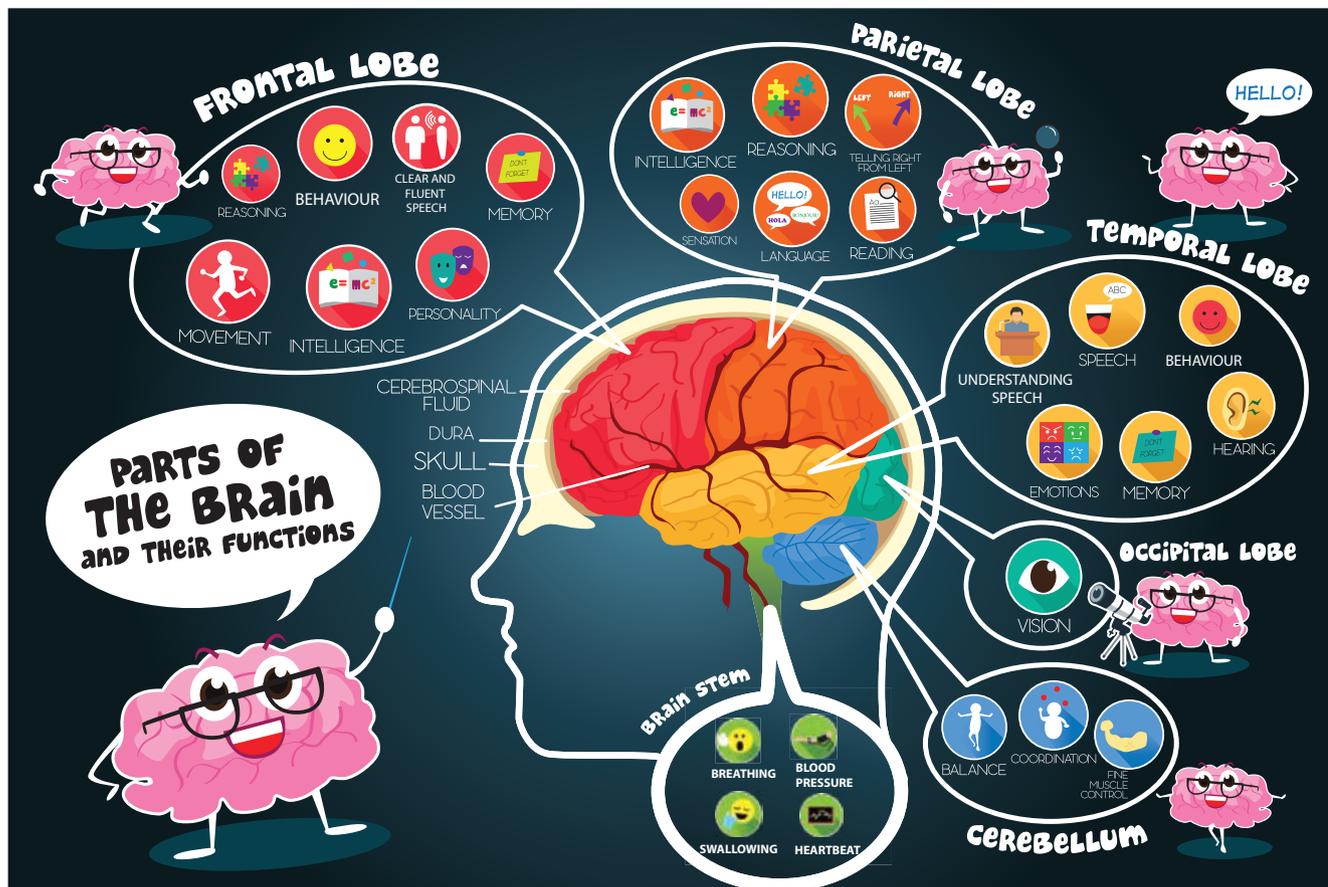


Figure 3.22 Specialised functions of the different lobes of the brain, as well as the cerebellum and brain stem, which are located below the cerebral cortex

Brain poster

Try this 3.6

Make a poster/slideshow that would be suitable for teaching Year 7 students about the brain.

Use information from this chapter, but you may also search for additional information online. Your poster should include:

- a side view of the brain clearly showing the frontal lobe (and motor cortex), parietal lobe (and somatosensory cortex), occipital lobe, temporal lobe and their functions
- Broca's area and Wernicke's area and describe their special roles
- a dorsal view of the brain (looking down from the top) showing the left and right hemisphere, corpus callosum and detail their roles in processing of sensory information and control of activities on each side of the body.

- 1 What are 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 List two structures found in the temporal lobe.
- 4 What is the role of the primary visual cortex?
- 5 Where in the brain is Broca's area found and what is its function?

Quick check 3.7

Structures within the brain

There are other important brain structures involved with behaviour that are not found on the cortex (outer) of the brain, but within the brain, as shown in Figure 3.23.

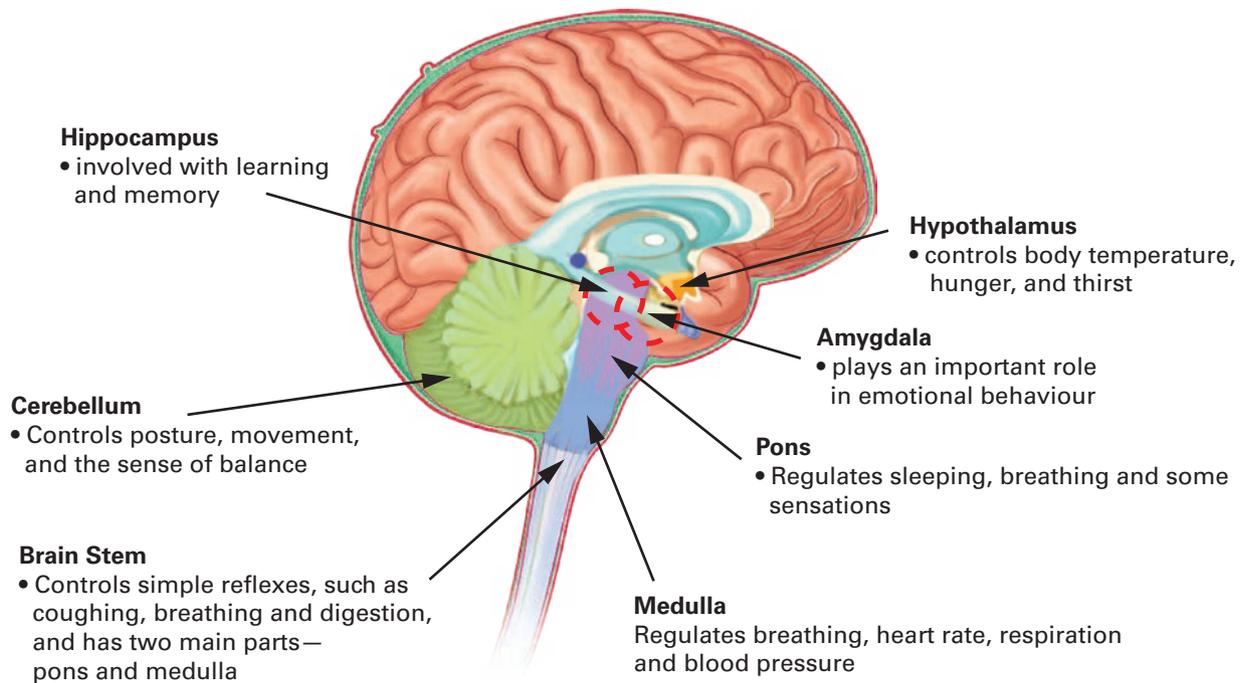


Figure 3.23 A cross-section of the brain, revealing the hidden structures within

Practical 3.3

Dissecting a sheep's brain

Aim

To observe the different regions within a sheep's brain.

Materials

- sheep's brain
- disinfectant
- scissors
- forceps
- probe
- Optional: pre-prepared slides of a cross-section of the brain tissue for observation under a microscope
- dissecting board
- disposable gloves
- newspaper
- paper towel

Be careful

Ensure gloves are worn at all times during the dissection.

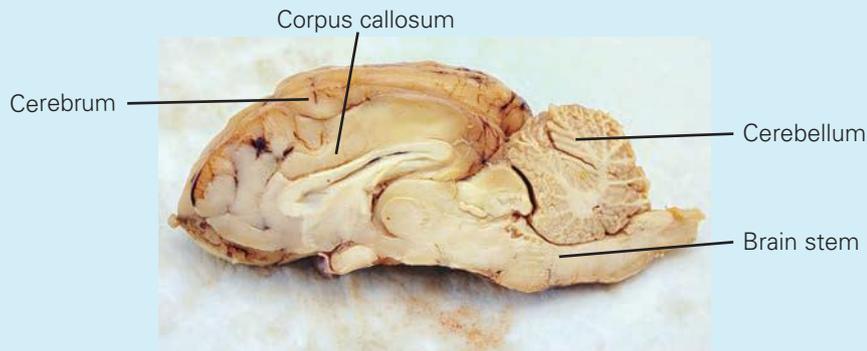
Method

- 1 Place a few sheets of newspaper on the workstation.
- 2 Put the dissecting board on top of the paper together with the dissecting implements.
- 3 Collect the brain and carefully place it on the board. Take care as it will be slippery.
- 4 Using the scissors, cut the brain into two symmetric halves (hemispheres). Identify the corpus callosum, cerebrum, cerebellum and brain stem.
- 5 Observe the colour and appearance of each section.
- 6 Cut one of the hemispheres lengthways to observe the cerebellum.
- 7 Draw and label a diagram of the brain.

continued...

...continued

- 8 Ensure dissection is discarded appropriately and the work area is disinfected.
- 9 Optional: view a pre-prepared cross-section of the brain under a microscope.



Results

Draw and label the diagram of the brain.

Evaluation

- 1 Why is the brain encased in the skull?
- 2 What is the difference between white and grey brain matter?
- 3 The brain stem is located at the base of the brain. What is it responsible for?
- 4 Explain why there are two hemispheres and detail their roles.
- 5 What connects the left and right hemispheres?
- 6 Can you easily differentiate between the lobes of the cerebral cortex?
- 7 What is the role of the cerebellum?

Conclusion

- 1 Make a claim from this experiment regarding sheep brains and human brains.
- 2 Support the statement by using the structures you observed.
- 3 Explain how your observations support your claim.

Brain freeze

Have you ever experienced a 'brain freeze' when drinking a very cold drink or eating ice cream? When something extremely cold touches the upper palate (roof of the mouth), it can lead to a feeling of a headache. Harvard University scientists have found that the headache stems from the constriction of the capillaries in your sinuses when a cold stimulus is applied. As they dilate (relax) again when warmer air touches the palate, there is a rush of blood through the brain's anterior cerebral artery. This rapid change near the sensitive nerves in the palate creates the 'brain freeze' phenomenon.

Did you know? 3.4



Figure 3.24 Any cold stimulus can result in the painful sensation of a brain freeze.

Practical 3.4

Does talking interfere with right-hand motor tasks?

Humans are the only animals which are predominantly right-handed. Don't believe me? 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.

Materials

- a 30 cm wooden rod or similar
- stopwatch

Method

- 1 Construct a hypothesis: 'Will people be better at balancing the rod when they are talking or silent? Will there be a difference between balancing on the left or right-hand side?'
- 2 Each person should practise balancing the rod on the left and also the right index finger. Ensure that the person balancing is standing, and that the rod is in the same position between the middle knuckles (as shown in the image).
- 3 Form groups of three and record whether each person is left- or right-handed.
- 4 Take it in turns: To begin with, the person being tested should balance the rod on their right finger and remove the steadying hand when instructed. Time how long they can balance it on their left and right hands. Record these results in the table.
- 5 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

- 6 Repeat the experiment with the other two group members.



Results

	Which is their dominant hand?	Time balanced (secs): Left hand, silent	Time balanced (secs): Right hand, silent	Time balanced (secs): Left hand, speaking	Time balanced (secs): Right hand, speaking
Person 1					
Person 2					
Person 3					
Average	N/A				

- 7 Create a graph of your results, showing each individual and their four times.

Evaluation

- 1 Do the results confirm your hypothesis?
- 2 Explain the average results obtained using the facts stated prior to the Aim.
- 3 Do you think the order the tasks were completed in might have affected the results of the experiment? Suggest a way the experimental design could be improved.
- 4 Suggest two potential sources of error in this experiment.

continued...

...continued

Conclusion

- 1 Make a claim from this experiment regarding left- or right-handedness and speaking.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Sensitivity of body parts

Figure 3.25 shows a **homunculus**, which is Latin for ‘little man’. It represents how sensitive the different parts of the body are by representing them as large if they are highly sensitive, and small if the body part is not very sensitive. This representation of touch was

homunculus

a representation of the body parts in the brain where size shows level of sensitivity

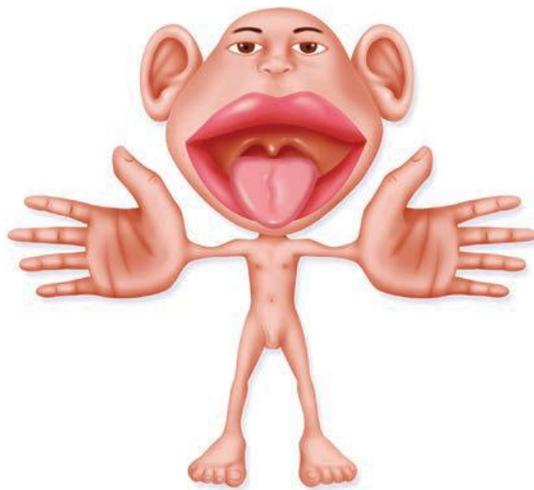


Figure 3.25 In the sensory homunculus the fingers, thumb, tongue and lips, are disproportionately represented to show that they are more sensitive and so more space in the primary somatosensory cortex is devoted to these body parts.

discovered by Penfield and Rasmussen. They mapped the primary somatosensory cortex by electrically stimulating different areas on the somatosensory cortex of patients whose skulls were opened for tumor removal. They asked the patients to identify where on their bodies they felt the sensation.

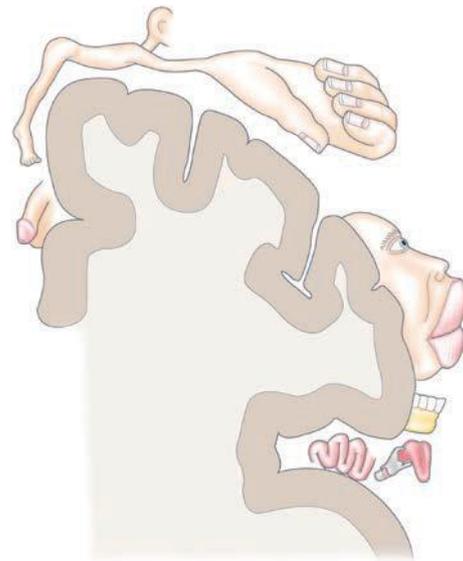


Figure 3.26 The pictorial representation of where the body parts are located along the actual primary somatosensory cortex. The larger the space along the cortex, the more sensitive the body part.

Practical 3.5

Determining the sensitivity of body parts

Aim

To determine whether the fingertip, upper arm or the back is the most sensitive body area.

Materials

- ruler with millimetres or centimetres
- paperclip
- paper and pencil

continued...

...continued

Method

- 1 Construct a hypothesis for this experiment: Predict which part of the body (fingertip, upper arm or back) will be the most sensitive and why.
- 2 Decide who will be the experimenter and who will be the participant.



- 3 Open your paperclip.
- 4 Spread the ends and use the ruler to measure the distance between them.
- 5 Adjust them until they are exactly 4 cm apart.
- 6 The experimenter alternates touching with either both ends of the paperclip or one end of the paperclip to the participant's fingertip. (A gentle touch is all that is required.)
- 7 If they correctly feel whether one or both ends were used, tick the column (✓), or place a (x) if they do not feel the number of ends correctly.
- 8 Repeat step 6 on the participant's upper arm and back and record your results in your table.
- 9 Repeat steps 5 and 6, bringing the paperclip ends closer each time until they are touching.
- 10 Complete the results table below using following ranges of distances and record in the table below.

Results

Distance between paperclip ends (cm)	Fingertip One point (✓)	Fingertip Two point (✓)	Upper arm One point (✓)	Upper arm Two point (✓)	Back One point (✓)	Back Two point (✓)
4 cm						
3 cm						
2 cm						
1 cm						
0.5 cm						
Ends touching						

Evaluation

- 1 Which body parts 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?
- 3 Looking back at the somatosensory cortex, suggest one other body part that would have tested as highly sensitive and one other body part that would have shown low sensitivity.
- 4 Suggest two ways the experimental design may have been improved.
- 5 What were two potential sources of error in this experiment?

Conclusion

- 1 Make a claim from this experiment regarding sensitivity of various areas of the body.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

- 1 What is the main role of the hippocampus?
- 2 A person suffers a brain stem stroke. What vital body functions might be affected?
- 3 What is the main role of the cerebellum of the brain?
- 4 Define the term 'homunculus' in your own words.

Quick check 3.8**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.

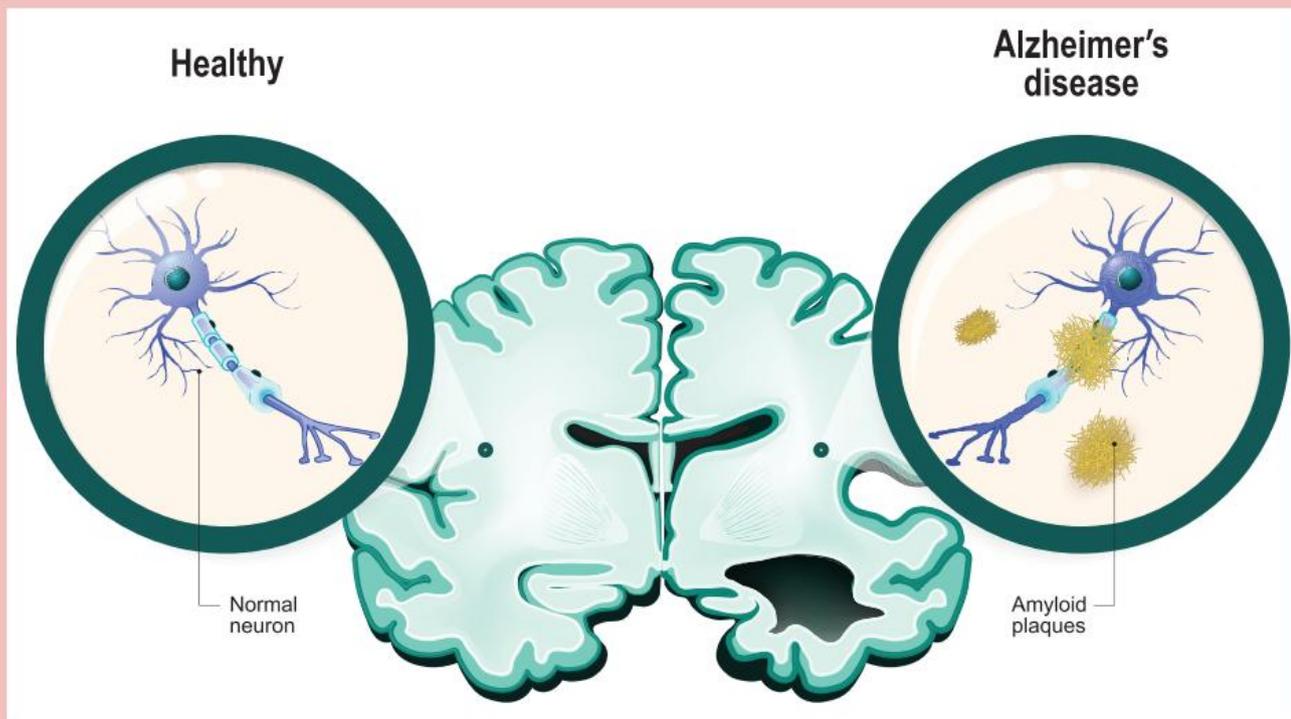
Science as a human endeavour 3.2

Figure 3.27 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 or PET scans. These scans are able to look at changes in the brain at a cellular level, while current 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.

continued...

...continued

This new way of using technology was tested on 53 adults and 33 pensioners without any neurodegeneration and 15 who had suspected Alzheimer's disease. The scientists were able to prove definitively which were clear, at risk and those who had the condition. The findings also have helped scientists understand more about how the neurofibrillary tangles and amyloid plaques build up as the brain ages.

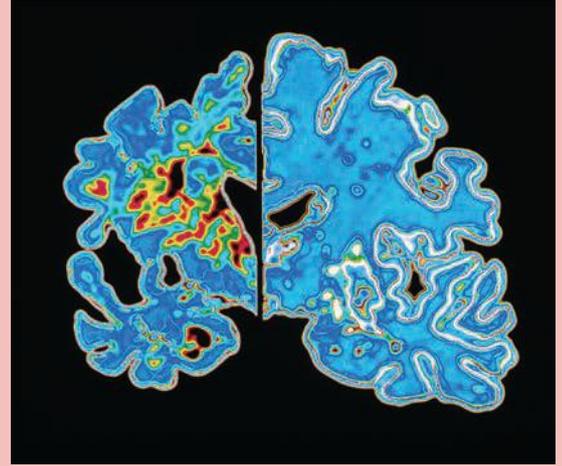


Figure 3.28 Computer graphic of a vertical slice through the brain of an Alzheimer's patient (left half) compared with a normal brain (right half).

The brain's plasticity

Plasticity is the term used to describe the ability of the brain's neural structure or

plasticity

the ability of the brain to change its neuron structure and function over time, in response to experiences

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). Plasticity is necessary for learning.

The development of the brain is an amazing process. We know that babies are born with approximately 100 billion neurons with each neuron having the capacity to connect with around 2500 other neurons. 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 electroencephalograms (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 motion capture. Despite the lack of verbal communication, the EEG detects,

amplifies and records the electrical activity of the brain, which allows scientists to make assumptions based on the readings.

A four-week-old foetus forms new neurons at a rate of 250 000 every minute. When a child is three years old, their brain will process close to 1000 trillion connections between neurons. It is no surprise then that a baby's brain uses three times the amount of energy that an adult's brain uses – that's a busy brain! By late childhood the number of connections increases to around



Figure 3.29 This infant is wearing an EEG during studies of cognitive development. By three years of age a child's brain will have grown to 80% the volume of an adult brain.

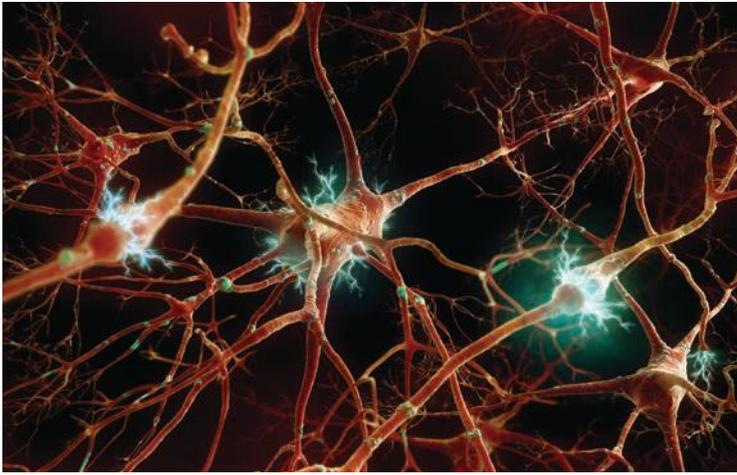


Figure 3.30 Each neuron can transmit 1000 nerve impulses per second and make tens of thousands of synaptic contacts with other neurons.

15 000 per neuron. Yet, by adulthood this number decreases to around 8000 as unused connections are destroyed.

As a child's brain has greater plasticity than an adult's, it is able to utilise other

parts of the brain to form alternative neural connections, which can 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.

One of the most famous plasticity findings occurred when Jody Miller, aged three-and-a-half, survived an 11-hour hemispherectomy, or the removal of the defective right hemisphere of her brain. The plasticity of a child's brain is what allowed for new neural connections to be made in Miller's left brain that would perform functions once handled by her right brain. For example, when she left the hospital 2 weeks following the surgery, she was walking on both legs, despite the whole right side of her brain being removed. Eight months later she was also completely free of seizures.

- 1 Define the term 'brain plasticity'.
- 2 What is brain plasticity useful for?
- 3 How much more energy does a baby's brain use compared to an adult's brain?
- 4 Explain what an EEG stands for and what it is used for.

Quick check 3.9

Bones in the human brain

The brain is protected by the solid bones of the skull, which is actually composed of 22 bones that are fused together. Newborns have soft spots on their head called fontanelles, where the areas of bone making up the skull have not hardened. To avoid brain damage, you must be extremely careful to protect a baby's head. It is not until the age of one when the skull begins to fuse together and harden, forming visible lines called sutures.

Did you know? 3.5



Figure 3.31 A medical professional gently feels the fontanelle.

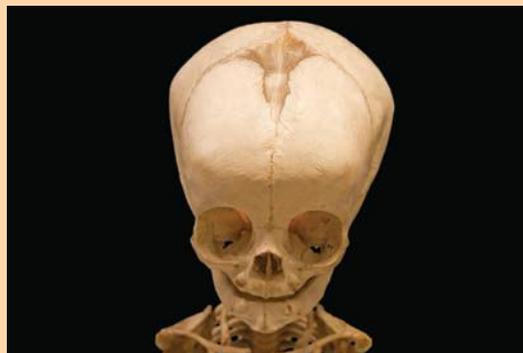


Figure 3.32 The skull of a 4-month old baby is not yet fused together completely.

Addiction and the adolescent brain

Magnetic resonance imaging (MRI) technology has given us an insight into why teenagers are prone to impulsive, risk-taking behaviours. A teenage brain is still developing, and continues to do so until around age 25. When you consider teenagers who have developed addictions to substances such as drugs and alcohol, it is necessary to remember that teenagers are not just 'less-experienced adults' but are still a work in progress. They are prone to errors in judgement and reliance on more primitive, emotion-driven areas of the brain such as the limbic system (thalamus, hypothalamus, hippocampus and amygdala). This is why adolescents are more at risk for substance addiction than any other age group. Unfortunately, the use of these substances can also have dramatic effects on their brain development, with risks for permanent intellectual and emotional damage.

Addiction is a condition that results when a person ingests a substance (such as alcohol, or nicotine) or engages in an

activity (such as gambling or shopping) that can be pleasurable, but the continuation of which becomes compulsive and interferes with the functioning of the person's life. This leads to dysfunction, which is a major characteristic of any mental illness. Engaging in the activity or substance actually triggers the release of the 'pleasure' hormone called dopamine. Addiction is preventable and treatable if intervention is early enough.

Neural connections that are activated on a regular basis become strengthened in the brain. This can be a positive thing in the case of learning and memory formation, but it can have negative consequences in terms of the forming of habits. At the same time, as your brain develops, unnecessary or underutilised neural connections are 'pruned' or disconnected in a process known as 'synaptic pruning', which continues from childhood through to early adulthood. Repeated actions become a habit, so for teenagers who develop a dependency on alcohol, this habit can slowly become ingrained in the wiring of the brain, for life.

So why are teenage brains wired for risk-taking? From an evolutionary perspective, this would have had advantages, as it is around this age that offspring would need to leave the safety of the home and head out to make lives of their own.

As the brain is developing during adolescence, there are sections of the brain that are highly sensitive to alcohol, as shown in Figure 3.34.

Heavy drinking during adolescence can lead to disruptions in some or all of these areas of the brain. Unfortunately, regular and excessive amounts of alcohol can even cause permanent brain damage. It is not surprising then that research shows that a hangover can be just as damaging to the brain as heavy drinking, compromising a person's ability to learn new information and recall memories.



Figure 3.33 Incorporating imaging techniques can allow a great deal of information to be gathered on patients. This image shows the composite of a magnetic resonance imaging (MRI) scan of the brain and 2D and 3D computed tomography (CT) scans.

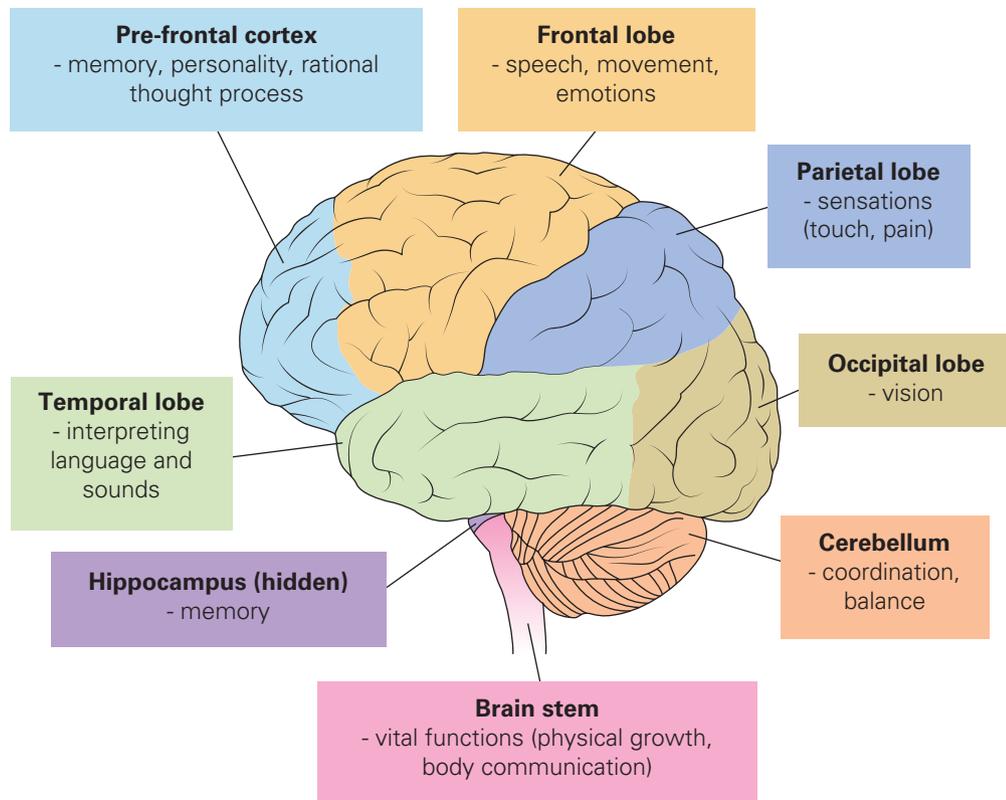


Figure 3.34 Areas of the adolescent brain that are susceptible to the effects of alcohol

Addiction

Explore! 3.5

Choose from one of the following diagnosable substance-use addictions: caffeine; cannabis; methamphetamine; cocaine; tobacco. Research and answer the following questions in any multimedia format: poster, video clip, PowerPoint (with or without voiceover), Prezi, website or similar.

- 1 Describe the addiction you are investigating and what it involves on a biological level. That is, explain the activation of specific neurotransmitters or brain areas when taking the addictive substance – especially in the developing adolescent brain.
- 2 Define the term 'withdrawal' in the context of addiction. List some symptoms that may be shown and explain why they occur.
- 3 What treatments are available? Describe one in detail.

- 1 Define the term 'addiction'.
- 2 Why are adolescent brains particularly vulnerable to addiction?
- 3 What symptoms would you expect to see in someone who has damaged their hippocampus and prefrontal cortex through excessive alcohol consumption during adolescence?
- 4 Which neurotransmitter is released when the reward pathway is activated?

Quick check 3.10

Section 3.4 questions



QUIZ

Remembering

- 1 Name the outer layer of the brain and state how thick it is.
- 2 Where does the word 'homunculus' come from and what does it mean?
- 3 Name the brain's most primitive part and state its functions.

Understanding

- 4 Explain what you might see if you were to remove the cerebral cortex.
- 5 Interpret the term 'brain plasticity'.
- 6 Outline reasons why adolescents are more vulnerable to addiction.
- 7 Explain why humans have a thick skull.

Applying

- 8 Why is it incorrect to say that someone is 'right-brained' or 'left-brained'?
- 9 Apply your knowledge of the sensitivity of body parts in order to explain the unusual dimensions of the 'homunculus man' on the primary somatosensory cortex.

Analysing

- 10 Mariam has suffered brain damage to her frontal lobe. List three symptoms she may display.

Evaluating

- 11 Evaluate whether you think it is easier for a child to learn a new language or skill compared to an adult. Justify your response.



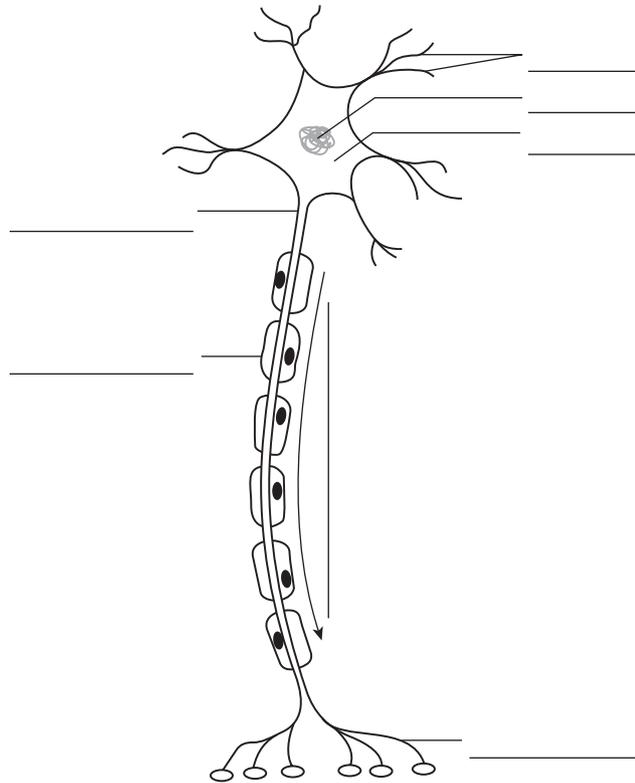
Review questions



SCORCHER

Remembering

- 1 Redraw and label the key structures of a neuron.



- 2 What is the synapse?
3 State the four lobes of the brain and one function for which they are responsible.

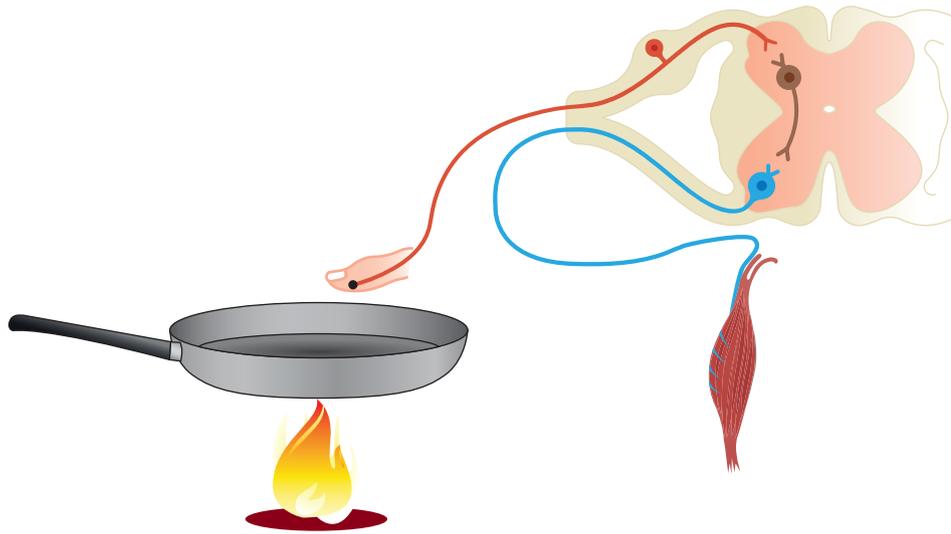
Understanding

- 4 List the steps involved in neurotransmission across a synapse.
5 How do paraplegics differ from quadriplegics?
6 How does the right side of the brain control the movement of the left side of the body?

Applying

- 7 Ali had a motorcycle accident and suffered brain damage in his left temporal lobe. Discuss three possible symptoms he may display.
8 If a particular drug blocked the receptor sites on the dendrites of the post-synaptic neuron, how may this impact the neurotransmitters?

- 9 Sophia accidentally touches a hot pan and automatically snatches her hand away from it. The diagram shows the structures involved in this action.
- a Label the diagram below.



- b Draw a stimulus–response model referring to the diagram above.
- 10 Construct a continuum showing these terms going from smallest to largest: molecule, atom, nervous system, neuron, brain, lobe, receptor.

Analysing

- 11 How does a neurodegenerative disease differ from brain damage due to an accident?

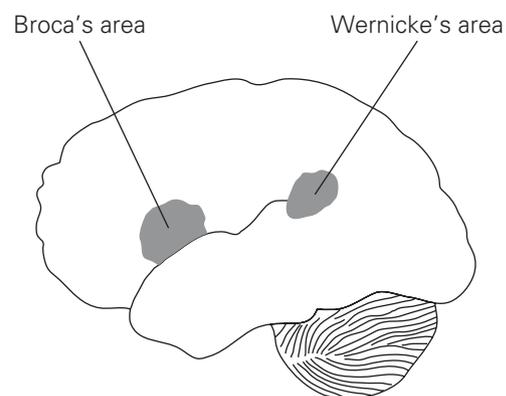
Evaluating

- 12 Taking the drug cocaine causes a build-up of dopamine in the synapse. Based on what you have read about dopamine, give your opinion on the statement, 'I will just take it a couple of times, it won't affect me'. Justify your response by discussing the effects that taking cocaine could have.

- 13 Broca's area is involved in speech and motor movement. Damage in that area results in the inability to speak fluently and affects grammar. Wernicke's area is involved in language comprehension and damage to the area may result in difficulties comprehending speech. Individuals may have trouble producing meaningful speech. Based on the information above, match which of the following would be more appropriate to aid talking to an individual suffering from each condition.

In your answer, refer to using:

- gestures
- questions that require yes/no answers.



STEM activity: Texting and reaction times – what do the numbers say?

Background information

Many people might consider that reacting to a stimulus is an automatic process, however, that could not be further from the truth. Imagine that you are in a car driven by a friend, you are all having a great time and getting ready to enjoy your outing when suddenly, a dog runs in front of the car. The driver reacts quickly and the dog manages to escape unharmed.

The example above can be used to illustrate the powerful cooperation between many sensors in our bodies and the brain. First, light sensors (your eyes) recognise the sudden change in light conditions on the road, that information is sent for processing, then your brain can decide what that information is and if any action is required. Then, your brain compares the information coming from your light sensors to information contained in a vast collection of images (memory), the brain finds a match and determines that something stored under the name 'dog' is very likely the same thing that is running in front of your car. Finally, the brain sends signals via



the nervous system with the correct combination of contraction and expansion of very specific muscles; this is when your friend presses the brake pedal. In the meantime, your brain sends an instruction to the light sensors asking them to keep feeding data while the whole process takes place, in case a different action is required.

This whole process described above takes place during 0.25 seconds on average. However, that value will considerably change, depending on your state of alertness! For example, imagine if your friend was texting while driving, do you think the outcome could have been different?



Figure 3.35 In Victoria there are penalties for using a mobile device while driving or stationary but not properly parked.

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

Activity instructions

In this activity, you will use materials, a very elegant mathematical formula and your imagination to create an experiment that produces:

- 1 at least three sets of data
- 2 at least three bar graphs
- 3 a conclusion that clearly answers the following scenario:

Victoria's Transport Accident Commission (TAC) is so worried about young people's attitudes towards texting while driving that it hired your young startup 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 amazing slow motion videos
- Microsoft PowerPoint for presentations
- video editing software for making short documentaries

Mathematical formula

$$t = \frac{\sqrt{2d}}{a}$$

where t = time, d = distance and $a = 9.80 \text{ cm/s}^2$ (acceleration due to gravity).

Evaluate and modify

- 1 Imagine that you received a table with reaction time values (t) for a laboratory experiment. Knowing that a (gravitational force) is almost constant and does not need to be worked out, how could you rework the equation below to estimate the distance value used in that experiment? In other words, how could you rework the equation below to solve for distance instead of time?

$$t = \frac{\sqrt{2d}}{a}$$

where t = time, d = distance and $a = 9.80 \text{ cm/s}^2$ (acceleration due to gravity).

- 2 Discuss with at least three of your colleagues the challenges you have encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.
- 3 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?
- 4 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 might have impact on the results.
- 5 Repeat this activity and compare your results when you use your dominant hand (the one you write with) and when you use your other hand. Is there any difference in reaction times between hands?
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?
- 6 Create a PowerPoint presentation to relay your findings to the TAC.

Chapter 4 Ecosystems

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 effectiveness 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 the environmental changes that can occur within ecosystems.

Curriculum

Ecosystems consist of communities of interdependent organisms and abiotic components of the environment; matter and energy flow through these systems (VCSSU121)

- | | |
|---|-----|
| • exploring interactions between organisms, for example, predator/prey, parasites, competitors, pollinators and disease vectors | 4.2 |
| • using modelling to examine factors that affect population sizes, for example, seasonal changes, destruction of habitats, introduced species | 4.3 |
| • investigating how ecosystems change as a result of environmental change, for example, bushfires, drought and flooding | 4.1 |

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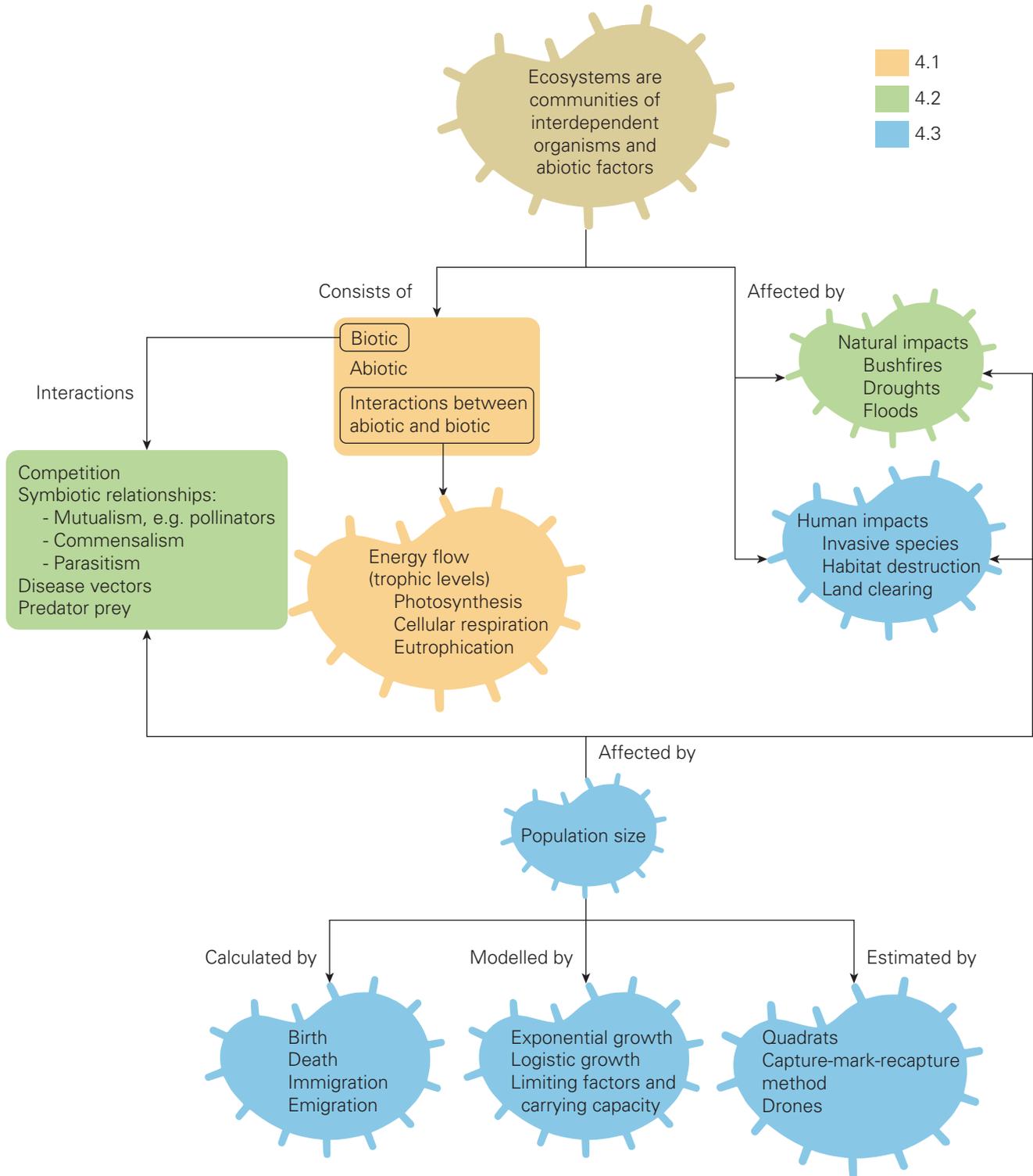


Glossary terms

abiotic	emigration	photosynthesis
apex predator	eutrophication	pollinator
autotroph	exponential growth	population
biome	food chain	predator
biotic	habitat	prey
capture–mark–recapture method	heterotroph	primary consumer
carrying capacity	immigration	producer
cellular respiration	interspecific competition	quadrat
commensalism	intraspecific competition	secondary consumer
community	limiting factor	symbiotic relationship
consumer	logistic growth	tertiary consumer
ecological niche	mutualism	trophic level
ecosystem	parasitism	vector



Concept map



- 4.1
- 4.2
- 4.3



4.1 What is an ecosystem?



Ecosystems consist of all the organisms living in a certain **community**, all of the non-living components (such as air, rocks, temperature, humidity, salinity) and all of the interactions taking place between the community and its surroundings.

ecosystem

a biological unit made up of the community of living organisms, the non-living components and the interactions between them

community

all the populations of different species living in a particular area at a given time

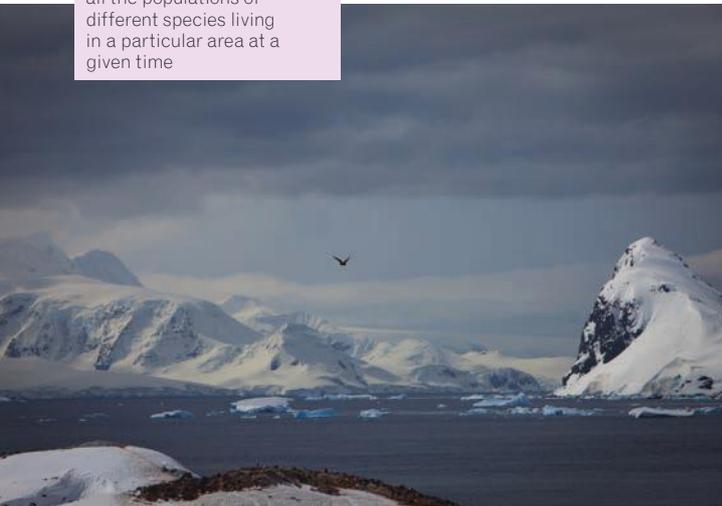


Figure 4.1 Antarctica is an example of a desert ecosystem with its thick ice sheet covering a continent made almost entirely of dry, bare rock. Only mosses grow in this desert ecosystem, supporting only a few bird species.

Ecosystems consist of many different habitats and are often connected in a larger biome.

biome

a region of Earth's surface and the particular combination of climate, plants and animals that are found within it

A **biome** is one of the world's major ecosystems, classified according to the main climatic feature, vegetation and specific adaptations of the organisms

within that environment. The biomes within Australia have their own organisms and climate and contain many of the major world biomes within it.



Figure 4.2 Location of some Australian ecosystems

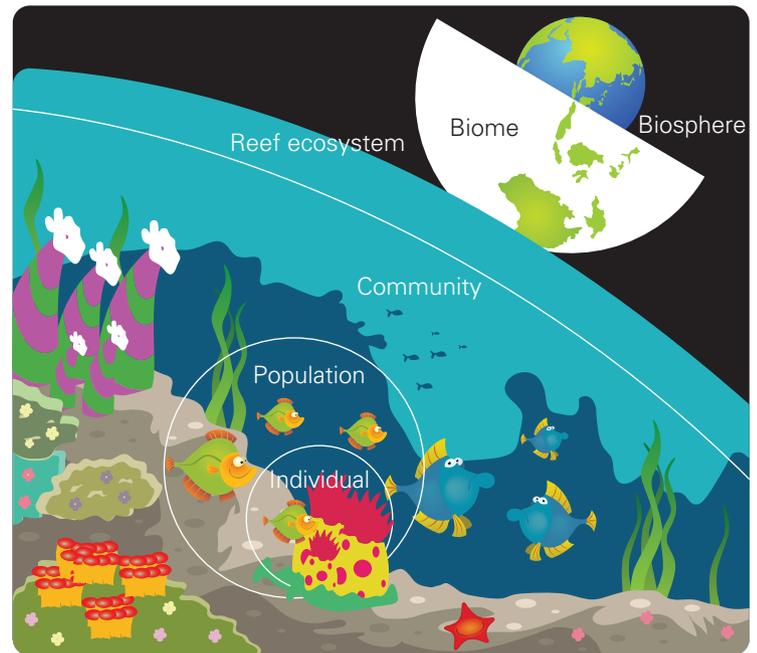


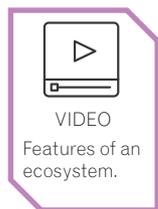
Figure 4.3 Levels of organisation in a reef ecosystem

Ecosystems vary greatly in size. The tide pools in Figure 4.4 represent quite a small ecosystem. When the tide is in, these pools

are underwater and organisms such as seaweed thrive. When the tide goes out, tiny pools are left and organisms, such as hermit crabs, come out in search of food.



Figure 4.4 Tidal pools at Cape Schanck on the Mornington Peninsula, Victoria



Components of an ecosystem

An ecosystem consists of three essential components:

- 1 A living component (**biotic** factors) made of different 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.
- 2 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.
- 3 The interaction between the biotic factors and the abiotic surroundings.

biotic
living factors, such as plants, animals and bacteria

abiotic
non-living factors, such as temperature, pH, salinity, rocks, water



Figure 4.5 Falls Meander Forest Reserve, Great Western Tiers, Tasmania, showing abiotic factors of sunlight, rocks and light intensity along with biotic factors of plant life

An ecosystem can also be classified as a community and its **habitat**.

habitat + community = 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, for example, a pond, grassland, treetop canopies. It is usually considered abiotic, but the habitat could be considered biotic if the organism lives on or in another organism.

A **population** is a group 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. They may be dispersed in an evenly spaced, clumped or random manner. Clumped patterns are the most frequently occurring within ecosystems. Abiotic factors play an important role in the overall distribution and abundance of organisms within an ecosystem.

habitat
the environment an organism lives within

population
members of one species living in a particular area at a given time

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. The river community might include the water

buffalo, but also the birds, grasses, bacteria, fish and crocodiles. All of the species in the

community interact with one another, but also with the habitat.

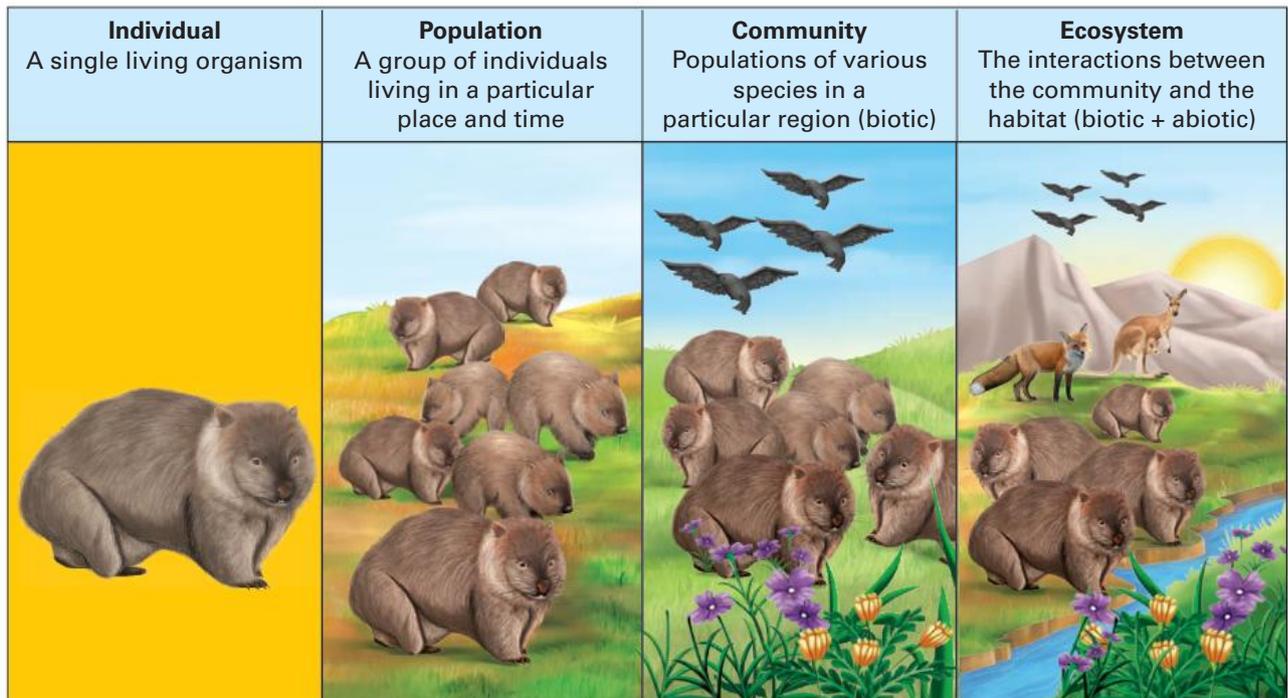
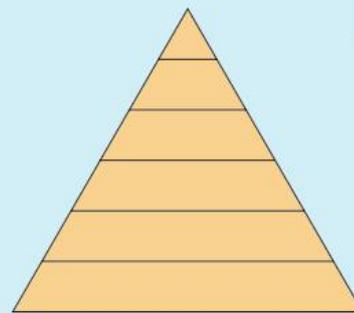


Figure 4.6 The various levels of complexity, beginning from an individual organism right through to a complete ecosystem

The interdependence of both biotic and abiotic factors is of utmost importance to the productivity of an ecosystem. This means that both biotic and abiotic factors rely on

each other to survive and thrive – they cannot live without the other. Living organisms tend to form different types of relationships with one another that benefit the community.

Draw a diagram or a flow chart connecting these key concepts: individual, ecosystem, biosphere, biome, population, community. Annotate arrows in the flow chart by demonstrating the links between the terms. If you are unsure where to begin, you might like to consider setting it out using a pyramid like the one shown at right. This will give you a starting place to organise the key terms by size.



Try this 4.1

- 1 Define the terms 'population', 'community' and 'ecosystem'.
- 2 What are the three essential components that are present within an ecosystem?
- 3 Distinguish between a biotic component and an abiotic component of an ecosystem. Include examples of each.

Quick check 4.1

Practical 4.1

Testing soil pH

Introduction

One of the abiotic factors that affects plant growth is the pH level of the soil. Plants are unable to absorb the nutrients they require for growth if the soil is too acidic ($\text{pH} < 7$) or too basic ($\text{pH} > 7$).

Aim

To determine the pH of a soil sample.

Materials

- 5 soil samples collected from different locations around the schoolgrounds
- distilled water
- 5 × 100 mL beakers
- 100 mL measuring cylinder
- spatula
- pH meter or universal indicator

Method

- 1 Using the measuring cylinder, add 50 mL of distilled water to a beaker and record its pH by using a pH meter or universal indicator.
- 2 Add half a spatula of soil to the 50 mL of distilled water.
- 3 Mix thoroughly then allow to sit for 2–3 minutes so that the sediment has time to settle on the base of the beaker.
- 4 Use a pH meter or universal indicator to determine the pH of the water above the sediment.
- 5 Repeat steps 1–4 for the other four samples of soil.

Results

Complete the results table.

Experiment	pH
Distilled water (control)	
Soil sample 1	
Soil sample 2	
Soil sample 3	
Soil sample 4	
Soil sample 5	

Discussion

- 1 Were your soil samples acidic, basic or neutral?
- 2 Describe the vegetation where your soil samples were taken from in terms of abundance, and overall health.
- 3 What conclusions can you draw about the measured pH and the health of the plant life where you took your samples from?
- 4 Suggest what could happen if the pH of the soil increased or decreased substantially.
- 5 Suggest two ways you could improve the design of this experiment.
- 6 Suggest two potential sources of error in this experiment.

Conclusion

- 1 Make a claim from this experiment regarding soil samples and pH.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.



Abiotic factors can be classified into chemical or physical components. Using the factors below, select whether they belong to the chemical or physical domain by copying the table and placing a tick in the appropriate column.

Try this 4.2

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		

Energy flow through ecosystems

The simplest way to describe the relationship between organisms within an ecosystem is by using a food chain, which you have already seen in Year 7. If you recall, within a food chain, organisms gain nutrients and energy from other organisms, as shown in this photograph of a kookaburra eating a snake on an Australian bush track.

A **food chain** shows the flow of energy from organism to organism through an ecosystem. The sun is the original source of all energy but is rarely included in the food chain. A simple example of a food chain is shown:

food chain
the flow of energy from organism to organism, in an ecosystem

plant → mouse → snake → kookaburra



Figure 4.7 A laughing kookaburra, *Dacelo novaeguineae*, eating a yellow-naped snake, in Queensland.

As in the previous example, food chains typically start with a **producer**, in this case, the plant. The **consumer** that eats the producer is called a **primary consumer** (in this case, the mouse), and the consumer that eats the primary consumer is called a secondary consumer (in this case, the snake). Organisms that then feed on **secondary consumers** are known as tertiary consumers (in this case, the kookaburra) and organisms feeding on **tertiary consumers** within an ecosystem are known as fourth order consumers. Numerous food chains exist within ecosystems and these can all be interlinked in a complex pattern called a food web.

producer

otherwise 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 first 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

Redraw the food chain we have been looking at and add the following labels: producer, primary consumer, secondary consumer, tertiary consumer. You can also annotate it to show which of the consumers are herbivores and which are carnivores.

Try this 4.3

Reflect: Must a primary consumer always be a herbivore?

The term **trophic level** refers to the feeding level of an organism, i.e. how far along the food chain the organism is. These 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 'Try this' activity. 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**.

trophic level

the feeding level of an organism within a food chain

apex predator

the highest level consumer in a food chain

The Sun is the key abiotic factor that provides plants with the energy required to

perform photosynthesis. Plants are able to turn the radiant energy they receive from the Sun into glucose, a form of sugar, which they can then use to grow. Because plants produce their own food they are called producers or **autotrophs** (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** (varied feeding). Without producers living within an ecosystem, 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.

autotroph

otherwise known as a producer, an organism capable of making its own food

heterotroph

also known as a consumer; an organism that must eat or consume plants or animals as a source of energy

Any organism may be classified as either an autotroph or a heterotroph according to their energy requirements and pathways. Now add the terms 'autotroph' and 'heterotroph' to the food chain diagram you drew in Try this 4.3.



Figure 4.8 Identify the autotrophs and heterotrophs in this picture. Can you also identify the apex predator?

Answer: autotrophs: trees and bushes; heterotrophs: mushrooms, all the animals; apex predator: crocodile.

You may recall from Year 7 that energy transfer between trophic levels is not very efficient, with only approximately 10% of the energy an organism takes in being 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 like faeces. Therefore, the amount of energy

available to organisms decreases with each trophic level. This produces a pattern called a 'pyramid of energy'.

The energy pyramid in Figure 4.9 shows how much energy is present in each stage of an Australian woodland ecosystem.

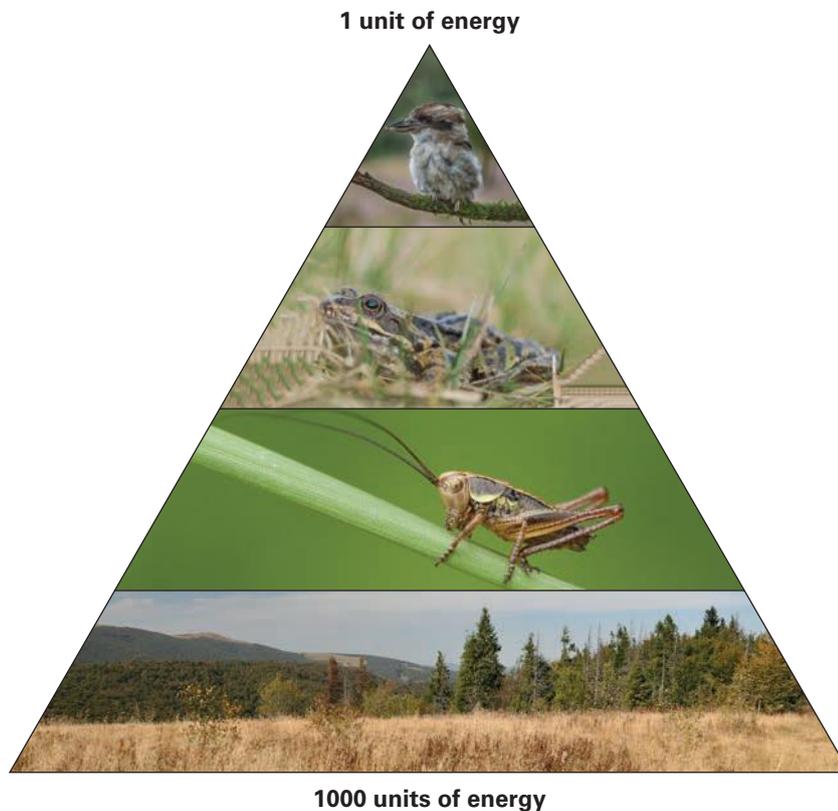


Figure 4.9 A trophic pyramid or 'pyramid of energy' showing the energy flow from the grass through to the kookaburra

- 1 Complete the energy pyramid in Figure 4.9 by showing the units of energy per trophic level.
- 2 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?
- 3 Do you think a pyramid is a good shape to represent how matter and energy transfer in an ecosystem? Why or why not?

Try this 4.4

- 1 Take a look at Figure 4.9. State the organism that would fulfil the following roles: producer, primary consumer, apex predator.
- 2 Construct a food chain for the diagram above.
- 3 Distinguish between a producer and a consumer, providing an example of each.
- 4 Explain why energy is an essential component required within an ecosystem.

Quick check 4.2

Practical 4.2: Self-design

Design your own ecosystem in a closed plastic bottle



Aim

To design and build a closed (sealed) ecosystem using plastic drink bottles.

Method

- 1 Create a drawing of your design, showing a step-by-step method of how your ecosystem will be made.
- 2 Make a list of all the materials you will need to use in your ecosystem; for example, dirt, worms, plant material.
- 3 Check your design with your teacher.
- 4 Once you have your teacher's approval, construct your ecosystem.

Results

Take some pictures of your completed ecosystem in a bottle each day for one week.

Evaluation

- 1 How is energy received and produced in your ecosystem?
- 2 Identify three producers and consumers of your ecosystem.
- 3 Explain how your ecosystem works.
- 4 List the biotic and abiotic factors that affect your ecosystem.
- 5 Discuss how efficient you believe your ecosystem is and provide reasons for your answer.
- 6 Suggest two ways you could improve the design of your ecosystem if you repeated this activity in the future.

Conclusion

Write a conclusion for this activity. Include the strengths and weaknesses of your design and what you learned.

Energy within ecosystems: photosynthesis, respiration and autotrophication

Photosynthesis

An ecosystem derives its energy from the Sun, and this energy is cycled through the plants, animals and microorganisms 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 us! Plants also use the glucose as their own energy source. Even the waste product of photosynthesis is incredibly useful for us humans, as plants release oxygen as a product of the chemical reaction.

photosynthesis

the chemical reaction by which organisms make their own food

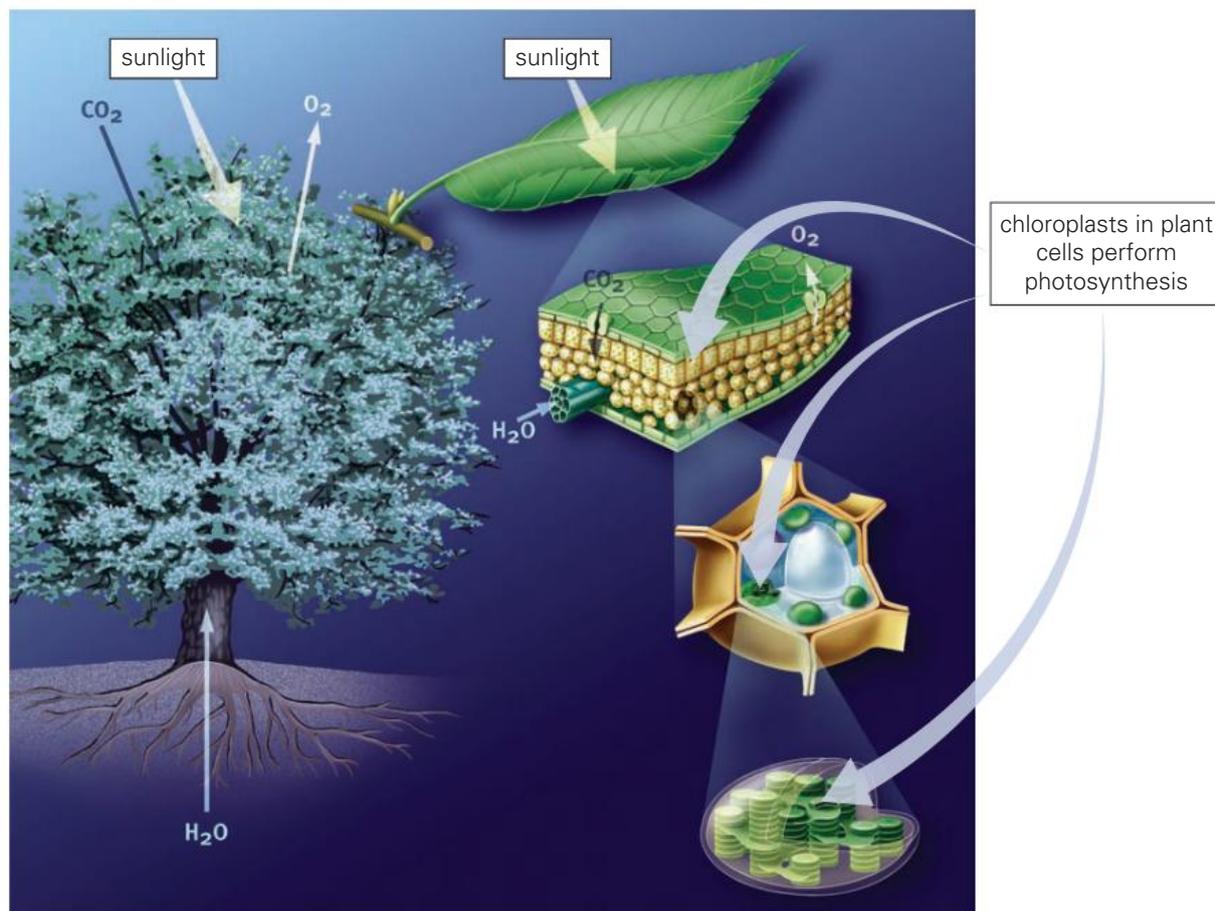


Figure 4.10 Plants trap sunlight in tiny organelles called chloroplasts and use it to produce glucose and oxygen from the reaction of carbon dioxide and water.

The chemical reaction named photosynthesis uses carbon dioxide and water, and in the presence of sunlight converts these into glucose and oxygen. The plant joins the glucose molecules together to form starch and stores it for later use.

This reaction can be described with the simple equations shown below:

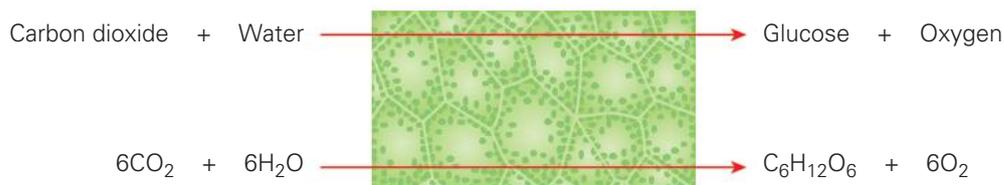


Figure 4.11 Chemical and word equations of the photosynthesis reaction

Photosynthesis occurs in chloroplasts, an organelle in plant cells that contains the substance chlorophyll, which is responsible for absorbing the Sun's energy. Light energy is converted and stored as chemical energy in glucose, through the steps of photosynthesis.

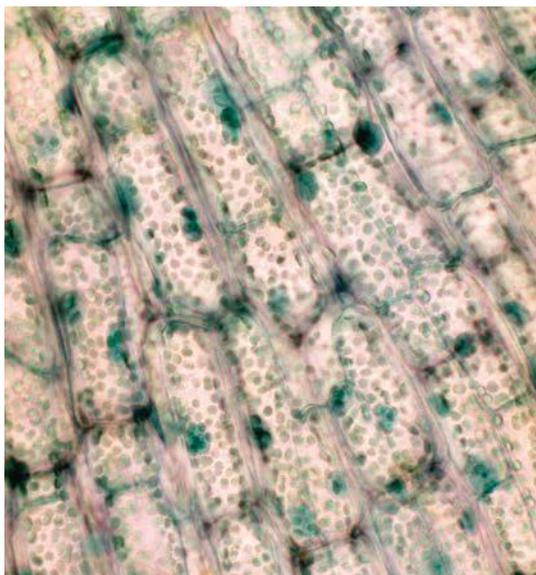


Figure 4.12 A leaf (from pondweed *Elodea canadensis*) as seen under a microscope at magnification of $\times 200$. Note the green chloroplasts.

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.

Practical 4.3

The effect of light on plants

Aim

To investigate whether light is needed for plants to produce glucose (stored as starch) by photosynthesis.

Materials

- a plant that has been left in a sunny position for 2–3 days. Some of its leaves should have been exposed to sunlight, while some of the leaves should have been wrapped in aluminium foil to block out the sunlight.
- 1% starch solution
- methylated spirits
- iodine
- hot water bath
- Petri dish
- 2 test tubes
- test tube holder
- white tile
- forceps

Method

- 1 Collect one leaf that has been exposed to sunlight and one leaf that was wrapped in foil.
- 2 Place each leaf in boiling water for 30 seconds.
- 3 Remove the leaves and place each in a test tube with enough methylated spirits to cover them.
Test tube 1: leaf from plant kept in light
Test tube 2: leaf from plant kept in dark
- 4 Place the test tubes in a hot water bath for approximately 10 minutes.
- 5 Remove the leaves from the test tubes with forceps and wash in cold water.
- 6 Place leaves in a Petri dish on a white tile and add 2–3 drops of iodine to each leaf. Iodine reacts with starch to produce a blue-black colour, as shown in the diagram on the next page. You can test this with the 1% starch solution by adding iodine to it.

continued...

Looking at chloroplasts under a light microscope

Try this 4.5

Materials

moss or spirogyra plant, dilute iodine solution, water, light microscope, slides, coverslips, tweezers

Method

- 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.

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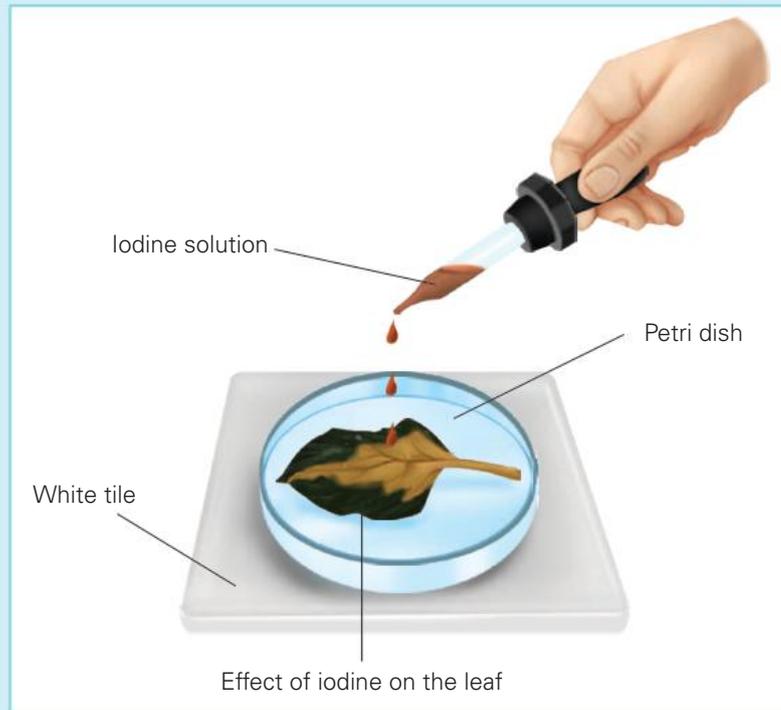


Figure 4.13 Experimental set-up

Results

Draw up a results table showing the leaf type, reaction and presence of starch.

Leaf type	Reaction of leaf to iodine	Starch present (✓) or absent (X)
Exposed to sunlight		
Wrapped in aluminium foil		

Evaluation

- 1 Why do you think the methylated spirits was added to the test tube?
- 2 What reaction happens when iodine encounters starch?
- 3 What did you observe when the methylated spirits was added to the leaves in the test tubes?
- 4 Identify the independent variable in this experiment.
- 5 Explain the results you obtained, with reference to the terms photosynthesis, chloroplasts, glucose and energy.
- 6 Did the results support your hypothesis? Why or why not?
- 7 Suggest two ways the experiment design could be improved.
- 8 Suggest two possible sources of error for this experiment.

Conclusion

- 1 Make a claim from this experiment regarding light and photosynthesis.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Cellular respiration

Plants do not simply perform photosynthesis to produce glucose just for consumers to eat!

cellular respiration
a chemical process where glucose is burnt with oxygen, producing carbon dioxide and water and releasing energy

Producers, just like consumers, need to break down that glucose to release energy in a useable form. This process is called **cellular respiration**.

dioxide and water as waste products. Small packets of energy (in the form of ATP) is also released, and plants, animals, bacteria and humans all need that energy to power the functions of our cells.

The chemical reaction for cellular respiration is shown in Figure 4.14.

During cellular respiration, glucose is broken down with oxygen and it produces carbon

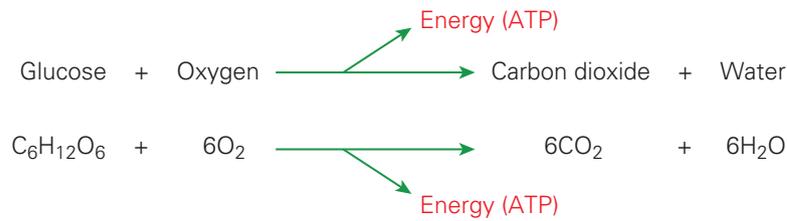


Figure 4.14 The process of cellular respiration

The overall process of respiration is carried out in cell organelles called mitochondria

(singular: mitochondrion) in plant and animal cells, as shown in Figure 4.15.

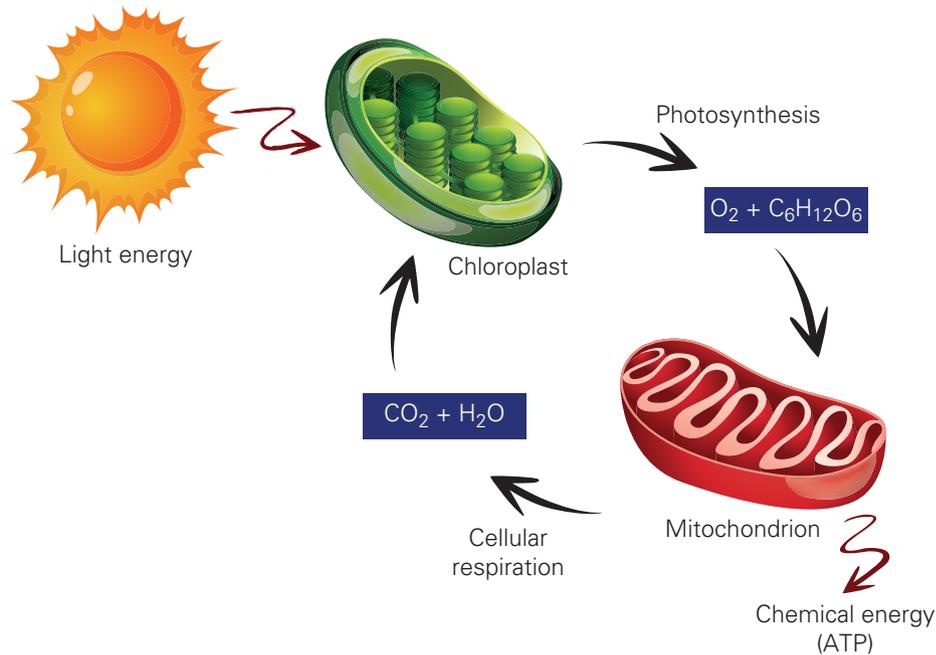


Figure 4.15 The relationship between photosynthesis and respiration. They are almost opposites of each other!

Eutrophication

eutrophication
killing of life in a lake as a result of excessive growth of algae

Linking back to the energy processes of photosynthesis and respiration, is another process known as eutrophication. **Eutrophication** is

the term given to killing of life in a lake as a result of excessive growth of algae, which has occurred as a result of an overabundance of nutrients in the water.

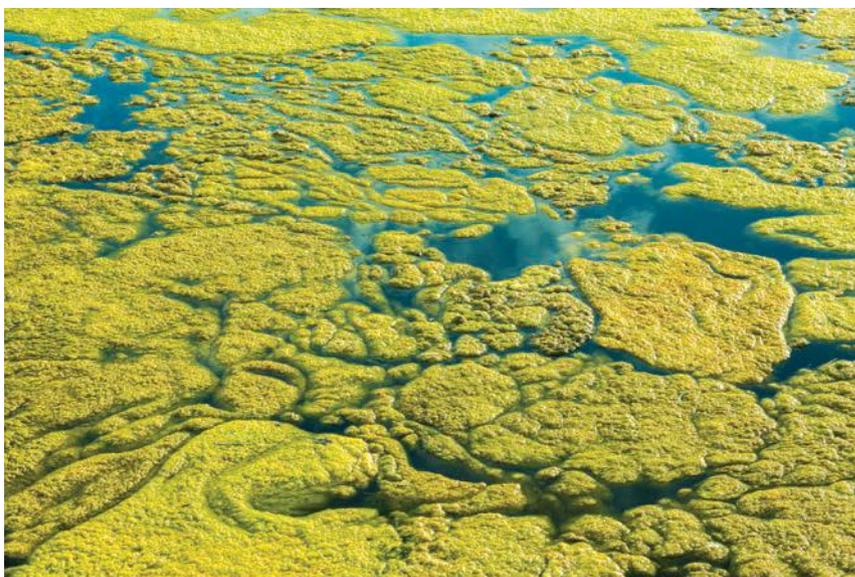


Figure 4.16 An example of algae overgrowth in a lake

Eutrophication

Explore! 4.1

- 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 or is occurring. Make a list of five waterways affected and the states of Australia 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 4.4

Phosphates in fertilisers and detergents

Aim

To investigate the effect of detergent on the health of plants.

Materials

- water plant
- detergent diluted to 84% solution (distilled water), 1% detergent, 5% detergent and 10% detergent
- 4 × 250 mL beakers
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- glass stirring rod
- weighing balance
- ruler

Method

- 1 Construct a hypothesis for this experiment relating to the effect that the detergent has on the overall health of the plant.
- 2 Cut four 20 cm lengths of a water plant then weigh and record each.
- 3 Label the beakers 1–4, and place one length of the water plant in each beaker.

continued...

...continued

- 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 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 window sill 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.

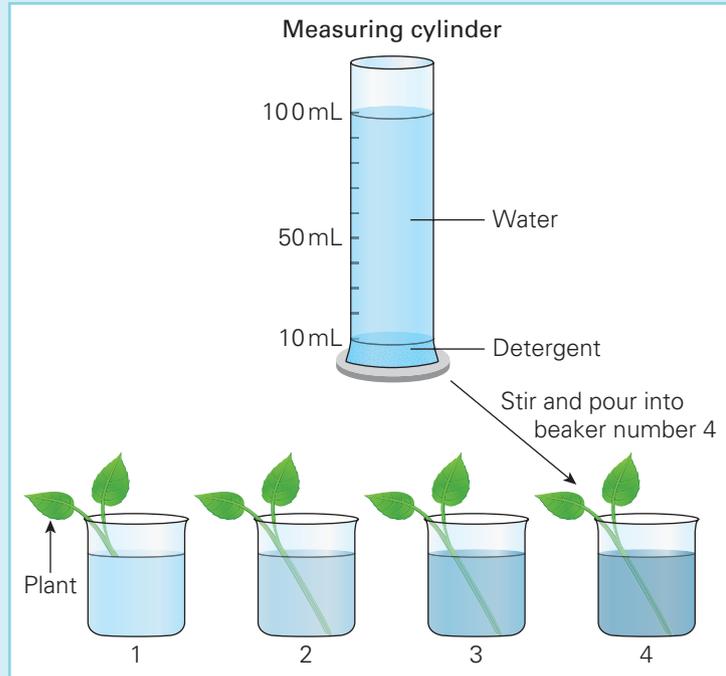


Figure 4.17 Experimental set-up

Results

Complete the results table below and graph these results.

Detergent solution	Plant mass (original)	Plant mass (after 7 days)	Observational change
0%			
1%			
5%			
10%			

Evaluation

- 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 related with 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 impact the plant the most.
- 5 Suggest two possible sources of error in this experiment.
- 6 Suggest two ways the experimental design could be improved.

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.

- 1 Rewrite these sentences by filling in the blanks:
 - 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 What are the worded equations for photosynthesis and cellular respiration?
- 3 What happens when an excess supply of nutrients is introduced to a healthy body of water?

Quick check 4.3

Environmental changes affecting ecosystems

Many biotic and abiotic factors may also 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 have consequences on population size of organisms living within ecosystems.

Seasonal changes 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, however, they can also be deliberately lit. Aboriginal and Torres Strait Islander Peoples learned to harness bushfires as an important tool for purposes such as:

- easier access through thorny and thick vegetation
- attracting animals for hunting purposes through new growth of vegetation
- developing the growth of useful plants for food and spiritual purposes.

The fires lit by Aboriginal and Torres Strait Islander Peoples were regular in frequency and low in intensity, contained within manageable areas. This regular use of fire likely resulted in vegetation of varying ages across the landscape.

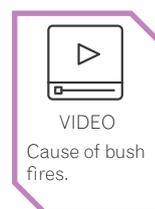


Figure 4.18 A controlled burn in the Northern Territory clears the brush.

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 greater than 30% moisture it will not ignite; however, when the moisture is lower, fires can ignite and spread easily. In Victoria on 'Black Saturday', 7 February 2009, the entire landscape for much of the afternoon had a moisture content of less than 5%. Under these conditions the

slightest spark can ignite the fuel and fires will spread very rapidly. 'Black Saturday' was Australia's worst-ever bushfire and worst peace time disaster. The fires, of which there were over 400 recorded, resulted in 173 confirmed deaths, and more than 2000 homes destroyed, with entire towns badly damaged and some almost destroyed.

Fire does not just destroy homes, but also destroys the landscape, therefore, many animals will either die in the fire or escape to a safer area, but are then unable to return to their natural habitat, because there are no food sources available or their home is gone. It may take years for the food sources to recover. This results in an increase in the death rate and a decrease in the birth rate.



Figure 4.19 New tree growth sprouts on the 3-month anniversary of 'Black Saturday'.

The positive outcomes of fire include:

- 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.

Practical 4.5

Seed germination after a fire

Aim

To determine whether it is the ash or the heat of the fire that encourages seeds to germinate.

Materials

- wattle seeds
- leaves to burn
- newspaper
- water

Be careful

Ensure only a small quantity of leaves is burning at any one time. Prolonged exposure of metal forceps to fire will cause the forceps to become hot. This may cause burns.

continued...

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- metal forceps
- container to burn leaves
- container with soil to plant seeds in
- matches

Method

- 1 Construct a hypothesis for this experiment.
- 2 Light some dry leaves using the matches. You can add some newspaper if you wish.
- 3 While the leaves are burning, subject half of the seeds to heat by holding them with forceps close to the fire.
- 4 Plant these seeds in one end of the container with the soil. Press small thumb holes into the soil, drop the seed in at a depth of around 0.5 cm and cover with soil. Label this end 'heat'.
- 5 Plant the other half of the seeds in the other end of the container. Instead of covering them with soil, drop them into the small holes and cover with ash. Label this end 'ash'.
- 6 Water gently.
- 7 Observe your seeds over the next two weeks.

Results

Record which seeds successfully germinated.

Evaluation

- 1 What do your results suggest about the effect of bushfires on seeds?
- 2 Did your results support your hypothesis? Give a reason for this.
- 3 Suggest two possible sources of error in this experiment.
- 4 Suggest two ways the experimental design could be improved in the future.

Conclusion

- 1 Make a claim from this experiment regarding seed germination and fire.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Seasonal changes effects on ecosystems: droughts and floods

Droughts can play a significant role on the overall effectiveness of ecosystems. 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. The negative impact that can result from flooding includes 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. In Australia, flooding is estimated to cause in excess of \$400 million in damage per year, more than any other natural disaster.



Figure 4.20 An example of soil after a drought

The environmental benefits of flooding result from recharging the underground water systems and flushing excess salts from the soil. They can also deposit sediments on the flood plains, resulting in a nutrient-rich soil, and allow fish and other animals that need the water to disperse to other areas. This results in an increase in emigration rates.

Quick check 4.4

- 1 State two negative and two positive outcomes of bushfire.
- 2 What is the main fuel for bushfires?
- 3 What is a flash flood?
- 4 State two environmental benefits of flooding.



QUIZ

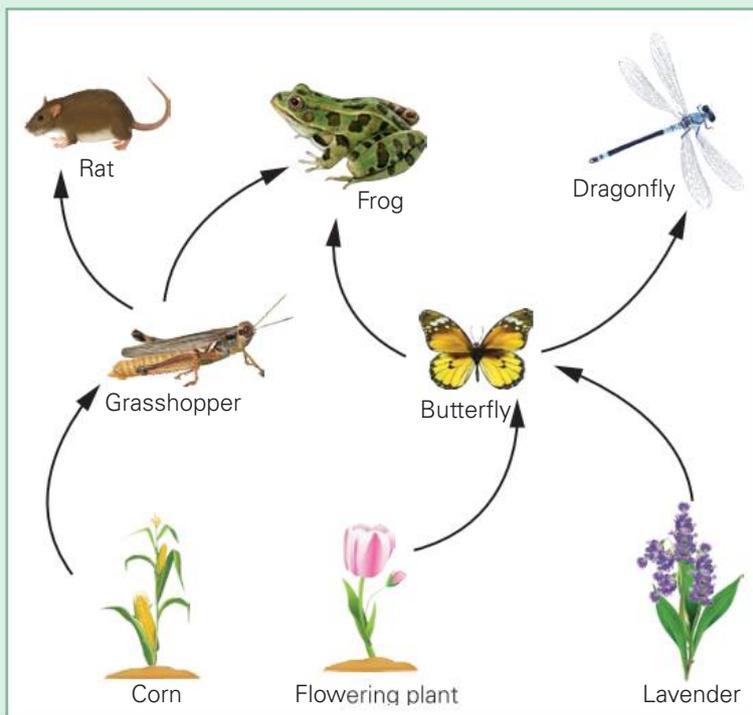
Section 4.1 questions

Remembering

- 1 What are the three components of an ecosystem?
- 2 What are the word and chemical equations for cellular respiration?
- 3 What are 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) approximately what percentage is efficiently transferred?
- 5 Provide two specific examples of biotic factors found within the biome of an Australian desert.
- 6 Recall how burning helps to maintain biodiversity within an ecosystem. List two ways that fire can maintain diversity.

Understanding

- 7 Explain why humans are not considered to be autotrophs.
- 8 Classify the organisms in the food web below 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 two examples of how floods may negatively influence an ecosystem.



Applying

- 11 Discuss the biological impacts that the use of detergents could have within ecosystems.

Analysing

- 12 Compare and contrast the role of a heterotroph with an autotroph within an ecosystem.
- 13 The table at the top of the next page shows oxygen levels around plants at different light intensities.
 - a Graph the results.
 - b Analyse the findings.

continued...

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Light intensity (%)	Oxygen ($\mu\text{L}/\text{min}$)
9	4
15	9
28	17
48	29
55	34
90	55
100	60

- 14 In your own words, outline one similarity and one difference between photosynthesis and respiration.
15 Explain the difference between a community and a habitat.

Evaluating

- 16 Construct a mind map showing the relationship between the different levels of consumer within an ecosystem.
17 Evaluate the following statement: 'Ecosystems would cease to exist, should producers be eliminated.'



Interactions between organisms and their environment

Abiotic factors play an important role in the overall distribution and abundance of organisms within an ecosystem. Some organisms will only tolerate a narrow range of a certain abiotic factor, for example, temperature, and this determines where they can live.

The role an organism fulfils within an ecosystem is known as the **ecological niche**

ecologic niche

the role an organism fulfils in an ecosystem, e.g. its habitat, nutrition, interactions with other organisms

of a species. This includes its habitat, its nutrition and its relationships or interactions with other organisms within

the ecosystem, for example, where it makes a home, what it eats, what time of the day it is active. The interaction between organisms may occur between the same species or

different species within the niche and takes into account changes in behaviour during different times of the day and different seasonal times. Examples of different types of interactions that take place include competition and symbiotic relationships such as mutualism, commensalism and parasitism.

Competition

Organisms in a similar niche within an ecosystem compete with one another when they use the same resources that are in short supply. Competition for finite resources usually means that different organisms require the same resources, such as food, space, shelter and mates, to survive and thrive. Competition within and between species is a common feature of all



communities. **Interspecific competition** refers to the competition for the same resource, such as a specific food source, between members of a different species. One such example is kangaroo and sheep competing for grass as their major food source. Whereas **intraspecific competition** refers to the competition that occurs between the members of the same species, such as male brolgas (Australian cranes) competing with one another to find a mate. Note that intraspecific competition is usually more intense than interspecific competition because organisms of the same species will have identical needs.

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



Figure 4.21 Male brolgas competing for mates is an example of intraspecific competition.

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 utilise the resource more than the other species. This may lead the less efficient competitor to leave the ecosystem to find an environment with less competition.

- 1 Define the term 'interspecific competition'.
- 2 Define the term 'intraspecific competition'.
- 3 What happens when two species are competing for food, and one species is better adapted or stronger?

Quick check 4.5

Symbiotic relationships

When individuals from two different species share a close and long-term biological relationship, it is known as a **symbiotic relationship**. There are three different forms of symbiotic relationships and they differ according to how the organisms are affected.

They are:

- 1 Mutualism
- 2 Commensalism
- 3 Parasitism.

Mutualism

Mutualism is a symbiotic relationship that occurs when both species within the relationship benefit from living closely together and neither are harmed.

For example, plants have a mutualistic relationship with **pollinators**. Pollinators are vital for many flowering plants to reproduce. Like grasses, some



Figure 4.22 A bee pollinating a flower is an example of mutualism.

symbiotic relationship

a relationship between two types of living things that help at least one of them survive

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.

plants can be pollinated by wind, yet many flowering plants do rely on pollinators such as 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.

Salamanders and algae relationship

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 eggs of the salamander, which was a mutualistic relationship. The algae releases oxygen into the egg 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.

Science as a human endeavour 4.1



Figure 4.23 A salamander hatching out of an egg

Commensalism

Commensalism is a symbiotic relationship in which one organism benefits, while the other organism is not affected (neither harmed nor benefits). These types of relationships are

much rarer than mutualism or parasitism. One example is that of a clownfish as seen in *Finding Nemo* that lives

commensalism

a symbiotic relationship where one organism benefits, and the other neither benefits nor is harmed

amongst stinging sea anemones in the Great Barrier Reef. The clownfish in this example typically uses the stinging sea anemone to hide in not for food but rather for survival: to protect it from predators. Other examples include hermit crabs making use of the shells from dead snails or seashells as their homes, and mites getting a 'free ride' by attaching to other larger insects.



Figure 4.24 An example of clown fish living amongst sea anemone to help protect it against predators



Figure 4.25 A hermit crab looking to upgrade his home to a larger shell

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 often 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.

parasitism
a symbiotic relationship where a parasite benefits from living on or in a host (which is harmed)

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 could be 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.

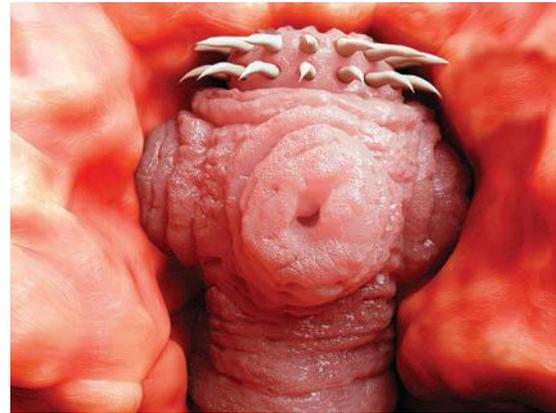
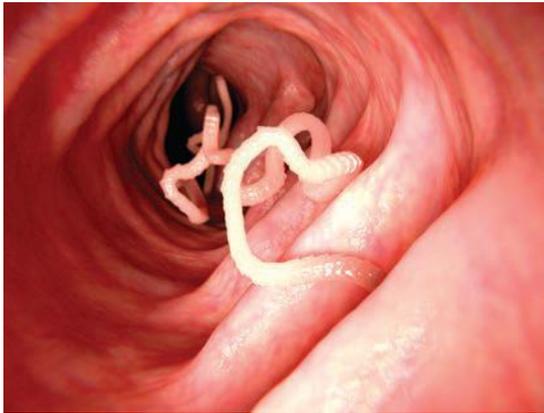


Figure 4.26 These are tapeworms, which are endoparasites that inhabit the digestive tracts of animals and humans. They use their specialised hooks to anchor themselves in the intestine and absorb nutrients through their body wall. Disturbingly, they can grow to several metres in length, but do not necessarily cause symptoms.

- 1 Complete the table below, describing the types of relationships between organisms. Use a smiley face, sad face or neutral face to show how each organism is affected.

Quick check 4.6

Relationship	Definition	Organism 1	Organism 2
Competition			
Mutualism			
Commensalism			
Parasitism			

- 2 What is the key difference between an ectoparasite and an endoparasite?

Disease vectors

Within an ecosystem there are organisms, called **vectors**, that are capable of spreading disease by carrying and transmitting a pathogen (a disease-causing agent, such as bacteria or a virus). Some examples of vectors are mosquitoes, ticks and flies. The disease can be transmitted directly into the

vector
an agent (either a human, animal or microorganism) that carries and transmits a pathogen (disease-causing agent) from an infected organism to a non-infected organism



Figure 4.27 Female mosquitoes of certain species within the genus *Anopheles* can transmit malaria.

bloodstream flow from a bite. According to the World Health Organization, mosquitoes are the primary vector for transmitting both malaria and the Zika virus.

Increase in vector-borne diseases may be linked to poorly designed water and

waste systems, as well as deforestation that results in loss of biodiversity. The areas in which vector organisms can breed can be reduced by managing our environment and ensuring there are not large, stagnant pools of water.

Zika virus

Explore! 4.2

The Zika virus is transmitted to people through the bite of an infected *Aedes* genus mosquito in tropical regions. This is the same mosquito that transmits dengue, chikungunya and yellow fever. A mosquito becomes infected with the Zika virus by sucking the blood of an infected person. The infection develops in the mosquito, and after 1–2 weeks, there will be viral particles present in the mosquito's saliva. When it bites another human, the viral particles can be transmitted, causing this previously healthy person to contract the Zika virus.

- 1 Research and summarise the latest statistics on the prevalence of Zika worldwide.
- 2 Summarise the key symptoms that a sufferer of Zika virus will show.
- 3 Integrated vector management (IVM) strategies are designed to interrupt or reduce the transmission of vector-borne viruses, such as the Zika virus. Make a list of the things you could do, while travelling in tropical regions, to prevent being bitten by a mosquito.

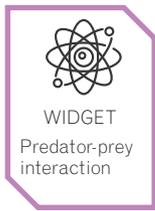
Mosquito factories

Did you know? 4.1

China is home of the world's largest mosquito factory. The factory's male mosquitoes are infected with a strain of *Wolbachia pipientis*, a common bacterium that is shown to inhibit the spread of the Zika virus or result in unsuccessful reproduction. These male mosquitoes are then released on Shazai and Dadao Islands to mate with wild female mosquitoes uninfected with *Wolbachia*. The resulting eggs are unable to hatch, so fewer mosquitoes develop. Researchers hope that this will help eradicate mosquitoes carrying the virus in areas affected by Zika and other diseases.



Figure 4.28 A lab technician pours mosquito pupae into containers at the facility in Guangzhou, China.



predator
an animal that hunts other animals as its source of food

prey
living animal that is captured and eaten by a predator

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 that if the prey species reduces in supply, the predator can

turn to other species to prey upon. For example, foxes prey on rabbits, but are also capable of hunting and eating newborn lambs and other small mammals.

The relationship that exists between predator and prey is usually balanced, but occasionally there is a change in balance due to a change in conditions. For example, under favourable conditions, there may be an increase in the prey population, and as a consequence, the number of predators can also increase. 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 amongst the predators.

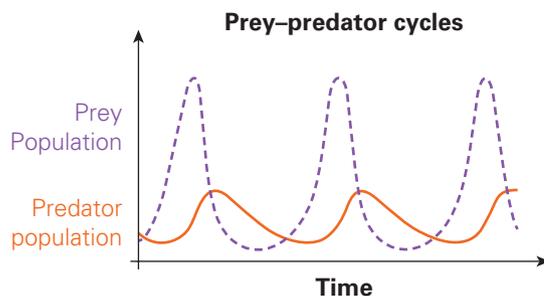


Figure 4.29 Predator and prey populations exhibit fluctuations in size. The prey cycle is mainly driven by an increase or decrease in predation, but other factors, such as a winter food shortage or drought, may also be important.

Modelling predator–prey cycle using the feral rabbit

In Australia, feral rabbits impact upon the natural ecosystems by competing with native wildlife, damaging vegetation and degrading the land through their burrowing. They also eat seeds and seedlings, which prevents regeneration. When food is scarce, such as immediately after a fire or during seasons

of drought, they eat whatever they are able to find, which amplifies their impact. They have contributed to the decline of native plants and animals, and have even been linked to the extinction of several small mammals in Australia.



Figure 4.30 Feral rabbits have caused damage in many different Australian habitats.

Rabbit-proofing

Explore! 4.3

Within Australia, there are three different methods used for effective rabbit control: biological, chemical and mechanical. Combining two or more techniques was found to be more effective than just using one.

Research the three methods that are currently used within Australia to control the population size of feral rabbits, and then summarise how each is used.



Figure 4.31 Despite the 1700 kilometre-long rabbit-proof fence that was built in 1901–07, rabbits have infiltrated Western Australia. The holes in the ground indicate their extensive warrens.

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 in the number of prey, then there will be fewer of their predator surviving in that environment. Another example of a predator and prey relationship in the deserts of Australia, is that of the red kangaroo and the dingo. The dingo is the key predator in this biome and although their prey are not usually kangaroos, sometimes when food is scarce, they will hunt and kill them.

Using the graph below, answer the following questions.

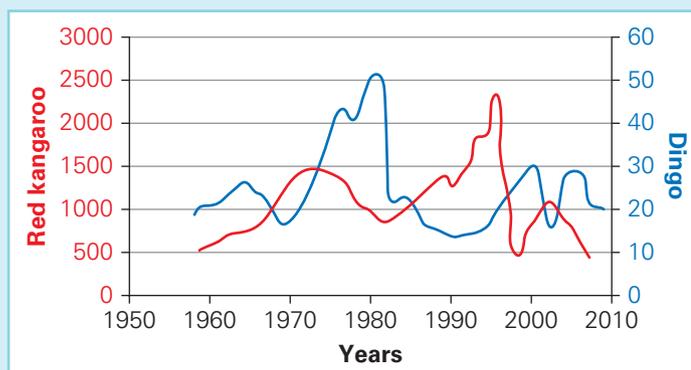
Try this 4.6


Figure 4.32 Population sizes changing 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 above.
- 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 4.2 questions
Remembering

- 1 What type of symbiotic relationship does a pollinator and a plant share?
- 2 List three insects that can act as vectors.
- 3 When there is a large increase in the population size of an animal that is prey, what tends to happen to the population size of the predators?

Understanding

- 4 Two male bull elephants fight for access to females. What sort of competition is this an example of?
- 5 A recent flood has left large pools of stagnant water in a rural village. Infer what might happen to mosquito-transmitted diseases in the area, giving a reason for your answer.
- 6 Explain what is meant by an organism's 'ecological niche'.

Applying

- 7 If all the predators from an area were removed, discuss the positive and negative effects on the overall sustainability of the ecosystem.
- 8 Copy and complete the table on page 152, detailing the types of relationships between organisms. Give an example that has not appeared in this chapter.

continued...



QUIZ

...continued

Relationship	Definition	New example
Competition – interspecific		
Competition – intraspecific		
Mutualism		
Commensalism		
Parasitism		
Predator–prey		

9 List three examples of predators and research what their preferred prey is.

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 Justify the importance of both interspecific and intraspecific competition within an ecosystem.

13 Decide whether the following descriptions are examples of mutualism, commensalism or parasitism.

- A man notices he has tinea (a fungus) growing between his toes.
- A woman notices her cat looks very bloated. She takes it to the vet and they suggest de worming the cat, as it likely has tapeworm.
- Small fish swim around on the back of whale-sharks for protection from predators.
- Birds stand close to wild buffalo and eat the insects that are stirred up as the buffalo graze.



4.3 Population dynamics within 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. There are four primary ecological events that determine population size:

- 1 Birth rates
- 2 Death rates
- 3 Immigration rates
- 4 Emigration rates.

It is the combination of these four factors that produce the change in the numbers and 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

$$\text{Change in population size} = (\text{births} + \text{immigration}) - (\text{deaths} + \text{emigration})$$

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 should increase in size, and vice versa. This is known as the population's growth rate. Many other factors may also affect population size and they include both biotic and abiotic factors. These factors are known as secondary ecological events as they have an influence over one or more of the four primary ecological factors discussed.

Population growth models

Exponential growth

Within an ecosystem, population growth fluctuates. When **exponential growth** is

exponential growth
a rapidly accelerating increase in population size

observed, the population's growth rate rapidly accelerates or increases over time.

Bacteria grown in a laboratory provide an excellent example of exponential growth, as shown in Figure 4.33. Bacteria reproduce by binary fission (splitting in half), and the time between divisions is about 20 minutes. For example, if we start by placing 10 bacteria in a flask with an unlimited supply of nutrients, after 20 minutes each bacterium will divide, yielding 20 bacteria, an increase of 10. After 40 minutes, each of the 20 bacteria will divide, producing 40 bacteria, an increase of 20 bacteria. After 2 hours, or 120 minutes, there would be 640 bacteria. The growth rate increases as the population increases.

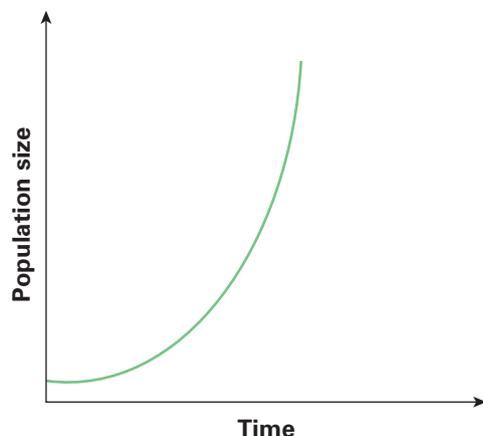


Figure 4.33 A graph showing an exponential increase in population size versus time

Exponential growth is not a very sustainable or realistic model within the real world as it depends on infinite amounts of resources, such as food. Even growth of bacteria in the lab will slow down eventually, as they start to compete for space and food, exhausting both.

Logistic growth

A better model that may be more realistic in the real world is known as **logistic growth**.

The population can increase rapidly at first, but then starts to plateau (flatten out) as resources are limited and competition increases. You can see in Figure 4.34 that this creates an S-shaped curve.

The population size at which the curve levels off, which represents the maximum population size a particular environment can support, is called the **carrying capacity** (in other words, the sustainable capacity of a given environment).

logistic growth
population growth that increases initially, but then plateaus (flattens out) once it reached a certain point

carrying capacity
the maximum population size a particular environment can support

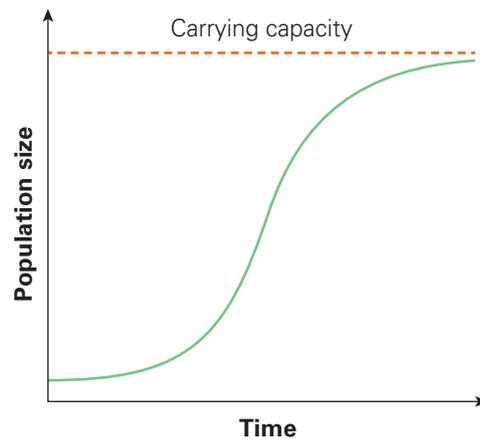


Figure 4.34 A graph showing logistic population growth versus time (note the S-shaped curve)

As populations approach their carrying capacity, individuals start to die because of insufficient resources. They may also emigrate to find areas with more space and resources.

Population size tends to conform to the carrying capacity, as shown in Figure 4.35 on page 154. For example, when a population of kangaroos move into a new area with abundant food, they may reproduce rapidly. However, there is only so much grass that can grow, so as the number of kangaroos

approaches the carrying capacity of that habitat, their rates of reproduction slows down to ensure the population size matches the carrying capacity.

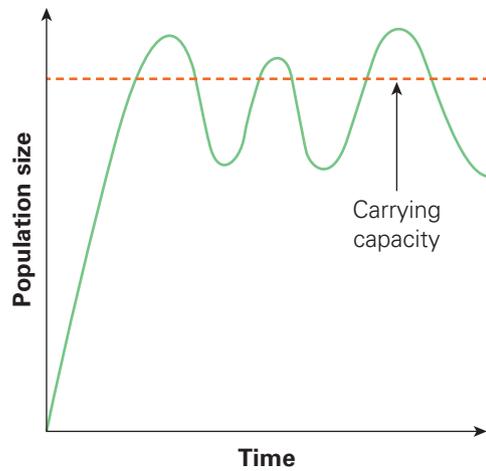


Figure 4.35 A graph showing population size versus time. Note how despite the fluctuations in population size, it tends to hover close to the carrying capacity.

Limiting factors versus carrying capacity

Any form of biotic or abiotic factors within an ecosystem that prevent the population

limiting factor

biotic or abiotic factor that prevent a population from growing

from growing any larger, are known as **limiting factors**. For example,

100 grey kangaroos may live in an ecosystem that has enough water, shelter and space to support 200 grey kangaroos, but if there is only enough food for 100 grey kangaroos, the population will not



Figure 4.36 The carrying capacity of the grey kangaroo population would be 100 if there are only enough resources for 100 grey kangaroos to feasibly survive.

grow any larger. In this example, food is the limiting factor.

Apart from food, there are other factors that can limit population growth such as:

- shelter (for example, owls that rely on hollows in trees will search new locations for nesting spots)
- the number of predators
- availability of water
- the balance of male and female numbers
- the presence of diseases.

Limiting factors are associated with carrying capacity. For example, a group of koalas may strip the leaves from a small group of eucalyptus trees. Food becomes a limiting factor and the forest now has a reduced carrying capacity for koalas as it requires time for the leaves to grow back. The koalas may need to move to another area to prevent starvation.

- 1 What is the difference between exponential growth and logistic growth within a population?
- 2 How do limiting factors relate to the carrying capacity of a species' population size within a habitat?

Quick check 4.7

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 the individual organisms would be impossible or impractical, and hence 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, without needing to count every organism. For example, a quadrat can be used to help count the population size of

quadrat

a tool used to measure species abundance

plants, slow-moving animals and marine algae. Using quadrats, the population number and density of each species can be estimated.



Figure 4.37 Using a 1-metre square quadrat, like this one shown above, would allow scientists to count the frequency of a particular species in that area.



Figure 4.38 Students using quadrats to examine the abundance of seaweed and other living organisms on the seashore

A quadrat is placed using random sampling or systematic sampling within the area you are studying, and the number of individual species you are studying is counted for each quadrat. To achieve truly random sampling, a grid of numbers and letters should be laid over the sampling area and the numbers and letters generated at random.

After counting the sample of plants or animals in a quadrat, you then calculate the average number of individuals per quadrat (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 are randomly placed in a bushland area of 1200 m² and the number of native orchids is counted. The results are as follows:

Quadrat 1	3 orchids
Quadrat 2	1 orchid
Quadrat 3	2 orchids
Quadrat 4	0 orchids

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 or orchids in this bushland area using the formula is:

$$\text{Total population} = \frac{\text{Average number per quadrat} \times \text{Total area being studied}}{\text{Area of quadrat}} = \frac{1.5 \times 1200}{1} = 1800 \text{ orchids}$$

Practical 4.6

Sampling an ecosystem

Aim

To investigate an ecosystem such as a bushland or native grassland.

Materials

- quadrats or wooden frames
- measuring tape or wheel
- string
- plant species identification guide

Methods

- 1 As a class, decide on the type of area you will be investigating and the number of quadrats that are needed to cover 5% of the total area being studied. This could be done around school or as part of an excursion by going out on a field trip to a designated national park, etc.
- 2 In groups of four, investigate the plant species found in one quadrat. Take photographs of the different species you see.
- 3 Using the plant species identification guide, try to identify the plant species. Alternatively, take a photo of plants within the quadrat for later analysis.

Results

Establish the percentage species cover by following these steps.

- 1 Using graph paper, divide into 100 squares to mark the location of each plant.
- 2 Estimate how much of each square the plant covers. For example, if it covers half the square, list it as 50%. If in the next square it covers a quarter of the square, list it as 25%.
- 3 You can do this for all 100 small squares, or you can take a sampling of say 10 squares, tally up the percentage, then divide it by 10 to get the average percentage cover.

$$\text{Percentage of species cover} = \frac{\text{Sum of \% cover from each square}}{\text{Total number of squares sampled}}$$

- 4 Collate the class results.



Figure 4.39 Setting up quadrats and counting plants. The dark green plant covers 25% of the 1 m by 1 m quadrat.

continued...

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Evaluation

- 1 Identify the most frequent vegetation species in the area that was investigated.
- 2 Discuss two factors within the area that may have contributed to it being the most frequent species.
- 3 Suggest a strength and a limitation of using a quadrat to determine plant abundance in certain areas.
- 4 Suggest a way you could improve this practical activity if you were to complete it again in the future.

Conclusion

Summarise your results, with reference to the Aim of your activity.

Capture–mark–recapture

Measuring the population size of fast-moving animal species is sometimes difficult. Therefore, a more appropriate 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**.

capture–mark–recapture method

a method for estimating animal population sizes that involves capturing, tagging, releasing and recapturing a sample of the animal

- 1 A sample of the species is captured (maybe about 100 individuals).
- 2 These individuals are tagged or marked in an inconspicuous way, and then released.
- 3 Sometime later, another sample of the **same size** is captured from the population.
- 4 Ecologists count how many marked individuals are in the second sample and then this information is used to find an estimate of the population size using the following equation:

$$\frac{N}{M} = \frac{n}{m}$$

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

Capture–recapture modelling

Try this 4.7

Be careful

No food items are to be consumed.

- 1 Several chocolates (M&Ms) have been put in a container. Look in the container and make an estimate as to 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 this.
- 3 To 'mark' these M&Ms, simply replace them with Smarties. These marked individuals must be placed 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 this.
- 5 How many of the chocolates in your second trapping sample were Smarties? This is m . Record it.
- 6 Now use the equation on the left to calculate your population estimate, N .
- 7 Count the actual number of total chocolates in the container. Record the number.
- 8 Was your estimate using the formula closer than your initial guess?
- 9 Suggest some ways that could increase the accuracy of your estimate.
- 10 Deduce for which species of animal this technique would work well. For which species would it not work well? Justify your opinions.

The northern hairy-nosed wombat

There were as few as 35 northern hairy-nosed wombats (*Lasiorhinus krefftii*) living in the wild at one stage, so the species was placed on the endangered species list. Over time the northern hairy-nosed wombat has undergone extensive environmental protection and management. To monitor the population size of this species of wombat, it is important to be able to accurately and regularly monitor the population. The most accurate technique used these days is using extracted DNA, which identifies the individual wombats. By placing strips of sticky tape across the burrow entrances, the hairs of the wombats can be collected and analysed by the scientists. Also, by counting the number of burrows and using cameras at the feed stations and burrows in the areas within the recovery program, it is possible to monitor wombat activity and identify reproductive females. It is now estimated that there are at least 200 northern hairy-nosed wombats in the wild, due to the implementation of the recovery program.



Figure 4.40 A significant part of the northern hairy-nosed wombat recovery program occurs at the Epping Forest National Park and a second colony has been established at Richard Underwood Nature Refuge, both in Queensland.

Did you know? 4.2

1 For which of the following organisms would a quadrat be an appropriate tool for estimating the population?

- a Hawks
- b Cacti
- c Starfish
- d Beetles

2 Place these 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. What is the name of this method?

Quick check 4.8**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 do review the data manually.

continued...

Science as a human endeavour 4.2

...continued

More research is required into the impact of the drones on the wildlife, so that drone protocols can be established to ensure no undue stress is caused to the animals.



Figure 4.41 Drone collecting data on elephant numbers in Botswana

Human impact on population dynamics

Many different organisms have been moved from one part of the country to another or brought to Australia from overseas, either deliberately or accidentally. In fact, approximately 24% of Victoria's flora consists of plant species that were not evident at the time of European settlement.



Figure 4.42 An ecologist collects a tiny beetle that has been released into strategic areas with the aim that it will kill the invasive Athel pine. This is a form of natural pest control.

These are some examples of invasive organisms.

- 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, and excretes concentrated salt through their leaves, making the ground under them much saltier, 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 from loss of habitat or competition and predation by a variety of introduced animals, resulting in adverse effects on the ecosystems that exist within Australia. The feral rabbit and feral camel are just a few examples of introduced animals.

Feral camels

Explore! 4.4

A lack of predators, increase in favourable conditions and available food sources would increase the birth rates within a population. An absence of natural predators allows the population to exceed carrying capacity, which may result in overgrazing of the habitat. Take, for example, the world's largest herd of feral camels. There are approximately 1 to 1.2 million feral camels in Australia, and their numbers are thought to be doubling every 8–9 years. Feral camels now roam freely across an area of 3.3 million square km encompassing the states of Western Australia, South Australia, Queensland and the Northern Territory. They are mainly dromedaries, but some are Bactrian camels.

continued...

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Figure 4.43 Wild camels in the outback of Australia

- 1 Find out when and why camels were introduced to Australia.
- 2 Not long after their introduction, the internal combustion engine was invented, and the camels were no longer needed, so several thousand were released into the wild. What sort of problems did the camels cause because of their release? Consider their impact on water availability, farms, cattle and sheep, and native animals.
- 3 Write a paragraph about the camels and their impact on native wildlife. Use words such as: competition, interspecific competition, herbivore, heterotroph, logistic growth, carrying capacity and limiting factors.

Are animals getting smaller?

Scientific research suggests that human-related impacts on natural ecosystems have caused many species to evolve to smaller body sizes. In fact, in Australia, the average mammal body mass today is only around one-tenth of what it was around 125 000 years ago. Over time, humans established themselves as the leading predator of mammals, preying upon large animals to feed hungry families. This led to shrinking mammals becoming more prevalent, with the overall size of many species much smaller today than it was in the past.

Dr Martino Malerba, a postdoctoral researcher from Monash University, and his team, conducted an experiment using microscopic algae called *Dunaliella tertiolecta* that revealed the physiological reasons why many species are becoming smaller in response to global warming, overhunting and overfishing. As the algae reproduced, the research team purposely allowed only the medium-sized algae to reproduce, removing the algae that were deemed too big, or too small. Findings from the experiments are that modifying the size of a species ultimately impacts its ability to use energy. Larger organisms can convert four times as much food into energy than the equivalent volume of smaller organisms. This means that being small can be quite a disadvantage, if you are not as efficient at converting food into energy.

Science as a human endeavour 4.3



Figure 4.44 The case of shrinking mammals may continue to claim species, like polar bears, who are a valuable part of our ecosystem. A reasonable concern is that eventually there may not be anything larger than an average dairy cow, worldwide.

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Figure 4.45 Tasmanian tigers were hunted to extinction by humans.

Human actions remain a major threat to a variety of species – whether through direct hunting, habitat destruction or indirectly due to global warming. In ecology a population with few, large individuals will have a much larger impact on the ecosystem compared to a population of many, smaller individuals. This can lead to future implications for the successful maintenance of species living within their specific ecosystems.

Section 4.3 questions

Remembering

- 1 State two events that can increase a population size and two events that can decrease a population size.
- 2 List the damage and hazards posed by feral camels.
- 3 What is the equation used to estimate the population size of a species using the capture–mark–recapture process? Define the variables (letters) in your answer.

Understanding

- 4 What is the word equation used to represent the change in population size?
- 5 Summarise the key advantages of using quadrats to determine the population size of marine algae within a tidal coast ecosystem.
- 6 A population of animals immigrates to a new area where there is abundant food and space. They begin reproducing rapidly. Which model best depicts their population growth?
- 7 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

- 8 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 occurs.

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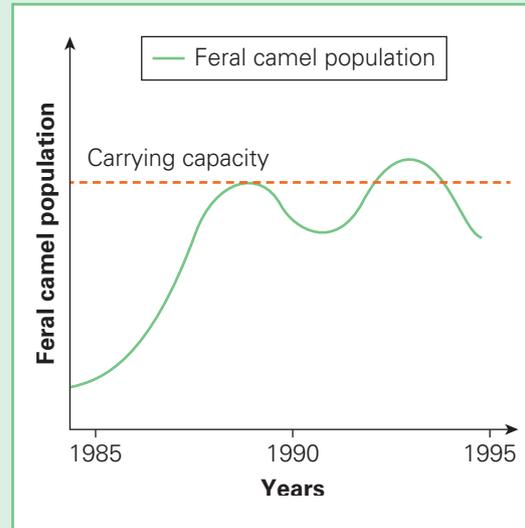
QUIZ

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9 Use the graph on the right to answer the questions about feral camels.

- a Provide one possible reason why the population decreased initially in 1990 after reaching its carrying capacity.
- b Hypothesise why the population exceeded its carrying capacity around 1992.

10 Estimate the population size of the northern hairy-nosed wombat, if 80 animals were captured and marked in the first sample, 60 were captured in the second sample, with 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 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 into 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 their traditions and culture.

Review questions

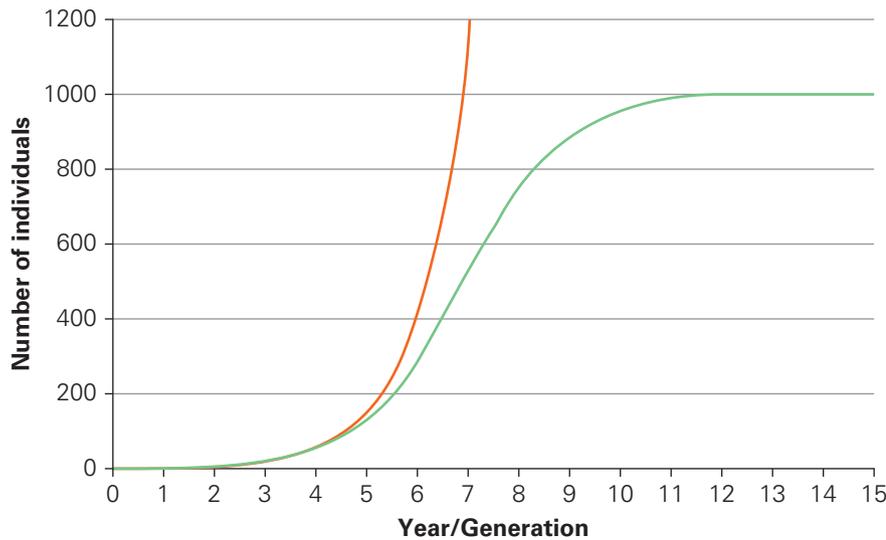
Remembering

- 1 What are the products from the process of photosynthesis?
- 2 What are the products from the process of cellular respiration?
- 3 What are the three components of an ecosystem?
- 4 Finish this sentence: A quadrat can be used to estimate _____.
- 5 How can seasonal changes affect ecosystems?



Understanding

- 6 Compare which organisms perform photosynthesis and which organisms perform cellular respiration.
- 7 Look at the population growth versus time graph below.

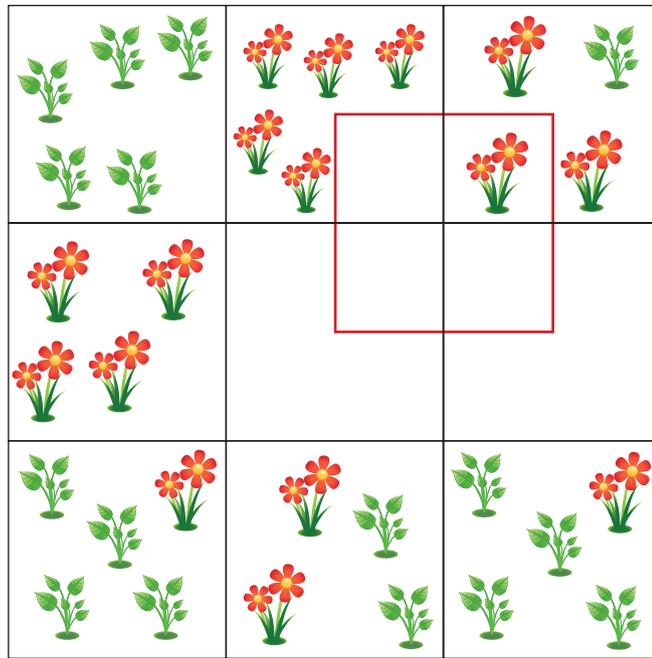


- a Identify the exponential growth graph from the logistic growth curve.
- b What is the carrying capacity of the population shown from this graph?
- 8 Outline the steps between the Sun (as a source of energy) and a secondary consumer.
- 9 Compare the roles of a bee and a flower in their mutualistic relationship.

Applying

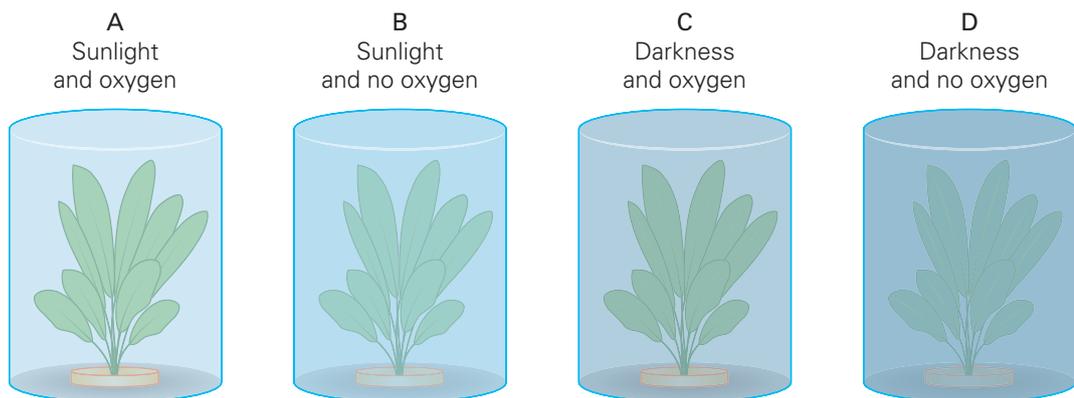
- 10 Model this scenario using beads or counters.
A population of 10 wallabies immigrates into a new area. Eight of the wallabies have a joey, one of whom dies when only a few days old. One of the mothers is shot by a farmer, and two new wallabies immigrate into their mob. How many wallabies remain?
- 11 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.

- 12 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.



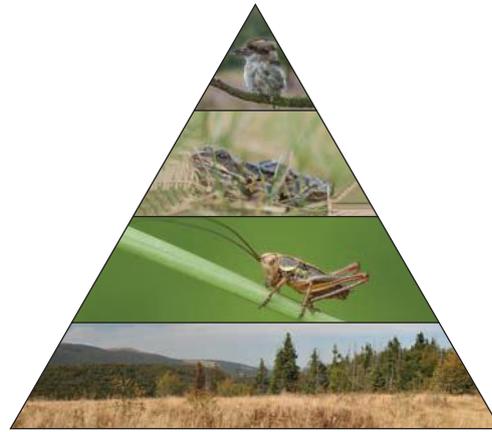
Analysing

- 13 It was suggested to Elijah that plants require sunlight and oxygen to grow. To test this, Elijah set up four glass jars, A to D, as shown below.



- a Examine the set-up above to justify which of the three jars demonstrate the answer to the question: 'Do plants need sunlight and oxygen to grow?'
- b List three variables that Elijah must control to get valid results.

14 The energy pyramid on the right shows how much energy is present in 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 on the right) weighs 5 grams and must consume half of its body mass in food per day. Use the energy pyramid to calculate how many blades of grass the grasshopper needs to eat per day.
- b Assume a lizard must eat five grasshoppers per day, while a kookaburra must eat two lizards 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

- 15 Judge which trophic level is the most important for an ecosystem and explain why.
- 16 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 and label of y-axis as well as a legend.
- b These population growth curves are said to fluctuate. Explain what this means, using data from the graph.
- c Give reasons for the relationship between the two population growth curves.
- d It can be stated that a good predator–prey relationship keeps the two populations ‘in balance’. Discuss what this means.

STEM activity: Saving an endangered species!

Background information

According to scientists, the extinction of species is happening at a scarily fast rate. Exact reasons are rarely known, but we do know that most contributing factors are a consequence of humans; for example, habitat destruction (clearing of land for agriculture or urban developments); habitat change and destruction (erosion, grazing, fires); introduced animals and plants (rabbits, goats, pigs, cane toads); and direct exploitation (hunting, fishing). Since many Australian species are found nowhere else in the world, Australians have a responsibility to conserve them.

What role do engineers play in the prevention of extinction?

Type of engineer	Example of a possible role
Materials engineers	Develop products that can act as alternatives to rainforest timber
Architectural engineers	Develop energy efficient buildings to reduce the impact of greenhouse gases and global warming on ecosystems
Chemical engineers	Develop a way to lessen the harmful effects starfish (sea stars) have on coral reef
Mechanical engineers	Develop technologies like clean cars that reduce the production of greenhouse gases
Environmental engineers	Develop ways to combat global warming, which adversely affects coral reef
Agricultural engineers	Develop farming techniques that limit depletion of soil nutrients and maintain soil health

VCSU121

VCMSP324

VCDSCD061

VCSIS137

VCSIS140



Figure 4.46 Southern corroboree frog



Figure 4.47 Mountain pygmy-possum

Design brief: Design a product that can help an endangered species survive.

Open-ended instructions on design

Taking on the role of an engineer, you and your team are going to work through the design process. This includes: defining the problem, researching the problem, proposing a solution, designing and building a prototype, testing the solution and evaluating.

As you work through the design process, you will need to select an endangered species from Victoria to investigate, research all about your organism, including why it is now endangered, and 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, as a class, you can evaluate your team's design and give feedback as critical friends.

Suggested materials

- web browser/internet access
- pencil
- paper

Evaluate and modify

- 1** Define, in your own words, the problem you are being asked to solve.
- 2** List all the questions you have about your endangered species and then write a detailed summary of your findings. Remember the important question of why your species is endangered. Include a map of Australia showing your species' distribution, tabulated data showing the population change of your species over time, and a graph representing this data.
- 3** Write a summary 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.
- 4** Discuss how you could test your prototype to determine if it meets your needs.
- 5** Discuss with your class the positive, negative and interesting features of each team's design.

Chapter 5 Atoms

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 and contrast 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.

Curriculum

All matter is made of atoms which are composed of protons, neutrons and electrons; natural radioactivity arises from the decay of nuclei in atoms (VCSSU122)

- | | |
|--|-----|
| • describing and modelling the structure of atoms in terms of the nucleus, protons, neutrons and electrons | 5.2 |
| • comparing the mass and charge of protons, neutrons and electrons | 5.2 |
| • describing in simple terms how alpha and beta particles and gamma radiation are released from unstable atoms | 5.5 |

The atomic structure and properties of elements are used to organise them in the periodic table (VCSSU123)

- | | |
|---|----------|
| • describing the structure of atoms in terms of electron shells | 5.3, 5.5 |
| • explaining how the electronic structure of an atom determines its position in the periodic table and its properties | 5.3, 5.5 |

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Glossary terms

alpha particle

atom

atomic number

beta particle

bioplastic

compound

electromagnetic spectrum

electron

gamma ray

ion

isotope

mass number

molecule

neutron

nucleus

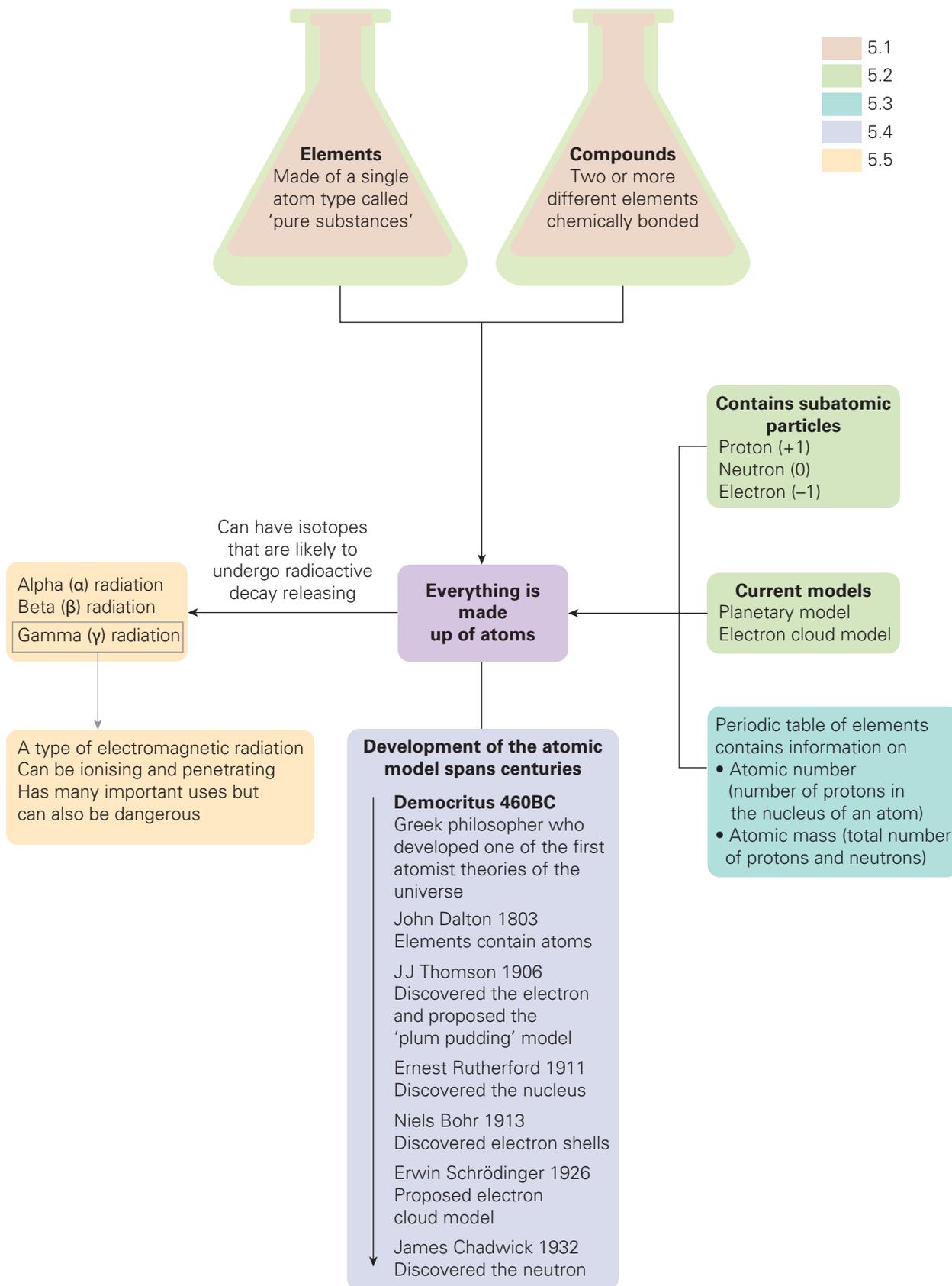
proton

radioactive decay

subatomic particle



Concept map





5.1 What are atoms, elements and compounds?

Atoms

Someone once told me not to trust **atoms** because they make up everything (apart from energy)! To develop a language, you need an alphabet; similarly, to build complex structures such as **molecules**, you need atoms. The word 'atom' comes from the Greek word *atomos*, which means 'indivisible' or 'un-cuttable'. This means that if you had an atom of silver, you would not be able to divide it into smaller pieces. Modern physics shows this is not true, which will be discussed later in the chapter.

An atom is the smallest possible form of an

atom
the building block of matter

molecule
a group of two or more atoms

element on the periodic table. There is a unique atom for every element. For example, if you had a silver ring and cut that ring in half and then in half again and continued to do this, you would be left with an atom of silver; however, if you cut this atom of silver in half, you would no longer be in possession of the element silver.



WORKSHEET



Figure 5.2 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 5.3 on the following 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 and 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.

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



Figure 5.1 A digital impression of an exploding supernova

Did you know? 5.1

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.

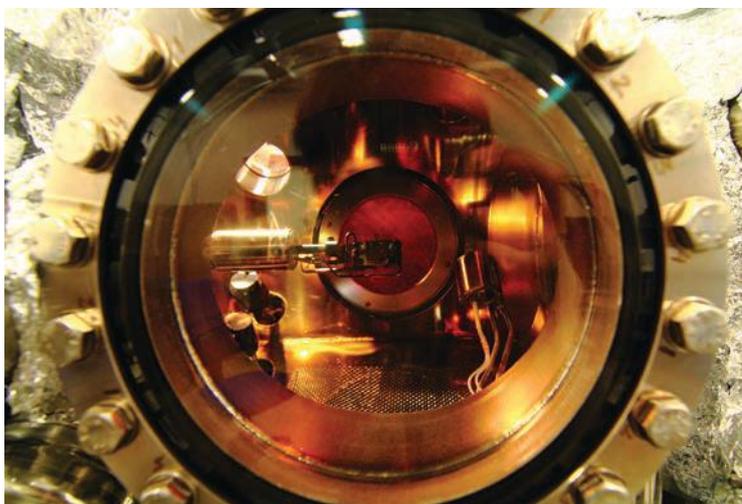


Figure 5.3 The interior of a scanning tunnelling microscope used to view the first image of an atom

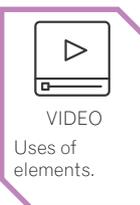
- 1 Define an atom.
- 2 Recall the name of the microscope which allowed scientists to view atoms.

Quick check 5.1

Elements and compounds

Elements

You might recall that elements are considered to be 'pure substances'. All elements contain atoms, but they contain only one unique type and these atoms are identical to one another. They cannot be changed chemically into a different type of atom. All the known elements are arranged on the periodic table (by their chemical symbol) according to their atomic properties.



The world's smallest movie

Science as a human endeavour 5.1

In 2013, researchers at IBM created the world's smallest movie. They used carbon monoxide molecules and the small tip of the scanning tunnelling microscope to make them move. The movie is entitled *A Boy and His Atom*, in which a boy meets an atom and they become friends. It was created using individual frames, which were then 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.

Strange element symbols

Did you know? 5.2

Most of the symbols for the chemical elements in the periodic table look like they go with their English name; for example, O for oxygen and Zn for zinc. There are, however, 11 elements whose symbols do not match their English name. Nine of these symbols come from Latin, one from Greek and one from German. *Hydrargyrum* is the Greek word for mercury (Hg) meaning 'liquid silver'. The symbol for tungsten (W) comes from its Germanic name *wolfram*, named after the mineral in which tungsten was discovered. See if you can pick out the nine elements whose symbols come from their Latin names.

Periodic Table of the Elements

1 H Hydrogen	2 He Helium	Atomic number → 8 ← Atomic mass Oxygen ← Symbol ← Name																10 Ne Neon							
3 Li Lithium	4 Be Beryllium	Chemistry is a branch of physical science that studies the composition, structure, properties and change of matter																11 Na Sodium	12 Mg Magnesium	13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulphur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton								
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon								
55 Cs Caesium	56 Ba Barium	57-71 Lanthanoids	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon								
87 Fr Francium	88 Ra Radium	89-103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson								
		57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium									
		89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium									
		Alkali metal		Alkaline earth metal		Lanthanide		Actinide		Transition metal		Post-transition metal													
		Metalloid		Polyatomic nonmetal		Diatomic nonmetal		Noble gas		Unknown chemical properties															

Figure 5.4 The periodic table.

Compounds

Compounds are formed when two or more elements combine with one another by chemically bonding. The properties of the compound formed are usually very different from the original elements that it is made up of. For example, aluminium is a shiny silver metal, oxygen is a colourless gas but their compound (aluminium oxide) is a white solid.

compounds
chemical combination of two or more elements combined in a fixed and definite proportion by weight.

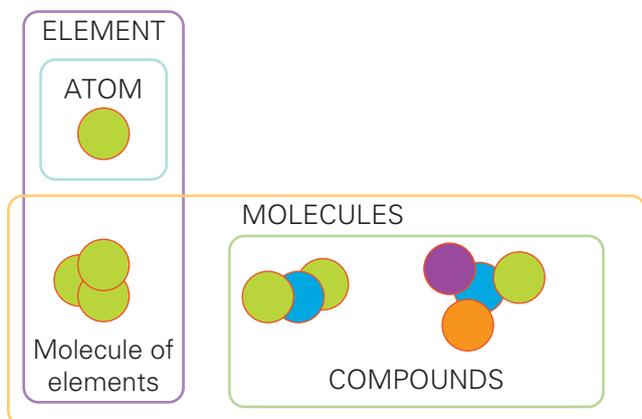


Figure 5.5 A diagram showing the difference between elements, compounds, atoms and molecules

Molecules

Explore! 5.1

The elemental form of hydrogen has the formula H_2 , meaning that two hydrogen atoms have bonded together. This form of hydrogen is called a hydrogen molecule. Water has the formula H_2O , meaning that two hydrogen atoms and one oxygen atom have bonded together to make a water molecule.

- 1 Account for why H_2 is described as a molecule and not a compound.
- 2 Discuss why water is described as both a molecule and a compound.

Practical 5.1

Splitting molecules into atoms

Aim

To split molecules into atoms.

Materials

- baking soda
- distilled water
- 250 mL beaker
- 250 mL measuring cylinder
- stirring rod
- safety glasses
- spatula
- 2 power leads
- 2 alligator clips
- power pack

Method

- 1 Using the 250 mL measuring cylinder measure 150 mL of distilled water and pour into the beaker.
- 2 Add a heaped spatula of the baking soda to the beaker and stir using the stirring rod until the baking soda has dissolved in the water.
- 3 Attach each lead to the DC terminals on the power pack, setting the voltage to 9V.
- 4 To the other end of each lead, attach an alligator clip, making sure the wires do not touch each other.
- 5 Put the ends of the leads with the alligator clips into the beaker of baking soda solution, again making sure the leads do not touch each other at any point.
- 6 Leave this set up for 10 minutes. During this time you should see bubbles forming at each wire.

Results

Compile a list of the observations that you could make from this experiment. Remember, observations are things that you can see happening, not an explanation of what is happening.

Be careful

Ensure connectors of the leads are separated and not in contact with each other when attached to the switched-on power pack.

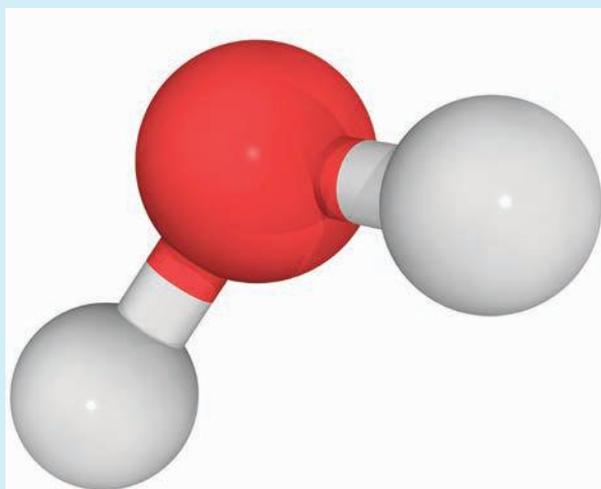


Figure 5.6 This molecular model of a water molecule shows two hydrogen atoms (white) and one oxygen atom (red).

continued...

...continued

Evaluation

- 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 Propose a reason why the use of distilled water was specified and suggest what, if any, effect this may have had on the outcome.

Conclusion

- 1 Make a claim from this experiment regarding water and compounds.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

- 1 Copy and complete the following table, showing the elements (types of atoms) that form each compound.

Quick check 5.2

Compound	Types of atoms that are chemically bonded
water – H ₂ O	
carbon dioxide – CO ₂	
sodium chloride – NaCl (table salt)	

- 2 Evaluate if you can tell whether a substance is an element or a compound by its chemical formula. Can you tell by its name?

Practical 5.2: Teacher demonstration

Forming a compound using magnesium and oxygen

Aim

To show that compounds formed from elements have different physical and chemical properties.

Be careful

Do not stare directly at
combusting magnesium.

Materials

- small piece of magnesium ribbon
- matches
- tongs
- Bunsen burner
- crucible
- heatproof mat
- safety glasses

Method

- 1 Set up a Bunsen burner on a heatproof mat.
- 2 Hold the piece of magnesium ribbon in the tongs and put it into the hottest part of the flame until it catches alight.
- 3 Collect the compound formed in a crucible and observe the contents.

Results

Complete the results table below, listing the physical properties (appearance) of the substances in the reaction.

Substance	Physical properties (appearance)
Magnesium metal	
Oxygen gas	
Compound formed	

continued...

...continued

Evaluation

- 1 Predict the name of the compound that was formed in the demonstration.
- 2 Propose a word equation for the reaction demonstrated.
- 3 List some other observations in the reaction other than the new substances formed.

Conclusion

- 1 Make a claim from this experiment regarding the formation of new compounds.
- 2 Support the statement by using your observations (include potential flaws).
- 3 Explain how your observations support your claim.

Section 5.1 questions

Remembering

- 1 Name the two most common elements in the universe.

Understanding

- 2 Outline the similarities and differences between an atom, an element and a compound.

Applying

- 3 Identify the different elements present in vinegar (CH_3COOH).

Analysing

- 4 Decide which of the following substances are compounds. Justify your choice.

oxygen	potassium	water	sugar
candle wax	hydrogen	petrol	

Evaluating

- 5 Evaluate why you do not find carbon dioxide (CO_2) on the periodic table.



QUIZ



5.2 The structure of the atom

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 modern chemistry’ 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.



Figure 5.7 Dmitri Mendeleev, often called the ‘father of modern chemistry’



WORKSHEET

As new technologies developed, physicists discovered that the atom is made up of three **subatomic particles: protons, neutrons and electrons**. Since 2008, physicists have learned

subatomic particles

the particles that make up an atom

proton

a subatomic particle with a positive charge in the nucleus of an atom

neutron

a subatomic particle with a neutral charge in the nucleus of an atom

electron

a subatomic particle with a negative charge found in all atoms

a lot more about particles within atoms from studies using the European Organization for Nuclear Research (CERN) Large Hadron Collider, a tunnel which spans 27 km in circumference around the France–Switzerland border. Here, subatomic particles

are smashed together at speeds close to the speed of light. The remains are then analysed. When the collider was first developed, some scientists believed that very small black holes (regions in space whose gravity is so strong that not even light can escape) could be created that could lead to other dimensions, while other scientists thought that a black hole big enough to swallow our planet could be made. No need to panic yet though! Many of these ideas came from a lack of understanding surrounding the world's biggest machine; science knows much more about its capabilities today.



Figure 5.8 The Large Hadron Collider

There are different numbers of these subatomic particles in each element. This will be discussed in more detail later in this chapter.

Ordinary hydrogen – an unusual element **Did you know? 5.3**

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!

Particles smaller than the electron **Explore! 5.2**

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? The size of an electron (due to its wavelike properties) is extremely problematic to define/measure/know. Some writers think that they could be larger than protons.



Figure 5.9 These Russian dolls fit inside each other, getting progressively smaller just like an atom and the subatomic particles within it.

Research the particles that make up protons, neutrons and electrons. What are their names? What is known about them?

Modern atomic models

Even with the most powerful microscopes scientists are, as yet, unable to 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.

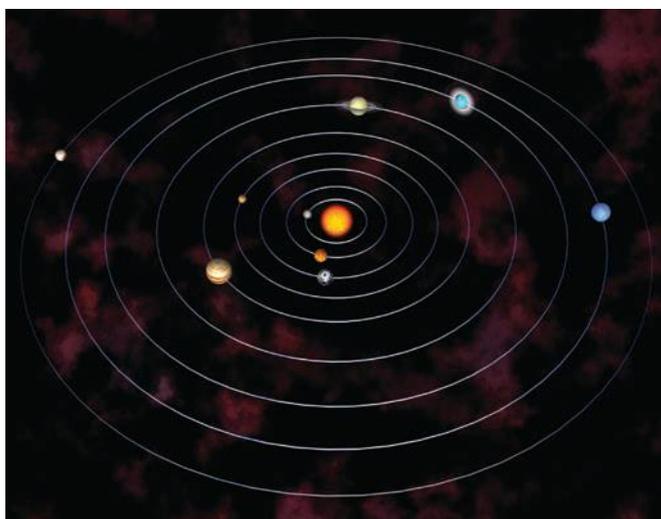


Figure 5.10 The solar system. The planetary model of the atom is based on the structure of our solar system.

The atom has a similar kind of structure. In the middle of the atom there is a structure called the **nucleus**, which is where the

nucleus
the central part of the atom containing its protons and neutrons (nuclei is the plural)

protons and neutrons are situated. Orbiting the nucleus in orbitals or shells

are the electrons. The shells are drawn as circles and are at different energy levels depending on how far they are away from the nucleus. This planetary-style model was proposed by Niels Bohr in 1913 and is often referred to as a Bohr diagram.

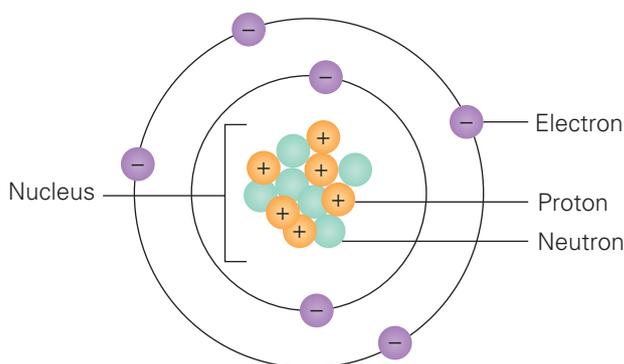


Figure 5.11 A Bohr diagram shows the positively charged nucleus (containing both protons and neutrons) and electrons orbiting in shells of different energy levels.

Just like the solar system, most of the atom is made up of empty space. To give you an idea of how empty, 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 a large area in the atom where electrons are most likely to be situated.

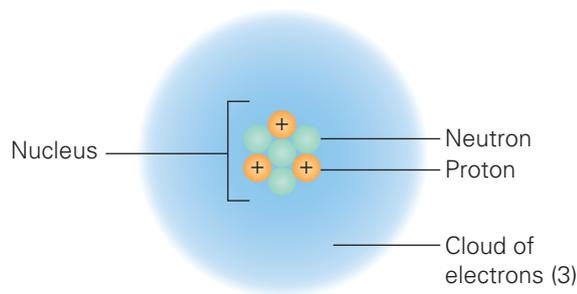


Figure 5.12 The electron cloud model shows the nucleus in the middle of a lithium atom surrounded by a cloud of electrons.

Build your own model of the atom using everyday household objects. Make sure that you include labels.

Try this 5.1

- 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?

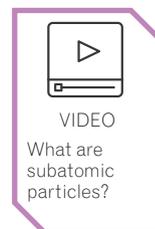
Quick check 5.3

Properties of subatomic particles

To understand more about atoms and how they behave, you need to know more about the three subatomic particles within them.

Charge

You may be wondering what keeps the electrons inside the atom. If they are whizzing around at enormous 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). Just like magnets, 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 also play their part. They are neutral, which means they have no

charge at all (0). Table 5.1 summarises what you need to know about the charges of the subatomic particles.

Subatomic particle	Charge
Proton	+1 (positive)
Neutron	0 (no charge)
Electron	−1 (negative)

Table 5.1 The charges of the three subatomic particles

Practical 5.3: Teacher demonstration

Demonstrating the attractions between charged objects

Aim

To investigate attractions between charged objects.

Experiment 1

Materials

- 2 balloons
- 2 pieces of string (about 1 m long)
- plastic tube

Method

- 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.

Experiment 2

Materials

- balloon
- a willing student to be a volunteer

Method

- 1 Rub the balloon on the hair of the volunteer.
- 2 Bring the balloon away from their head and observe what happens.

Results

Record your observations for each experiment.

Evaluation

- 1 Determine which experiment showed repulsion. Suggest a reason for your answer.
- 2 Determine which experiment showed attraction. Suggest a reason for your answer.

Conclusion

- 1 Make a claim from this experiment regarding the attraction between charged objects.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Mass

As well as knowing the charge of the subatomic particles, you also need to be able to recall their masses. Protons and neutrons both have very similar masses. Protons have a mass of 1.673×10^{-24} grams and neutrons have a mass of 1.675×10^{-24} grams. These are very small numbers, too small for scientists to do calculations with, so atomic mass units (amu) are used instead. When using atomic mass units, protons and neutrons both have a mass of 1 amu, which is much easier to remember and work with. They have a mass

$\frac{1}{1840}$ th of a proton or a neutron. Table 5.2

summarises what you need to know about the masses of the three subatomic particles.

Subatomic particle	Relative mass
Proton	1
Neutron	1
Electron	$\frac{1}{1840}$

Table 5.2 The relative mass of the three subatomic particles

Complete this table summarising the differences in charge and mass of the three subatomic particles.

Quick check 5.4

Subatomic particle	Symbol	Location	Charge	Mass
Proton	p			
Neutron	n			
Electron	e ⁻			

Section 5.2 questions

Remembering

- 1 Name the three subatomic particles that make up the atom.
- 2 Identify which subatomic particle has the smallest mass.
- 3 Recall the name of the structure at the centre of atom where the protons and neutrons are located.

Understanding

- 4 Compare and contrast the properties of protons, neutrons and electrons.

Applying

- 5 Construct a labelled diagram that shows the planetary model of the atom.

Analysing

- 6 Draw the electron cloud model of the atom. Using your Bohr diagram from question 5, examine the similarities and differences between the two models.

Evaluating

- 7 Propose several reasons why models are so useful in science. Explain the limitations of using models.



QUIZ



Atomic number and mass number



WORKSHEET

Periodic Table of the Elements

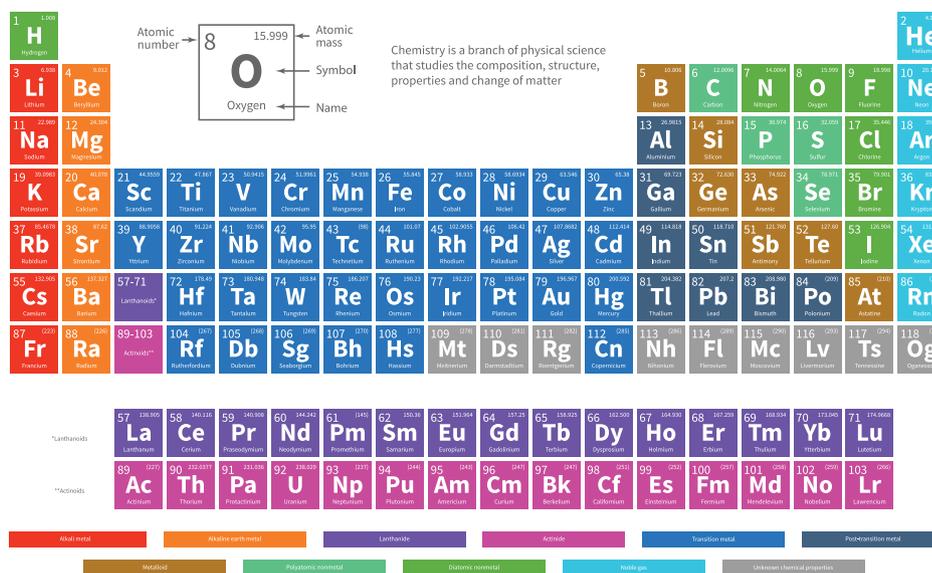


Figure 5.13 The periodic table of elements

The number of subatomic particles in an atom depends on the type of element on the periodic table. 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 a each atom.

Atomic number

The smaller of the two numbers given with each element is called the **atomic number**.

This will usually be the top number on the elements on most of the periodic tables you will see; however, you may also

see some periodic tables where the atomic number is at the bottom. This is why it is important that you remember the atomic number as the smaller of the two numbers.

atomic number
the number that denotes the number of protons in an atom of an element

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.

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

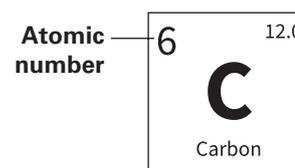


Figure 5.14 The atomic symbol for carbon shows the atomic number of 6. You can therefore conclude that it has six protons.

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 5.15 Carbon, a black solid with an atomic number of 6



Figure 5.16 Liquid nitrogen, a colourless gas cooled down to -196°C with an atomic number of 7

This is the same for any other element on the periodic table. Likewise, hydrogen has one proton. Any other substance found to have one proton will be the element hydrogen.

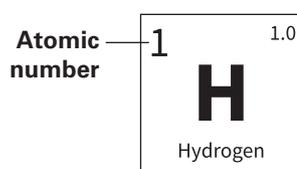


Figure 5.17 The atomic symbol for hydrogen shows the atomic number of 1, so you can conclude that it has one proton.

Using an element of your choice as an example, explain what the atomic number tells you about the atom.

Quick check 5.5

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 or six positively charged particles. Therefore, for the atom to have zero charge it must have six negative electrons. So, neutral atoms have the same number of electrons as they do protons.

Changing the number of electrons in an element will not change the type of element, as you saw with protons; however, 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 (+) or (–) sign after the chemical symbol.

A (+) sign indicates the atom has become more positive (lost negatively charged electrons), whereas a (–) sign indicates the atom has become more negative (gained negatively charged electrons). For example, Mg^{2+} denotes a magnesium atom that has donated two electrons to another atom 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. Atoms tend to give or receive electrons according to how many electrons they possess in their outer shell – you can explore these patterns further in Explore! 5.3.

ion
a charged version of an atom that has either gained or lost electrons

Charged particles**Explore! 5.3**

When the number of electrons is changed in an atom, the properties of the element are affected. You are going to research why this happens.

- When fluorine atoms become ions (negatively charged) they can combine with other element-forming fluorides. An example would be sodium fluoride. Research the properties of fluorine and compare them with the properties of sodium fluoride.
- The elements in the last group (column) of the periodic table are known as the noble gases. They all possess a full outer shell of electrons and do not form ions readily. The elements in the second last group of the periodic table (depending on whether you include the middle section of the table, this is group 7 or 17) are known as the halogens and all are one electron short of a full outer shell. Research what type of ions they form.
- The elements in the first group of the periodic table are known as the alkali metals. They all possess one electron in their outer shell. Consider, whether it would be easier to donate one electron to have a full outer shell, or to try to gain seven! Research what type of ions they form.
- The elements in the second group of the periodic table are known as the alkaline earth metals. They all possess two electrons in their outer shell. Research what type of ions they form.
- Predict what type of ion the following elements would form.
 - Sulfur
 - Barium
 - Iodine

- How does an atom become positively or negatively charged?
- 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.

Quick check 5.6**Mass number**

The **mass number**, or relative atomic mass, is the larger of the two numbers and usually

is the bottom number. The mass number gives us information about the total mass of the atom, but as you learned in section 5.2,

mass number

also known as relative atomic mass; it gives the mass of the atom (usually thought of as the number of protons and neutrons in the nucleus)

electrons barely contribute to the mass of the atom. Therefore you can think of it as the mass of the nucleus (and equal to the number of protons and neutrons in the nucleus). (number of protons and neutrons in the nucleus). Mass numbers are usually not whole numbers because of different forms of elements called **isotopes**, which will be discussed later in the chapter. For now, you will just round the mass numbers to the nearest whole number.

isotope

form of the same element with the same number of protons but different number of neutrons

Number of neutrons

The mass number 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:

$$\begin{aligned} & \text{number of neutrons} \\ &= \text{relative atomic mass} - \text{atomic number} \end{aligned}$$

Recall the example of carbon. Carbon has a relative atomic mass of 12 (rounded to the nearest whole number) and an atomic number of 6. Using the equation above, you can calculate that carbon has a total of six neutrons.

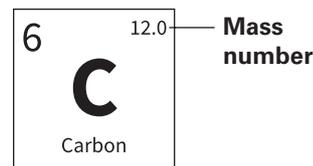


Figure 5.18 The atomic symbols for carbon showing the atomic number of 6 and relative atomic mass of 12. These numbers can be used to calculate the number of neutrons in a carbon atom.

$$\begin{aligned} & \text{Number of neutrons in a carbon atom} \\ &= \text{relative atomic mass} - \text{atomic number} \\ &= 12 - 6 \\ &= 6 \end{aligned}$$

Unlike the number of 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.

Locate the following elements on the periodic table. Using their atomic numbers and their relative mass (rounded to the nearest whole number), state the number of protons, neutrons and electrons each atom contains.

Quick check 5.7

	Atomic number	Relative atomic mass (amu) (rounded to nearest whole number)	Number of protons	Number of neutrons	Number of electrons
Nitrogen					
Sodium					
Sulfur					
Gold					

Practical 5.4: Teacher demonstration
Invisible spaces in water
Aim

To investigate the three-dimensional structure of molecules.

Materials

- 100 mL propan-2-ol
- 250 mL beaker
- 100 mL measuring cylinder

Method

- 1 Measure 100 mL of water using the 100 mL measuring cylinder and pour into the beaker.
- 2 Using the same measuring cylinder measure 100 mL of propan-2-ol and pour into the same beaker already containing water.

Results

Complete the table below to summarise your 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	

Evaluation

- 1 Predict what will happen to the total volume when the alcohol is added to the water. Propose what the total volume of the solution should be.
- 2 Note the actual total volume when the two solutions are mixed together. Propose a reason why this volume is not the same as your prediction.

Conclusion

- 1 Make a claim from this experiment regarding the structure of molecules.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.



QUIZ

Section 5.3 questions**Remembering**

- 1 State the names of the two numbers that accompany each element on the periodic table.
- 2 Identify which of the numbers you have named in question 1 is always the largest.
- 3 What is the name of the element that has an atomic number of 20?

Understanding

- 4 Explain why the mass of the electron is not considered in the mass number.
- 5 An atom has a mass number of 45 and an atomic number of 16. How many neutrons does it have? Show your working.

Applying

- 6 Identify the subatomic particles that have nearly the same mass.

Analysing

- 7 Compare the mass number and the atomic number of an element.
- 8 Copy and complete the table using the information in the periodic table.

	Atomic number	Relative atomic mass (amu) (to nearest whole number)	Number of protons	Number of neutrons	Number of electrons
Hydrogen					
Oxygen					
Potassium					
Aluminium					

Evaluating

- 9 'The mass number determines the identity of the element.' Propose whether this statement is true or false. Justify your answer.
- 10 Justify why there are no elements on the periodic table with the same atomic number.
- 11 'Atoms always are neutral.' True or false? Explain your answer.



5.4 Development of the atomic model



WORKSHEET

Discussions surrounding our understanding of the atom and its structure have been ongoing within the scientific community throughout history. In this section you will examine the major

discoveries that have contributed to our understanding of the atom and highlight how new experimental evidence can lead to a scientific model being updated or replaced.

Significant developments in the atomic model throughout history

Explore! 5.4

Before you read on and find out about the significant developments that occurred surrounding our understanding of atomic structure, it would be useful for you to do some of your own research.

- 1 Make a list of at least five scientists who have contributed to our understanding of atomic structure.
- 2 What were their significant discoveries and how did each discovery change the model of the atom around at that time?

Democritus 460–370 BCE

Democritus was the first scientist to theorise about the atom. In the year 442 BCE he said, 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. He thought, for example, that gold was made of gold atoms, bread was made of bread atoms and soil was made of soil atoms. This may sound silly now, but it was quite a sophisticated idea at the time, bearing in mind he had no modern technology, such as microscopes, to view these substances.

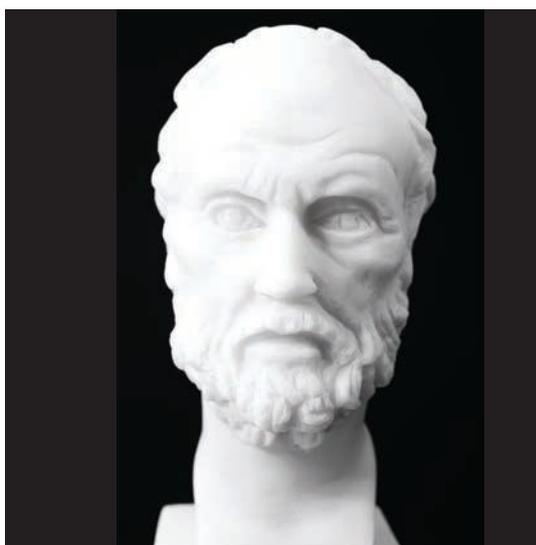


Figure 5.19 Sculpture of the Greek philosopher Democritus

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. Aristotle had such an influence over people at the time that it took about 2000 years for Democritus’ theory to be re-examined.

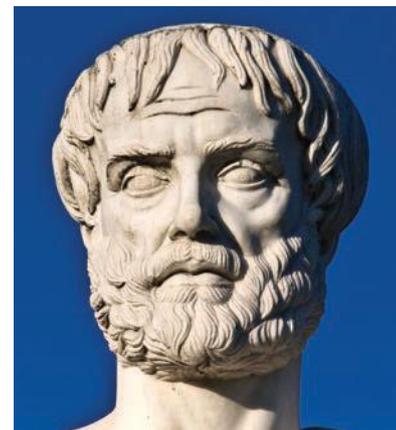


Figure 5.20 Sculpture of the Greek philosopher Aristotle

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. He suggested that all elements, which were now arranged in the periodic table, contained atoms, and that atoms of the same element would be identical in size, shape and mass. He also stated that compounds were a combination of elements. The question he could not answer though, was why atoms behaved the way they do.



Figure 5.21 John Dalton was an English chemist, physicist and meteorologist. He is best known for sparking research into modern atomic theory.

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 he won a Nobel prize for his work in 1906. By studying ‘rays’ within a cathode ray tube, Thomson was able to determine



Figure 5.22 J.J. Thomson proposed the 'plum pudding' model and is credited with discovering the electron.

that these 'rays' had a mass 1000 times smaller than a hydrogen atom, the lightest piece of matter known to science at the time. He therefore concluded that these 'rays' were not rays at all, but very light particles. These particles were also attracted to a positively charged metal plate, indicating that they themselves were likely to be negatively charged. He named these particles 'corpuscles'; however, they are now called electrons.

The first model of the structure of the atom was proposed by Thomson and named the plum pudding model. He knew that electrons were negatively charged and that atoms are 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'.

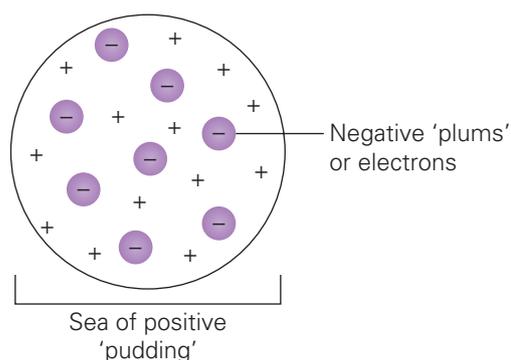


Figure 5.23 The plum pudding model, comprising a sea of positive charge (the pudding) and, scattered through this, negative electrons (the plums).

Ernest Rutherford 1871–1937

In 1911, Ernest Rutherford and his team of scientists fired alpha particles (helium nuclei) at a thin piece of gold foil, in his famous gold foil experiment.

He 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. He 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 5.24 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.

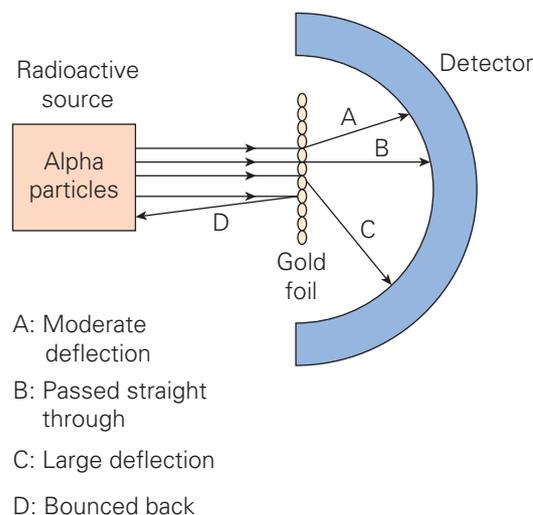


Figure 5.25 The gold foil experiment conducted by Ernest Rutherford proved that most of the atom was empty space and that there was an area of charge and mass concentrated in the middle of the atom.

In analysing the results of this experiment, Rutherford devised his own model of the atom. This model depicts a charged area with substantial mass concentrated in the middle of the atom, called the nucleus, which 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. 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.

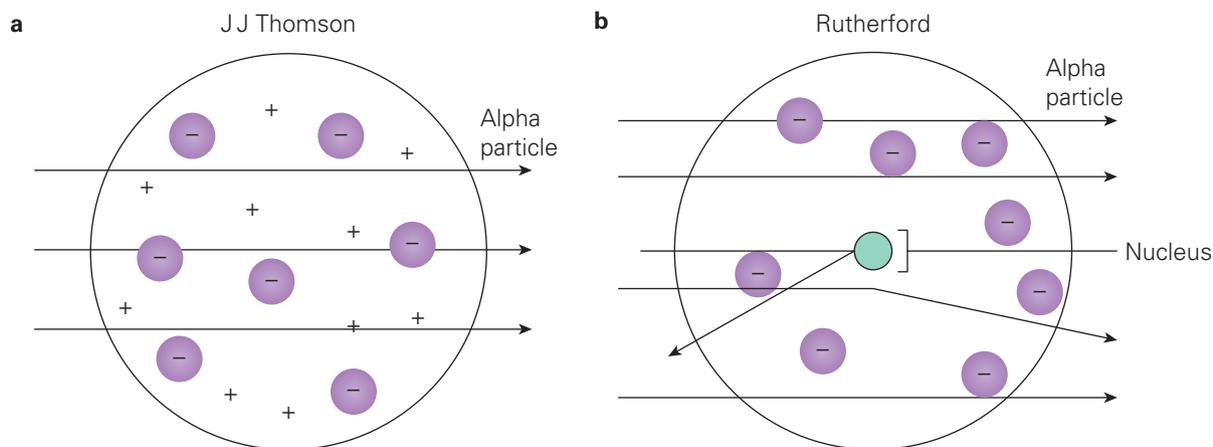


Figure 5.26 Comparison between atomic models: (a) Thomson's plum pudding and (b) Rutherford's central region of mass and charge

- 1 Recall what Aristotle believed all matter on Earth was composed of.
- 2 What subatomic particle did Thomson discover and what was the name of his atomic model?
- 3 Complete the sentence below using the word list.

alpha empty space plum pudding model
concentrated mass and positive charge 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 hit a region of _____ or _____, disproving the _____ theory.

Quick check 5.8

Practical 5.5

Most of an atom is empty space

In this experiment, you are going to make a scale model of a hydrogen atom. Hydrogen atoms contain one proton and one electron, it is the simplest atom on Earth. You may need a larger space than the classroom to do this, therefore 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.

continued...

...continued

Aim

To represent the distances between subatomic particles in an atom.

Materials

- calculator
- metre ruler
- various spherical objects; for example, marbles, table tennis balls, dried peas
- pencil
- 30 cm ruler
- scissors
- ball of string
- pair of compasses (for drawing a circle)
- A4 plain paper

Method

- 1 Using the pair of compasses, draw a small circle on a piece of paper and record the exact diameter in the results table. This represents a proton.
- 2 Using the important facts at the start of the activity, calculate the relative distance of the electron from the proton.
- 3 Measure a piece of string to the distance calculated in step **2** 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.
- 4 Measure the diameter of your chosen spherical object with the 30 cm ruler and record it in the results table.
- 5 This is the new diameter of the proton, now calculate the relative distance of the electron from the proton in hydrogen.
- 6 Measure a piece of string to the distance calculated in step **2** 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.
- 7 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	

Evaluation

- 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.

Conclusion

What can you conclude about the size of the proton and the distance between it and the electron?

By the early twentieth century, scientists had a fairly good idea about atomic structure, they just needed to work out what exactly the electrons were doing in the atom.

Niels Bohr 1885–1962

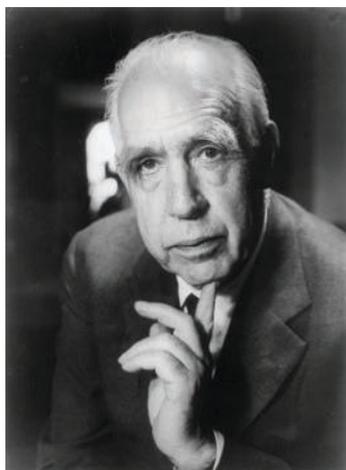


Figure 5.27 Niels Bohr proposed that electrons were not just spread across the atom randomly but were arranged in discrete energy levels or shells.

Niels Bohr proposed his model of the atom (a modification of Rutherford's theory) in 1913 after looking at the behaviour of electrons. Bohr was trying to compare the behaviour of electrons and light. He said electrons moved in fixed circular orbits around the nucleus in structures called shells, and that these shells were specific distances away from

the nucleus and the same for all atoms.

Electrons located in shells that were further away from the nucleus had higher energies than those closer to it. He stated that when electrons absorb energy, or get excited, they will jump to the next energy level or shell. When they fall back to their original level they will emit some light, which matches the amount of absorbed energy.

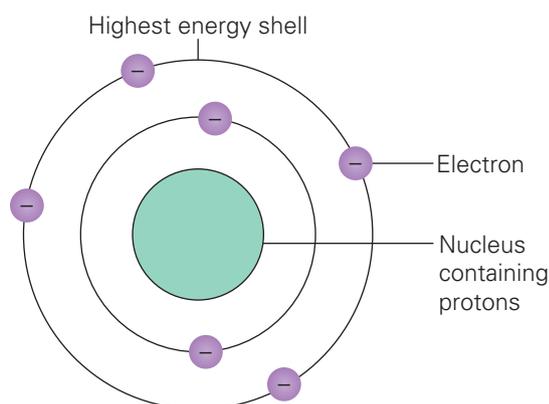


Figure 5.28 Bohr's model of the atom is sometimes called the planetary model. It shows electrons in fixed shells around a central nucleus.

Scientists now know that Bohr's model was flawed, but it provided some important understanding surrounding 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

The position and behaviour of electrons in the atom was still an area that scientists knew very little about. 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. This is connected with the wave properties of the electron (quantum- or wave-mechanics).



Figure 5.29 Erwin Schrödinger proposed the electron cloud model, contradicting Bohr's model of fixed electron shells.

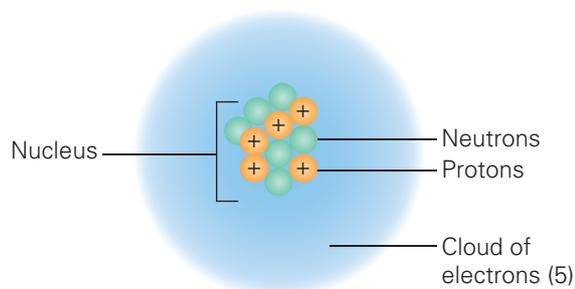


Figure 5.30 The electron cloud model of a boron atom

James Chadwick 1891–1974

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



Figure 5.31 James Chadwick discovered the neutron, completing the atomic model in use today.

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.

- 1 Recall the name Bohr gave to the structures that contained electrons.
- 2 How did this explanation of these structures differ from Rutherford's model?
- 3 Identify the subatomic particle that James Chadwick discovered.

Quick check 5.9

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 he named the Higgs boson. The detection of this particle now became his goal as well as the goal of many other theoretical physicists around that time.

In 2012, CERN announced that they had conducted experiments 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 won 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!

Science as a human endeavour 5.2

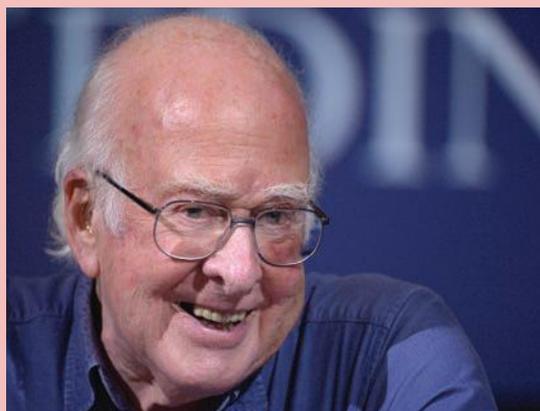


Figure 5.32 Peter Higgs (1929–present) discovered the presence of a new particle, which was named the Higgs boson.



Figure 5.33 Engineers attending to a part of the Large Hadron Collider at CERN where the Higgs boson was discovered

The evolution of the atomic model is an excellent example of how different scientists individually contribute 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 5.35 summarises the development of the modern atomic model.

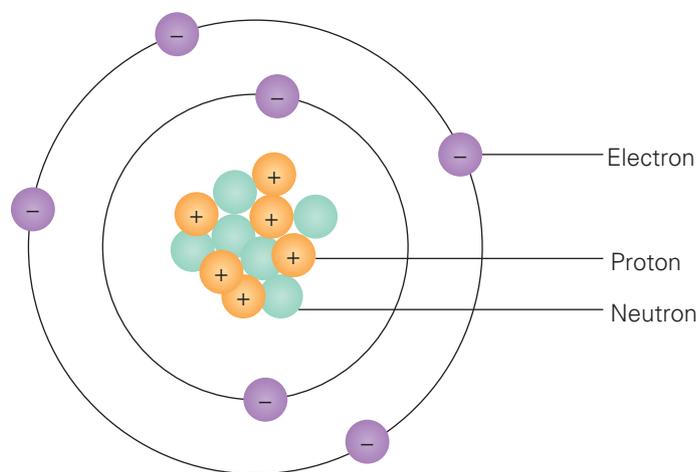


Figure 5.34 The modern-day atomic model

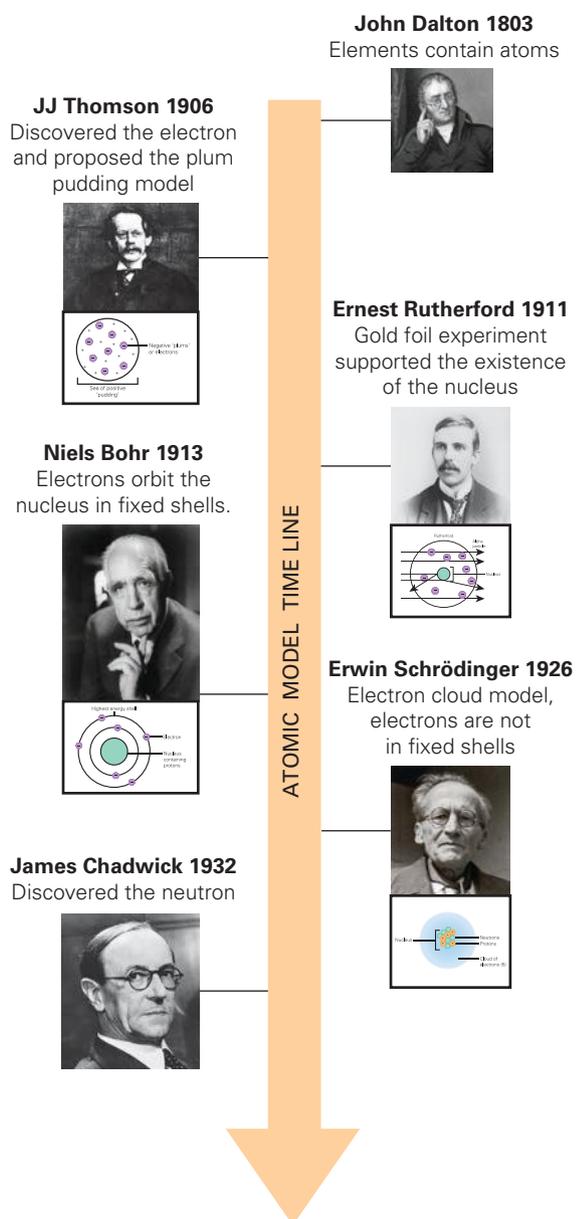


Figure 5.35 A summary of the development of the atomic model

Section 5.4 questions



QUIZ

Remembering

- 1 What does the Greek word *atomos* mean in English? How does this relate to the word 'atom'?
- 2 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.

Analysing

- 6 Analyse the differences between Schrödinger's and Bohr's models of the atom.

Evaluating

- 7 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.

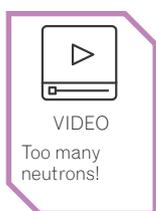


Isotopes



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.

Who discovered isotopes?

The presence of isotopes was first proposed by Fredrick Soddy in 1913. In his early career Soddy worked closely with Ernest Rutherford in Canada, but it was his



Figure 5.36 Fredrick Soddy discovered isotopes in 1913 in his work on uranium.

work on uranium, which he conducted in Scotland, that earned him the Nobel Prize for Chemistry in 1921. He noticed that atoms of the same element could have different atomic masses but behave the same. He named these elements isotopes, which means 'same place', as they were in the same place on the periodic table. For a while, scientists could not explain why this

occurred until James Chadwick discovered the neutron.

Let's take a look at an example. There are three forms of carbon that exist naturally. All three of these forms are the element carbon as they all have an atomic number of 12 (12 protons).

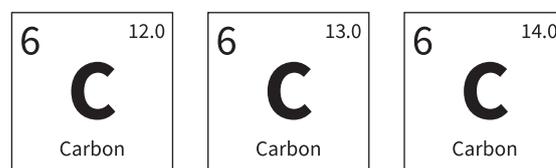


Figure 5.37 The three naturally occurring isotopes of carbon

Notice that they all have different mass numbers. This difference in mass number is because they all 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

It is important that you learn the conventions when naming isotopes. They are named based on their mass number. The element name comes first and then the mass number. You will notice that on the periodic table the atomic number is written at the top, this is because this is the number used to define the element. When you write the symbols for isotopes,

the convention is to write the mass number on the top and the atomic number on the bottom, as this time it is the mass number that defines the isotope. For example, the first isotope of hydrogen in Figure 5.38 is called hydrogen-1 (H-1), also known as protium; the second is hydrogen-2 (H-2) or deuterium and the third, as you may have guessed, is hydrogen-3 (H-3) or tritium.

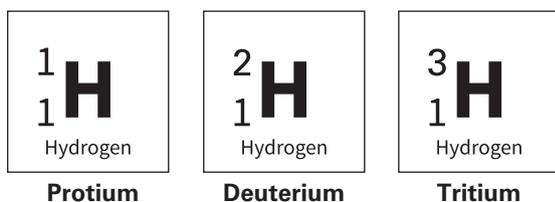


Figure 5.38 The three naturally occurring isotopes of hydrogen

Unusual mass numbers

Explore! 5.5

The mass number 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. Chlorine has two naturally occurring stable isotopes, Cl-35 and Cl-37.

Use the information above and your own research to answer the following questions.

- 1 What is the difference between Cl-35 and Cl-37?
- 2 Why is the mass number of chlorine recorded as 35.5 on the periodic table?
- 3 Which isotope of chlorine do you think there is more of in nature?

- 1 Define the term 'isotope'.
- 2 How would you name an isotope of magnesium that has a mass number of 25?

Quick check 5.10

Practical 5.6

Isotopes

Aim

To investigate the number of subatomic particles in isotopes of the same element.

Materials

- 3 plastic containers containing two different colours of balls of similar size

Method

- 1 Fill each container with two different colours of balls of similar size. These containers represent individual atoms. Each container must have the same number of balls of one colour, and varying numbers of the other colour. The number that does not change is representative of the protons, and the other, the number of neutrons.
- 2 Count the number of 'protons' in each of the isotopes and record in the results table.
- 3 Count the number of 'neutrons' in each of the isotopes and record in the results table.
- 4 Using the number of protons and neutrons record the mass number of the isotopes in the results table.

Results

Copy and complete the results table below.

Isotope	Number of protons	Number of neutrons	Mass number
1			
2			
3			

Evaluation

- 1 If the three isotopes were weighed using a balance, would they all have the same mass? Give a reason for your answer.
- 2 Propose a way of determining the average mass of the three isotopes.

continued...

...continued

- 3 What is the same about all three isotopes?
- 4 Other than the number of neutrons, explain what else is different between the isotopes.

Conclusion

Describe the composition of subatomic particles in isotopes of the same element.

Stable and unstable isotopes

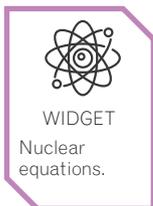
The stability of an isotope means how likely it is to break down or decay into other, lighter elements. Often, the heavier the isotope (that is, the more neutrons it has), the less stable it is. Unstable isotopes, such as the isotopes of the element uranium, are often called radioisotopes. In

these types of isotopes **radioactive decay** occurs to try to achieve a stable nucleus. (This will be 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 (splitting of the nucleus). Elements can have more than one stable isotope, such as carbon-12 and carbon-13. Table 5.3 summarises the differences between stable and unstable isotopes.

radioactive decay

when an unstable nucleus emits radiation (alpha and beta particles or gamma waves) and breaks down to form another element



Stable isotopes	Unstable isotopes
Have a stable nucleus	Have an unstable nucleus
Not radioactive	Radioactive

Table 5.3 A comparison between stable and unstable isotopes

Mass numbers in brackets

Look at francium (Fr) on the bottom left of the periodic table. It has parentheses around its mass number (223). Elements written like this are radioactive, so they are very unstable. Most of their isotopes decay into other elements relatively quickly. The mass number in parentheses therefore represents the most stable isotope of that element – the one that exists the longest.

Can you find other radioactive elements on the periodic table?

Did you know? 5.4

Recall the characteristics of unstable isotopes.

Quick check 5.11

Radioactive decay

You have already learned that isotopes of atoms that have an unstable nucleus are likely to undergo radioactive decay. The radiation that is released during the decay or splitting up of a nucleus can be alpha (α), beta (β) or gamma (γ) radiation.

Alpha decay

An alpha particle consists of two protons and two neutrons, which is the same as the nucleus of a helium atom. 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, in this case two elements lower on the periodic table. The equation in Figure 5.39 shows what happens when an atom of uranium undergoes alpha decay.

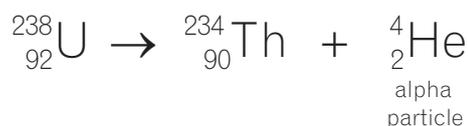


Figure 5.39 When a uranium-238 nucleus undergoes alpha decay, it becomes a thorium-234 atom. The atom of uranium has changed into an atom of thorium.

As a helium nucleus is emitted, the uranium atom loses two protons and therefore becomes a thorium atom. The mass number also decreases by 4 from 238 to 234. You will also see that a helium nucleus is emitted in the process.

When this happens, the emitted He-4 is often described as an alpha particle. Note that the helium nucleus has a +2 charge as there are no electrons involved in the decay; however, nuclear equations such as this are typically not concerned with showing the charges of atoms.

Beta decay

Beta particles are just fast-moving electrons emitted from the nucleus. During beta decay,

beta particles

a charged particle that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom.

a neutron is converted into a proton and an electron. The mass number of the remaining atom will not be affected as it has lost a neutron but

gained a proton. Consequently, the atomic number will increase by one, which changes the identity of the element altogether. The equation in Figure 5.40 shows what happens during beta decay. The potassium atom has gained a proton and lost a neutron to become a calcium atom and a high-energy beta particle (electron) has been emitted.

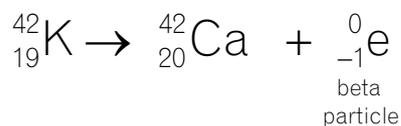


Figure 5.40 When a potassium-42 nucleus undergoes beta decay, it becomes a calcium-42 atom and emits a beta particle.

Gamma decay

Gamma decay is different from alpha and beta decay in that the atom that is 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 rather than a particle. The equation in Figure 5.41 shows gamma decay of radioactive iodine.



Figure 5.41 When radioactive iodine decays, a gamma ray is emitted.

Electromagnetic radiation

As previously discussed, a **gamma ray** (sometimes called photons) is a high-energy wave and unlike the emissions from alpha and beta decay. You might be surprised to learn that this emission is in fact a form of light! Light can move in the form of a wave, even if our eyes cannot detect it.

gamma rays

are electromagnetic radiation with an energy level above a specified amount/wavelength shorter than a specified amount

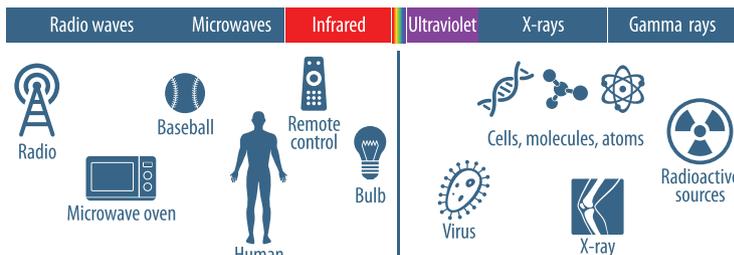
The full range of the forms of light is called the **electromagnetic spectrum**. The light you see in your daily life is a form of light called visible light and is only a tiny sliver of the whole spectrum, therefore you cannot see the other types of waves.

electromagnetic spectrum

the range of all possible forms that light can take, plotted out in terms of lowest to highest frequency of the light wave

ELECTROMAGNETIC SPECTRUM

WAVELENGTHS



VISIBLE SPECTRUM



FREQUENCY



Figure 5.42 Depending on the frequency and wavelength of the wave, light can take forms including radio waves, microwaves, infrared (IR) radiation, ultraviolet (UV) radiation, X-rays and gamma rays. Look at how small the visible light section is on the spectrum. There is a lot going on in the world around us, even if you cannot see it!

The discovery and manipulation of electromagnetic radiation has led to enormous benefits throughout society. The transmission of microwaves is essential to using wireless internet, mobile phones, radar technology and microwave ovens. In the case of wireless internet and communication, microwaves are transmitted from your modem at a set frequency and your device such as a phone or computer has a detector to pick up that same frequency.

Ultraviolet (UV) radiation is emitted by the Sun and UV-emitting torches known as 'black lights' are used by forensic scientists to help solve crimes by revealing material no longer visible to the human eye. Electromagnetic radiation is also incredibly important to the field of

medicine. Without X-rays, doctors could not easily spot fractures (broken bones), and gamma rays are widely used in the treatment of cancer.

Many animals, such as birds, fish and snakes, can 'see' beyond visible light. Research one of these animals and find out how they use greater access to the electromagnetic spectrum to their advantage.

Explore! 5.6

Ionising versus penetrating radiation

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 5.4 and Figure 5.43 summarise the properties of the three types of radiation.

Type of radiation	Penetrating power	Ionisation power
Alpha	Least penetrating. It can be stopped by a sheet of paper.	Very strongly ionising therefore 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.	Not very ionising therefore cause the least damage, but they can penetrate the body, and strong gamma rays are used to kill cancer cells.

Table 5.4 Properties of the three different types of radiation

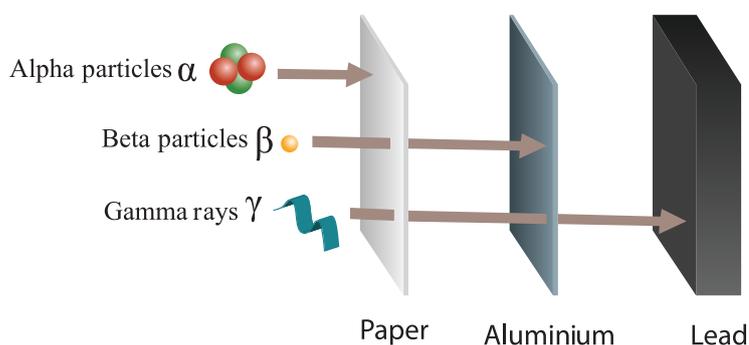


Figure 5.43 The penetrating power of alpha, beta and gamma radiation

- 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.
- 4 List the different types of energy in the electromagnetic spectrum.

Quick check 5.12

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.

Other isotopes used in daily life include: sodium-24 (Na-24), which is used in detecting leakages in pipes that are difficult

to access; carbon-14 (C-14), which is used in dating historical artefacts and nitrogen-14 (N-14), which is used in detecting explosives.

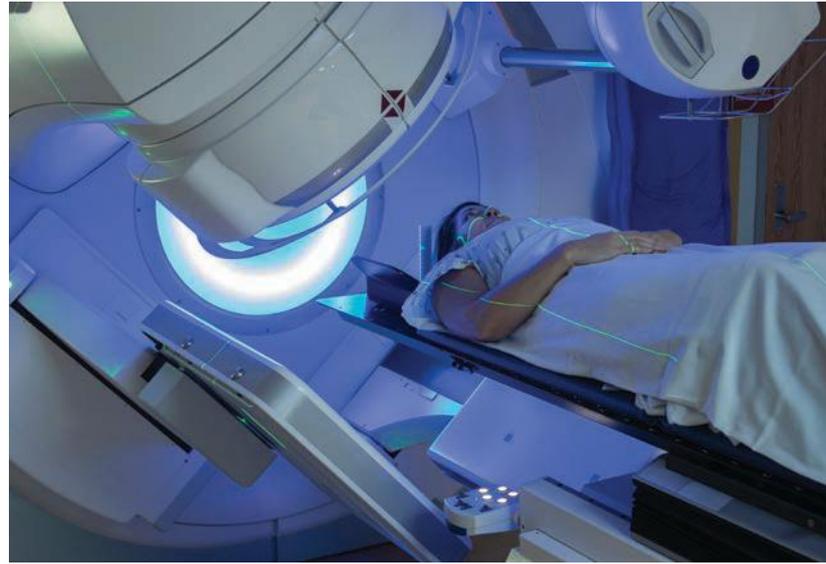


Figure 5.44 A patient undergoing radiotherapy for cancer

Practical 5.7: Self-design & Teacher demonstration

Investigating the penetration of alpha, beta and gamma radiation

You have been provided with the following materials. Suggest an experiment that could be done using this equipment to show the penetrating properties of alpha, beta and gamma radiation. You may wish to draw a diagram or write a method to demonstrate that you have done this task.

Aim

To investigate the penetrative strengths of ionising radiation.

Materials

- alpha radiation source
- beta radiation source
- gamma radiation source
- Geiger–Müller tube (detects radiation)
- absorbing materials:
 - sheet of paper
 - aluminium sheet
 - lead sheet

Method

Your teacher will now 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		

continued...

Be careful

This practical should only be undertaken by properly trained personnel.

...continued

Evaluation

- 1 Identify the most penetrating radiation and justify your choice.
- 2 Discuss how the experiment could be modified to show the effectiveness of the radiation over different ranges and thickness of absorbers.
- 3 Propose which type of radiation you think could cause the most damage if it gets into our bodies.
- 4 Research the effects that radiation can have on the body to explain why it is so damaging.

Conclusion

- 1 Make a claim from this experiment regarding the penetrating power of various types of radiation.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.



QUIZ

Section 5.5 questions

Remembering

- 1 Define the term 'isotope'.
- 2 Identify the name of an isotope of barium with a mass number of 130.
- 3 What is the name of an isotope of potassium with 22 neutrons?
- 4 Name three important uses of radioisotopes.
- 5 Define the electromagnetic spectrum.

Understanding

- 6 Compare and contrast these isotopes of sodium: Na-23 and Na-24.
- 7 Outline the relationship between the mass of an isotope and its stability.
- 8 Summarise what happens to the nucleus of an element during alpha decay.

Applying

- 9 Construct an equation to show the alpha decay of uranium-235 to thorium-231.

Analysing

- 10 List the main differences between stable isotopes and radioisotopes.

Evaluating

- 11 An element undergoes radioactive decay; its atomic number and mass number are not affected. Deduce the type of decay.
- 12 During the radioactive decay of an isotope a high-energy electron is released. Deduce the type of decay.

Review questions

Remembering

- 1 Give the names of the three subatomic particles within the atom.
- 2 In the table below, match the subatomic particle to the correct charge.

Subatomic particle	Charge (e)
Proton	0
Neutron	-1
Electron	+1



SCORCHER

- 3 Define the term 'isotope'.
- 4 Where are the protons and neutrons located within the atom?
- 5 What is the difference between an element and a compound?
- 6 If an atom has 18 protons, how many electrons does it have?
- 7 What type of particle is released during beta decay?

Understanding

- 8 Describe the planetary model of the atom.
- 9 Explain why atoms of elements have a neutral overall charge.
- 10 Complete the equation to show the particle released during alpha decay.



- 11 Explain how Rutherford's gold foil experiment led to the discovery of the nucleus.
- 12 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

- 13 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).
- 14 Explain why the neutron was difficult to discover.
- 15 Deduce the relationship between the mass of an element and how stable it is.
- 16 Explain why radioactive sources in schools must be stored in lead-lined boxes.

Analysing

- 17 Describe the differences between isotopes of the same element.
- 18 Compare the properties of the subatomic particles in terms of their mass and charge.
- 19 Ionising radiation is used in smoke detectors. Which type of radiation would you choose for this use and why?
- 20 Democritus and Aristotle were philosophers, not modern scientists. In what ways were their thoughts 'scientific' and in what ways are they 'not scientific'? Discuss how significant their contributions were to atomic theory.

Evaluating

- 21 Suggest why the atomic model has changed and why it may continue to do so.
- 22 'The current atomic model is perfect and accurate.' Appraise the accuracy of this statement.
- 23 Do you expect the atomic model to change significantly in the future? Justify your answer.
- 24 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.

STEM activity: Designing and creating a product using bioplastics

Background information

Plastic is one of the most commonly used substances today. It is used for everything from food packaging to toys, from building materials to clothing, and even medical implants. Plastic was invented in 1907 and has revolutionised manufacturing of a multitude of different products because of its versatility. Plastic can be hard, soft, stretchy, bendable, strong or durable.

Molecules are atoms that are bonded together. Chemically, plastic consists of long chains of molecules called polymers. This is why the names of many plastics start with poly-. The polymers are made up of carbon and hydrogen, and sometimes oxygen, nitrogen, sulfur, phosphorus, fluorine or silicon.

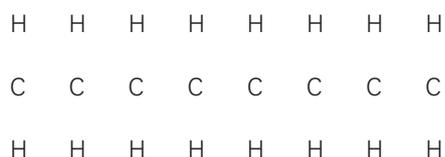
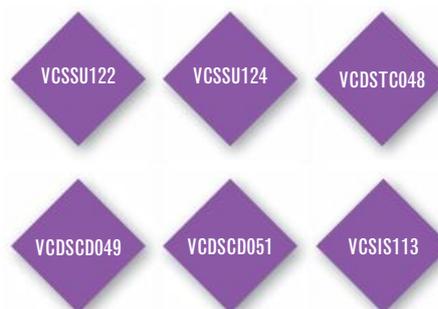


Figure 5.45 Polyethylene is the simplest plastic, consisting of a long chain of carbon atoms and hydrogen atoms.



There are two main problems with the amount of plastic that is used. Firstly, most plastic is made from crude oil, a limited resource that is harmful to the environment to extract. Secondly, because of their molecular structure, plastic is very difficult to biodegrade (break down). Plastic litter builds up in our waterways and kills wildlife, as well as leaching harmful toxins into the environment.



Figure 5.46 Plastic litter builds up on our beaches.



Figure 5.47 An oil refinery

Bioplastics are a type of plastic made from renewable resources like plants. They can easily be

Bioplastic

a type of plastic made from renewable resources like plants

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. You can start by brainstorming everything you have used today that is made of plastic and documenting these ideas using a cognitive organiser like a mind map. You should then show your ideas to your teacher and ask them to approve your idea before beginning your design.

You will need to research how to make bioplastic and decide on a method. Write down the ingredients you will need and their quantities, and the method you will follow.

Once your teacher has approved your method and design, you may begin creating your product.

Suggested materials

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.

- corn starch
- vinegar
- glycerine
- water
- non-stick/baking paper/aluminium foil and tray
- cookie cutters or moulds to shape the plastic
- Safety glasses
- food dye (optional)
- saucepan
- wooden spoon
- hotplate

Evaluate and modify

- 1 Describe any difficulties you encounter when creating your product out of the bioplastic.
- 2 Suggest ways that the design of your product could be improved.
- 3 List the physical properties of your bioplastic and comment on how appropriate these properties were for your product.
- 4 Test your product by using it for its intended purpose under different conditions.
- 5 Evaluate the effectiveness of your product.

Chapter 6 Chemical reactions

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 to classify reactions as exothermic or endothermic. Finally, you will find out what is formed when acids react with bases, metals and carbonates.

Curriculum

Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed (VCSSU124)

- | | |
|---|-----|
| • modelling chemical reactions in terms of rearrangement of atoms | 6.1 |
| • considering the role of energy in chemical reactions | 6.3 |
| • recognising that the conservation of mass in a chemical reaction can be demonstrated by simple chemical equations | 6.2 |

Chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer (VCSSU126)

- | | |
|--|-----|
| • investigating a range of different reactions to classify them as exothermic or endothermic | 6.3 |
| • comparing respiration and photosynthesis and their role in biological processes | 6.4 |
| • investigating reactions of acids with metals, bases, and carbonates | 6.5 |

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Glossary terms

acid

activation energy

base

chemical change

combustion

conservation of mass

endothermic

exothermic

neutralisation

photosynthesis

product

reactant

reaction conditions

rearranged

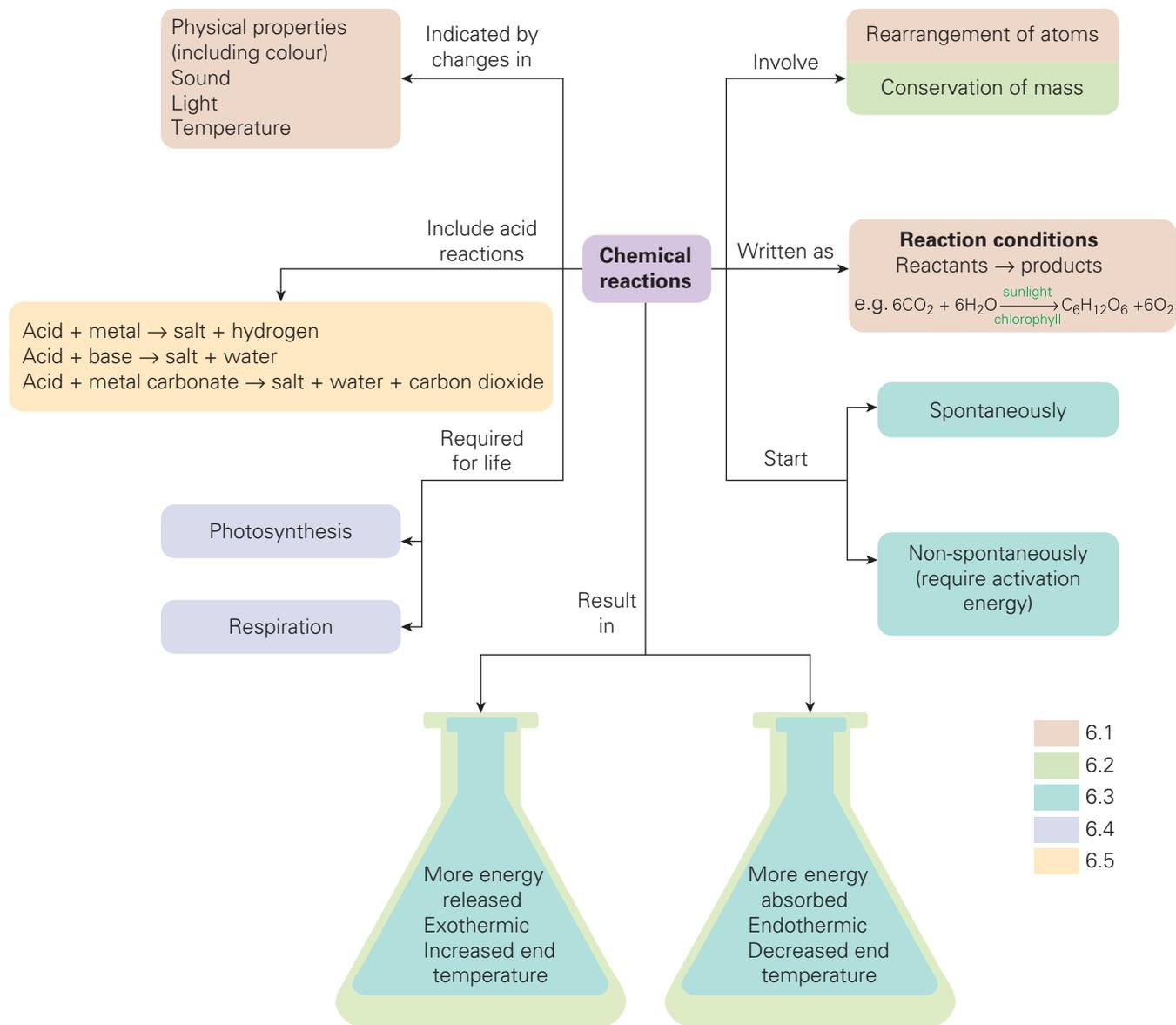
respiration

salt

spontaneous reaction



Concept map





6.1 Introduction to chemical reactions

By now in your Science lessons you will have carried out a number of chemical reactions, all for different purposes. But did you know that almost everything around you has been created because of chemical reactions? The bread that you eat as part of your sandwich at lunchtime, the paper that these words are written on, the very reason we all exist, is because of chemical reactions.



Figure 6.1 All the ingredients in your sandwich, from bread to salt, were made by chemical reactions.

What is a chemical reaction?

The simplest way to describe a chemical reaction is that existing substances are converted into new substances, but of course it is not as simple as that. During chemical reactions, the atoms in the existing substances are rearranged to make new substances. For this to happen, bonds holding the atoms together in the existing substances must be broken and new bonds need to form in different arrangements to make the new substances.

Figure 6.2 shows an example of 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; that is, the atoms have been **rearranged**. The new substances are different from the original substances, therefore a chemical reaction has taken place. The arrow in a chemical reaction separates the original substances that react together with the new substances produced by the reaction. When reading a chemical equation aloud, the arrow is often read as ‘yields’.



WORKSHEET

rearranged
the process of moving things into a different order

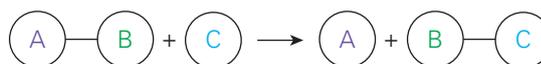


Figure 6.2 Rearranging atoms in a chemical reaction

Let’s look at a real-life example. Figure 6.3 shows the chemical reaction between carbon and oxygen. In this chemical reaction the bond between the two oxygen atoms is broken, the atoms are rearranged, and new bonds are formed between each oxygen atom and the carbon atom. The new substance formed has the name carbon dioxide.

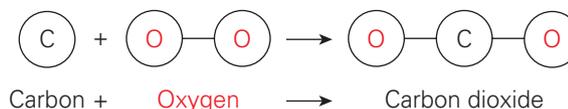


Figure 6.3 Formation of carbon dioxide is a chemical reaction.

The rearrangement of the atoms has a huge effect on these 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 6.3 are so different from the existing substances.

Practical 6.1: Teacher demonstration

Forming a compound from its elements

Aim

To investigate the change in physical properties in a chemical reaction.

Materials

- steel wool
- metal tongs
- 9 V battery
- digital balance

Method

- 1 Weigh an amount of steel wool on the balance and record the weight.
- 2 Using the metal tongs, hold the steel wool and ignite the wool with the 9 V battery.
- 3 Reweigh the steel wool after it is sufficiently burned and no longer sparking.

Results

Reactants	Properties
Iron	
Oxygen	

Product	Properties
Iron oxide	

Evaluation

- 1 List the physical properties of the two existing substances and describe how they are different from the new substance formed.
- 2 Outline the other indications that showed that this was a chemical reaction.
- 3 Complete the word equation below to show what happened in this chemical reaction.
 _____ + _____ → iron oxide
- 4 Is iron oxide an element, compound or mixture? How do you know? (Remember that an element is made up of only one type of atom; a compound is a molecule made up of two or more **different** atoms bonded together, and a mixture is a substance made up of different elements and/or compounds that are not chemically bonded.)

Conclusion

- 1 Make a claim from this experiment regarding chemical reactions and physical properties.
- 2 Support the statement by using your observations (include potential faults in the experiment).
- 3 Explain how your observations support your claim.

Be careful

Ensure protective equipment is used as fire is involved.

- 1 Explain how new substances are formed during a chemical reaction.
- 2 Describe what is happening to the substances in the equation below.



Quick check 6.1

Living concrete that can repair itself

Concrete is the one of the world's most popular building materials and has been used since the Roman times. 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, has discovered a solution to this problem: concrete containing bacteria that can repair itself. The bacteria that was selected for this process needed to be able to survive dormant for long periods of time, without food or oxygen as well as withstand the alkaline conditions of the concrete itself.

Bacillus bacteria were chosen for the job, but *Bacillus* does not naturally produce the limestone, which is needed to repair the material. Henk 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, Henk 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 lactate into limestone, and the crack closes. He had made concrete that repairs itself!

Science as a human endeavour 6.1



Figure 6.4 The ageing and cracked concrete walls of Naples Island are in danger of collapse, which could flood the homes located along the canals.



Figure 6.5 *Bacillus* bacteria under a microscope

Indicators of a chemical change

The difference in properties between the existing and new substances is one way you can tell that a

chemical reaction has occurred, but there are other

distinctive ways in which this can be determined. In Year 8 you learned about the differences between a physical and a **chemical change**. Table 6.1 lists the main indicators of a chemical reaction to remind you.

chemical change

a rearrangement of atoms which is often irreversible



VIDEO
Indicators of a chemical reaction.

Change	Example
Colour	A silver-coloured iron nail reacting with oxygen and water to form red rust. 

continued...

Table 6.1 Indicators of a chemical reaction

Change	Example
Physical properties	<p>Sodium (a soft metal) reacting with water (a colourless liquid) produces sodium hydroxide (a colourless solution) and hydrogen gas.</p> 
Sound	<p>Hydrogen and oxygen reacting together to make water creates a loud bang.</p> 
Light	<p>Snapping a glow stick starts a chemical reaction that produces light.</p> 

TABLE 6.1 Continued...

Change	Example
Temperature	Magnesium metal reacting with an acid causes heat to be released.



TABLE 6.1 Continued...

Remember that a chemical change differs from a physical change, as chemical changes are sometimes irreversible. In such cases, this means that when a new substance has been formed in a chemical reaction, you cannot simply convert the new substance back into the original substances. Of course some chemical reactions that are irreversible by themselves can undergo further reactions to retrieve some of these original substances (for example, the copper cycle). All the reactions that have already been mentioned are all examples of chemical changes.

On the other hand, a physical change is reversible. The melting and freezing of water is an example of a physical change. (Note that physical change is not the same as a physical property change: a change in physical property is an indicator of chemical change.)

- 1 Recall examples of a chemical change occurring.
- 2 Indicate if the following statement is true or false. 'All chemical changes are irreversible.'
- 3 When a pan of water is heated on a cooker top, the water turns into steam. When the steam hits a cold window, it will condense back into liquid water. Is this an example of a physical change, chemical change or both?

Quick check 6.2

How is a chemical equation written?

Reactants and products

In a chemical reaction there will always be substances reacting with each other to form new substances. Until now you have referred to the substances reacting together as existing substances. As these are the substances doing the reacting, they are called **reactants**. Reactants are always on the left-hand side of

reactant
substance that is reacting in a chemical reaction



Figure 6.6 Ice melting and forming water is an example of a physical change.

product
substance formed in a
chemical reaction

a chemical equation; that is, they are always written first. The new substances that are formed are called **products**. Products are always written on

the right-hand side of an equation; that is, they are always written last. Figure 6.7 shows the reaction between magnesium and hydrochloric acid.

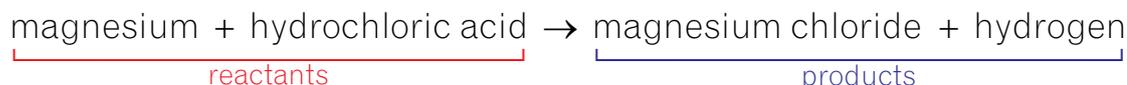


Figure 6.7 Chemical reaction between magnesium and hydrochloric acid

Magnesium and hydrochloric acid are reactants and, as you can see, they are on the left-hand side of the arrow. Magnesium chloride and hydrogen are products, so they are written on the right-hand side of the arrow. Notice that in-between the reactants and products is an arrow, not an equals sign. A chemical equation does not have an equals sign.

Reaction conditions

Not all chemical reactions happen spontaneously without us having to do anything to them. Some reactions require

heat or light energy to get started, some require a high pressure, some need a chemical called a catalyst to speed up the reaction, and others just require a longer amount of time.

These are all called **reaction conditions**. When they are present, they are written

reaction conditions
conditions required for
a chemical reaction to
proceed

above the arrow in a chemical equation. This shows that they are required for the reaction but do not get involved in the reaction. Think about the reaction conditions required when baking a cake – you certainly cannot do this without time and an oven!



Figure 6.8 The burning of petrol in car engine requires heat as a reaction condition.

- 1 On which side of a chemical equation are the products written?
- 2 On which side of a chemical equation are the reactants written?
- 3 Where should the reaction conditions be written in a chemical equation?

Quick check 6.3

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/browning meat, give other uses of this reaction.



Figure 6.9 Searing or browning of steak is an example of the Maillard reaction.

Explore! 6.1**Types of chemical equations**

You can represent chemical equations in three different ways: word equations, formula equations and molecular equations. All three ways have the same structure; an

arrow separating the reactants on the left and the products on the right. They only differ because of the way the reactants and products are represented. You will learn more about this next year.

Section 6.1 questions**Remembering**

- 1 State what \rightarrow means in a chemical reaction.
- 2 Name the reactants in 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 Name the products of the reactions in question 2.
- 4 Match the following keywords to the definitions.

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.

Understanding

- 5 Describe what happens to the atoms in reactants during a chemical reaction.
- 6 Compare and contrast the similarities and differences between physical and chemical changes.

continued...



QUIZ

*...continued***Applying**

7 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.

Analysing

8 Categorise the following examples as physical or chemical changes.

- a Sugar dissolving in a cup of tea
- b Iron nail rusting
- c Ice melting to form water
- d Frying an egg
- e Toasting bread

Evaluating

9 The following equation shows what happens during respiration in which glucose and oxygen (reactants) react together to make carbon dioxide and water (products). Deduce the three mistakes which have been made.



6.2 Conservation of mass



WORKSHEET

VIDEO
Law of conservation.

conservation of mass
a law that states that matter and energy can neither be created nor destroyed

One of the fundamental laws of chemistry is the law of **conservation of mass**. This law states that matter and energy can neither be created nor destroyed.

The history

In the eighteenth century, scientists thought that for something to burn it had to contain the element called

Mass and the universe

If the law of conservation of mass states that matter or energy can neither be created nor destroyed, how did the matter that is present now get here?

Carl Sagan, an American astronomer, said that 'we are made of starstuff'. 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 \times speed of light² or $E = mc^2$) explain this?

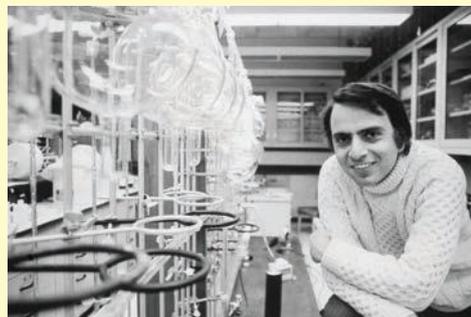


Figure 6.10 Carl Sagan said that 'we are made of starstuff'.

Explore! 6.2*continued...*

...continued

- 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?

phlogiston (from the Greek *phlox*, which means flame). They noticed that when something burns, the mass decreases, which led them to believe that phlogiston must be released when something is burned. That was

until Antoine Lavoisier, a French scientist, noticed that if you burn something in a closed environment, meaning that no substances can escape, the mass of the substances at the end stayed the same as the mass of the substances at the start. In 1789 he called this Lavoisier's law, which was later renamed the law of conservation of mass.



Figure 6.11 Antoine Lavoisier proposed the law of conservation of mass.



Figure 6.12 The mass of the pancake batter should equal the mass of all the pancakes made from it. This is the law of conservation of mass in action.

Putting the law of conservation of mass into practice

Earlier in this chapter you learned that the law of conservation of mass means that matter and energy can neither be created nor destroyed – but what does this mean? Take the mass of all the ingredients used to make a pancake (flour, eggs and milk). When the pancakes have been cooked, the mass of all the pancakes made from the batter should equal the mass of the starting ingredients. This means that no matter is created or destroyed. However, as this is not a closed environment, there might be a difference between the two as water evaporates from the batter during the cooking and matter appears to be lost.

On the other hand, a full glass of water left outside on a hot day will become half 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 steam, which leaves the glass and goes into the air. Steam has mass. The steam 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; that is, one in which nothing can escape. In an open system, reactions that produce gases will appear to lose or gain mass.



Figure 6.13
Leave a glass of water outside on a hot day and it will appear to lose mass.

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 6.14. Here copper chloride (CuCl_2) is being broken down into its elements: copper (Cu) and chlorine (Cl_2).

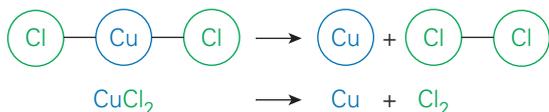


Figure 6.14 The molecular and symbol equations showing the breaking down of copper chloride into its elements

For this reaction to observe the law of conservation of mass, there must be the same number of atoms of each element in the reactants and products. In the reactants, 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 thing that is different is how the atoms are arranged.

Figure 6.15 shows the molecular and symbol equation for the reaction between magnesium (Mg) and oxygen (O_2) to form magnesium oxide (MgO).

- Quick check 6.4**

 - Who discovered the law of conservation of mass?
 - What is the definition of the law of conservation of mass?
 - If the mass of reactants is 30 g what will the mass of products be?
 - Discuss why it is difficult to observe the law of conservation of mass in an open system.
 - Explain why the mass of a glass of water left out on a hot day decreases.

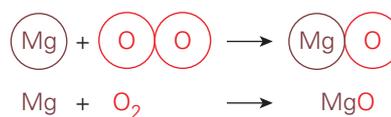


Figure 6.15 The reaction between magnesium and oxygen forms magnesium oxide.

What do you notice about the number of each type of atom in the reactants compared to the products? The number of each type of atom in the reactants and products is different. This means that this equation is not observing the law of conservation of mass. There is one magnesium atom on each side of the arrow; however, there are two oxygen atoms on the left-hand side and only one on the right, resulting in the products having less mass than the reactants. This simply does not happen. Therefore the chemical equation must be made to show that the law of conservation of mass is observed.

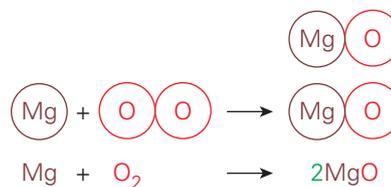


Figure 6.16 This equation now has the correct number of oxygen atoms. It is still not observing the law of conservation of mass though.

You should now be able to see that by adding another molecule of magnesium oxide, the same number of oxygen atoms is on each side of the equation, as shown

in Figure 6.16. Notice that the symbol equation also shows that there are two magnesium oxide molecules. However, at the same time another magnesium atom has also been added. The reaction therefore requires two atoms of magnesium to react with the oxygen. By adding another magnesium atom to complete the balanced equation, the same numbers of each atom are now on each side of the equation (two magnesium atoms and two oxygen atoms), as shown in Figure 6.17. Again, notice that the symbol equation also reflects the addition of another magnesium atom.

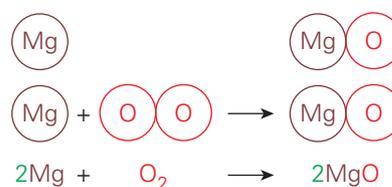


Figure 6.17 The correct balanced equation which has the same number of each atom in the reactants and products and therefore observes the law of conservation of mass.

For now, you just need to concentrate on identifying whether equations observe the law of conservation of mass. In Year 10 you will learn how to balance chemical equations so that they follow this law.

- 1 Explain why it is necessary to balance equations.
- 2 Harry and Rebecca were doing an experiment in the laboratory. They measured the mass of reactants as 50 g. After the reaction had completed, the mass of the products was 34 g. They noticed that a gas was given off during the reaction so they wanted to find out the mass of this gas. Explain to Harry and Rebecca how they could calculate this.

Quick check 6.5

Practical 6.2

Observing the law of conservation of mass (1)

Aim

To observe the law of conservation of mass by reacting vinegar and baking soda.

Materials

- $\frac{1}{2}$ cup of vinegar (acetic acid)
- $\frac{1}{2}$ cup of baking soda
- balance
- 2 plastic cups
- resealable plastic bag (big enough to fit in the two cups comfortably)

Method

- 1 Draw the results table.
- 2 Pour the vinegar into one cup until it is half full.
- 3 Fill the second cup halfway with baking soda.
- 4 Put both cups into the plastic bag. DO NOT spill any of the contents of the cups.
- 5 Measure the mass of the two filled cups 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 cup of baking soda.

continued...

...continued

- 8 When you think the chemical reaction has finished, record the mass of the contents without opening the bag. Record this in your results table.
- 9 Calculate the change in mass using the initial mass and final mass results. Record these in your results table.

Results

Initial mass (g)	Final mass (g)	Change in mass (g)

Evaluation

- 1 Describe your observations when the vinegar and baking soda reacted in the plastic bag. How did you know that a chemical change had occurred?
- 2 The gas produced in the reaction is the same as one of the ones you breathe out. What is the name and formula of this gas?
- 3 When vinegar (acetic acid) reacts with baking soda (sodium bicarbonate), sodium acetate, water and carbon dioxide are produced. Write a word equation for this reaction.
- 4 This experiment was carried out in a closed system. Deduce what you think this means.
- 5 Explain why this reaction is a difficult example for showing the law of conservation of mass.
- 6 Propose how you could have made it easier to demonstrate the law of conservation of mass.

Conclusion

- 1 Make a claim from this experiment regarding chemical reactions and the conservation of mass.
- 2 Support the statement by using your observations (include potential faults in the experiment).
- 3 Explain how your observations support your claim.

Practical 6.3: Self-design

Observing the law of conservation of mass (2)

Aim

To design and conduct an experiment to demonstrate the law of conservation of mass.

Materials

- 3 Alka-Seltzer® tablets
- water
- balloon
- conical flask
- measuring cylinder
- any other equipment available upon request to your teacher

Method

Write a step-by-step method of how you will carry out the experiment. Remember, the steps must be in chronological order and include command words at the start of each step, for example, 'Measure ...'

continued...

...continued

Results

Initial mass (g)	Final mass (g)	Change in mass (g)

Evaluation

- 1 Propose how you could have improved the experimental design to more effectively measure the change in mass.
- 2 Explain how you know that a chemical reaction has taken place.
- 3 When Alka-Seltzer[®] is added to water it does not react with the water, but it reacts with itself. Research what happens to the chemicals within the Alka-Seltzer[®] tablet when it mixes with water.
- 4 When an Alka-Seltzer[®] tablet is mixed with water, the reactants – citric acid and sodium bicarbonate – react together to produce the products – water, sodium citrate and carbon dioxide. Construct a word equation for this reaction.

Conclusion

- 1 Make a claim from this experiment regarding chemical reactions and the conservation of mass.
- 2 Support the statement by using your observations (include potential faults in the experiment).
- 3 Explain how your observations support your claim.

Section 6.2 questions

Remembering

- 1 Recall the law of conservation of mass.

Understanding

- 2 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

- 3 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

- 4 Identify the mass of the products in the following scenarios.
 - a 35 g of reactants
 - b 12 g of reactants
 - c 2 g of one reactant added to 24 g of another reactant
 - d 6 g of one reactant added to 3 g of another reactant

continued...

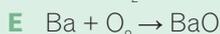
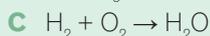
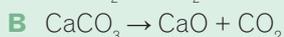


QUIZ

...continued

Analysing

5 Analyse the following chemical equations to determine which of them observe the law of conservation of mass.



6 Distinguish between an open and a closed system.

Evaluating

7 Decide whether an open or a closed system is better to observe the law of conservation of mass. Justify your choice.

8 In a chemical reaction, the mass of the reactants was 15 g. The mass of the products was 12 g. Decide whether this reaction followed the law of conservation of mass. Justify your choice.

9 Joy and Paul leave a glass of water on their balcony. 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.



6.3 Energy and chemical reactions



WORKSHEET

In many chemical reactions, the energy consumed or released can play a huge part in whether the reaction is considered useful or efficient.

Spontaneous versus non-spontaneous reactions

If you have carried out chemical reactions in your Science lessons already, you may have observed that some of them happened quickly, as soon as the reactants were mixed, and others may have required some energy, most likely in the form of heat, to get them started. Reactions that do not require any

energy input to get started are called **spontaneous reactions**; that is, they happen straight away. The rusting of iron in oxygen and water is an example of

a spontaneous reaction, and although it is slow, it requires no other energy input for the reaction occur. Non-spontaneous reactions are those that require an energy input. This energy input is called the **activation energy**. Baking bread is an example of this type of reaction, as you need to heat the dough in an oven for the reaction to start.

spontaneous reaction
reaction that does not require any energy input to get started

activation energy
energy required for a non-spontaneous chemical reaction to occur



Figure 6.18 Baking bread is an example of a non-spontaneous reaction as it requires heat energy to start.

Any reactions in your Science lessons that require a Bunsen burner to start them are all examples of non-spontaneous reactions.

On the other hand, there are substances that will not react at all, even if a huge amount of energy is given.



Figure 6.19 Any reactions that need a Bunsen burner to get them started are non-spontaneous.

Exothermic and endothermic reactions

Because you cannot see atoms and molecules in a chemical equation, it can be easy to think of them as stationary (because you cannot see what happens in a chemical equation). However, molecules and atoms are constantly moving, which means they have kinetic (movement) energy. There is also potential energy stored within the bonds between atoms in molecules and compounds. When the atoms rearrange in a chemical reaction, the potential energy stored in the bonds also changes. Sometimes energy is lost from the reaction 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.

exothermic
heat is released from a reaction characterised by an increase in surrounding temperature



Figure 6.20 Burning wood is an example of an exothermic reaction because heat is released.

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; that is, heat leaving the reaction. You can tell if a reaction is exothermic because you will see a rise in its temperature. Heat has left the reaction and gone into the surroundings; it is the temperature of the surroundings that you will measure in an experiment.

EXO **THERMIC**
External Heat

Figure 6.21 The word 'exothermic' when split up means external heat.

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 6.22.

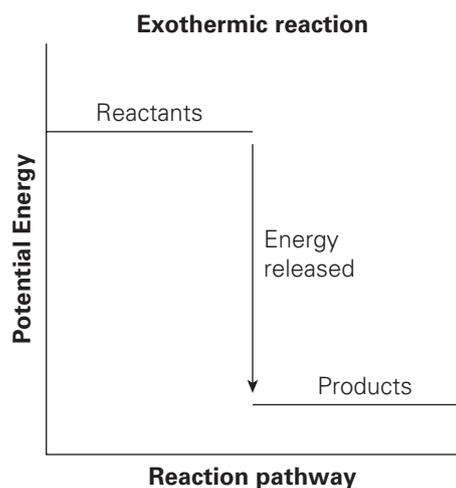


Figure 6.22 An energy level diagram for an exothermic reaction

In this reaction, the reactants have more energy than the products, so there is surplus energy released into the surroundings. This is indicative of an exothermic reaction.

- Quick check 6.6**
- 1 State the name of the reactions that occur without needing energy input.
 - 2 State the name of the energy input to start a chemical reaction.
 - 3 During a chemical reaction between hydrochloric acid and sodium hydroxide, the temperature went up by 5°C. Identify the reaction type.
 - 4 Burning wood is an example of an exothermic reaction because the products have more potential energy than the reactants. Propose whether this is true or false.

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.

endothermic
an absorption of heat characterised by a decrease in surrounding temperature

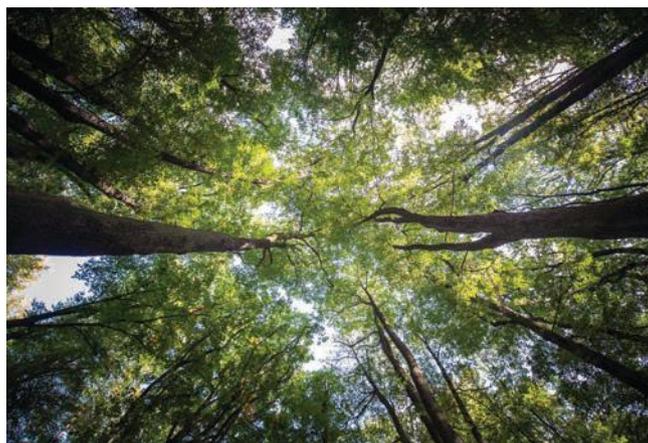


Figure 6.23 Photosynthesis, in which plants use the Sun's light energy to make their own food, is an example of an endothermic reaction.

Again, if you split up the word, *endo* means internal and *thermic* means heat. You can tell if a reaction is endothermic because you will see a decrease in temperature: heat has left the surroundings and has gone into the reaction. In an experiment, you measure the temperature of the surroundings.

ENDO THERMIC

Internal Heat

Figure 6.24 The word 'endothermic' means internal heat.

In endothermic reactions the products have more energy than the reactants, which is why this 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 6.25. In this reaction, the products have more energy than the reactants, so energy is absorbed into the reaction from the surroundings.

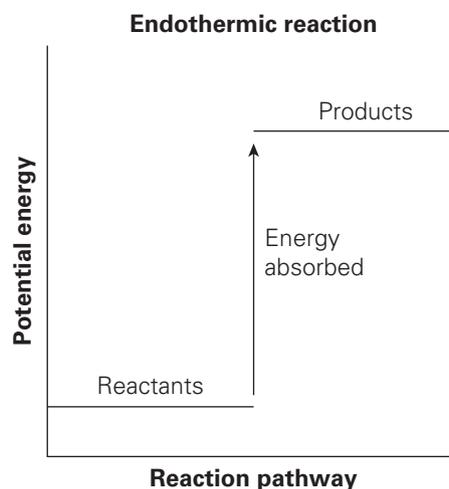


Figure 6.25 An energy level diagram for an endothermic reaction

- 1 During a chemical reaction the temperature of the solution decreases. What type of reaction is this?
- 2 Respiration is an example of an endothermic reaction because it releases energy into the surroundings. Is this statement true or false?

Quick check 6.7

Practical 6.4: Teacher demonstration

Endothermic and exothermic reactions

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
- thermometer

Method

Draw 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.
- 4 Add the potassium iodide to the flask, stand back and watch.

Be careful

Ensure correct protective equipment is used. Do not touch, inhale or ingest hydrogen peroxide.

continued...

...continued

Experiment 2

- Put a drop of water on the wooden block and place the 250 mL beaker on top of the water.
- Mix the two solids together in the beaker, stirring with the thermometer and observe the change in temperature.
- Now try to remove the beaker from the block.
- Pass the wooden block around the class and feel the change in temperature.

Results

Experiment	Observations	Exothermic or endothermic
1		
2		

Evaluation

- How did you know that a chemical reaction had taken place in both experiments?
- Draw a potential energy level diagram for each of the experiments.
- Explain why the two solids in Experiment 2 melted without any heat being applied to the beaker.
- Determine why the reaction mixture shot out of the measuring cylinder in Experiment 1.

Conclusion

- Make a claim from this experiment regarding determining endothermic and exothermic reactions.
- Support the statement by using your observations (include potential faults in the experiment).
- Explain how your observations support your claim.

Practical 6.5

Classifying reactions as endothermic or exothermic

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 bicarbonate
- 3 cm piece magnesium ribbon
- 1 spatula of zinc powder
- 1 spatula of citric acid
- 10 mL measuring cylinder
- thermometer
- polystyrene cup with lid

Method

- Draw the results table on the next page.
- Pour 10 mL of the first substance in Experiment 1 into the cup and measure the starting temperature. Record the temperature in your results table.
- Add the required amount of the other chemical listed in the first experiment to the cup, poke the thermometer through the lid and attach the lid to the cup.
- When the temperature on the thermometer remains stable, record the final temperature in the results table.

continued...

Be careful

Ensure that appropriate gloves and protective equipment are worn during this experiment. Hydrochloric acid is a strong acid and sodium hydroxide is a strong base. Flammable gases may be produced by reactions. Exothermic reactions produce heat.

...continued

- 5 Work out the temperature change and decide whether the reaction is endothermic or exothermic.
- 6 Repeat for the other experiments.

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				

Evaluation

- 1 Experiment 2 was a reaction between an acid and a base. Research what type of reaction this is.
- 2 Describe what happened to the energy in the reaction between sodium hydrogen carbonate and citric acid in Experiment 4.

Conclusion

- 1 Make a claim from this experiment regarding determining endothermic and exothermic reactions.
- 2 Support the statement by using your observations (include potential faults in the experiment).
- 3 Explain how your observations support your claim.

Combustion reactions

Combustion reactions are specific examples of reactions that are exothermic in nature.

combustion
the reaction of a fuel with oxygen usually producing heat and light

It is just the scientific term for burning and you know already that when fuels burn they release heat. For a fuel to burn, oxygen is required. Combustion reactions often take the format shown in Figure 6.26.



Figure 6.26 A typical combustion reaction

Fuels that contain hydrogen and carbon are called hydrocarbons. The equation in Figure 6.27 shows what happens when the simplest hydrocarbon, methane, is burned in oxygen.



Figure 6.27 Complete combustion of methane

This is an example of complete combustion because enough oxygen is present to combine with both the hydrogen and carbon in the fuel. If only a limited supply of oxygen is available, methane will undergo incomplete combustion in which there can be two possible outcomes: carbon monoxide and carbon, as shown in Figure 6.28.

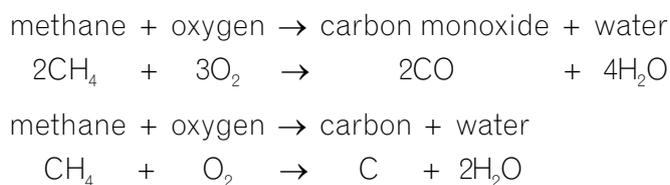


Figure 6.28 Incomplete combustion of methane

Carbon monoxide is produced instead of carbon dioxide when the oxygen supply is reduced slightly. If there is very little oxygen available, only the hydrogen will combine with it, making water, and leaving carbon on its own. Other outcomes are possible during an incomplete combustion of a hydrocarbon. Propane for instance produces both carbon monoxide and carbon dioxide in addition to water.

- 1 Explain why combustion reactions are described as exothermic reactions.
- 2 Identify the gas required for all types of combustion reactions.
- 3 During the combustion of octane, carbon dioxide and water are released. Write a word equation to demonstrate this reaction.

Quick check 6.8

Internal combustion engine **Explore! 6.3**

Figure 6.29 shows an internal combustion engine. Use the internet to research the following questions.

- 1 How does the internal combustion engine work?
- 2 Identify the products of the reaction in the car engine.
- 3 Discuss the effects of these products on the environment.
- 4 Compare the external combustion engine in a steam train to the internal combustion engine in a car.



Figure 6.29 An internal combustion engine in a car



QUIZ

Section 6.3 questions

Remembering

- 1 Identify the gases that are a product of complete combustion reactions involving carbon.
- 2 Recall one example of an endothermic reaction and one example of an exothermic reaction.

Understanding

- 3 Explain why fire blankets, when put over a fire, cause the fire to be put out.
- 4 During photosynthesis, plants use the Sun's energy to make their own food. Explain why this is an example of an endothermic reaction.

Applying

- 5 Compare and contrast explosions with burning. Some people think they are different, some people think they are the same thing.
- 6 Construct a word equation for the complete combustion of butane (BBQ gas) to form carbon dioxide and water.

Analysing

- 7 Distinguish between complete and incomplete combustion.
- 8 Contrast exothermic and endothermic reactions.
- 9 Nitrogen and oxygen in the atmosphere react together during lightning strikes. Classify this as a spontaneous or a non-spontaneous reaction and explain your decision.
- 10 Classify the following as exothermic or endothermic reactions.
 - a A reaction in which the temperature decreases
 - b Releasing energy from food in respiration
 - c Baking a cake
 - d Combustion

Evaluating

- 11 Is this statement true or false? 'Combustion is a chemical reaction.' Justify your choice.



6.4 Reactions of life

photosynthesis

the chemical reaction by which 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 perhaps the two most important chemical reactions you will ever study. Photosynthesis is carried out by plants; respiration is carried out by animals and plants.

Photosynthesis

Photosynthesis is the process by which plants 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 can be summarised by the word equation and balanced formula equation shown in Figure 6.30.

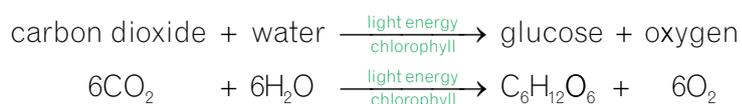
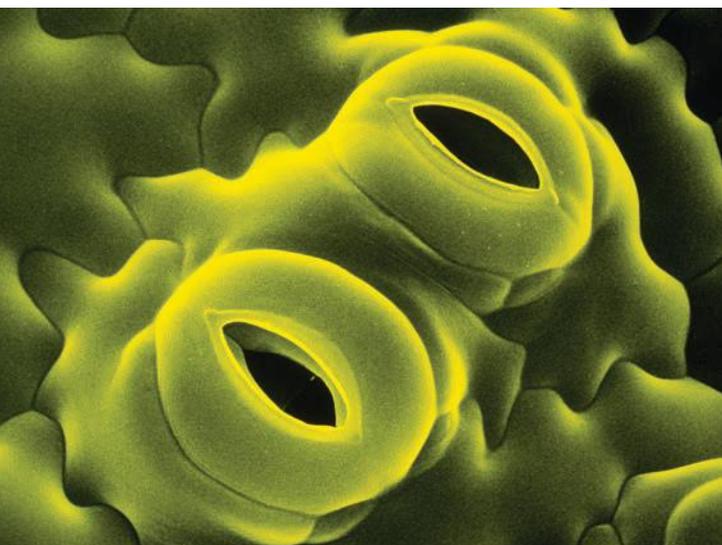


Figure 6.30 The word and formula equations for photosynthesis



For photosynthesis to occur, plants 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 6.31). Water in the soil is taken up into the plant by its roots (see Figure 6.32).



WORKSHEET

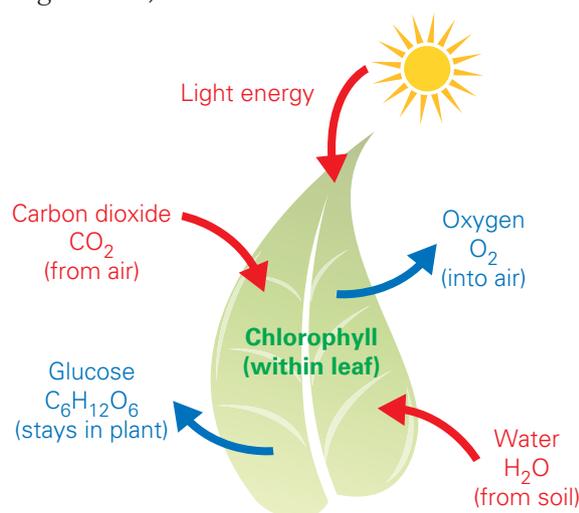


Figure 6.32 Photosynthesis: where the raw materials come from and what happens to the products

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. The green chemical, chlorophyll, 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 6.31 A scanning electron microscope image of leaf stomata (tiny holes on the underside of the leaf). Carbon dioxide moves into the leaf through the stomata.

Table 6.2 summarises the chemicals and energy involved in photosynthesis.

Reactants	Reaction conditions	Products
Carbon dioxide	Light energy	Glucose
Water	Chlorophyll	Oxygen

Table 6.2 Chemicals and energy involved in photosynthesis

Practical 6.6

Investigating factors that affect the rate of photosynthesis

Aim

To investigate how the amount of light affects the rate of photosynthesis.

Be careful

Lamp may be hot
(if incandescent)

Hypothesis

Write a hypothesis for your investigation. Remember, it needs to include the independent variables and dependent variables, and it must be testable.

Materials

- water plant
- 250 mL conical flask
- 100 mL measuring cylinder
- electric lamp
- scissors
- metre ruler
- stop clock

Method

- 1 Draw the results table below.
- 2 Set up the lamp. Using the metre ruler, measure five distances 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 at the correct distance away from the lamp.
- 5 Cut a 10 cm length strip of the water plant and add it to the conical flask and 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 you can repeat each distance again. Alternatively, you could share your results with the rest of your class so you can calculate the mean number of bubbles.

Results

Distance away from the lamp (cm)	Number of bubbles produced

continued...

...continued

Evaluation

- 1 Name the independent variable in this investigation.
- 2 Name the dependent variable in this investigation.
- 3 List some of the control variables in this investigation. Why it is important that they need to be controlled?
- 4 Plot a scatter graph (with a trend line or a line of best fit) of your results.
- 5 Describe the trend in your graph.
- 6 Explain the trend in your graph.
- 7 Identify the gas you assume is present in the bubbles.
- 8 Propose how you could improve the experiment to make the results more:
 - a accurate
 - b reliable.
- 9 Design a similar experiment to investigate another factor that may affect the rate of photosynthesis.

Conclusion

- 1 Make a claim from this experiment regarding the amount of light and the rate of photosynthesis.
- 2 Support the statement by using your observations (include potential faults in the experiment).
- 3 Explain how your observations support your claim.

- 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.

Quick check 6.9

Respiration

Respiration is the process by which plants and animals produce energy from glucose. Both plants and animals carry out a process called aerobic respiration, which means respiration requiring oxygen. Oxygen comes from the air for both organisms, which is

why animals breathe. When you exercise, you need more energy from respiration and therefore more oxygen, which is why your breathing rate increases.

You know already that the glucose that plants use in respiration is formed during photosynthesis, whereas animals get their glucose from the food they eat. Aerobic respiration takes place in the mitochondria (tiny structures inside cells). Alongside the useful product of respiration, energy, other less useful products, carbon dioxide and water are also produced.

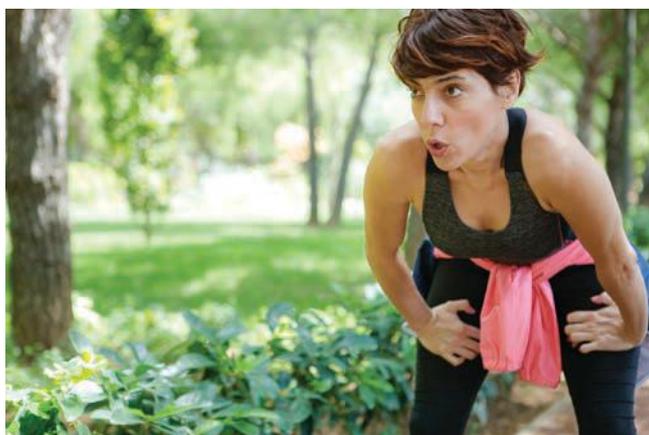


Figure 6.33 When you exercise, more energy is required, so you breathe more.

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?

Try this 6.1

Aerobic respiration can be summarised by the word equation and balanced formula equation below.

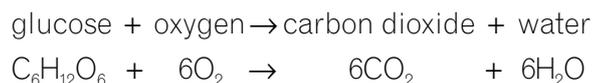


Figure 6.34 The word and formula equations for aerobic respiration

Aerobic and anaerobic respiration

Explore! 6.4



Figure 6.35 Haile Gebrselassie won the Berlin marathon in 2009



Figure 6.36 Usain Bolt crossing the finish line. He is perhaps the greatest sprinter of all time.

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-distances races, including marathons. The energy requirements for these races differ dramatically and therefore so does the rate and type of respiration.

- 1 During a race, how would the breathing rates of each runner 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 to explain why the types of respiration used in each race differ.
- 3 In a marathon, runners pick up glucose drinks at various points during a race. Propose a reason for this.

- 1 Name the two reactants required for aerobic respiration.
- 2 Name the three products produced during aerobic respiration.
- 3 Identify where aerobic respiration take place.

Quick check 6.10

Comparing photosynthesis and respiration

Table 6.3 summarises the key similarities and differences between respiration and photosynthesis.

Respiration	Photosynthesis
Produces energy	Uses energy
Produces carbon dioxide	Uses carbon dioxide
Uses glucose	Makes glucose
Takes place in mitochondria	Takes place in chloroplasts
Happens at all times of the day	Happens during the day only when light is present

Table 6.3 Comparison between photosynthesis and respiration

Section 6.4 questions

Remembering

- 1 Name the molecule that is 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 Recall the word equation for aerobic respiration.
- 4 Complete the word equation for photosynthesis.
carbon dioxide + _____ → glucose + _____

Understanding

- 5 Compare and contrast photosynthesis and respiration.
- 6 Explain why light energy is written above the arrow and chlorophyll is written below in the word equation for photosynthesis.
- 7 Outline the reason why leaves are often flattened and do not overlap.

Applying

- 8 During anaerobic respiration in yeast, glucose is broken down into carbon dioxide and ethanol. Construct a word equation for this reaction.

Analysing

- 9 Contrast the ways that plants and animals get the raw materials required for aerobic respiration.
- 10 Classify respiration and photosynthesis as endothermic or exothermic reactions. Explain your decisions.
- 11 List some factors that can affect the rate of photosynthesis and explain why they affect the rate of the reaction.

Evaluating

- 12 Discuss the reasons why plants can respire at any time of the day but only photosynthesise during daylight hours.



QUIZ



6.5 Acid reactions

Can acids and carbonates create an explosion?

Try this 6.2

Be careful

Wear appropriate protective equipment.

Get an empty 3-litre soft-drink bottle and a cork that will fit in the mouth of the bottle. Fill the bottle a quarter full with vinegar. Place some baking powder in a small piece of paper towel (small enough to fit in the bottle). Now find a large space outside. Add the paper towel to the bottle, put the cork in the end and stand back!

You could make this into a science experiment to observe the force of the reaction with different amounts of vinegar and baking soda.



Figure 6.37 The reaction between vinegar and baking soda is quite impressive!



Figure 6.38 Lemon juice is a common household acid.

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 it has a pH of less than 7. pH 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. The most common acids that you will come across in the science laboratory are nitric, hydrochloric and sulfuric acid.

acid

a substance that has a pH of less than 7

base

a substance that has a pH greater than 7

In all the reactions that will be discussed, a **salt** will always be one of the products formed. You probably know salt as the stuff that you put on chips; however, in chemistry a salt is a substance that is formed when acids react with bases, metals or metal carbonates and 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 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

salt

a product formed when an acid reacts with a metal, base or carbonate and comprises of a metal and a non-metal

used, the salt will be a sulfate. Table 6.4 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 6.4 A summary of the type of salt formed when different acids react

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 6.5 summarises how to predict the name of a salt in reactions that involve acids.

Type of acid	Other reactant	Metal present	Type of salt	Name of salt
Hydrochloric acid	Magnesium	Magnesium	Chloride	Magnesium chloride
Nitric acid	Calcium hydroxide	Calcium	Nitrate	Calcium nitrate
Sulfuric acid	Sodium carbonate	Sodium	Sulfate	Sodium sulfate

Table 6.5 A summary on how to name the salt produced in acid reactions

- 1 What is the pH of an acid?
- 2 Name a household acid and an acid used in your science laboratory.
- 3 Recall what a salt is.
- 4 Name the salt produced when calcium carbonate reacts with sulfuric acid.
- 5 Describe the two rules when naming a salt.

Quick check 6.11

Acid–metal reactions

Acid–metal reactions occur when an acid reacts with a metal to produce a salt and hydrogen. The hydrogen produced in the reaction can be identified using a simple pop test. The general word equation for any acid reacting with any metal can be seen in Figure 6.39.



Figure 6.39 The word equation for any acid reacting with any metal

When hydrochloric acid reacts with magnesium, the salt magnesium chloride is formed, with the other product in the reaction being hydrogen. Remember, 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.

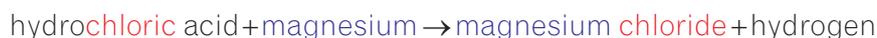


Figure 6.40 The word equation for a specific acid–metal reaction

The reaction between acids and metals is a problem in everyday life. There is acid in rain and as many buildings are made of metals, a large amount of damage can be done.



Figure 6.41 The orange toxic water produced here is due to the reaction of acid rain with the metal in this abandoned mine.

- 1 What is the general word equation for when any metal reacts with any acid?
- 2 What is the test to show that hydrogen is formed in a reaction between a metal and an acid?
- 3 Complete the word equation below.

nitric acid + _____ → copper _____ + hydrogen

Quick check 6.12

Practical 6.7

Reaction of acids with metals

Aim

To observe what happens when metals react with acids.

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

Method

- 1 Draw the results tables on the next page.
- 2 Place the six test tubes in the test-tube rack.
- 3 In four of the test tubes, add 2–3 cm depth of hydrochloric acid.
- 4 In the other four test tubes, add 2–3 cm depth of sulfuric acid.

Be careful

Ensure appropriate protective equipment is worn.

continued...

...continued

- 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.
- 6 After about 30 seconds, light a wooden splint, remove the stopper and hold the flame to the mouth of the test tube. Again, record your observations.
- 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, 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?

Evaluation

- 1 Discuss which of the metals reacted with hydrochloric acid. How did you know?
- 2 Discuss which of the metals reacted with sulfuric acid. How did you know?
- 3 What happened to some of the reactions when the lit splint was put at the mouth of the test tube?
- 4 What does this experiment tell you about the reactivity of metals?
- 5 Write three-word equations for some of the reactions you carried out in this practical.
- 6 During this reaction, you may have felt the temperature of the reaction increase. Recall the name of this type of reaction.

Conclusion

- 1 Make a claim from this experiment regarding metal-acid reactions and the production of hydrogen gas.
- 2 Support the statement by using your observations (include potential faults in this experiment).
- 3 Explain how your observations support your claim.

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 it is water that is made. A base is a substance that has a

pH greater than 7, they 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 come across in your science laboratory include sodium hydroxide, calcium hydroxide and magnesium hydroxide.



Figure 6.42 Washing-up liquid is an example of a household base.

The general word equation for any acid reacting with any base can be seen in Figure 6.43.

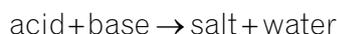


Figure 6.43 The word equation for any acid reacting with any base

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 6.45 A wasp sting is soothed because of a neutralisation reaction.



Figure 6.44 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 make a solution that is neutral (pH 7). Curing indigestion and soothing a wasp sting are examples of common neutralisation reactions.

neutralisation

a reaction between an acid and a base, forming a solution that has a neutral pH

- Quick check 6.13**
- 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 6.8

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 and colour chart (full range)
- spotting tile
- pH meter

Method

- 1 Draw the results table below.
- 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 six hollows on the spotting tile.
- 4 Using the stirring rod, 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 Complete steps 4 and 5, recording your results in the results table.
- 8 Now add the other volumes of sodium hydroxide one by one, each time measuring the pH of the solution using the universal indicator paper and the pH meter.

Results

Volume of sodium hydroxide (mL)	pH using universal indicator paper	pH using digital meter
0		
5		
10		
15		
20		
25		

Evaluation

- 1 Discuss what you expected the final pH of the solution to be. Is this reflected in your results?
- 2 Explain what happened to the pH as you gradually added more and more base.
- 3 Describe the differences in the readings with the universal indicator and the pH meter. Which one is more accurate and why?
- 4 Identify the type of reaction that you carried out in this experiment.
- 5 Write a word equation for the reaction that you investigated.
- 6 To demonstrate this type of reaction, explain why it is important that the same concentration and volume of the acid and base are used.

Conclusion

- 1 Make a claim from this experiment regarding determining acid-base reactions.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Be careful

Ensure that appropriate gloves and protective equipment is worn during this experiment. Hydrochloric acid is a strong acid, and sodium hydroxide is a strong base.

Acid-carbonate reactions

Acid-carbonate reactions occur when any acid reacts with any metal carbonate to produce a salt, water and carbon dioxide. Again, a salt is produced; however, 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.

The general word equation for any acid reacting with any carbonate can be seen in Figure 6.46.



Figure 6.46 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 6.47 The word equation for a specific acid-carbonate reaction

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. Along with water/liquid they react slowly in a cooking mixture, producing carbon dioxide and making your cakes light and fluffy.

Did you know? 6.1



Figure 6.48 An acid-carbonate reaction causes cakes to rise in the oven.

- 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

Quick check 6.14

Practical 6.9

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
- Alternatively, this can be done with a side-arm test tube.

Method

- 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 full 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 (Figure 6.49).

Be careful

Ensure appropriate protective equipment is worn. Nitric acid is a corrosive acid and can cause chemical burns.

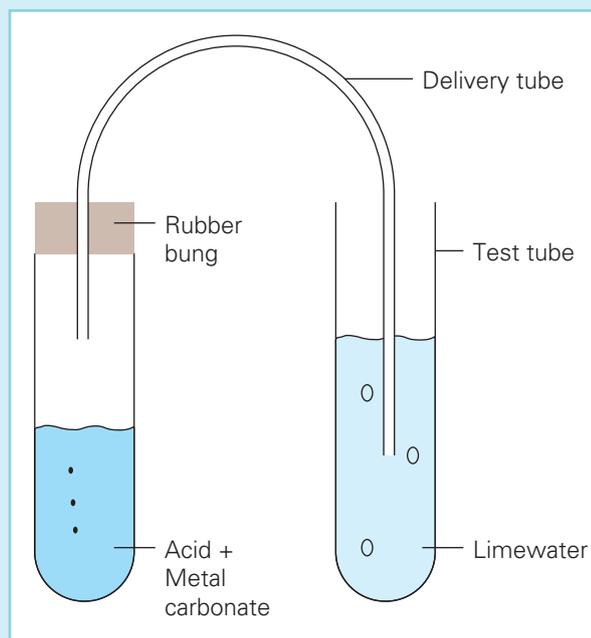


Figure 6.49 Testing for the presence of carbon dioxide using a delivery tube

Results

Record your observations.

continued...

...continued

Evaluation

- 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.

Conclusion

- 1 Make a claim from this experiment regarding determining acid carbonate reactions.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Weathering

Explore! 6.5

Headstones are an important insight into what life used to be like and often hold huge sentimental value. The two pictures below show headstones of a similar age. The headstone in Figure 6.50 is made of limestone (calcium carbonate) and the one in Figure 6.51 is made of granite.

- 1 Describe the observations you can make about the quality of the headstones in each picture.
- 2 Explain in your own words why it is more difficult to read the inscriptions on the limestone (calcium carbonate) headstone.
- 3 Write a word equation to explain your ideas in question 2.
- 4 Despite the obvious difference in quality, most of the headstones found in graveyards are made of limestone. Why do you think this is?
- 5 How could you reduce the degradation of limestone headstones?



Figure 6.50 Limestone headstone



Figure 6.51 Granite headstone

Section 6.5 questions



QUIZ

Remembering

- 1 Recall the products of the following reactions.
 - a acid + metal \rightarrow
 - b acid + base \rightarrow
 - c acid + carbonate \rightarrow
- 2 State the pH range of an acid and a base.
- 3 Recall the two rules when naming a salt.
- 4 What is the pH of a neutral solution?

Understanding

- 5 Compare and contrast acid–base reactions with acid–metal reactions.
- 6 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.

Applying

- 7 Identify the salts in the following list.
 - a Calcium oxide
 - b Sodium chloride
 - c Sodium carbonate
 - d Copper chloride
 - e Barium nitrate
- 8 Construct word equations for the following scenarios.
 - a Magnesium hydroxide is added to nitric acid in a neutralisation reaction to form magnesium nitrate and water.
 - b Hydrochloric acid and calcium carbonate are mixed together.
 - c The products formed in this reaction are copper chloride and hydrogen.

Analysing

- 9 Categorise the following equations as acid–base, acid–carbonate or acid–metal reactions.
 - a Produces a salt and water as products
 - b Produces a gas that can be identified by the squeaky pop test
 - c Nitric acid + sodium \rightarrow sodium nitrate + hydrogen
 - d Produces a gas that turns limewater milky
 - e Is an example of a neutralisation reaction
 - f Forms a salt

Evaluating

- 10 Heartburn is caused by acid from the stomach entering the oesophagus. Justify the use of antacids to alleviate the pain caused by heartburn.



Review questions

Remembering

- Name the gases produced when:
 - a hydrocarbon is completely combusted
 - carbon dioxide and water react during photosynthesis
 - nitric acid reacts with nickel carbonate.
- Name the tiny holes that open to allow carbon dioxide to enter a plant during photosynthesis.
- With reference to the equation for aerobic respiration, explain why you breathe out carbon dioxide.
- Name an example of a spontaneous chemical reaction.
- Describe ways in which a pot plant can increase its rate of photosynthesis.
- Complete the table:

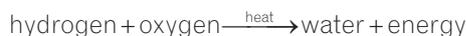
Acid	Type of salt
Hydrochloric acid	
	Sulfate
	Nitrate

Understanding

- Explain why condensation forms when you breathe out onto a cold window.
- Recall what you learned in this chapter about what a chemical reaction is and about the activation energy. Use this information to explain why heat is often needed in a chemical reaction.
- Explain how the law of conservation of mass is shown in chemical equations.
- Compare aerobic respiration to a combustion reaction.
- Explain why plants compete with each other to be the tallest.
- Predict the products of the following reactions.
 - Hydrochloric acid + copper carbonate
 - Nitric acid + potassium hydroxide
 - Sulfuric acid + iron

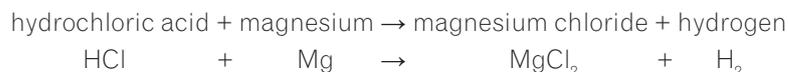
Applying

- Construct an energy level diagram for the reaction between copper sulfate and zinc in which the temperature of the reaction rose by 40°C.
- Construct a paragraph to explain what is happening in this reaction. Use the keywords: reactants, products, spontaneous, reaction condition.



Analysing

- Analyse the following word equation and formula equation to identify the following:

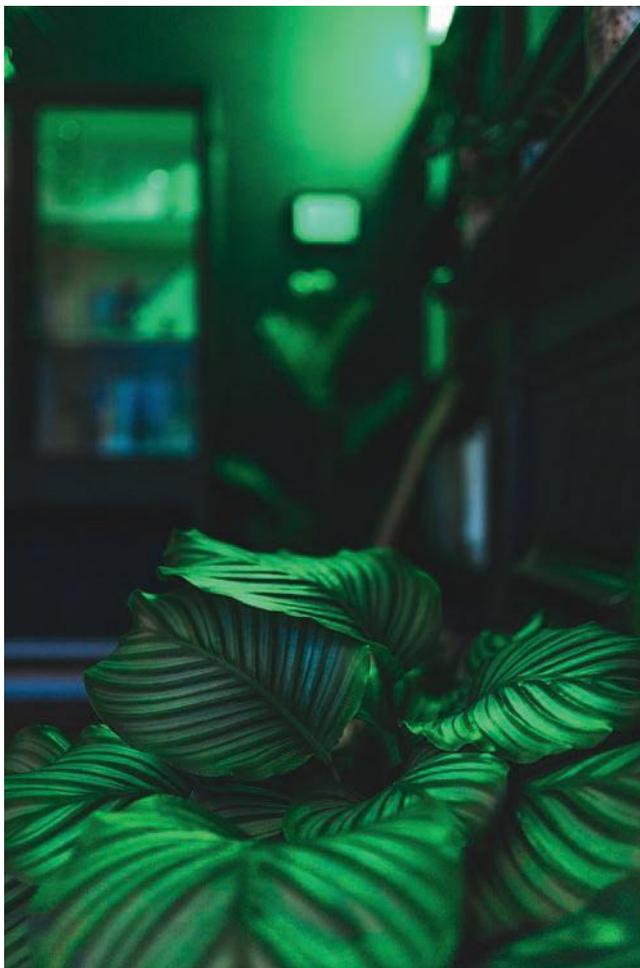


- The reactants
- The products
- Whether it observes the law of conservation of mass
- The chemical formula of magnesium chloride

- e The chemical formula of the product which can be identified in a pop test
 - f The type of reaction
- 16 Make an inference for why autumn leaves are orange or brown. Research via the internet to assess if you were on the right track.

Evaluating

- 17 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.
- 18 In a darkened room with a plentiful supply of carbon dioxide and water, light is described as a limiting factor. Deduce what is meant by the term 'limiting factor'.



- 19 The following reaction shows the thermal decomposition (breaking down) of calcium carbonate. Determine whether you think this is an exothermic or an endothermic reaction. Justify your choice.



- 20 'Photosynthesis and respiration are the reverse reactions of one another.' Decide whether you agree or disagree with the statement and justify your response.
- 21 Julia is observing a reaction and notices steam rising out of the test tube.
- a Evaluate whether the reaction is exothermic or endothermic.
 - b Justify your choice.

STEM activity: Baristas and the curdling milk problem

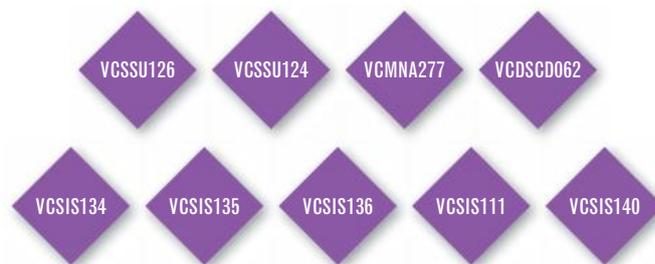
Background information

Science has applications in all industries: medicine, technology, business. Did you know it is also key to the Food and Beverage industry?

Baristas in Australian coffee shops have felt the frustration of milk curdling. They want to be able to offer their customers rice milk, almond milk, coconut milk, lactose-free milk, soy milk, cow's milk etc. but all of these milk-like products respond differently to tea and coffee, and also to temperature.

What is curdling and why would milk curdle? Curdling is the process of coagulation that occurs when the protein components in the milk clump together. Certain blends of coffee can be quite acidic, 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. When adding 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. Sometimes curdling is something you want to happen, but only if you are making yoghurt or cheese. If you are trying to make a soy latte, curdling is very undesirable.

Chemical engineers apply the principles of chemistry, biology, physics and maths to implement best-practice strategies involving chemicals, drugs and food. In 2015, an Australian milk brand, MILKLAB, worked together with baristas to create a range of soy milk that would not curdle to acidic coffee blends. However, not all coffee shops can afford speciality products.



Figure 6.52 Australians drink nearly 4 billion cups of coffee each year, therefore it is important that baristas in Melbourne know how to make a coffee in which the milk does not curdle into an unpalatable mess.

Design brief: Create an infographic for baristas, based on your experimentation results for best practice with milk.

Activity instructions

As the chemical engineer representing the Hipsters Coffee Union of Australia, you are responsible for ensuring that baristas in Melbourne know how to make a coffee where the milk does not curdle, so no barista loses their job over split milk. You will propose the best pH, temperature and coffee to milk volume ratio for a range of milk types in order to prevent curdling. To do this you will need to design several tests or trials. Be sure your milk samples are fresh, use the same amount of milk for each test, determine a way of measuring the acidity of the milk and record the weight of any curdled milk produced. Be sure to record all your data, amounts and settings for your trials, so that you can create your infographic for the Union with confidence.

Note: an infographic is a visual representation of information, designed to make the data and information easy to understand at a glance. These are different from graphs, which are meant to be analysed. An infographic is simple, understandable and meant to communicate messages quickly.

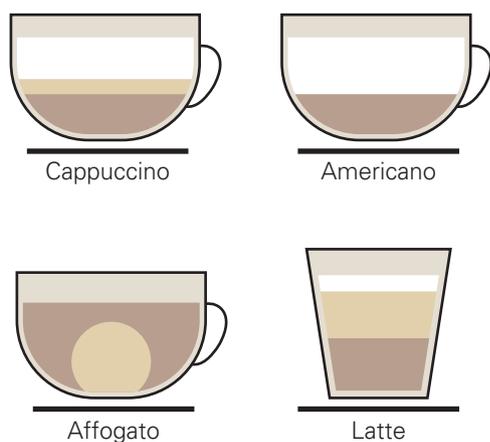


Figure 6.53 An infographic showing the various coffee, milk and froth ratios for different types of coffee drinks

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 for making coffee and warm coffee
- measuring cylinder
- transfer bulb pipettes
- spoons or stirring rods
- clear plastic cups for cold coffee
- kettle
- paper towels
- several pieces of cheesecloth or cotton fabric
- thermometer
- data-logging pH meter or alternative method for measuring pH
- a digital balance
- permanent marker
- gloves

Evaluate and modify

- 1 Discuss your findings with your colleagues.
- 2 Propose the best ratio of coffee to milk for preventing the curdling of coffee for acidic coffee blends with different milk products.
- 3 Identify possible sources of error in your testing procedure and suggest some ways to improve and modify your experiments in the future.
- 4 Predict how the temperature of the milk may affect your findings.
- 5 Create an A5 'cheat sheet' for baristas using infographics so they can easily identify the ratios possible for normal milk and soy milk at the most acidic coffee blends. You may do this by hand or search for free infographic design tools on the internet.

Chapter 7 Our changing Earth

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 was like the skin of an apple (unbroken)! In this chapter, you will learn about the changing ideas surrounding the structure of Earth and how this has led to understanding more about why natural disasters occur. You will look at the impact of natural disasters and how early detection methods by modern-day technology has reduced these impacts.

Curriculum

The theory of plate tectonics explains global patterns of geological activity and continental movement (VCSSU127)

• recognising the major plates on a world map	7.2
• considering the role of heat energy and convection currents in the movement of tectonic plates	7.2
• modelling seafloor spreading	7.1
• relating the occurrence of earthquakes and volcanic activity to constructive and destructive plate boundaries	7.2, 7.3
• relating the extreme age and stability of a large part of the Australian continent to its plate tectonic history	7.2, 7.3

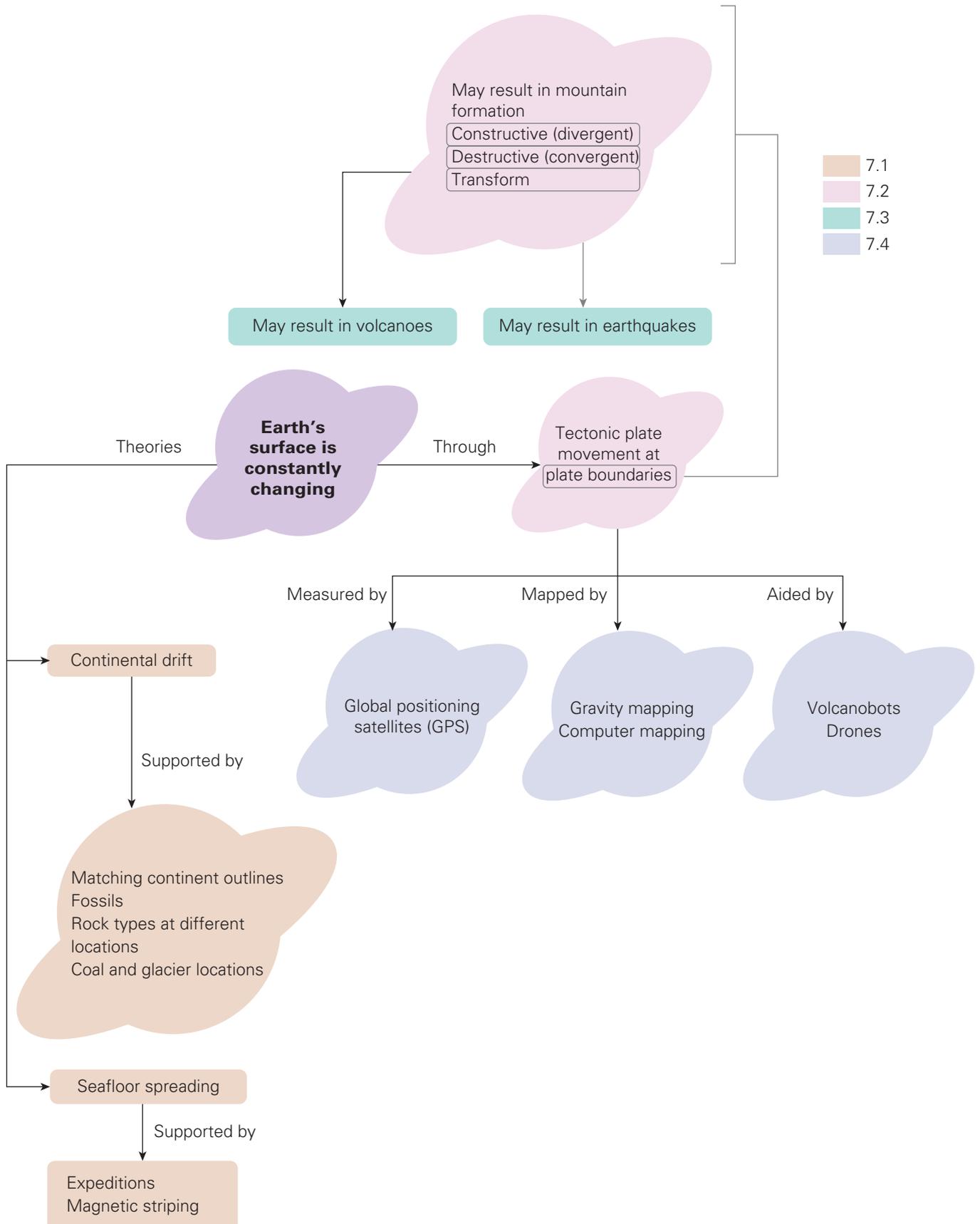
Victorian Curriculum F–10 © VCAA (2016)

Glossary terms

constructive (divergent)	hotspot	Richter scale
continental drift	lag time	seafloor spreading
convection currents	lava	seismic wave
core	lithosphere	seismogram
crust	magma	seismometer
destructive (convergent)	mantle	subduction
epicentre	Pangaea	tectonic plates
focus	plate boundaries	transform
geoid	plate tectonics	tsunami
GPS	pyroclastic	



Concept map





Continent movement theories

Since the late sixteenth century, scientists have speculated that continents may have drifted away from each other. In this section, you will

Pangaea

the supercontinent which has since broken into pieces and drifted apart

learn about the contribution that various scientists have made to the understanding of the theory of continental drift.

Alfred Wegener – continental drift

continental drift

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

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



632

Alfred Wegener

1880–1930

Figure 7.1 Alfred Wegener

Wegener hypothesised that Earth's continents were once part of a giant landmass called **Pangaea**.

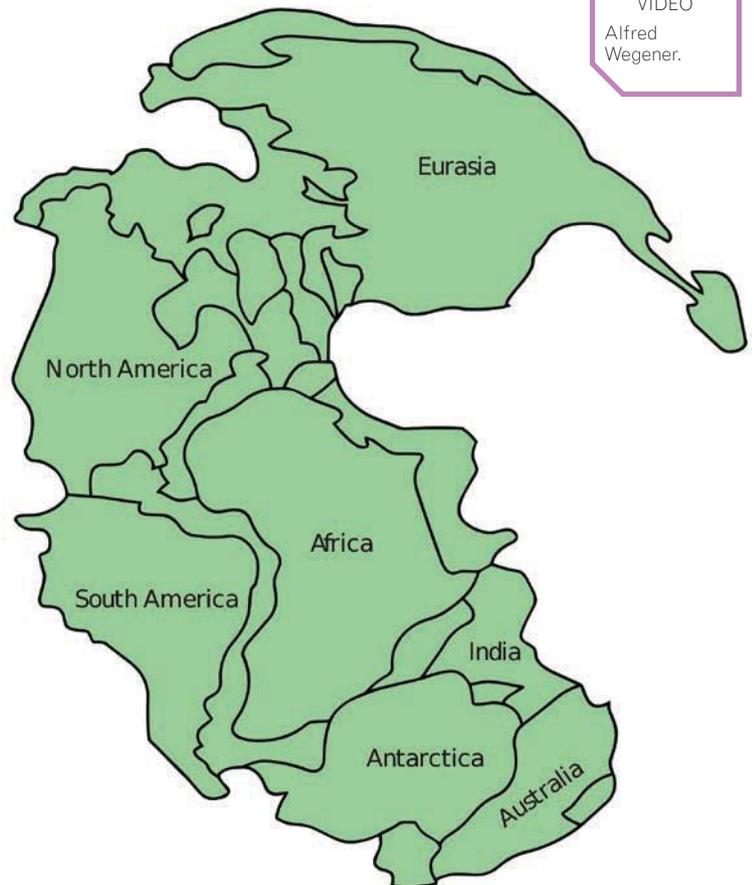


Figure 7.2 Wegener proposed that all the continents were once together in a giant landmass called Pangaea.

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.



WORKSHEET



VIDEO
Alfred Wegener.

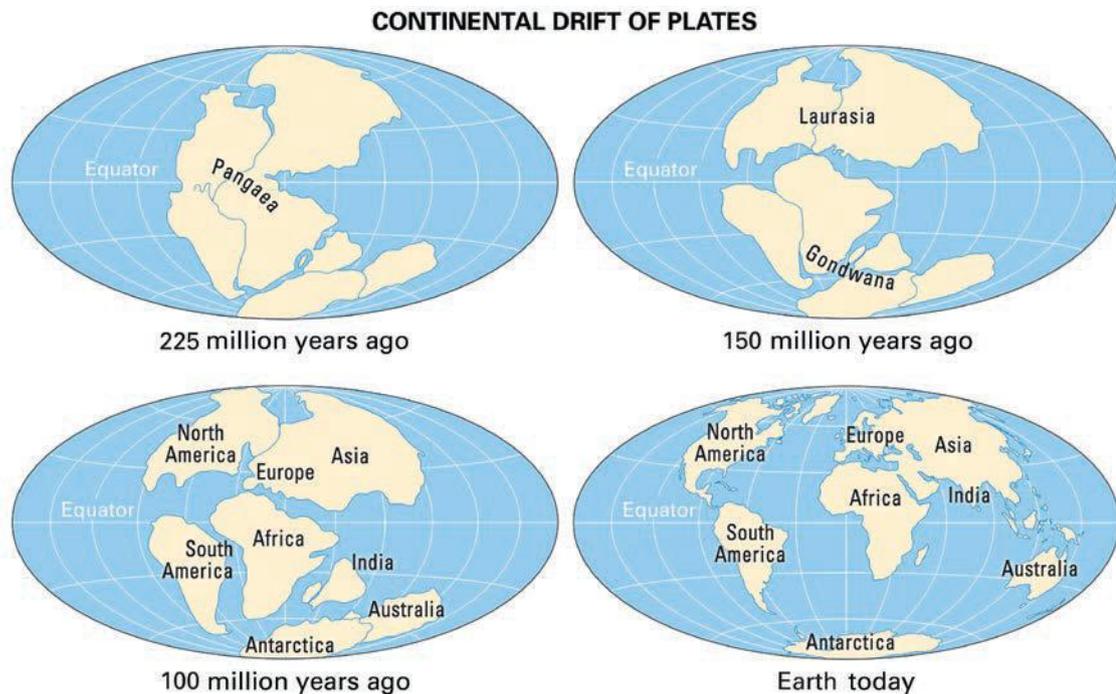


Figure 7.3 The movement of the continents from a single landmass (Pangaea) formed the continents that exist today.

A scientific theory though, 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

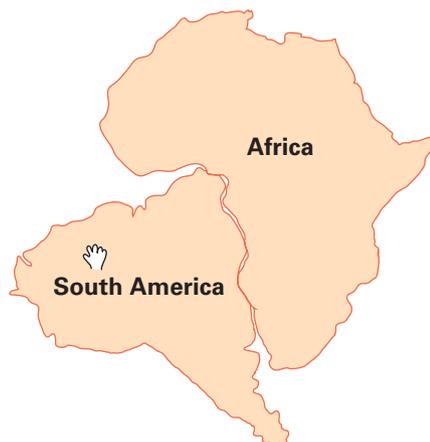


Figure 7.4 The outlines of Africa and South America fit together like pieces in a jigsaw puzzle.

pieces of a broken jigsaw puzzle. You could argue, however, that this is just a coincidence. Wegener therefore needed more evidence to back up his theory.

2 Fossils of prehistoric creatures 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 were separated by oceans, as shown in Figure 7.5. He stated that the landmasses must have been together at some stage because these animals could not swim from one continent to another. Opposing geologists argued that land bridges could have existed due to lower ocean levels, which 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.

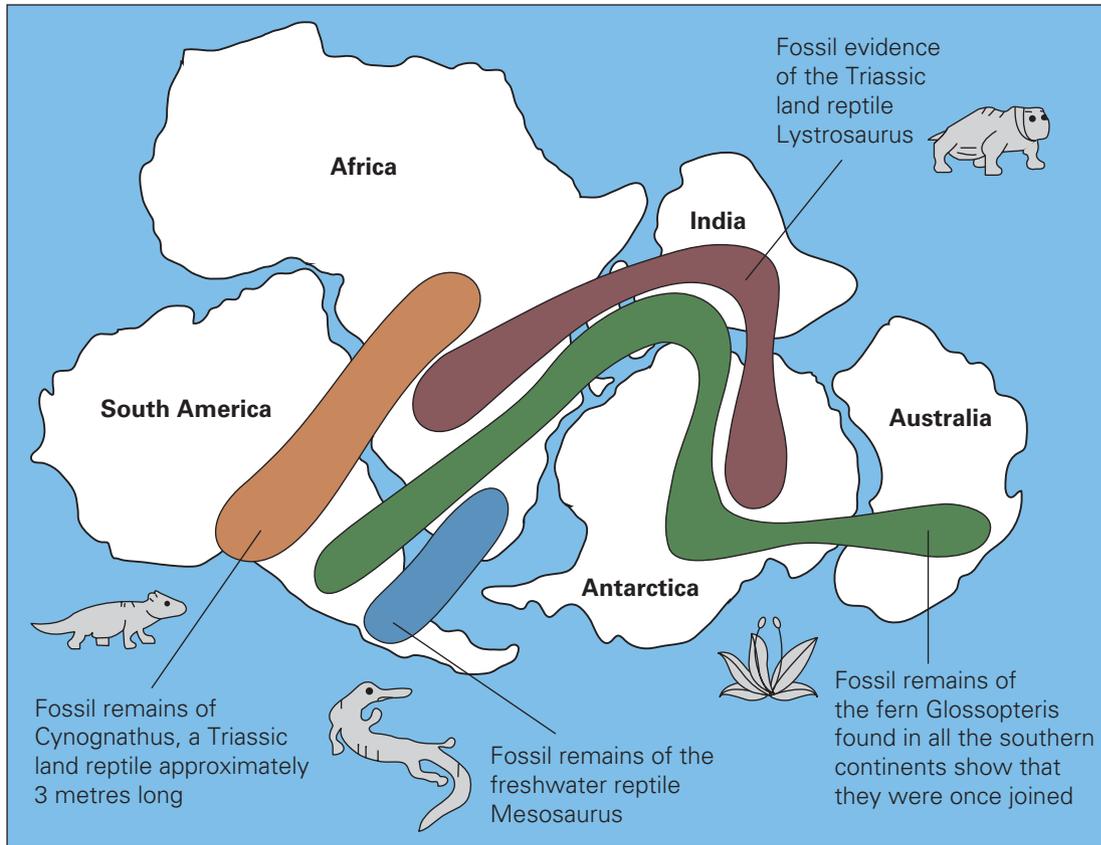


Figure 7.5 Fossils on different continents also matched up, supporting Wegener's theory further.

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

Coal only forms in hot and humid areas, glaciers only form in cold areas, so how could there be coal in cold areas and glaciers in tropical areas? Wegener concluded that this land could have once been part of the same landmass.

Despite all the evidence proposed by Wegener, he was unable to convince the scientific community at the time of the validity of his hypothesis. Wegener's ideas could certainly explain why the same fossils matched up on different continents; however, other scientists proposed that land bridges allowed animals to cross between continents. Geologists questioned



Figure 7.6 Coal only forms in hot, swampy areas; glaciers only form in cold areas.

the credibility of Wegener as 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 simply had no explanation for the mechanism behind the movement of the continents.

- 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 the year of 1930 on an expedition to Greenland he got caught in a blizzard. He

did not survive and was buried there with a pair of skis marking the grave. 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, and when they bounce back they are picked up as an echo. The time they take to bounce back indicates the depth of that part of the ocean.

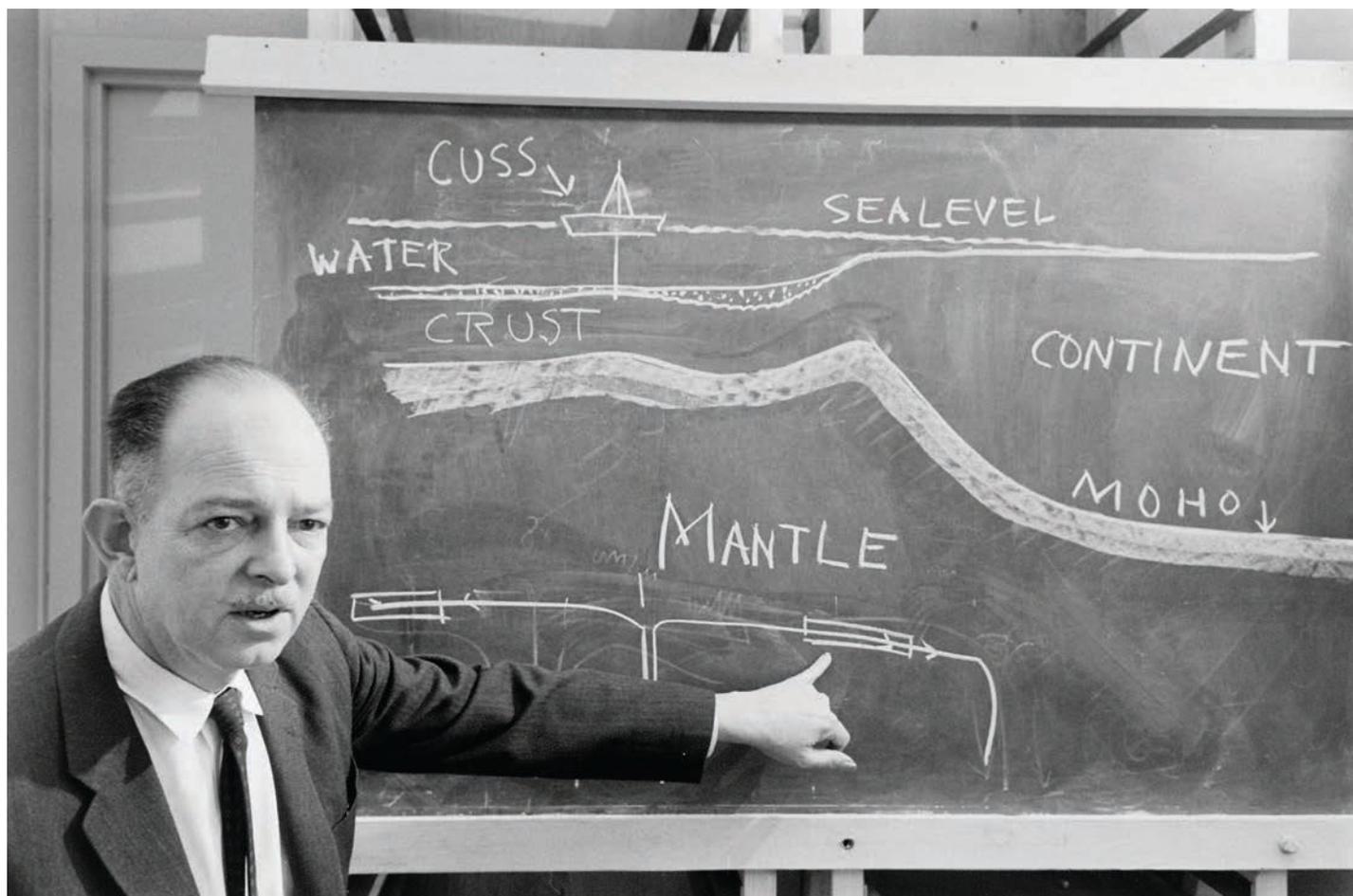


Figure 7.7 Harry Hess, a professor of geology who mapped the ocean floor

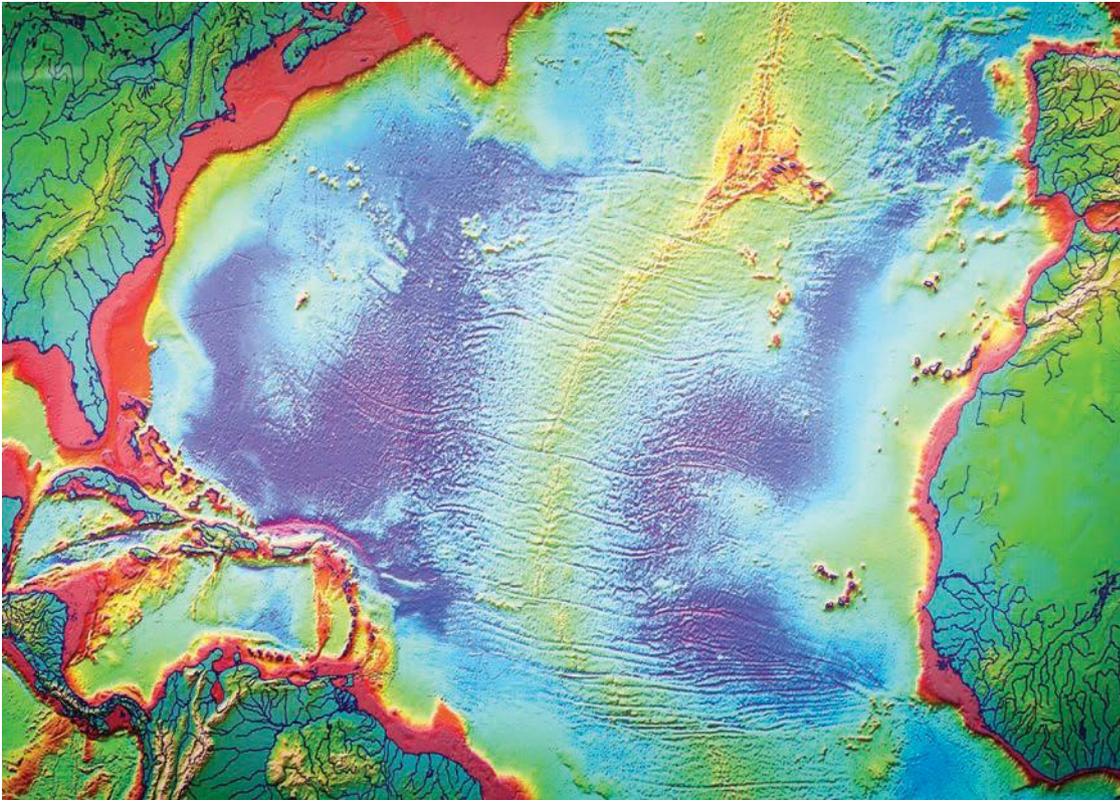


Figure 7.8 A map of the Mid-Atlantic Ridge and its volcanoes, running down the middle of the Atlantic Ocean

Most people at that time thought that the ocean floor was flat. However, when Hess mapped the ocean floor he found it contained deep trenches as well as underwater mountain ranges and volcanoes. What surprised Hess the most was that his findings appeared to show that the ocean floor was changing. He identified the presence of mid-ocean ridges that were raised about 1.5 km above the flat sea floor.

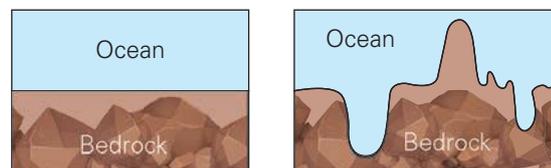
In his book *The History of Ocean Basins*, Hess said that volcanoes lining up along these ocean ridges bring up molten rock from under Earth's crust. This molten rock cools and forms new oceanic rock. As more and

more oceanic rock is produced, the sea floor moves away from the ridges. Hess called this process **seafloor spreading**.

seafloor spreading

a process by which new oceanic crust is produced as sea floor moves away from ocean ridges

This was a crucial piece of evidence to support Wegener's theory. If oceans are moving away from one another, then continents at either side of the ocean must be doing the same. He 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!

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 10 994 metres. It is named after the Challenger expedition that made discoveries important to the foundation of oceanography during 1872–1876. Richard Branson and the Virgin Oceanic adventurers are aiming to reach the bottom.

They will not be the first humans to reach the bottom though, as this was achieved in 1960 by Don Walsh and Jacques Piccard. They did so in a bathyscaphe, a free diving and self-propelled submersible vehicle that was used for deep-sea dives. 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, very cramped for two adults. About 9400 metres down they heard a loud bang, but there appeared to be nothing wrong, so they carried on. Later they found out that a window had cracked.

They fell for nearly five 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 back to the surface.

Science as a human endeavour 7.1



Figure 7.10 Richard Branson and his team of Virgin Oceanic adventurers are aiming to reach the bottom of the Mariana Trench.

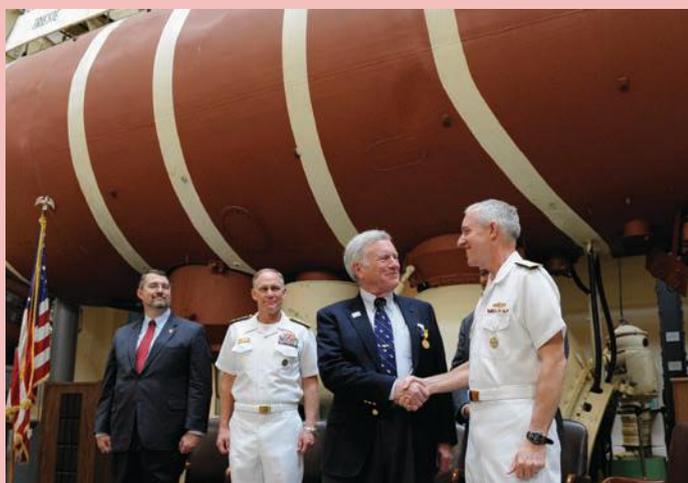


Figure 7.11 Don Walsh reached the bottom of the Mariana Trench in 1960.

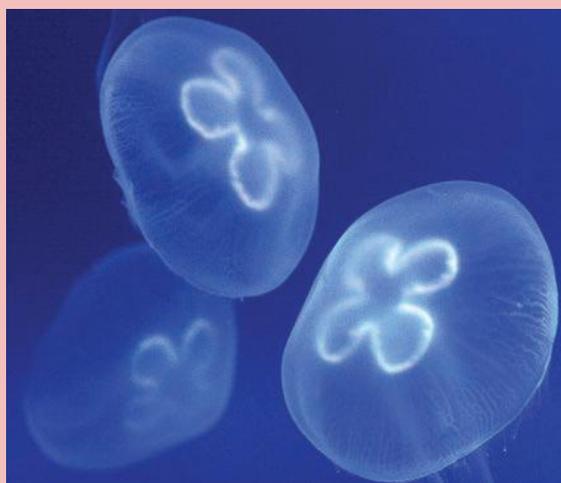


Figure 7.12 The only light that can be observed at these depths is light created by the animals that live there. This is called bioluminescence.

Secrets in Australia

In 2012, James Cameron, the Hollywood film director, also successfully reached the bottom of Challenger Deep. Cameron's submersible, *Deepsea Challenger*, had been secretly built in Australia.

Did you know? 7.1

- 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 – magnetic striping

A few years later, further evidence was discovered to support this theory. Frederick Vine and Drummond Matthews

were British geologists who first worked together when Vine was a PhD student under Matthews at Cambridge University. Earlier work using magnetometers (devices which can measure the direction of magnetic fields) showed that on the sea floor there were bands of alternating normal and reverse magnetism, running parallel to the mid-ocean ridges. At about the same time, but quite independently, Canadian geologist Lawrence Morley developed the same idea. However, Vine and Matthews were the first to publish their hypothesis.

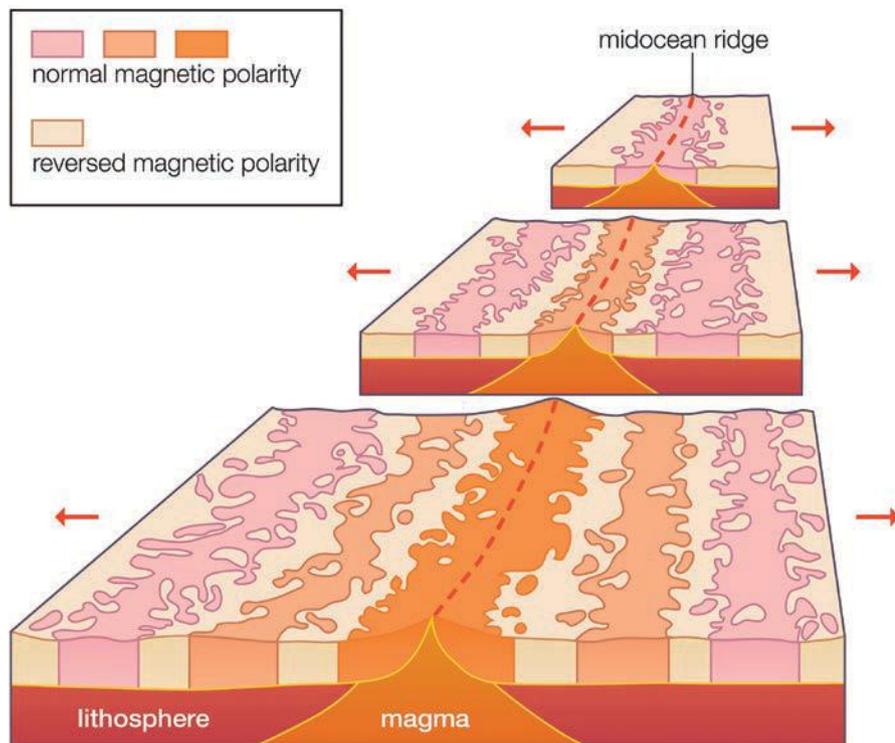


Figure 7.13 The pattern of magnetic stripes on the ocean floor

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 own magnetic field by facing north. Earth's magnetic field swaps around every 200 000 to 300 000 years, and the cooling of the 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 is symmetrical, this led to scientists to conclude that new sea floor was being added equally to each side of the ridge.

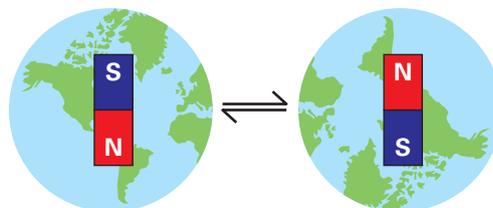


Figure 7.14 Earth's magnetic field has switched direction 170 times in the past 76 million years.

Earth's magnetic field

Explore! 7.1

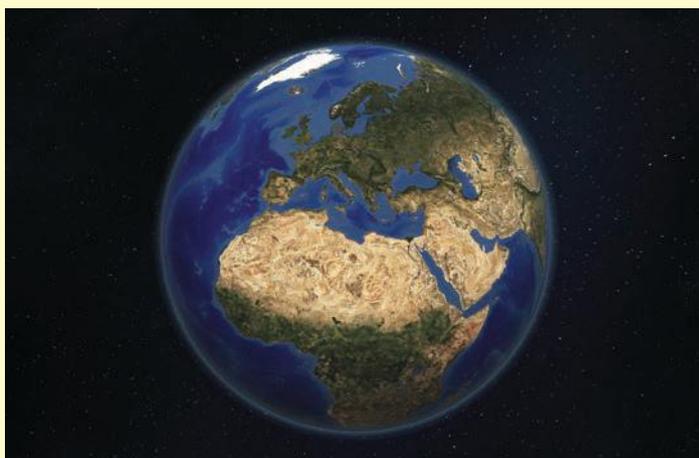


Figure 7.15 The next switching of Earth's magnetic field is overdue.

On average, Earth's polarity switches in a full reversal every 200 000 to 300 000 years. The last time Earth's poles switched was 780 000 years ago. This means that at any time there could be a reversal in Earth's magnetic field.

- 1 On average, how long does it take for Earth to complete a full reversal?
- 2 If you were using a compass to navigate at the time when the Earth's poles were reversing, how would this affect the direction you were taking?
- 3 Research and describe how nature uses Earth's magnetic field.
- 4 Discuss the consequences of Earth's magnetic field weakening for a significant period.

Further evidence to support the notion of seafloor spreading was the age of the rock. If new rock is forming at the ridge and spreading out equally in opposite

directions, you would expect that as you move further away from the ridge, the rock would increase in age. This is exactly what they found.

- 1 Identify the name of the mineral in molten rock that is magnetic.
- 2 Discuss what happens to this magnetic mineral when the molten rock cools.
- 3 How did the presence of magnetic stripes in rocks parallel to ocean ridges prove that the sea floor was spreading?
- 4 What other piece of evidence supports Hess's theory of seafloor spreading?

Quick check 7.3

Practical 7.1

Making a compass

Aim

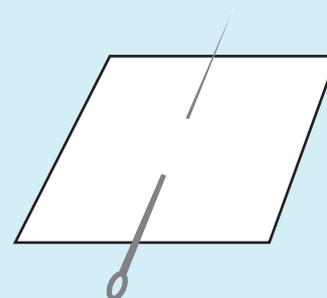
To make a simple compass.

Materials

- 250 mL beaker half full of water
- needle
- small square of paper
- bar magnet

Method

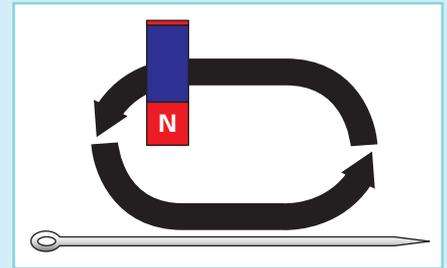
- 1 Draw the results table.
- 2 Thread the needle through the small square piece of paper as shown on the right.



continued...

...continued

- 3 Stroke the needle 20 times with the bar magnet. You must stroke in **one** direction only and with one end only.
- 4 Put the piece of paper with the needle into the water, making sure that it floats.
- 5 Record in the results table the direction that the needle points.
- 6 Turn the beaker 90° and record the direction that the needle points in the results table.
- 7 Turn the beaker a further 90° and again record the direction in the results table.



Results

First position	Rotated 90°	Rotated a further 90°

Evaluation

- 1 Describe what happened to the magnetised needle when the beaker of water was rotated.
- 2 Explain the role of the paper in this experiment.
- 3 The needle in this experiment is acting as a temporary magnet. What is a temporary magnet and how does it differ from a permanent magnet?
- 4 Discuss the importance of having the needle magnetised only in one direction.

Conclusion

- 1 Make a claim from this experiment regarding what is required to make a compass.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

- 1 Get a piece of paper and re-create the diagram below.

Try this 7.1

700	600	500	400	300	200	100	P R E S E N T	100	200	300	400	500	600	700
-----	-----	-----	-----	-----	-----	-----	---------------------------------	-----	-----	-----	-----	-----	-----	-----

- 2 Toss a coin to decide whether each of the 100 years should be magnetised north or south and draw arrows on your piece of paper to show this. Each period appears twice, so you will need to toss the coin seven times.
- 3 Cut the paper in half down the present line.
- 4 Put the paper into a gap between two tables.
- 5 Pull apart the paper to show the movement of the sea floor away from an ocean ridge.

You have just modelled seafloor spreading!



QUIZ

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 What piece of evidence proved that 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

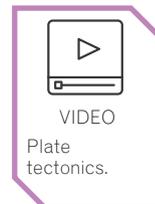
- 12 Deduce what would happen to a compass if Earth's magnetic field was to change direction now.
- 13 Prove by use of a diagram that Earth's magnetic field has switched over time.
- 14 With the example of Alfred Wegener and Harry Hess, assess the impact of current scientific ideas with the willingness to adopt new theories.



7.2 Plate tectonics and plate movement



WORKSHEET



With the help of Harry Hess, Fredrick Vine and Drummond Matthews the 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.

crust

the top layer of the Earth which supports all of life on Earth and is split into giant slabs called tectonic plates

mantle

the layer of the Earth underneath the crust which is made up of 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 upper mantle

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 upper solid mantle and the crust.

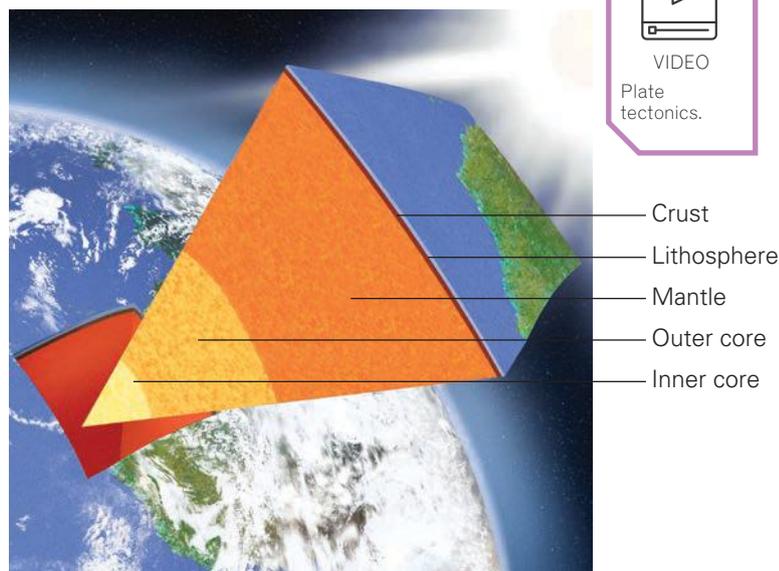


Figure 7.16 Earth's layers

The inner core is made up of heavy metals like iron and nickel. Even though the temperatures in the inner core are hotter than the surface of the sun, these metals are in solid form due to the intense pressure from all the layers above. The outer core is completely liquid and, like the inner core, contains heavy metals. The mantle is mostly made of solid rock which is quite dense. The crust is the thinnest layer and supports all the life on Earth. It is made of two different types, oceanic and continental crust. Oceanic crust is much thinner and denser than continental crust, and supports the world's oceans. The continental crust lies beneath the world's continents.

plate tectonics

the theory that the Earth's crust is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

Scientists need to focus on Earth's lithosphere to explain how continents move. Scientists first proposed the theory of **plate tectonics** in the

late 1950s and early 1960s. They said that Earth's crust is split into **tectonic plates**, gigantic slabs of rigid rock, which float on top of Earth's lower mantle.

tectonic plates

Earth's crust is split into gigantic slabs of rigid rock which float on top of Earth's mantle

- 1 List the layers of the Earth from the surface to the centre of Earth.
- 2 State the name given to the giant slabs of rock that make up Earth's crust.
- 3 Describe the differences between oceanic and continental crusts.

Quick check 7.4

Tectonic plates

As you can see from Figure 7.17, 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



Figure 7.17 The major tectonic plates on Earth's surface

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, any size tectonic plate still plays a role in shaping the Earth. One of the smallest plates, the Juan de Fuca plate, located off the eastern coast of North America, is largely responsible for the volcanic activity there.

How do the plates move?

Tectonic plates float on top of the mantle. The mantle is made up of semi-molten rock called **magma**. In the upper parts of the mantle, the lithosphere, the rock is hard, but lower down the rock is soft and beginning to melt, a bit like toffee when it is heated.

magma

molten rock below the surface of Earth

The temperature increases as you move down through the mantle and get closer to the core. The core is thousands of degrees hotter than the surface of the Earth. The heat created by the core heats the solid rocks in the lower



Figure 7.18 Rocks in the mantle behave a bit like toffee. They have a solid, rigid structure in the top of the mantle where it is cooler, and a softer, more flexible structure further down the mantle where it is hotter.

mantle causing them to become less dense and rise towards the crust. As they rise towards the cooler surface they themselves start to cool down and become denser. They are pushed aside by hot rocks that are still rising and fall back towards the core,

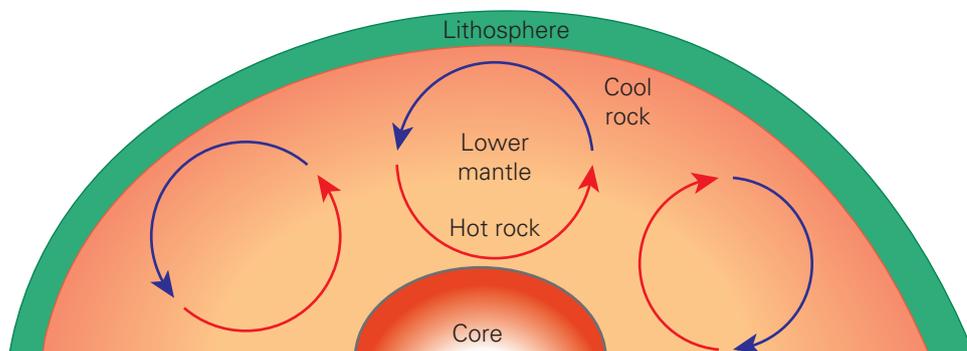


Figure 7.19 Convection currents in Earth's mantle drive the movement of the tectonic plates.

as shown in Figure 7.19. This cycle of hot rock rising and cooler rock sinking is called

convection currents
a form of heat transfer
which works due to different
densities of materials

a convection cycle 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 7.20 shows what can happen when the sideways movements of rocks in the mantle are in opposite directions.

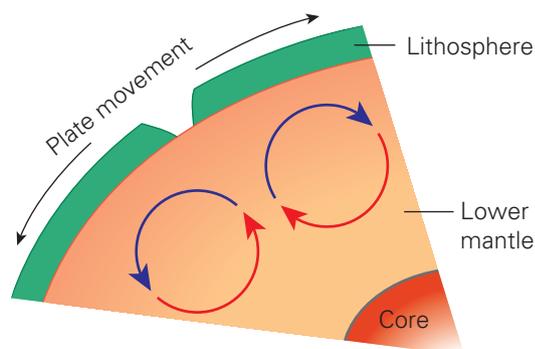


Figure 7.20 The sideways movements of rocks in this example cause the tectonic plates to move in opposite directions, away from each other.

- 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 lower mantle drives the movement of tectonic plates.

Quick check 7.5

Practical 7.2: Teacher demonstration

Modelling plate movement using convection currents

Aim

To model plate movements using biscuits and golden syrup

Materials

- packet of plain biscuits
- 250 mL of golden syrup
- 500 mL beaker
- Bunsen burner
- gauze mat
- tripod
- heatproof mat

Be careful

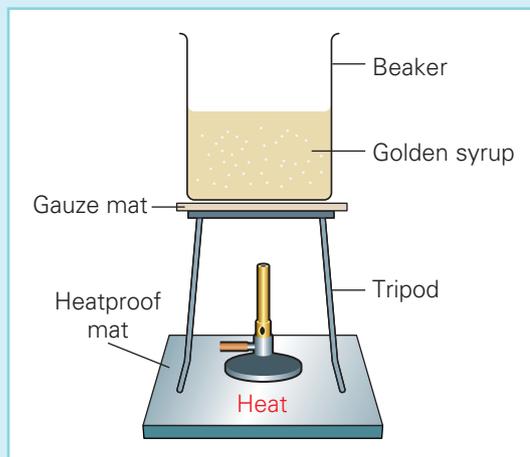
Ensure no food is consumed in the laboratory. Do not heat golden syrup for prolonged periods as it may decompose and produce carbon monoxide. Wear safety glasses.

continued...

...continued

Method

- 1 Half fill a 500 mL beaker with golden syrup.
- 2 Set up the equipment as shown in the diagram.



- 3 Break up a biscuit into different sized pieces and place them back together in their original shape on top of the golden syrup in the beaker.
- 4 Using the Bunsen burner, heat one corner of the golden syrup.
- 5 Observe what happens to the biscuits and record your observations.

Results

Record your observations.

Evaluation

- 1 Outline what the biscuits, golden syrup and Bunsen burner are representing in this model.
- 2 Explain why the biscuits moved apart in the demonstration. Use the following keywords: convection currents, dense, rise, sink, more, less.

Conclusion

Evaluate how successful you think this model is in modelling the movement of tectonic plates by convection currents in Earth's mantle.

Practical 7.3

Observing convection currents

Aim

To observe convection currents.

Materials

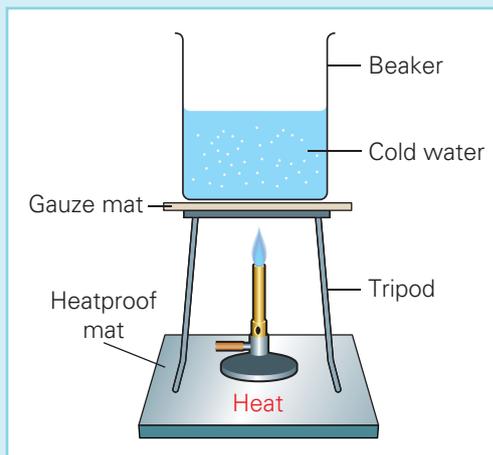
- dark food colouring
- cold water
- 250 mL beaker
- ice cube tray
- Bunsen burner
- gauze mat
- tripod
- heatproof mat

continued...

...continued

Method

- 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.
- 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 record your observations.

Results

Record your observations.

Evaluation

- 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.

Conclusion

- 1 Make a claim from this experiment regarding how convection currents occur.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

How fast is Australia moving?

Australia is situated in the middle of the Australian plate. Since the last adjustment was made to Global Positioning System (GPS) coordinates in 1994 the continent has moved 1.5 m.

GPS

a radio navigation system that allows land, sea and airborne users to determine their exact location, velocity and time

That's about 7 cm a year. In contrast the North American plate has been moving roughly 2.5 cm a year. This means that maps drawn after 1994, but still using the 1994 data, do not show Australia in its correct position for the time the map was drawn, let alone today. Older maps are even more out in their placement of Australia. Corrections to its geographical location have been made four times over the past 50 years. However, because continents move so slowly, most maps do not need to be updated for continental drift. Look at the map in Figure 7.21 and you will see that 1.5 m would make little observable difference to its location on the map. It is

only important to the mapping systems, such as the GPS used worldwide for navigation, and other applications, such as traffic signal timing and synchronisation of mobile phone base stations, which rely on such accurate mapping.

What happens at plate boundaries?

You have learnt that convection currents in Earth's mantle cause the tectonic plates floating on top to move in different directions. The direction of plate movement causes different types of **plate boundaries** to form. Figure 7.22 shows the major tectonic plates and the direction they are travelling.

plate boundaries
three types: divergent, convergent and transform.

There are three types of plate boundaries: destructive (convergent), constructive (divergent) and transform, relating to the movement of plates towards, away and alongside each other.

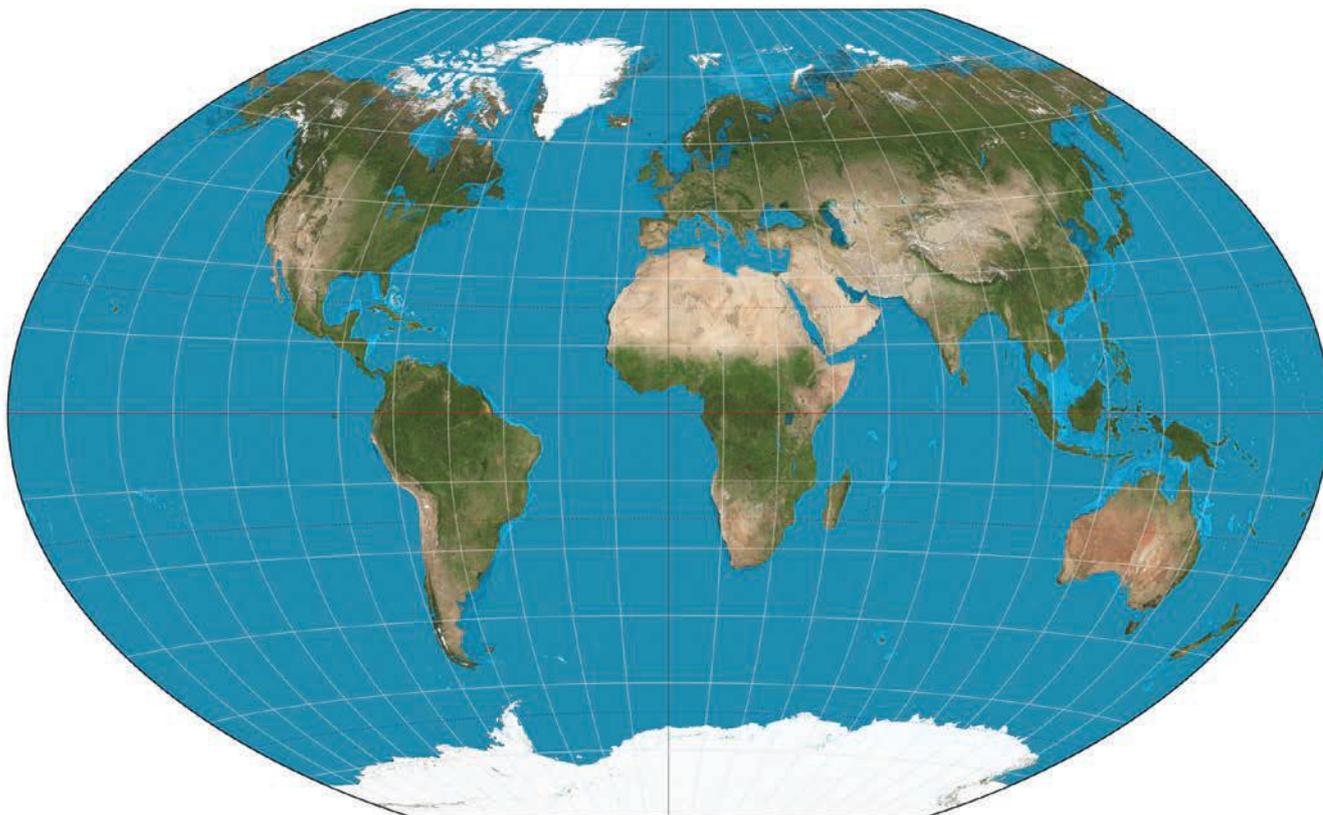


Figure 7.21 Maps drawn using 1994 (and older) GPS data do not show Australia in its correct geographical location, due to the relatively fast movement of the Australian plate.

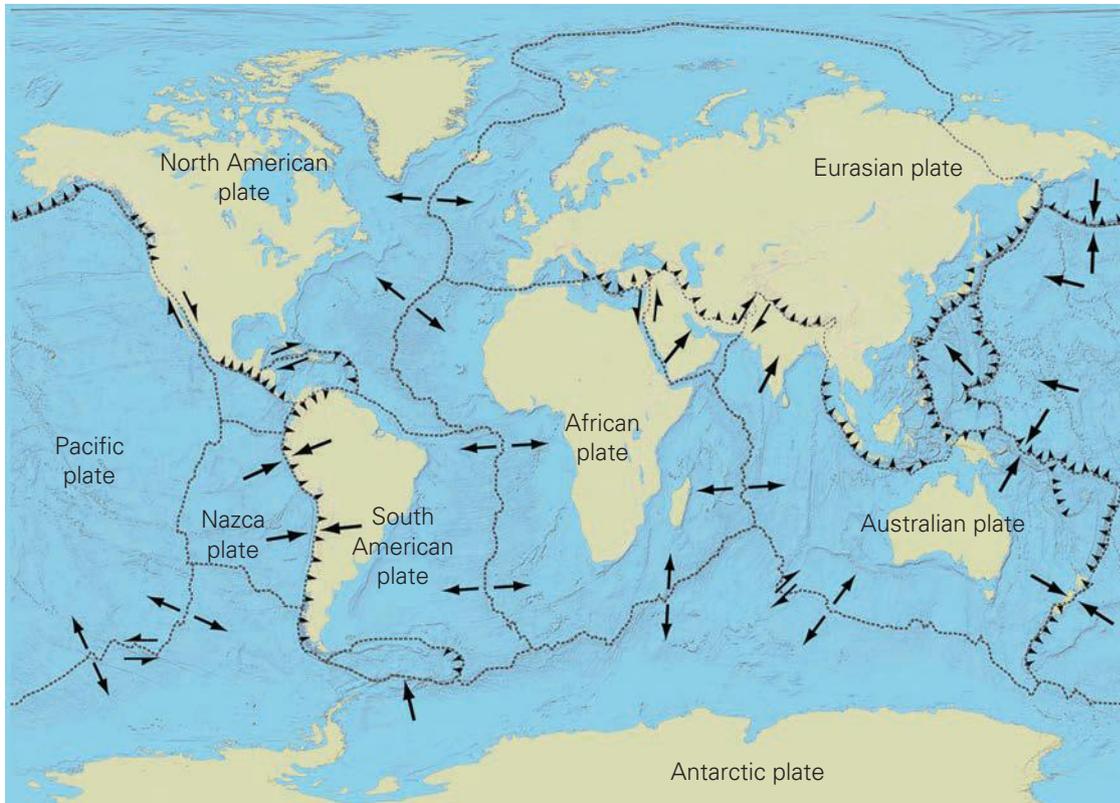


Figure 7.22 The major tectonic plates and their direction of travel. The small triangles on the lines indicate that it is a convergent plate boundary.

The Chile Triple Junction

The Chile Triple Junction is located on the sea floor of the Pacific Ocean off the southern coast of Chile. It is the only geologically active place on Earth where three tectonic plates meet. 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.

Explore! 7.2

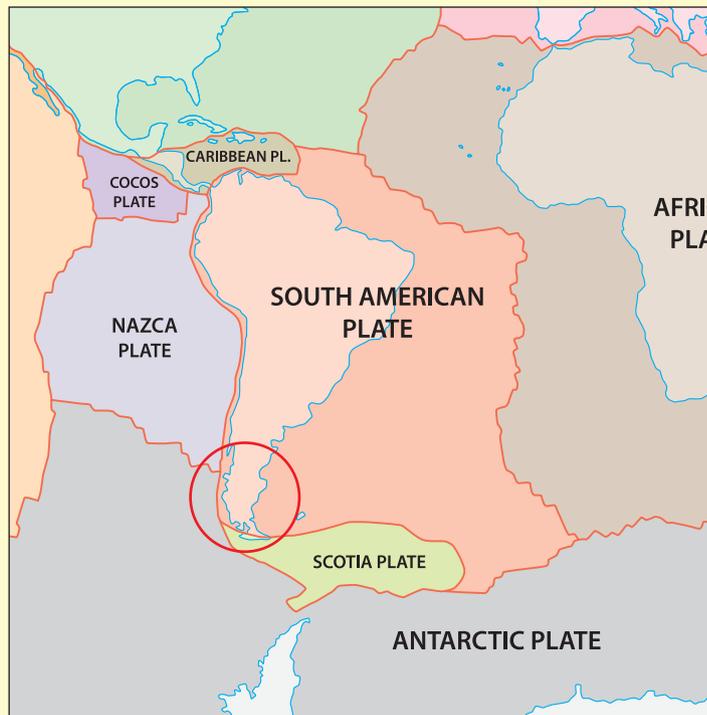


Figure 7.23 The Chile Triple Junction

Destructive boundaries

When plates are moving towards one another, this is called a **destructive** plate boundary. The plates are colliding, hence they are also called **convergent** plate boundaries. The effects

destructive (convergent)
a type of plate boundary that occurs when plates move towards one another

and the features that form at these boundaries depend on what the two plates are made from. You have already learned that there are two types of crust – oceanic and continental. Oceanic crust is thin and dense whereas, in comparison, continental crust is thicker and less dense. So, what happens when plates with two different types of crust on top of the upper mantle collide?

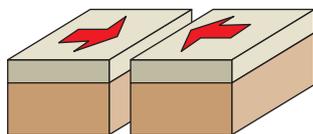


Figure 7.24 A destructive, or convergent, plate boundary

- 1 Describe the movement of plates at a destructive plate boundary.
- 2 What affects the features that form at this type of plate boundary?

Quick check 7.6

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**.

subduction

when the denser oceanic crust sinks underneath less dense continental crust

As the oceanic plate sinks deeper

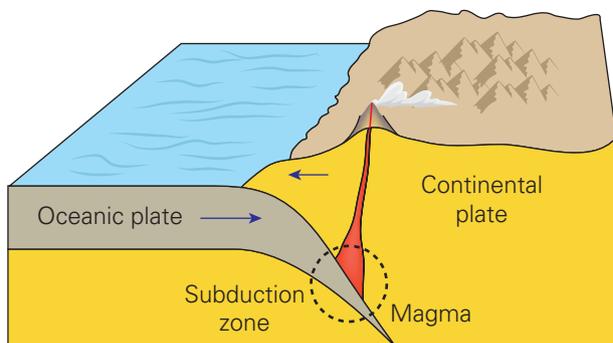


Figure 7.25 A subduction zone forms when the denser oceanic plate subducts underneath the less dense continental plate.

and deeper into the mantle it begins to melt, forming magma. This magma can rise up through the continental plate to form volcanoes.

The Hikurangi subduction zone located off the east coast of the North Island of New Zealand has formed because of the subduction of the Pacific plate underneath the Australian plate. It poses the largest threat of earthquakes and tsunamis to the residents of New Zealand.

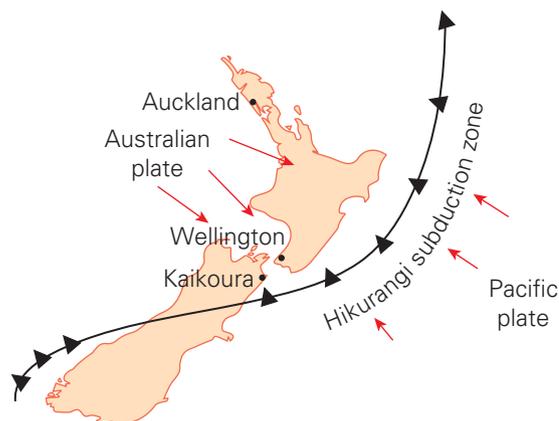


Figure 7.26 The Hikurangi subduction zone is located off the coast of New Zealand's North Island.

Mountains and deep ocean trenches also form at this type of destructive boundary. The Andes mountains on the west coast of South America continue to grow in size because the Nazca oceanic plate is subducting underneath the South American continental plate.



Figure 7.27 The Andes mountains in South America formed due to the subduction of the Nazca plate underneath the South American plate.

When two continental plates meet

In this case, both of the plates have the same density, therefore when they collide, subduction does not take place. Instead, when the two plates collide, the crust buckles and breaks down. This forces the damaged crust upwards eventually forming mountains.

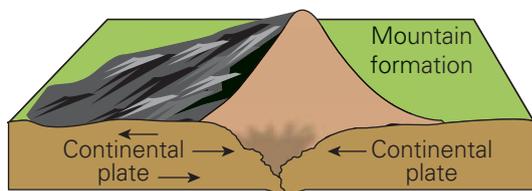


Figure 7.28 The formation of mountains when two continental plates collide

The Indian plate and the Eurasian plate are colliding in this type of boundary. Over 50 million years ago these plates collided causing a huge uplift of the land and the formation of the Himalayas mountain range, the highest mountain range in the world.



Figure 7.29 The Himalayas mountain range, the highest in the world was formed and is continuing to form at a destructive plate boundary.

When two oceanic plates meet

Several things may happen when two oceanic plates meet. If one plate is less dense than the other, a subduction zone will be created. If they are equal in density, then may create a ridge instead, potentially forming islands.

- 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.

Quick check 7.7

Practical 7.4

How dense are different rocks?

Aim

To compare the densities of different rock types.

Materials

- 4 different types of rock (basalt, granite, sandstone and chalk)
- 10 mL measuring cylinder
- displacement can
- balance

Method

- 1 Draw the results table.
- 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 cm^3 in the results table (Note: $1 \text{ mL} = 1 \text{ cm}^3$)
- 6 Repeat twice more.

continued...

continued...

- 7 Following the same procedure repeat for the other rock types.
- 8 Calculate the average volume of water expelled from the displacement can.
- 9 Using the formula below calculate the density of each rock type.

$$\text{density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

Results

Type of rock	Mass (g)	Volume of water expelled (cm ³)			Average volume (cm ³)	Density (g/cm ³)
		1	2	3		
Basalt						
Granite						
Sandstone						
Chalk						

Evaluation

- 1 Which rock was the densest? Which was the 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 secondary sources on the internet. How close were you to those values?

Conclusion

Using your results, explain why oceanic crust made of basalt subducts underneath continental crust made of predominantly granite at **destructive** plate boundaries.

As the Eurasian and Indian plates are constantly moving towards each other, Mount Everest – the highest mountain in the world at 8850 metres tall – is actually getting taller each year, by 4 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!!

Did you know? 7.2

Constructive boundaries

Plates moving away from one another are called **constructive** plate boundaries.

constructive (divergent)
a type of plate boundary that occurs when plates move away from one another

They are also more widely known as **divergent** plate boundaries and can occur beneath the ocean or on land.

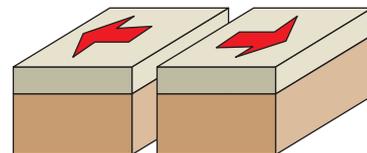


Figure 7.30 At constructive plate boundaries, plates move apart.

In the ocean

When plates move apart in the ocean, the hot mantle is exposed. The magma (molten rock) rises to fill the gap. As it reaches the colder surface, it cools forming igneous rock gradually building more oceanic crust. The Mid-Atlantic Ridge, a series of under the sea volcanoes running down the Atlantic Ocean between Africa and America, is an example of this type of plate boundary. Here the North American and South American plates are moving away from the Eurasian and African plates.

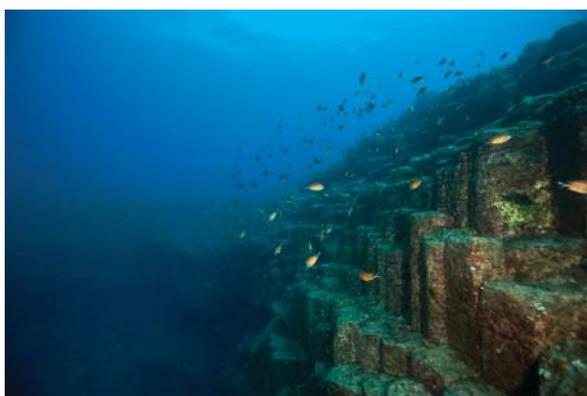


Figure 7.31 A volcanic crater of basalt rocks near Portugal.

On land

Constructive plate boundaries that occur on land form rift zones. An active rift zone is currently threatening to separate Eastern Africa from the rest of Africa. This rift will eventually be filled with ocean, creating



Figure 7.32 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.

a new island version of East Africa. It is already having damaging effects with major roads in cities cracking and caving under the strain. Scientists think it is moving so fast due to a superplume. A superplume occurs when heat from Earth's core rises up through the mantle, intensifying the convection currents and causing the plates to separate much faster.

- 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 diverging boundaries?

Transform boundaries

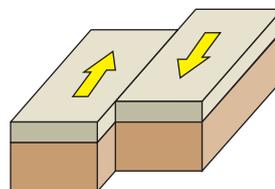


Figure 7.33 At transform plate boundaries, plates slide past one another.



At **transform** plate boundaries, plates are moving parallel to one another, but in opposite directions.

Crust is neither created nor destroyed so they are sometimes called conservative plate boundaries. When plates move in this way 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 stopping them from moving, the pressure is released in the form of earthquakes. An example of a transform plate boundary is the San Andreas Fault running down the east coast of North America through California. Here, the North American plate and the Pacific plate are sliding past each other.

transform
a type of plate boundary that occurs when plates move parallel to one another



Figure 7.34 The San Andreas Fault is the boundary between the North American and Pacific plates.



Figure 7.35 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!



WIDGET
Plate movement at boundaries.

- 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?

Quick check 7.9

Table 7.1 summarises each type of plate boundary.

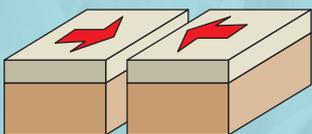
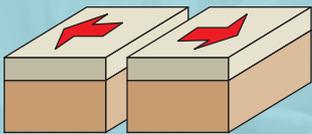
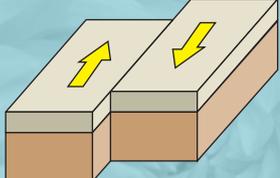
Type of boundary	Diagram	Type of movement	What happens to the crust?	Key features
Destructive (convergent)		Plates move towards each other	Destroyed	Mountains Trenches Subduction zones Volcanoes
Constructive (divergent)		Plates move away from each other	Created	Volcanoes Rifts Ocean ridges
Transform (conservative)		Plates move parallel to each other in opposite directions	Conserved	Earthquakes

Table 7.1 A summary of each type of plate boundary

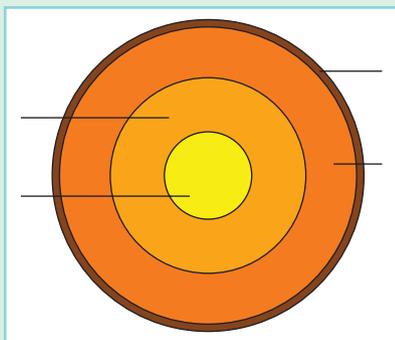
Section 7.2 questions



QUIZ

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.



- 4 Name a real-life example of each of the three types of plate boundaries.
- 5 Name two types of crust.

Understanding

- 6 Describe how temperature affects the structure of rocks in the mantle.
- 7 Explain why the physical states of the inner and outer core differ.
- 8 At destructive plate boundaries crust is destroyed. Explain why the overall amount of crust on the Earth has stayed the same despite this destruction.
- 9 Outline how magma forms at a subduction zone.

Applying

- 10 Construct a labelled diagram to show an oceanic plate subducting underneath a continental plate.
- 11 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

Analysing

- 12 Compare and contrast oceanic and continental crusts.
- 13 Analyse why mountains and trenches continue to increase in size.

Evaluating

- 14 Propose reasons why countries like Australia do not experience significant amounts of geological activity.
- 15 Explain why tectonic plates move across the surface of the Earth.
- 16 Propose your own reasons why some tectonic plates move faster than others.



7.3 The effects of plate movement



If you reside 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.

When this magma erupts at the bottom of the sea it can make a chain of volcanoes called island arcs. Figure 7.37 shows the island arc of the Aleutian Islands. They are made up of a long chain of volcanoes associated with the Aleutian Trench.

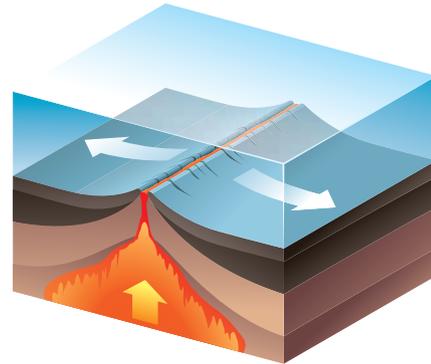


Figure 7.36 A constructive plate boundary forms where magma rises to fill the gap when the plates move apart.

At a destructive boundary, in particular, at subduction zones, friction caused by one plate subducting underneath another causes the production of 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.

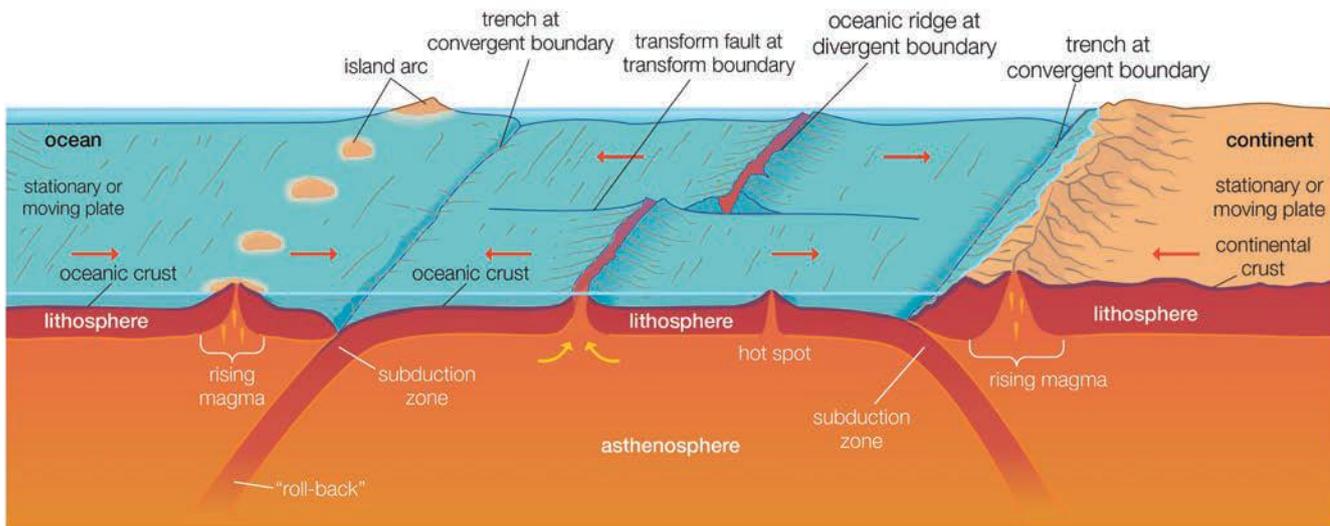


Figure 7.37 Volcanoes can form at destructive and constructive plate boundaries.

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 7.38.

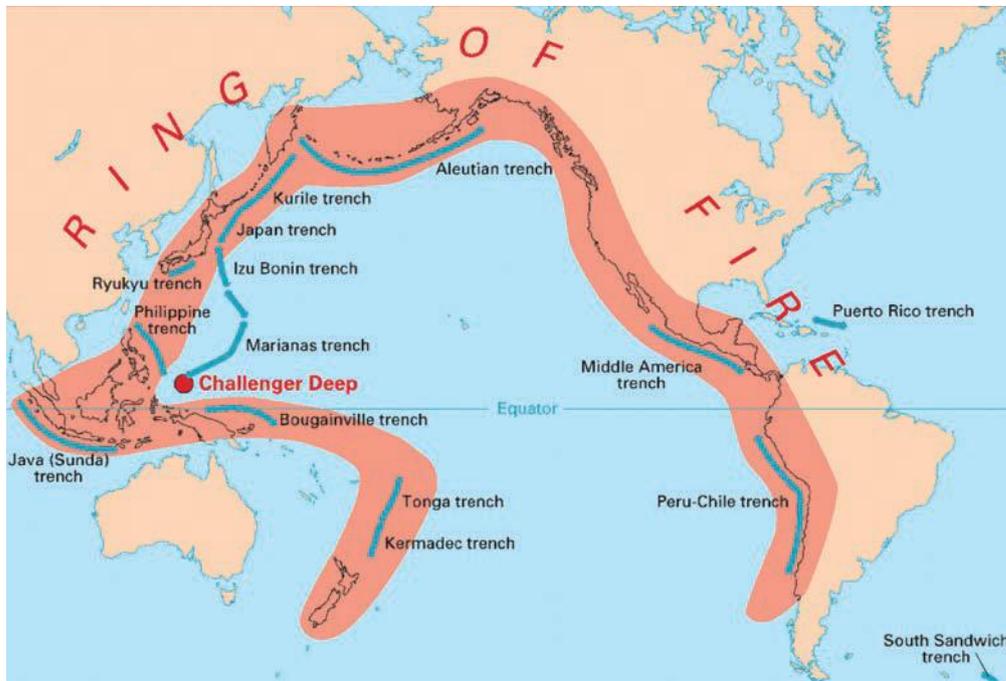


Figure 7.38 The Ring of Fire is an active area of many subduction zones around the Pacific Ocean.

Volcanoes are unique geological events 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 around 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

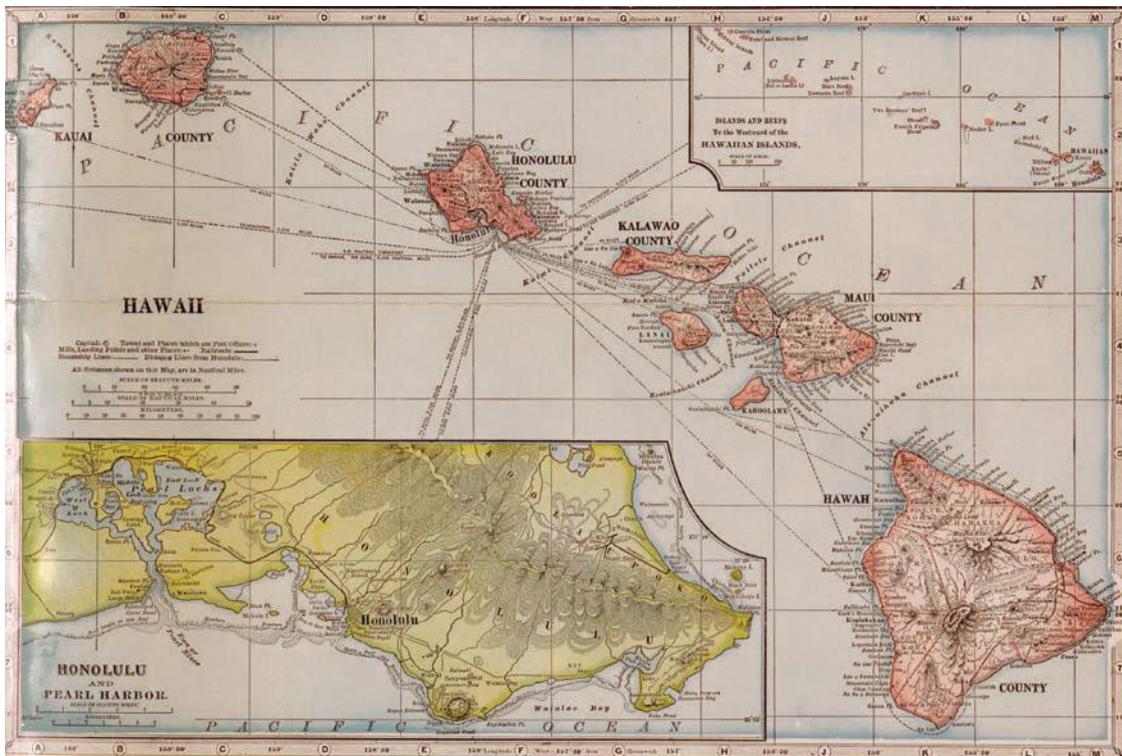


Figure 7.39 The Hawaiian Islands were created by a number of hotspot volcanoes.

- 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.

Quick check 7.10**What happens during a volcanic eruption?**

When the pressure of the magma rising to the surface increases too quickly, a volcano can erupt. When magma reaches the surface, it is called **lava**. The type of lava that is produced by a volcano makes a huge difference to the effects of a volcanic

eruption. Lava with large amounts of silica is viscous (thick and sticky) like golden syrup. Air pockets can build up in viscous lava leading to a very explosive eruption. Lava which contains a small amount of silica is less viscous, but it will travel further from an eruption, putting larger areas at risk.

lava
molten rock that has reached the surface



Figure 7.40 The viscosity of the lava has a huge effect on the damage caused by a volcanic eruption.

Practical 7.5**Comparing the viscosity of liquids****Aim**

To compare the viscosity of different liquids.

Materials

- 4 different household liquids (such as corn syrup, shampoo, liquid soap, vegetable oil, golden syrup)
- 4 × 100 mL measuring cylinders
- 4 marbles
- stopwatch

Method

- 1 Write a hypothesis for this investigation.
- 2 Draw the results table.
- 3 Measure 75 mL of one of the liquids into a 100 mL measuring cylinder.
- 4 Drop the marble into the liquid and at the same time start the stopwatch.
- 5 Stop the stopwatch when the marble hits the bottom of the measuring cylinder and record this time in the results table.

continued...

...continued

- 6 Collect the marble from the bottom of the measuring cylinder and repeat twice more for the same liquid.
- 7 Repeat the procedure for the other liquids.
- 8 Calculate the average time for the marble to drop for each liquid.

Results

Type of liquid	Time taken for the marble to reach the bottom of the measuring cylinder (s)			Average time (s)
	1	2	3	

Evaluation

- 1 Identify which liquid was the most viscous. Explain how you know.
- 2 Identify which liquid was the least viscous. Explain how you know.
- 3 Describe the control variables in this investigation.
- 4 Give the independent variable.
- 5 Name the dependent variable.

Conclusion

- 1 Make a claim from this experiment regarding the viscosity of varying liquids.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Lava is not the only hazard of a volcanic eruption. Gas and ash clouds, acidic gas causing acid rain and **pyroclastic** flows made up

of hot gas and rock also have the potential to cause major damage, not only to the surrounding areas but across the world, as shown in Figure 7.41.

pyroclastic

consisting of or relating to small pieces of rock from a volcano



Figure 7.41 Pyroclastic flows from the eruption of the Sinabung volcano in Indonesia in October 2017

- 1 Distinguish between magma and lava.
- 2 Explain how the viscosity of lava affects a volcanic eruption.

Quick check 7.11

Iceland's Eyjafjallajökull volcanic eruption in 2010

On 20 March 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 for how long the volcano was dormant for 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.

Explore! 7.3



Figure 7.42 This satellite image shows the force of the explosion observed from Iceland's erupting Eyjafjallajökull volcano in 2010.

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 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**.

seismic wave

wave that moves through Earth during an earthquake

focus

the exact point under Earth where the earthquake occurs

epicentre

the part of Earth's surface directly above the focus of an earthquake

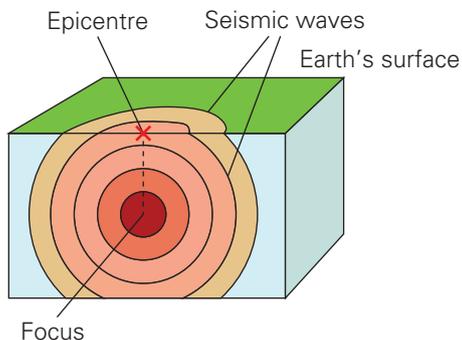


Figure 7.43 A diagram showing the location of an earthquake's focus and epicentre

How are earthquakes detected?

Earthquakes are detected by using a piece of technology called a **seismometer**. A simple seismometer is shown in Figure 7.44. 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.

seismometer

an instrument that measures the intensity and duration of seismic waves during an earthquake

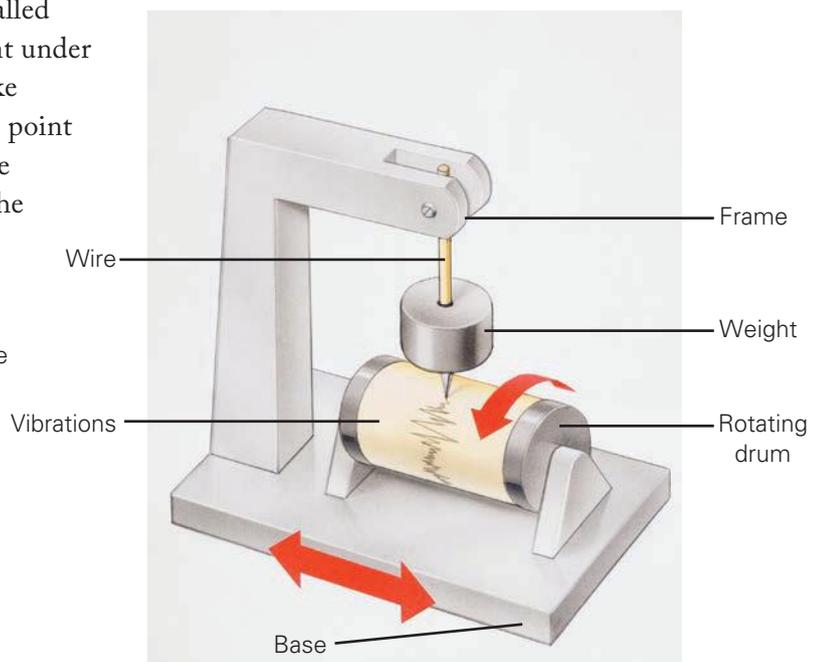


Figure 7.44 A simple seismometer

When the land moves from side to side, the box remains fixed to the ground and moves with it, but the mass on the end of the spring stays in its original position. It is not affected by the movement of the ground. The pen attached to the mass records the movement of the box in relationship to the stationary mass. The resulting pattern is called a **seismogram**. Note that seismometers are also available for many smartphones.

seismogram

the pattern produced when seismic activity is recorded by a seismometer

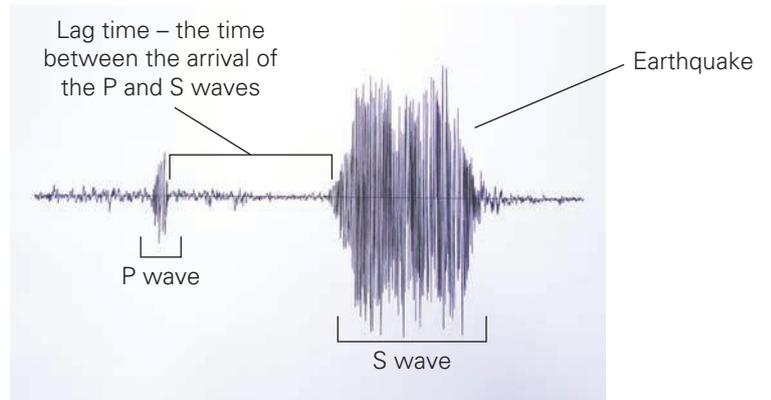


Figure 7.45 A seismogram of seismic activity within the Earth

Practical 7.6: Student design

Designing a seismometer

Aim

To design a seismometer to measure seismic activity.

Materials

- 100 g masses
- pen and paper
- cardboard box
- scissors
- plastic cup
- ball of string
- modelling clay
- retort stand and clamp
- any other materials required after requesting them from your teacher

Method

- 1 Using the materials listed above and any other materials that you think you might need, draw a labelled diagram for your design of a seismometer.
- 2 Show your design to your teacher. If they approve, start making a prototype of your design.
- 3 Test your seismometer by gently moving the desk from side to side while moving the paper forwards.

Evaluation

- 1 Evaluate the success of your model seismometer.
- 2 If you were to build another model, propose how you would improve it.
- 3 Compare your model of a simple seismometer to more complex ones used today.

Conclusion

- 1 Make a claim from this experiment regarding what is required for a functioning seismometer.
- 2 Support the statement by using your observations (include potential flaws in your design).
- 3 Explain how your observations support your claim.

The two main types of seismic waves produced by an earthquake are primary (P) waves and secondary (S) waves. The properties of these waves are summarised in Table 7.2.

As P waves are the fastest 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 7.45. The S waves are slower and so arrive second. They are also the most intense and so register larger movements on the seismogram.

	P waves	S waves
Name	Primary	Secondary
Speed	Fast	Slow
Movement	Longitudinal (up and down)	Transverse (side to side)
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

- 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 waves are the fastest and therefore arrive first following an earthquake?

Quick check 7.12

How do P and S waves give us evidence for the structure of the Earth?

Explore! 7.4

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.

- 1 What can you conclude about the movements of P and S waves through Earth using the diagram in Figure 7.46?
- 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.

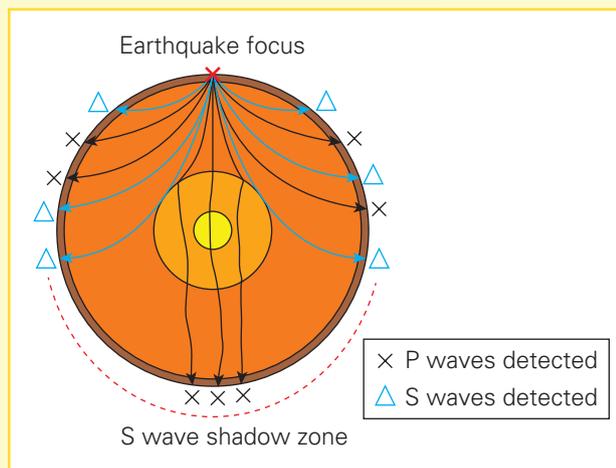


Figure 7.46 The pattern of seismic activity away from an earthquake's focus

The effects of earthquakes

Richter scale

a system used to measure the strength of an earthquake

The severity of an earthquake is measured using the **Richter scale**: the more severe the earthquake, the higher the number on the Richter scale. An earthquake measured as four on this scale is ten times more severe than an earthquake measured at three on the same scale.

The largest earthquake ever recorded occurred in Chile on 22 May 1960. It was recorded at 9.5 on the Richter scale. It killed 1655 people and displaced more than two million people from their homes.

Did you know? 7.3

If an earthquake occurs in the ocean it can produce a large wave called a **tsunami**. When this wave reaches shallow water, it suddenly grows to tens of metres in height and can be devastating.

tsunami

a great wave produced by earthquakes in the ocean



Figure 7.47 A tsunami breaching the embankments after an earthquake measuring 9 on the Richter scale hit off the coast of northern Japan in 2011.

On Boxing Day 2004 an earthquake was measured in the Indian Ocean at 9.1 on the Richter scale. The tsunami waves produced following this earthquake reached up to 15 metres high in some places near to land and affected more than 14 different countries. A quarter of a million people died and two million people were left homeless.



Figure 7.48 An aerial view of the devastation caused by the Boxing Day tsunami in 2004

- 1 How many times more intense is a magnitude 7.0 earthquake compared to a magnitude 5.0 earthquake on the Richter scale?
- 2 Clarify what a tsunami is and how it forms.

Quick check 7.13

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.



Figure 7.49 Rescue workers trying to find survivors under the rubble beneath the Kent Hotel in Hamilton, Newcastle, after the 1989 earthquake

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 7.50 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.



QUIZ

Section 7.3 questions

Remembering

- 1 Recall the name for the volcanic hazard that produces hot fast-moving gas and rocks.
- 2 Name the equipment used to measure the seismic activity of the Earth.
- 3 Name the scale used to measure the magnitude of an earthquake.
- 4 Name the point on Earth's surface directly above the focus of an earthquake.

Understanding

- 5 Describe how earthquakes cause tsunamis.
- 6 Explain why plates at a transform or destructive plate boundary do not slide past each other all the time.
- 7 Explain how the silica content of lava can affect the outcome of a volcanic eruption.
- 8 Outline the reasons why the Ring of Fire in the Pacific is so volcanically active.

Applying

- 9 On the seismogram below, identify which is the P wave and which is the S wave.



- 10 Research the term '**lag time**' in relation to seismic waves and identify this on the seismograph below.



lag time

the time between the arrival of the P and S waves

Analysing

- 11 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.
- 12 Compare and contrast the properties of P waves and S waves.
- 13 Contrast magma and lava.

Evaluating

- 14 There are many different types of volcanoes. Deduce definitions for the following types of volcanoes:
 - a dormant
 - b extinct
 - c active
- 15 Decide whether more geological activity is experienced by countries in the middle of a plate 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

As technology improves, so does our understanding of geological patterns and changes. This greater understanding has allowed scientists to predict the continuing 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 satellites (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 Earth as well as GPS receivers on the ground which detect the radio signals from the satellites. To determine precise locations on

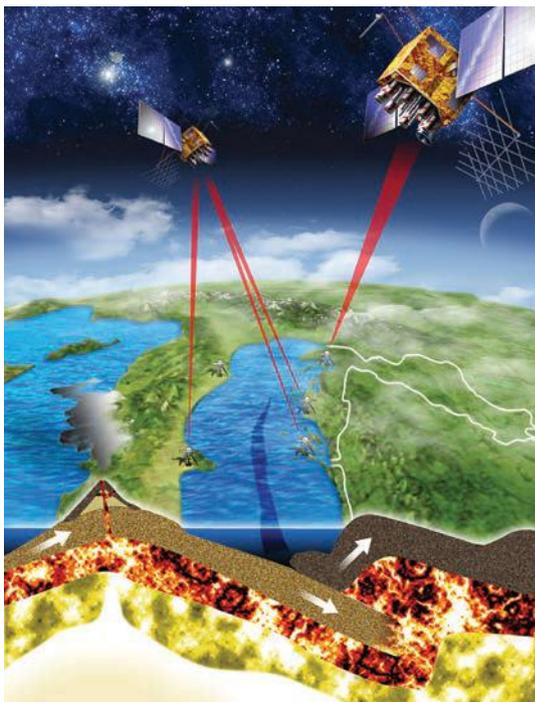


Figure 751 GPS is used to measure position and therefore the rate of movement of tectonic plates.

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

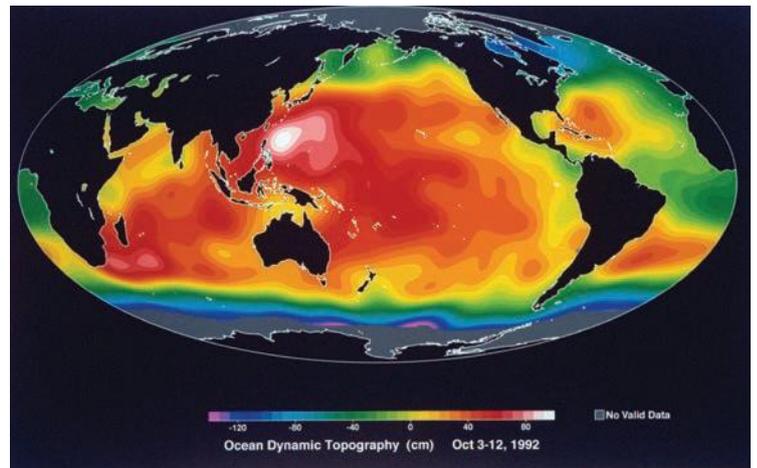


Figure 752 A geoid of the Earth. Red areas show strong gravity, blue areas show weaker gravity.

Gravity can be stronger and weaker at different points of Earth's surface. 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 surface which defines zero elevation

Computer modelling

Computer models simulating the way tectonic plates move, are becoming more and more accurate. A new model built by scientists in 2012 was found to be highly accurate in predicting plate motion and the way in which plate boundaries deform. The model focuses on the mantle and it allows for variations in the physical properties of the mantle which can either speed up or resist plate movement.



Figure 7.53 3D visualisation and geological modelling suite being used by geologists to interpret seismic data from an oilfield.

- 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?

Quick check 7.14

Predicting and responding to natural disasters

NASA Volcanobots



Figure 7.54 Robots similar to the one used in the mission to Mars are being created to explore areas of volcanoes that humans could never access.

Studying active volcanoes is a risky business. 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



Figure 7.55 Drones are being used to search for survivors following natural disasters.

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 most significant 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. They are also useful for getting medical aid into areas that have been blocked off by landslides or collapsed buildings.

- 1 State the name given to scientists that study volcanoes.
- 2 Give one use of drones after an earthquake.

Quick check 7.15

Most buildings are designed to support vertical forces, like the walls and roof. However, earthquakes provide sideways or horizontal forces, which is why many current buildings struggle to withstand high magnitude earthquakes. There are three ways that a building can be made 'earthquake proof'.

- 1 Base isolation.
Here, 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.
Tying the walls, roof and foundations into a rigid box that holds together when shaken by an earthquake.

Earthquake-Resistant House

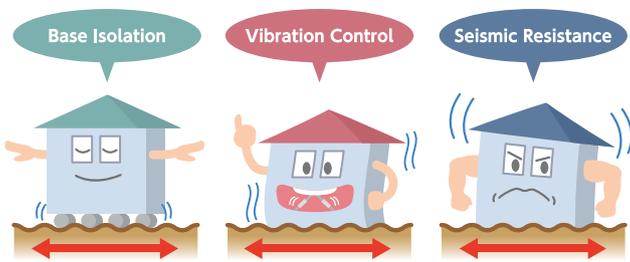


Figure 7.56 Buildings can be made earthquake proof by three different methods.

- Quick check 7.16**
- 1 Give one way in which a building can be earthquake proofed.
 - 2 Discuss why existing buildings are not able to withstand high magnitude earthquakes.

Levitating houses!

Science as a human endeavour 7.2

Air Danshin, a company in Japan, have 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 7.57 Would you want to live in a floating house?

The Taipei World Financial Centre

This building located in Taiwan 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?

Explore! 7.5

Practical 7.7: Student design

Designing earthquake-proof building bases

Aim

To observe the effect of base isolation on damage to buildings during an earthquake.

Materials

- 100 g masses
- plastic or paper straws
- masking tape
- cardboard
- string
- wooden block
- wooden dowels or pens

Method

- 1 Will base isolation create more or less damage to a building during an earthquake? Write a hypothesis for your investigation.
- 2 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.)
- 3 Draw the results table.
- 4 Put your finished design on a table and shake the table for 20 seconds. Record what happened in your results table.
- 5 Now lay the pens or the wooden dowels on the table so they align.
- 6 Place the wooden block on top of the pens or dowels and put your second building on top.
- 7 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)	

Evaluation

- 1 Identify which structure was the most earthquake resistant and why.
- 2 Identify which structure was the least earthquake resistant and why.
- 3 Examine how base isolation helps the building survive an earthquake.
- 4 Discuss how the design and construction decisions make the building more earthquake resistant.
- 5 Recommend what you would do differently next time in the construction of your building. Explain why.

Conclusion

- 1 Make a claim from this experiment regarding the role of base isolation during earthquakes.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Section 7.4 questions



QUIZ

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.

Applying

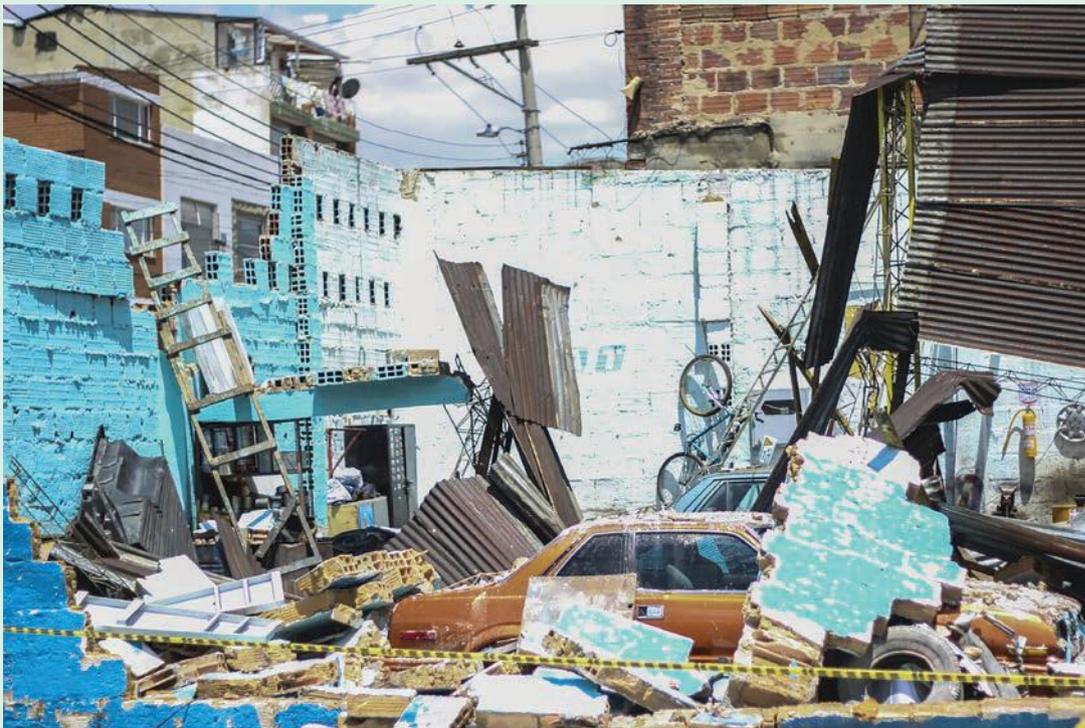
- 7 Apply your knowledge of tsunamis to explain why levitating homes are not effective in preventing damage caused by them.

Analysing

- 8 Compare and contrast the three methods of protecting buildings from earthquakes.

Evaluating

- 9 Propose reasons why humans cannot enter some parts of volcanoes.
- 10 Suggest benefits and shortcomings of using technologies to map plate movement and Earth's geology by using examples.
- 11 Recall the various earthquake-proofing methods you have learned about. Propose which earthquake-proofing method you would choose and justify your choice.



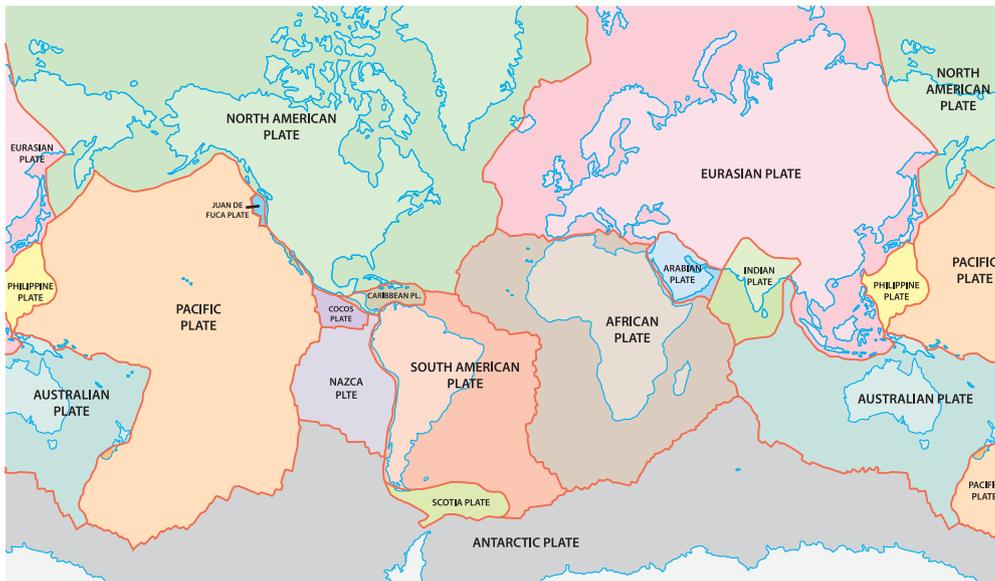
Review questions



SCORCHER

Remembering

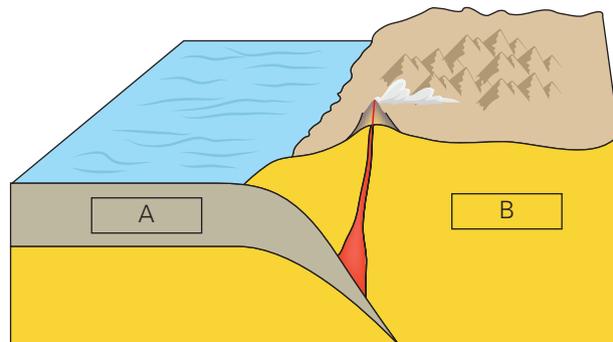
1 List five major tectonic plates using the image below.



2 Match the layer of the Earth (A–D) to its physical properties (1–4).

A Crust	1 Made of metals (iron and nickel) Very hot temperatures Under intense pressure from the layers above so is a solid structure
B Mantle	2 Made of dense solid rock which flows in the hot temperatures
C Outer core	3 Thinnest layer Supports all the life on Earth
D Inner core	4 Made of metals (iron and nickel) Very hot temperatures Liquid

- 3 Give the name of one piece of technology used to measure plate movements.
- 4 Name the tectonic plate which lies underneath Australia.
- 5 Name the mechanism in Earth's mantle that causes tectonic plates to move.
- 6 Label the continental and oceanic plates at the subduction zone in the diagram opposite.

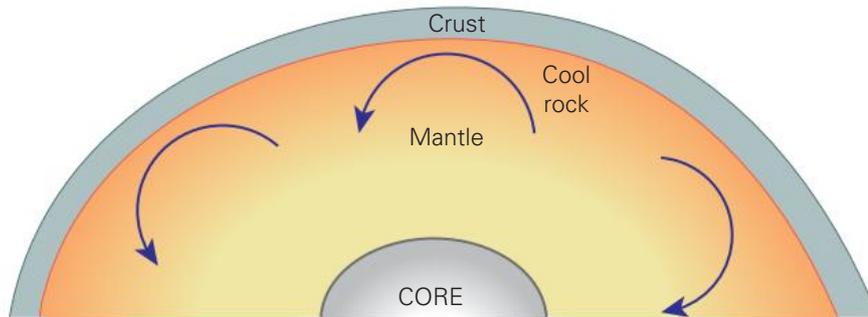


Understanding

- 7 Describe the three types of plate boundaries and how they affect the amount of crust.
- 8 Explain how mid-ocean ridges form.
- 9 Outline the evidence proposed by Alfred Wegener for his continental drift theory.
- 10 Explain why the rocks in the sea floor are magnetised and how this supports Hess's theory of seafloor spreading.
- 11 Describe how a seismometer works.

Applying

- 12 Identify the source of heat causing convection currents in Earth's mantle.
- 13 Using the diagram below, model how convection currents in the mantle move tectonic plates.



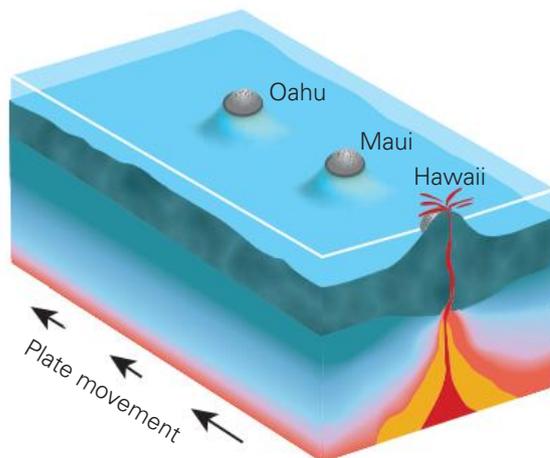
- 14 Identify the type of seismic wave from the description:
- A transverse wave which cannot travel through liquids
 - A longitudinal wave that can be detected on the opposite side of Earth to the epicentre of an earthquake.

Analysing

- 15 Examine the results from Harry Hess's mapping of the sea floor. How did this account for movements of tectonic plates?
- 16 Compare and contrast the two types of destructive plate boundaries.
- 17 Make an inference as to whether the following effects indicate a constructive, destructive or transform plate boundary.
- No mountains form
 - Island arcs
 - Crust is conserved
- 18 Classify the following as constructive, destructive or transform plate boundaries.
- The Himalayas
 - Mid-Atlantic Ridge
 - Mariana Trench

Evaluating

- 19 At the East African Rift zone, the plates are moving away from each other. Predict what will happen to the continent of Africa in the next million years.
- 20 Determine which island is the oldest from the diagram below. What type of volcano is shown in the diagram?



- 21 Predict what you think will happen to the Earth's continents in the next 100 million years.

STEM activity: Earthquake-proof structures

Background information

In this chapter, you have gained an insight on the inner workings of our planet. You learned that, contrary to appearances, our planet has been very active for over 4 billion years! Our planet is constantly changing via many important geological processes over eons, and some of the movements produce earthquakes.

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Figure 758 (a–c) Damage caused by earthquakes in Papua New Guinea. Earthquakes occur all over the world, in developed and underdeveloped countries. They have the power to destroy whole cities, move entire mountains and lift the ground by many metres. **(d)** Scientists analyse data collected during an earthquake.

Unfortunately, poorer countries have been greatly impacted by earthquakes over the centuries, as whole populations live in high earthquake areas (for example, the Pacific ring of fire and the Andes). Experts have demonstrated that most deaths in earthquakes occur because buildings and dwellings collapse due to poor construction.

Papua New Guinea (PNG) is located in the Australasia 'ecozone', which includes Australia, New Zealand, eastern Indonesia, and several Pacific island groups, such as the Solomon Islands and Vanuatu. PNG is one of the poorest countries in the world and is severely affected by earthquakes. Earthquakes are particularly severe in PNG

because of a combination of factors: steep terrain, poor infrastructure and housing, lack of roads, and extensive seasonal rains, all of which create an environment that is prone to collapse after an earthquake.

Knowledge has the power to improve people's lives. How can you use technology and your knowledge of geometry to improve the lives of people living in these high-risk areas?

Design brief: Improving building design in earthquake zones.

Activity instructions

In teams (a maximum of three people), investigate how housing design can affect the stability of a building. Use your observations to improve a given design to make it more stable and therefore safer. Finally, present (show) how changes to the original design can improve the lives of people living in high-risk areas.

Scenario

Whole populations in PNG currently live in high-risk areas susceptible to major earthquakes. People living in the high hills in the countryside have no access to roads or airports, making them particularly vulnerable during an evacuation process. For example, the PNG earthquake in March 2018 killed more than 200 people and destroyed around 7000 houses. Most of these houses were flattened because they were poorly constructed (see Figure 7.58c) and had little chance of withstanding a major tremor.

Your team has been hired by the local Red Cross branch to demonstrate, using simple models, to local authorities and villagers how simple tweaks to housing design can be an effective way to save lives.

Suggested materials

- wooden sticks
- sticky tape
- glue

Evaluate and modify

- 1 Take time to think about the investment required to change the lives of villagers. Imagine that a 10 cm wooden stick used to build your model costs around \$10 to purchase, and that the piece that joins them costs \$2. Calculate the current cost of building a house using cubes (teachers, see the teacher guide for this activity in the Online Teaching Suite for models). Estimate the savings or increase price of your proposed design.
- 2 It is important to remember who your target audience is throughout this project. Discuss with your colleagues how your team should approach the communication of your ideas to local authorities in PNG.
- 3 Suggest a strategy you could use to improve the way you demonstrate to people in poor countries that simple tweaks to designs can save their lives.
- 4 How will your new design perform compared to your teacher's model? What will be different? Consider these predictions and use them to help evaluate the performance of your design solution.
- 5 It is now time to show the improvements to the original design by performing the following tests.

Draw a results table.

- A Shake test:** Place the original design on a table and secure it using tape. Shake the table forwards and backwards four times. Now, repeat the same process using your design. Describe how successful your design was. Did it fail? And if so, where and why?
 - B Weight test:** Your design has survived the shake test! Now, it is time to compare how it behaves when 0.5 kg masses are placed on top of it.
 - C Combination test:** Your design is still standing – that is great! Now, repeat tests **A** and **B** at the same time. Describe what happened.
- 6 Repeat the tests using your teacher's model.

Chapter 8 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.

Curriculum

Electric circuits can be designed for diverse purposes using different components; the operation of circuits can be explained by the concepts of voltage and current (VCSSU130)

• investigating parallel and series circuits and measuring voltage drops across and currents through various components	8.1, 8.3
• investigating the properties of components such as LEDs, and temperature and light sensors	8.2
• comparing circuit design to household wiring	8.3
• exploring the use of sensors in robotics and control devices	8.2, 8.3

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Glossary terms

alternating current

ammeter

ampere

battery

circuit

circuit breaker (ordinary)

circuit breaker (RCI)

component

conductor

coulomb

current

direct current

double-insulated

dry cell

earthed

electricity

electrocution

electrostatic

fuse

insulator

load

mains electricity

ohm

Ohm's law

parallel circuit

resistance

series circuit

short circuit

static electricity

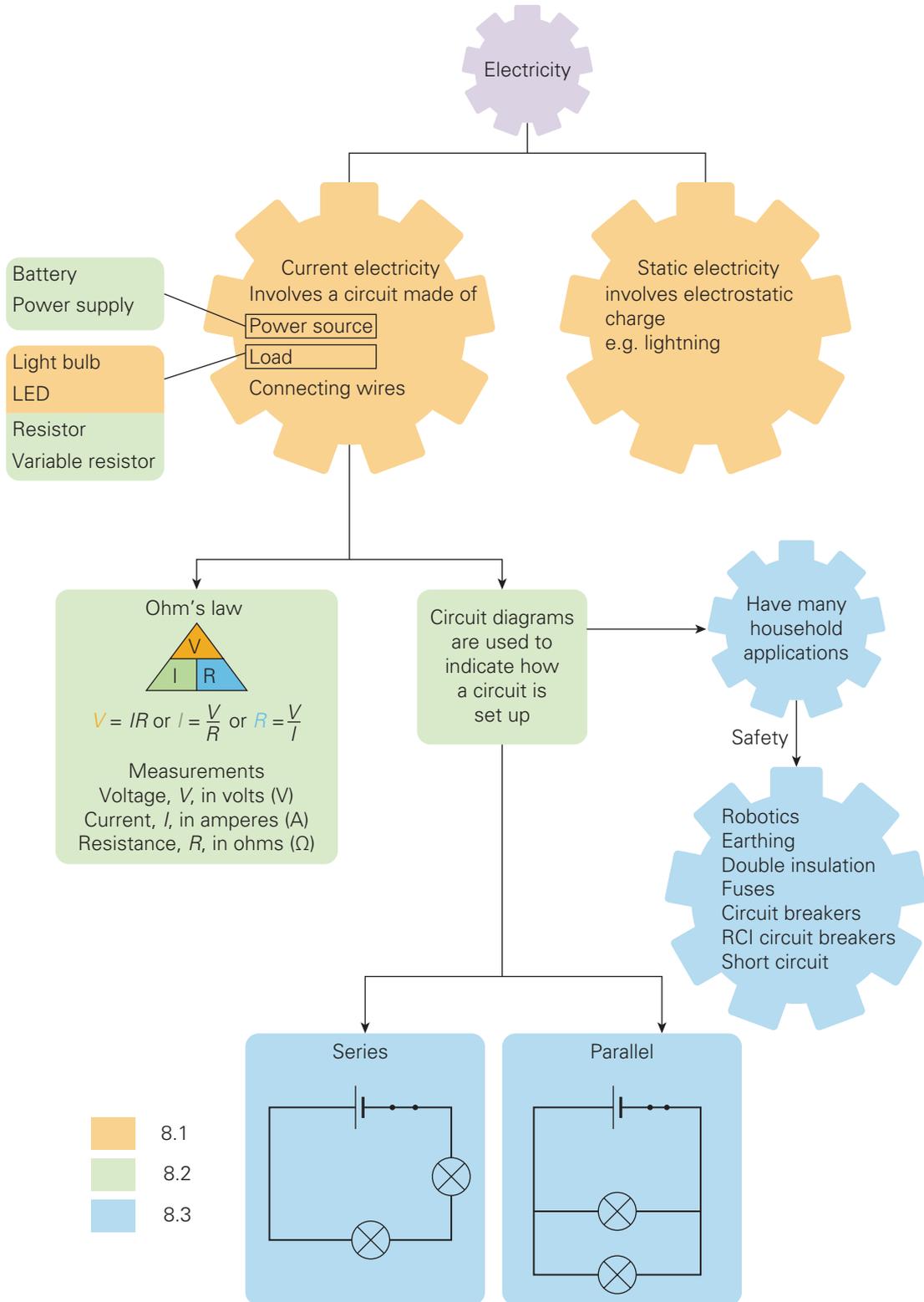
voltage

voltage drop

voltmeter



Concept map





8.1 What is electricity?

Electricity is a form of energy that results from either the accumulation of charge or the flow of charge. Charge can be positive (+) or negative (-). Recall from Chapter 5 that atoms contain positive charge in the form of protons and negative charge in the form of electrons. It is generally the movement of the negatively charged electrons that results in movement and separation of charge.



WORKSHEET



VIDEO
Electricity.

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

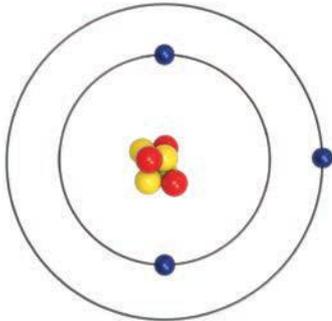


Figure 8.1 This is the Bohr model of a lithium atom with the 3 neutrons, 3 positively charged protons, and 3 negatively charged electrons. The net charge is neutral, but when it loses an electron, the atom becomes positively charged.

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 of the car. 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.

static electricity
an imbalance of charge on objects

electrostatic
charge that stays on an object

Lightning

Have you ever received a small shock from your car or doorknob, or seen sparks when you take your jumper off? That's static electricity. Lightning occurs because of the same principles. When particles of ice bump into each other in storm clouds, a huge amount of charge is built up. The top of the cloud becomes positively charged, while the bottom of the cloud is negatively charged. Eventually, the attraction between the charges becomes too great and a discharge of electrical energy occurs between them, producing lightning in the cloud. Sometimes the lightning moves from the cloud to the ground.

Explore! 8.1



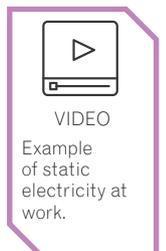
Figure 8.2 Lightning being discharged between clouds

- 1 Statistically, does lightning strike more men than women?
- 2 Propose several reasons why this might be the case.
- 3 Explain what the lightning 30–30 rule is.

Blow up a balloon and tie it up. Rub it against your hair or find a colleague 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?

Try this 8.1

Nowadays, to demonstrate aspects of static electricity a Van de Graaff generator may be used, as shown in Figure 8.3 on the following page. This can produce voltages in the order of 50 000–100 000 volts (50–100 kV). The Van de Graaff generator should only be used under controlled conditions (i.e. by your Science teacher or at places like Scienceworks).



VIDEO
Example of static electricity at work.



Figure 8.3 (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 is now positive in charge. Recall that like charges repel and opposite charges attract, so the hair (+) is now attracted to the balloon (–). **(c)** Static electricity created by a Van de Graaff generator causes a student's hair to rise. This is due to all the hair strands having the same charge and repelling each other.

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, he 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.

Did you know? 8.1



Figure 8.4 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.

Figure 8.5 The aeroplane is connected to earthing wires during refuelling to avoid sparks and a possible explosion.



- 1 Outline the structure of an atom.
- 2 Define the following terms.

a Electricity	b Charge	c Static electricity
---------------	----------	----------------------
- 3 How does rubbing of two different materials together sometimes create static electricity?
- 4 How is static electricity created by combing your hair?

Quick check 8.1

Practical 8.1**Exploring static electricity****Aim**

To explore the effects of static electricity.

Materials

- 2 inflated balloons with strings attached
- empty aluminium soft-drink can
- woollen fabric
- your hair
- mirror

Method

- 1 Rub the two balloons one at a time with the woollen fabric. Try to move the balloons together. Record what you notice.
- 2 Rub one of the balloons back and forth on your hair then slowly move it away from your head. Look at yourself in a mirror. What do you notice?
- 3 Put the empty aluminium soft-drink can on its side on a table. Rub the balloon against the woollen fabric. Hold the charged balloon close to the can (but do not touch the can with the balloon) and watch as it rolls towards it. Slowly move the balloon away from the can and note what happens.

Results

Record all observations from each step of the method.

Evaluation

- 1 Explain how rubbing the balloons against the woollen fabric or your hair creates static electricity.
- 2 Discuss why the two balloons in step **1** of the experiment repelled each other. Use a labelled diagram in your explanation.
- 3 Explain what happened to your hair in step **2** of the experiment. Why did this happen? Use a labelled diagram in your explanation.
- 4 Explain how your charged balloon made the aluminium can roll along in step **3** of the experiment. Use a labelled diagram in your explanation.
- 5 What faults might there be for this experiment and how could they be resolved?

Conclusion

- 1 Make a claim from this experiment regarding how static electricity can be created.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

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 electrical **components**, such as a light bulb, 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 8.2

Figure 8.6 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.

circuit
structure through which
charges can move

load
something that uses energy
in a circuit

It is current electricity that moves in a **circuit** (a closed loop of wires, power source and electrical components).

If there is a break in the loop, then electricity would stop flowing in

that loop. Electrons need a path out of the power source, and back to the power source to continue moving around the circuit.

An electrical circuit always has these three components:

- a power source (provides energy to electrons like a battery or power pack)

- a **load** (something that uses the energy like a light bulb)
- connecting wires (carry the moving electrons).

Power source

Figure 8.7 shows the symbol for a battery, the power source in a circuit. The longer vertical line represents the positive terminal, and the shorter line represents the negative terminal. Because there is an imbalance of charge, when the negative terminal is connected via a circuit to the positive terminal, electrons flow from the negative to the positive terminal. The battery supplies the energy to the electrons which are then carried around the circuit.



Figure 8.7 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 can flatten or damage the battery.

What happens to used batteries?**Did you know? 8.2**

Australia goes through approximately 350 million batteries every year. Around 80% of these are alkaline batteries, which are the most commonly used **dry cell**, amounting to 6000 tonnes. Most people do not utilise the recycling options available, and only around 4% of batteries are recycled. Some batteries contain cadmium, lead, mercury, nickel or lithium, which are all toxic, as well as corrosive chemicals that will corrode the casing and release these toxic metals to the water supply if buried in landfills.

dry cell
a battery in which the electrolyte is absorbed in a solid to form a paste

Let's all do our part and recycle disposable batteries!

Load

Electrons moving through the 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 light globes, the energy being carried by the electrons is transformed into light energy.



Figure 8.8 An older-style light globe transforms electrical energy into light energy. These are typically only 3–4% efficient in transforming electrical energy into light.

Figure 8.9 shows the circuit symbol for an incandescent light globe. Only a small amount of the energy is transformed into light energy – around 96% is wasted as heat. Some light bulbs that are not very energy efficient can get quite hot!

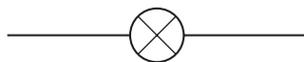


Figure 8.9 Circuit symbol for a light globe

LEDs

Light emitting diodes (LEDs) are like tiny light bulbs that fit into electric circuits, as shown in Figure 8.10. They transform



Figure 8.10 LEDs (light emitting diodes)

electrical energy into light energy. They are much more efficient than light bulbs, and only 20% of the energy is lost as heat.

The lifespan of LEDs is also much longer than incandescent light globes. LEDs are often used in appliances such as watches, microwaves, calculators, and when collected together, traffic lights and TV screens. The symbol for an LED is shown in Figure 8.11.

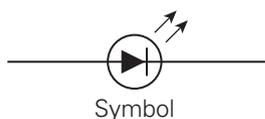


Figure 8.11 Circuit symbol for an LED

Connecting wires

Current is the name given to the electrons flowing through the connecting wires in a circuit. While it is known that it is the negatively charged electrons that move, the current direction is indicated as the opposite direction; that is, the imagined direction of positive charge movement. This is the historical convention of current still in use today.

alternating current

a form of electricity where the current reverses direction in regular cycles

battery

a portable source of power

direct current

a form of electricity when the current flows in one direction

In an **alternating current** (AC) electricity source (like an AC power pack), the current reverses direction around 50 times every second! This is what is used in the power supplies where you plug appliances into. A **battery**, on the other hand, produces a **direct current** (DC), and the current flows only in one direction. In this chapter you will mainly be using DC sources.

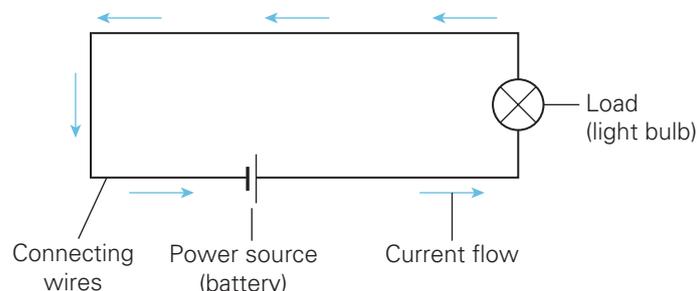


Figure 8.12 Current is indicated in this simple circuit as flowing from the positive terminal to the negative terminal of a battery. The connecting wires are drawn as straight lines.

- 1 Contrast current and static electricity.
 - 2 Contrast direct current and alternating current.
 - 3 Identify what flows in the connecting wires of a battery circuit.
 - 4 Why must a circuit be 'closed' or complete for it to work?

Quick check 8.2

Using a 2.5 V torch light bulb, a 1.5 V battery and two connecting wires, try different arrangements to see how many ways you can make your light globe light up. Remember, do not connect the positive terminal to the negative terminal directly with a connecting wire as it will get very hot, and can flatten or damage the batteries. Draw a circuit diagram for each successful arrangement.

Try this 8.3

Electric cars

There are many reasons why electrical 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 your 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!

Science as a human endeavour 8.1

continued...

...continued

While electric cars are ideal for city and suburban runs (having a typical range of approximately 200–300 km), they cannot yet manage long-distance journeys. Petrol and diesel cars can typically do 500–800 km on a tank of petrol/diesel and can be refilled in 10 minutes at numerous petrol stations dotting the highways. Electric recharge stations are still few and far between in Australia, especially when you think that the first electric car was made in Australia in 2008! The infrastructure required needs a critical mass of electric cars to make it economically feasible. Electric cars also take a longer time to recharge (often more than 1 hour to do a fast recharge).

A Melbourne to Sydney 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.



Figure 8.13 Fast charging an electric car. The 85 kWh battery pack has a mass of 540 kg and contains 7104 lithium-ion battery cells in 16 modules wired in series.

Practical 8.2

Investigating a lemon battery

Aim

To investigate lemon batteries.

Materials

- 2–4 lemons
- microammeter
- 2–4 galvanised nails
- 2–4 pieces of thin copper strip or uninsulated copper wire
- 3–5 connecting leads

Method

- 1 Roll two lemons on a table while pushing down on them a little. The squeezing action releases the juice inside the lemon and makes the battery work better.
- 2 Insert half the galvanised nail into each of the two lemons.
- 3 Insert half the piece of copper strip or copper wire into each of the two lemons.

Important: The galvanised nail and copper strip/wire should be about 2 cm apart.

- 4 Use the connecting leads to connect the copper strip to the positive terminal of the ammeter and the galvanised nail to the negative terminal of the ammeter.
- 5 Record the electric current – this is a measure of the flow of charge, measured in amperes (A). (This is covered later in the next section.)



Figure 8.14 Experimental set-up for a 2-lemon battery

continued...

...continued

- 6 Observe what happens to the electric current when you make the following changes.
- Push the electrodes further into the lemon. Record your results.
 - Increase the distance between the nail and the copper wire. Record your results.
 - Add another one or two lemons. Record your results.

Results

Record the current for step **5**, and then for the changes in steps **6a**, **b**, and **c** of your method.

Evaluation

- Propose why you need different metals for the battery to work.
- Identify the function of the lemon juice/acid in this lemon battery.
- Describe what happened when the depth of the electrodes and the distance between the electrodes was changed. How did it affect the current produced by your lemon battery?
- How did changing the number of lemons affect the current produced by your lemon battery?
- Propose why lemon batteries are not used in everyday life.
- Identify any potential faults with the experiment and suggest how you may overcome them.

Conclusion

- Make a claim from this experiment regarding the electrical properties of lemon batteries.
- Support the statement by using your observations (include potential sources of faults).
- Explain how your observations support your claim.



QUIZ

Section 8.1 questions

Remembering

- What is the electric charge on a neutron, an electron, a proton and an atom? Give your answer in terms of the elementary charge e .
- Recall what an elementary charge is.
- Name the charged particles that carry an electric current through a circuit.
- Define the following terms.
 - Direct current
 - Conventional current
 - Electron current

Understanding

- How does rubbing amber produce electric sparks?
- Draw a simple circuit diagram that shows how to light a LED. What is the role of the connecting wires in an electric circuit?
- Contrast static and current electricity and give examples of each.

Applying

- Explain how the spray painting of cars relies on static electricity.
- Your body relies on electricity to function. Your nervous system sends electric signals through your body, as you learned in Chapter 3. Draw a simple model of the electric circuit and label what the energy source, connecting wires and load are in your body.

Analysing

- 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. What is a possible explanation for this effect?

continued...

...continued

11 Modern laser printers use static electricity as part of the printing process.

The printing process is a 4-step process as follows. Note 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

12 An electrostatic smoke stack is used to remove pollutants from the smoke before they are released into the environment. Explain how neutral particles can be attracted to the statically charged rods hanging in the smoke stack. Determine if this is a good method to remove pollutants from industrial smokestacks and justify your answer.

13 Give reasons why the electricity from lightning bolts is not captured for our electrical needs, although lightning bolts contain large amounts of electrical energy.



8.2 Simple circuits

Circuit diagrams

The circuit in Figure 8.15 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.

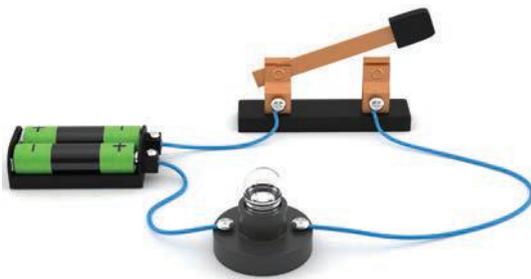


Figure 8.15 A simple circuit with a power source, light globe and a switch

To understand a circuit and analyse how it works, you need to identify its component parts and see how they work together to make the circuit operate. Many circuits are shown in the form of a diagram in which each symbol represents a different electrical component. Figure 8.16 shows the equivalent circuit diagram to Figure 8.15 but using circuit symbols.

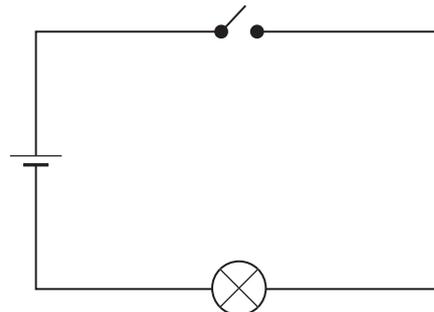


Figure 8.16 A circuit diagram of a light globe, power source and switch



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. Similar to an Etch-a-Sketch, this means the circuits can be erased and reconfigured numerous times.

This type of circuit would be transparent as well, leading to electronics being embedded in windows.

Science as a human endeavour 8.2

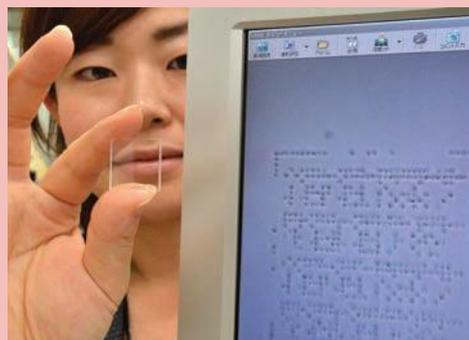


Figure 8.17 Laser beams create dots on glass in order to store data. Electrical circuits in crystals are the next step!

As you investigate current electricity in closed circuits, you will use more and more of these simplified diagrams as a representation of circuits. You will begin by looking at the different symbols used for the different components of circuits.

Circuit symbols

You have already seen some common electrical components and their circuit symbols in the previous section (battery, load and connecting wires). Table 8.1 shows several other useful electrical components and their associated circuit symbols.

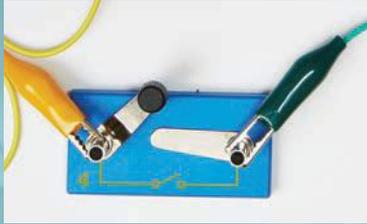
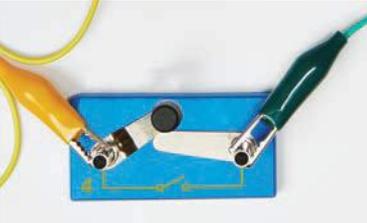
Component	Image	Symbol
Connecting wire		
Switch open		
Switch closed		

Table 8.1 Electrical components and their circuit symbols

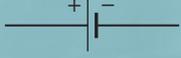
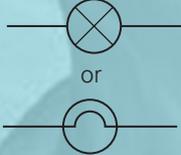
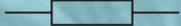
Component	Image	Symbol
Single battery		
Power supply or battery pack		
Load or light bulb		
Ammeter <div style="background-color: #f0e6f8; padding: 5px; margin-top: 5px;"> ammeter a device for measuring the strength of an electric current </div>		
Voltmeter <div style="background-color: #f0e6f8; padding: 5px; margin-top: 5px;"> voltmeter a device for measuring voltage between two points on an electric circuit </div>		
Resistor		
Variable resistor		

TABLE 8.1 *continued...*

Drawing circuit diagrams

A circuit diagram is a diagrammatical representation of an electrical circuit using basic symbols. It is a simple and fast way to

see how all the components in a circuit are connected. Circuit diagrams should always be drawn with a ruler and pencil. All lines should be straight and joined at right angles.

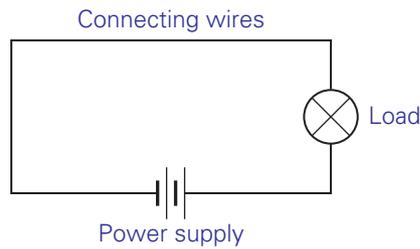
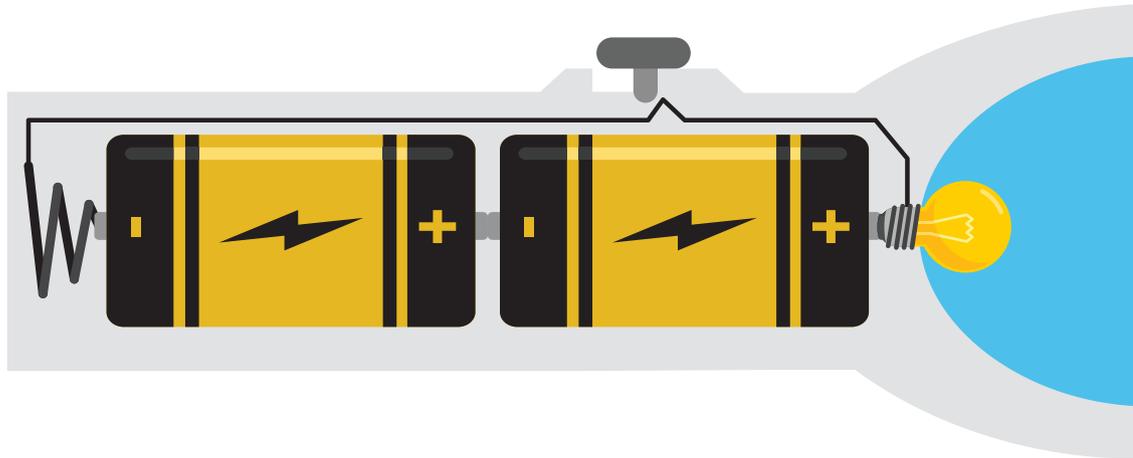
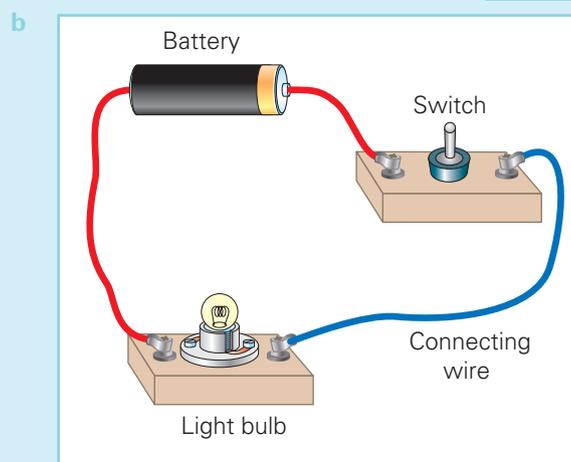
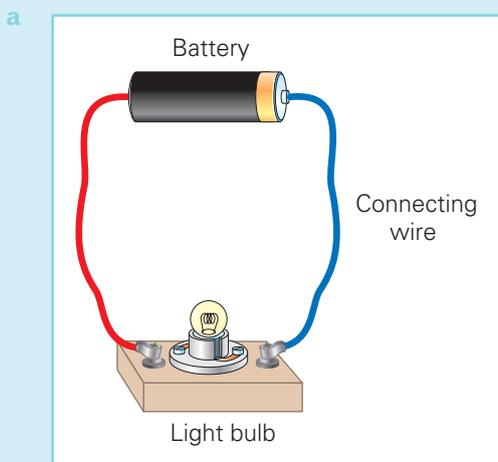


Figure 8.18 The top drawing is the inside of a torch, but you use a simplified diagram like the bottom one to represent the circuit. The batteries are the energy source, and the light bulb is the load. Can you think of one component that needs to be added to the diagram?

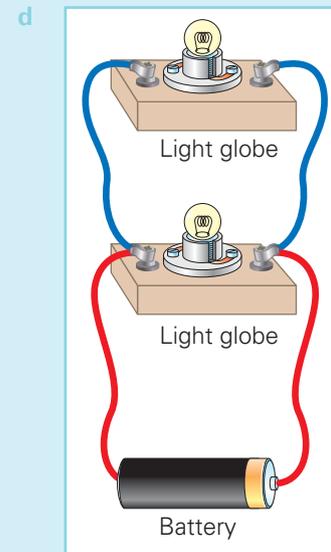
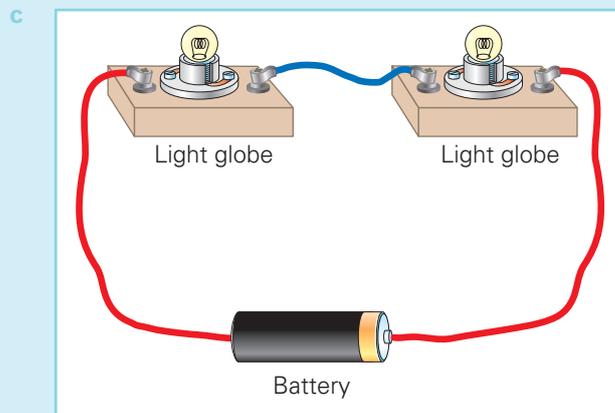
Draw circuit diagrams for the following circuits.

Try this 8.4



continued...

continued...



- 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.

Quick check 8.3

Voltage

Voltage is supplied by the power source of a circuit and is a measurement of how

voltage

a measurement of how much energy each charge is given

voltage drop

the difference in energy the charges carry before and after the load

much energy each electron or charge is given. For example, a 1.5 volt battery supplies 1.5 joules of energy to each unit of charge (remember that a joule (J) is a unit of energy) and that a unit of charge is a coulomb). Components such as light globes and speakers transform the energy supplied by charges into light, heat and sound. The difference in 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 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. A voltmeter needs to be connected to the start and the end of the component whose voltage you are measuring in a circuit to measure the voltage drop **across** the component. The circuit symbol for a voltmeter is shown in Figure 8.19.

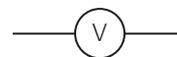


Figure 8.19 Circuit symbol for a voltmeter

Current

You already know that current is the movement of charge or electrons around a circuit. It is possible to measure the rate at which charge passes any point in a circuit. Imagine being able to see the electrons moving along a conductor carrying an electric current. You could count the number which pass any particular point in one second and use that number as a measure of the current (in electrons per second). The unit of current is defined this way where one **coulomb** per second is one **ampere** (A), or amp

coulomb

the amount of charge transferred in one second with a current of one amp

ampere

one coulomb per second

for short. A coulomb can be described as the amount of charge transferred in one 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. The circuit symbol for an ammeter is shown in Figure 8.20.

An ammeter can measure current in amperes (A) or in milliamperes (mA):

$$1 \text{ A} = 1000 \text{ mA}; \quad 1 \text{ mA} = \frac{1}{1000} \text{ A}$$



Figure 8.20 Circuit symbol for an ammeter

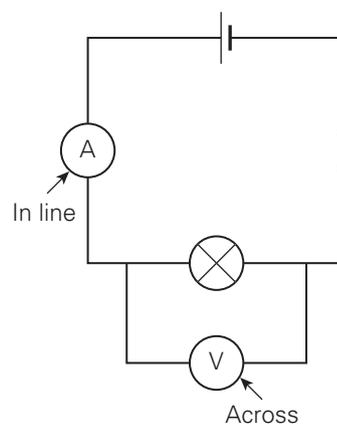


Figure 8.21 An example of how voltmeters and ammeters are positioned in a circuit

1 Define the following terms.

- | | |
|----------------|-----------|
| a Voltage | d Current |
| b Voltage drop | e Ampere |
| c Voltmeter | f Ammeter |

2 How does current differ in a circuit when the switch is open and closed? Explain your answer.

Quick check 8.4

Practical 8.3

Measuring current and voltage

Aim

To practise measuring current and voltage in simple circuits.

Materials

- power supply (6 V DC)
- 6 V light globe and light holder
- 4–6 connecting leads with alligator clips or other connectors.
- switch
- ammeter
- voltmeter

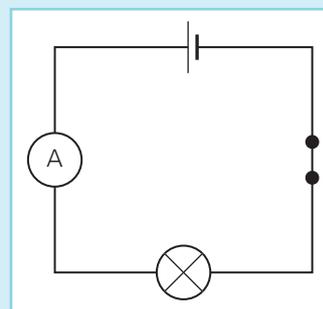
Method

1 Set up the circuit A shown in the diagram at right.

- Use the ammeter to measure the electric current in circuit A with the switch **open**. Record your measurement in the results table.
- Repeat with the switch **closed**. Record your measurement in the results table.
- Move the ammeter to the other side of the globe. Repeat with the switch **closed**. Record your measurement in the results table.

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

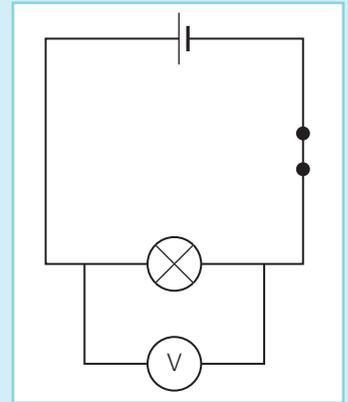


Circuit A

continued...

...continued

- 2 Remove the ammeter from the circuit.
- 3 Now set up the circuit using the voltmeter as shown below in circuit B.
- 4 Set the switch to **open** and use the voltmeter to determine the following measurements.
 - a Measure the voltage across the light globe. Record your measurement in the results table.
 - b Measure the voltage across the power supply. Record your measurement in the results table.
 - c Measure the voltage across the switch. Record your measurement in the results table.
- 5 Now repeat steps **4a**, **b** and **c** with the switch **closed**.



Circuit B

Results

Circuit A	Current
Switch open	
Switch closed	
Ammeter on other side	

Circuit B	Voltage when switch is open	Voltage when switch is closed
Across light globe		
Across power supply		
Across switch		

Evaluation

- 1 Is there any difference between the current measurements when the ammeter is either side of the globe in circuit A? Explain.
- 2 Compare the voltage across the terminals of the power supply with the voltage across the light globe when the switch is **open** in circuit B.
- 3 Compare the voltage across the terminals of the power supply with the voltage across the light globe when the switch is **closed** in circuit B.
- 4 Deduce the form of energy most of the electrical energy converted to in circuits A and B. Explain the energy conversions.

Conclusion

- 1 Make a claim from this experiment regarding the electrical properties of current and voltage.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

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 Ω .

resistance

the degree to which a substance resists the flow of an electric current through it

ohm

the unit of resistance

Conductors

If the current can flow easily through a material, you say that it has a low resistance.

Low resistance materials are called **conductors**. Metals are a good example of conductors.

conductor

a material that allows electric current to flow easily

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. It is, however, much more expensive than copper. Because it does not easily oxidise and therefore deteriorate, it is used in small amounts in critical electronic components such as computer chips and



Figure 8.22 High-voltage (typically 550 000 volts) power lines distributing electricity most often use aluminium wires as their main conductor.

spacecraft electronics. Aluminium is another very good low-resistance conductor (at 20°C it is approximately 60% more resistive than copper). However, it is much lighter than copper. This makes it suitable for conducting electricity in the high voltage transmission lines that criss-cross the country.

A digital multimeter is a tool often used to measure current, voltage and resistance.



Figure 8.23 A typical digital multimeter



Figure 8.24 An AED can increase the chance of survival during a heart attack.

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 can increase the chance of survival from between 21 to 51%.

Did you know? 8.3

Insulators

High resistance means that it is difficult for electrons to pass through the material.

Some materials have such a 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

Electrical engineering as a career

Explore! 8.2



Figure 8.25 This electrical engineer is carrying a high-voltage electrical insulator ready for installation.

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.

- 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.

- 1 Define the term 'resistance'.
- 2 Explain what a conductor and an insulator are and give an example of each.

Quick check 8.5

Ohm's law

Georg Simon Ohm was a German physicist. In 1827, Ohm began his research with the battery invented by the Italian scientist Alessandro Volta. Constructing his own equipment, Ohm found that electric current 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 (Ω), V is the voltage drop in volts (V) and I is the current in amperes (A).

Ohm's law
the law that states: There is a direct proportionality between the voltage applied across some conductors and the resultant electric current

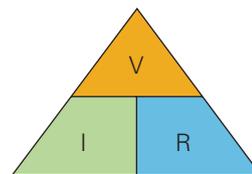


Figure 8.26 Ohm's law triangle describes the relationship between voltage, current and resistance.

$$V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$

For example, if you have a circuit with a 2.5 V power source and a 1 Ω resistor, the current would be $I = \frac{2.5 \text{ V}}{1 \Omega} = 2.5 \text{ A}$. If the resistor is changed to having a 2 Ω 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.

1 Explain the relationship between current and voltage as stated in Ohm's law.

2 Using the formulas $V = IR$, $I = \frac{V}{R}$, $R = \frac{V}{I}$, calculate:

- the resistance of a circuit where the voltage supplied is 6 V and the current is 2 A.
- the current in a circuit where the resistance is 50 Ω and the voltage is 25 V
- the voltage in a circuit where the resistance is 100 Ω and the current in the circuit is 0.5 A.

Quick check 8.6

Practical 8.4

Investigating resistance

Aim

To observe and compare the flow of electrical energy through objects with varied resistance and explore the relationship between voltage and resistance.

Materials

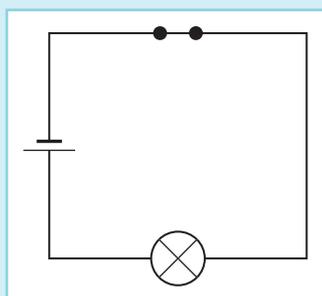
- DC power supply (6 V)
- 2 \times 6 V light globes
- 2 \times 6 V globe holders
- connecting leads (alligator clips)
- small piece of cylindrical plastic
- small piece of cylindrical carbon
- standard iron or steel nail
- ammeter
- voltmeter

Method

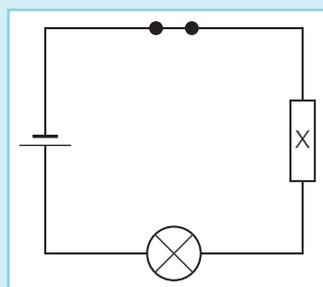
In this experiment, you will be setting up various circuits as shown in the following diagrams. Draw each circuit diagram in the results section.

Record your observations of the relative brightness of globes in your results table.

- Set up circuit 1. Record the brightness of the globe.



Circuit 1



Circuit 2

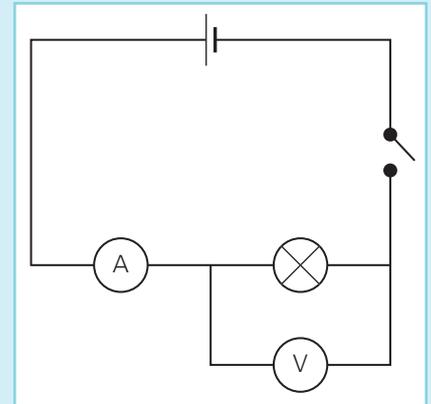
continued...

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

...continued

- 2 Set up circuit 2. Place the plastic, carbon and then the iron nail in turn at the position labelled **X**.
- 3 Record the brightness of the globe for each material and compare the brightness of the globe with that produced in circuit 1.
- 4 Set up circuit 3. Set your power source to 2 V. Connect the ammeter and voltmeter as shown at right.
- 5 Record the brightness of the globe and the readings from the ammeter and voltmeter in your results table.
- 6 Repeat step 5 for 4 V and 6 V, recording the current and voltage in your results table for each voltage.



Results

Circuit 3

	Brightness of globe	Current (A)	Voltage (V)
Circuit 1			
Circuit 2 with nail			
Circuit 2 with plastic			
Circuit 2 with carbon			
Circuit 3 2 V			
Circuit 3 4 V			
Circuit 3 6 V			

Evaluation

- 1 Describe how the brightness of the globe changed between circuits.
- 2 Explain the reason for the difference in globe brightness for the nail and the plastic.
- 3 Describe the relationship between the number of volts and amps for each of the conditions in circuit 3.

Conclusion

- 1 Make a claim from this experiment regarding voltage and resistance.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Variable resistors

Resistors can be tailored for various circuits to control the amount of current that flows through the other components. There are also variable resistors. These can be used to control the sound volumes on stereos and televisions, or the brightness of the lights in dimmer switches. Examples of fixed and variable resistors and their symbols are shown in Figures 8.27 and 8.28.



Figure 8.27 Fixed resistors



Figure 8.28 Symbol for a fixed resistor (left) and a variable resistor (right)

A light-dependent resistor (LDR) is a special type of variable resistor because the resistance of it changes depending on the amount of light falling on it. As light intensity increases, the substance they are made of has less resistance. LDRs are used in light-sensitive electronic circuits and act as light-sensitive switches; for example, 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. You would not realise it but when you set your air conditioner or ducted heating to a certain point, or even your refrigerator, it is a thermistor that helps regulate the temperature using the relationship between voltage and resistance.

Practical 8.5

Current and resistance

Aim

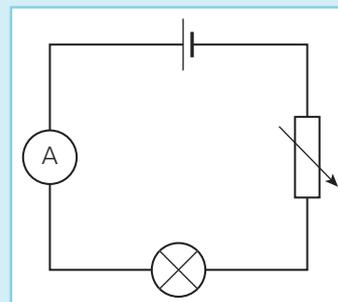
To investigate the relationship between current and resistance using a variable resistor.

Materials

- 6 V power supply
- 6 V light globe
- variable resistor
- 4 connecting wires and connectors
- ammeter

Method

- 1 Set up the circuit as shown in the diagram at right and set the power supply to 6 V.
- 2 Adjust the variable resistor so that the light globe is at its brightest. Record the current shown.
- 3 Adjust the variable resistor so that the light globe gets dimmer and dimmer, recording the current at various points until it is at its dimmest.



Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

Results

Brightness of globe	Current
Brightest	
Bright	
Dim	
Dimmest	

Evaluation

- 1 Describe what happens to the current in the circuit as the resistance of the variable resistor increases.
- 2 Describe what happens to the brightness of the globe as the resistance is increased.
- 3 Predict what is happening to the voltage across the globe as it gets dimmer.

Conclusion

- 1 Make a claim from this experiment regarding resistance and current.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Explain how a variable resistor works and give an example of how it may be used in your home.

Quick check 8.7

Robotic sensors

Humans have five main senses: sight, smell, touch, hearing and taste. Engineers take a lot of inspiration from these senses and incorporate them into other pieces of technology, such as robots. For example, there are now robotic vacuum cleaners that have sensors which tell the robot what part of the room it is in and where it has already vacuumed.



Figure 8.29 The Roomba vacuum cleaner



Figure 8.30 Bionic hands need to be able to replicate the senses in a working human hand to operate effectively.

Explore! 8.3

- 1 Research how sensors are being used in robots.
- 2 How can the study of human senses help people in the medical field?

Section 8.2 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 and give an example of each.

a Conductor	c Resistor
b Insulator	d Variable resistor
- 3 Recall the device that measures current.
- 4 Recall the device that measures voltage.
- 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').

continued...



QUIZ

...continued

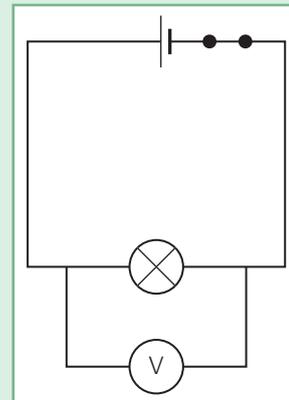
- 7 Contrast the terms 'voltage' and 'voltage drop'.
8 Outline how a variable resistor works.

Applying

- 9 Both aluminium and copper conduct electricity. Which one of these two conducting metals would you most likely find in the following? Give reasons why.
a In household wiring
b In high-voltage transmission lines
- 10 Use your knowledge of thermistors and light-dependent resistors to propose a household appliance that uses them.

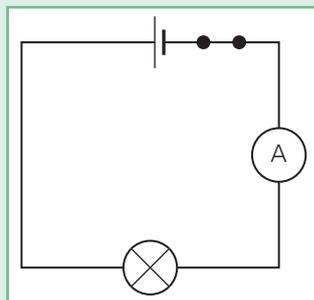
Analysing

- 11 The circuit on the right 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.
c Copy and complete the following table for the voltage across each component when the switch is open (off) and closed (on).



Component	Switch open Voltage	Switch closed Voltage
Battery		
Switch		
Globe		

- 12 The following circuit has been constructed using a 6 V battery, a switch, a 6 V light globe with a resistance of $5\ \Omega$ and an ammeter.



Copy and complete 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 Research measures that can be taken to stop the wastage of resources associated with the excessive use of dry cell non-rechargeable batteries in Australia.
14 Propose three arguments supporting, and three arguments against, the widespread adoption and use of electric cars in Australia.



More circuits and their applications

Series circuits

A torch circuit (see Figure 8.31) where the batteries, the switch and the globe are

series circuit

a circuit in which the batteries and other components are all connected one after the other

all connected one after the other is an example of a **series circuit**.

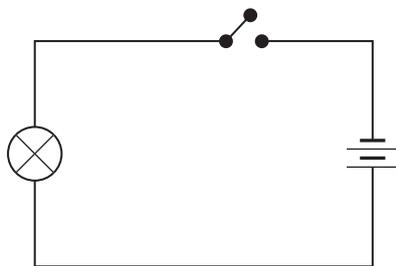


Figure 8.31 A series circuit diagram of a torch

Series circuits are easy to make and connect. However, if any one part of the circuit fails, the circuit will not work because there is a break in the path. In the example of the torch circuit, any one or more of a flat battery, a faulty switch or a faulty globe would cause the circuit to stop working. Troubleshooting a faulty torch circuit would require systematically looking at each of these three components in turn. Could you use a series circuit for car headlights? 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 km/h around a corner on a country road on a dark night.

In a series circuit, the voltage, or energy, is shared among the load. For example, in the following circuit, if the light globes are identical, the voltage across each is half that

of the power source. The current is the same throughout the circuit.

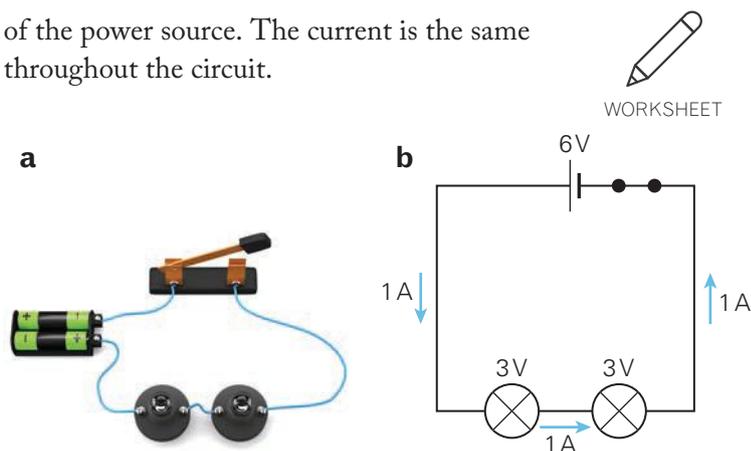


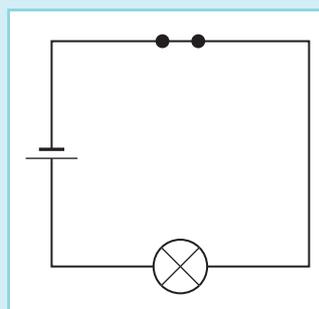
Figure 8.32 (a) Car headlight circuit modelled as a series circuit. (b) Matching circuit diagram with a 6V power source and identical globes.

Series circuits

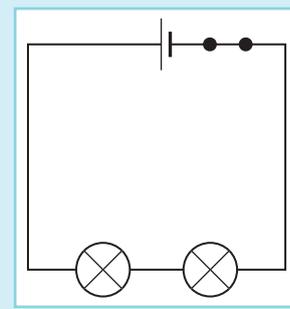
Two circuits have been set up for you.

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 – Simple



Circuit 2 – Series

- 1 Are the globes glowing as brightly as the globe was in circuit 1? Explain why or why not.
- 2 Predict what will happen if you disconnect the lead between the two globes in circuit.
- 3 Disconnect the lead and note what happens. Explain what you observe.
- 4 What happens if you add another globe in series? Explain what you observe.

Parallel circuits

An alternative car headlight circuit could be constructed using the same components as you used previously, to prevent both lights from turning off. In this instance,

parallel circuit

a circuit in which each component is connected in a separate conducting path

you will model the headlight circuit using a **parallel circuit**, as shown in Figure 8.33.

In a parallel circuit, the current is split at each branching. For example, in the following circuit, if the light globes are identical, the current in each branch is half that of the current from the main wire coming from the power source. The voltage drop is the same for all the components.

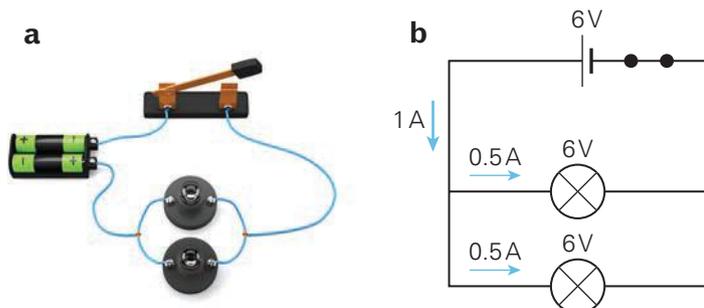
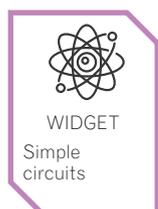


Figure 8.33 (a) Car headlight circuit modelled as a parallel circuit. **(b)** Matching circuit diagram with the blue arrows indicating current split.



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. You may have seen a car travelling with just one headlight at night. This indicates that car headlights have been wired in parallel.

In a parallel circuit therefore, each component is connected in a separate conducting path. This means that if one load component of the circuit is faulty, the other load components will still work. Most modern Christmas tree lights are connected in parallel. If one of the 200 fairy light globes fails, then the other 199 globes will still glow. In older-style Christmas tree lights, 20 globes were connected in series. This meant that if one globe failed, then all 20 globes would not glow. Each individual globe had

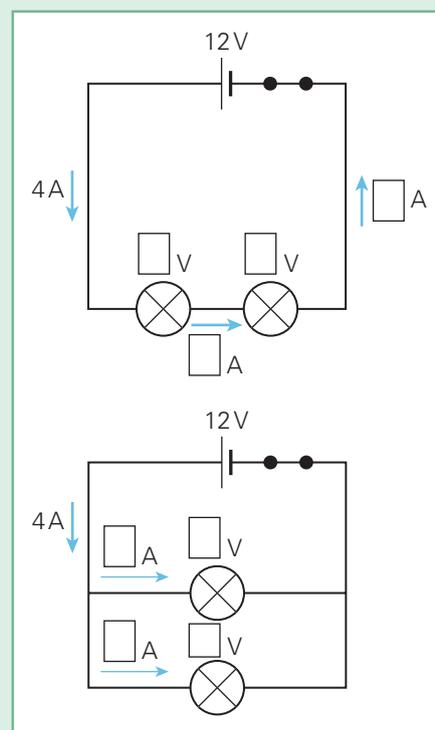
to be taken out one by one and replaced with a working globe until the whole circuit lit up again when the faulty one was found!



Figure 8.34 Christmas tree fairy lights are wired in a parallel circuit.

- 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 a series and parallel circuit?
- 4** Assuming that each light globe is identical, copy and complete the following diagrams.

Quick check 8.8

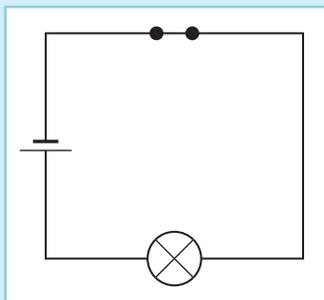
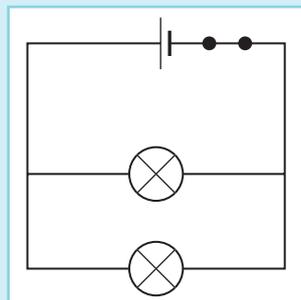


Parallel circuits**Try this 8.6**

Two circuits have been set up for you.

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** – Simple**Circuit 2** – 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 Disconnect the lead. What happens to the brightness of the other globe? Explain what you observe.
- 4 What happens if you add another globe in parallel? Explain what you observe.
- 5 What happens if you add another globe in series with the bottom globe? Explain what you observe.

Practical 8.6**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

Method**Series**

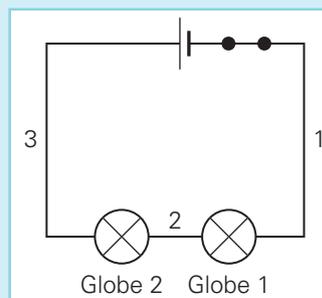
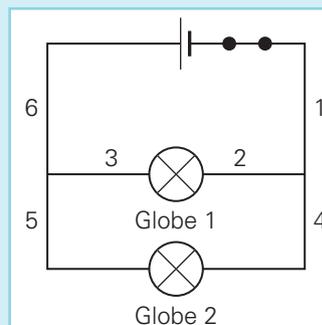
- 1 Set up circuit 1 so that the two globes are connected in series.
- 2 Measure the current in the circuit and voltage in three different positions; across the power pack, across globe 1, across globe 2. Record the readings in your results table.

Parallel

- 3 Set up circuit 2 so that the two globes are connected in parallel.
- 4 Measure and record the current in the circuit at each number and voltage across each globe.

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

**Circuit 1** – Series**Circuit 2** – Parallel*continued...*

...continued

Results

Series circuit	
Position	Current (A)
1	
2	
3	
Parallel circuit	
Position	Current (A)
1	
2	
3	
4	
5	
6	

Series circuit	
Component	Voltage (V)
Power source	
Globe 1	
Globe 2	
Parallel circuit	
Component	Voltage (V)
Power source	
Globe 1	
Globe 2	

Evaluate

- 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.

Conclusion

- 1 Make a claim from this experiment regarding series and parallel circuits.
- 2 Support the statement by using your observations (include potential sources of error).
- 3 Explain how your observations support your claim.

Household electricity

In your household all your electrical appliances and your lights transform the electrical energy into other forms of energy as the electrons flow through the different components. Power stations supply AC rather than DC through the power points, which you will learn about in the next chapter. In

Australia, electricity is supplied to homes at a voltage of 230 volts and is referred to as the **mains electricity**.

mains electricity
the electricity that is supplied to homes

Power points in the home have three sockets (active, neutral and earth). When you plug in an electrical device and switch the power on, current flows between sockets at the top through the appliance (that is, between the

active and the neutral via the appliance). The third socket is the earth socket. It is normally connected to a metal pipe in the ground; that is, directly connected locally to the earth.



Figure 8.35 An Australian power point

Electrical plugs are designed to fit into these sockets. They may be 2-pin plugs or 3-pin plugs. This is because some electrical appliances are **double-**

double-insulated
appliances that have two levels of insulating materials between the electrical parts of the appliance and any parts on the outside that you touch

insulated and only require an active–neutral connection. These appliances use a 2-pin plug. An example of a 2-pin plug you might have at home would probably be your laptop computer. Other electrical appliances need to

be **earthed** to protect the user from stray current. These appliances use a 3-pin plug. An example of a 3-pin plug that you might have at home would probably be your toaster.

earthed
a pin in a plug through which the electric current will flow via the earth pin to the ground in the case of a fault



Figure 8.36 A 2-pin plug (left) and a 3-pin plug (right)

Smart homes

Research shows that by 2021, around 140 million ‘smart’ home products will be connected.

Appliances such as lights, alarms, heaters, air conditioners, speaker systems and fridges can be connected to, and controlled by, your smartphone or PC via the internet. You can control these aspects of your house even when you are away from home!

- 1 Explain what it means to have a ‘smart’ home and the devices that can be connected.
- 2 Research and identify how expensive it is to have a ‘smart’ home.
- 3 Discuss how ‘smart’ homes can save energy.
- 4 Discuss the obstacles that need to be overcome in the industry and propose solutions for each challenge.

Explore! 8.4



Figure 8.37 You can use your smartphone to control aspects of your home remotely.

Safety

Earthing

You saw earlier that, in Australia, toasters and some other appliances have a plug with three pins, but why and how does earthing protect you? If your toaster has a metal casing, then the bottom earth pin

fits into the earth socket. If there is a fault in the appliance, and the metal casing accidentally becomes ‘live’, the electric current will 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.

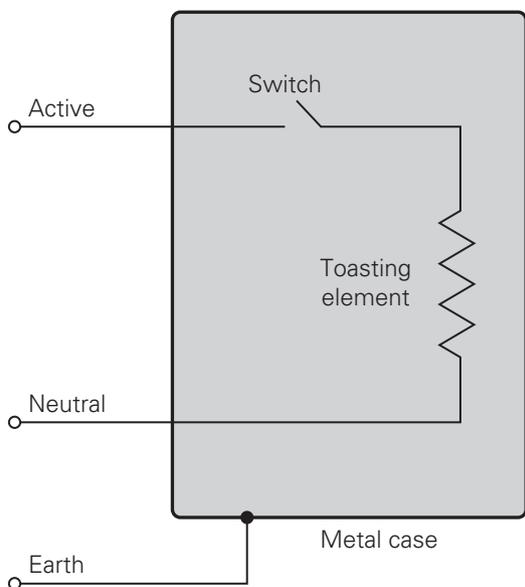


Figure 8.38 In an earthed appliance, like this toaster, any metal parts that can come into contact with the active part of the circuit and become 'live', automatically cause a large current to run to earth and blow a fuse or trip a circuit breaker. (This will be covered later in this chapter.) This is much better than having the current run through the user of the appliance!

Double insulation

Many newer small electrical appliances have two pins without the earth pin. Typical examples you may have at home are computers, printers, hair dryers and drills. These appliances are examples of 'double insulation'. They have two levels of insulating materials between the electrical parts of the appliance and any parts on the outside that you touch. The symbol placed on all double insulated appliances is shown in Figure 8.40.

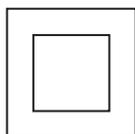


Figure 8.40 Symbol placed on all double-insulated appliances

Electrical wiring it

Did you know? 8.4

In Australia, the following modern colour code is used for electrical wiring. The old colour code is put in brackets, which you may still see on some older electrical appliances.

The active wire (which is at mains voltage, 230 V) is coloured brown (it used to be red – a colour which is normally associated with danger).

The neutral wire (which is nominally at 0 V) is coloured blue (it used to be black).

The earth wire (which is connected to the earth) is striped green and yellow (used to be only green).

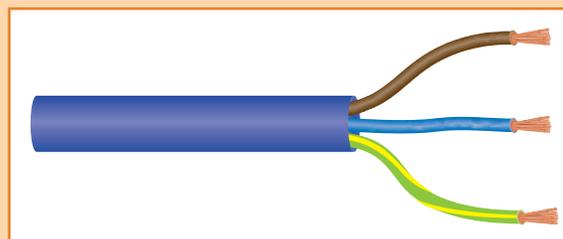


Figure 8.39 Modern colour-coded electrical wire

So, the primary difference between a 3-pin plug electric drill and a 2-pin plug electric drill is the drill case material. If it is made of conductive material (for example, metal) then it must have an earth pin (3-pin plug). Industrial appliances generally have three pins as in the rougher environment they may encounter rougher treatment, whereas a commercial appliance is more likely to have double insulation and two pins.

Household electrical devices and appliances

Try this 8.7

Work in a small group of 3 or 4 students.

- 1 Create a table with the following headings and four blank rows underneath.

Electrical device/appliance	Connects to a 230 V power point	Has 2-pin connector	Has 3-pin connector	Has rechargeable battery	Has a non-rechargeable battery	Typical daily use (hrs)
LED/LCD TV	Yes	Yes	No	No	No	5.0
Laptop computer	Yes	Yes	No	Yes	No	7.5
Fridge	Yes	No	Yes	No	No	24
Old style smoke alarm*	No	N/A	N/A	No	Yes	24

* Note new smoke alarms are connected to the mains electricity (230 V) and have a 9.0 V backup battery for blackouts. [N/A – not applicable].

continued...

...continued

- 2 Four electrical devices have been suggested in the table. Brainstorm in your group four other electrical devices commonly used in and around the home, place them in the table and determine their characteristics.
- 3 Explain why some plug-in devices have three pins while others only have two.
- 4 Explain why some devices have rechargeable batteries and others non-rechargeable batteries.
- 5 Which electrical devices in your table are an inconvenience, or a nuisance, if you cannot use them if there is a blackout in the evening from 6.00 pm to midnight?
- 6 Which electrical devices in your table are critical if there is a sustained blackout (say 24 hours)?

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. People are injured or die every

electrocution
electric current passing through the body

year because of carelessness, negligence and DIY (Do It Yourself) electrical work. One of the main causes of **electrocution**

in the home is the use of damaged cords and plugs. Frayed cords and plugs can expose the active, neutral and earth plastic covered wires inside. If these wires are cracked, you could come in direct contact with a bare active wire. As Table 8.2 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 too will most likely paralyse their muscles as well placing two people at risk of electrocution.



Figure 8.41 Electrical hazard symbol

Most modern homes have quick-acting special RCI circuit breakers that can cut the current off in less than one-thirtieth of a heartbeat! You will explore these a little further shortly.

With appropriate care and caution, many of these unfortunate electrical incidents can easily be avoided.

Current (mA)	Effect on the human body
1	Can be felt
3	Is likely to 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 8.2 Effect of different currents 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 8.42 – notice the car fuse on the right no longer provides an electrical connection.

fuse
a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

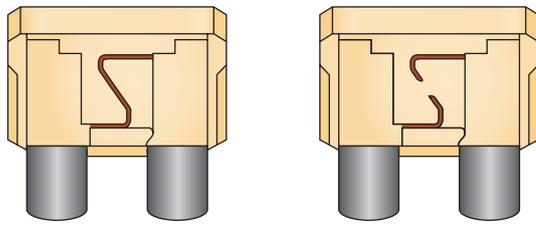


Figure 8.42 The difference between a good fuse (left) and bad fuse (right)

A **circuit breaker** as shown in Figure 8.43 carries out the same function as a fuse by breaking the circuit when the current exceeds some safety limit - for example 20 A.

circuit breaker

carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

NOTE: most modern houses have replaced fuses with such circuit breakers. Safety switches (RCI circuit breakers) are different. They detect current leaking from circuits,

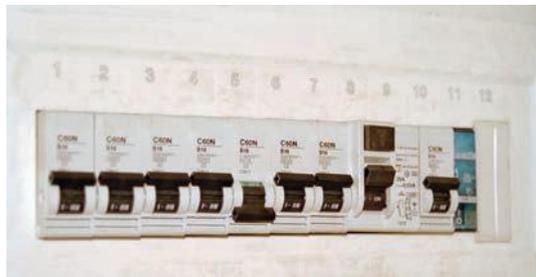


Figure 8.43 An RCI circuit breaker is designed to turn off the current in less than one-thirtieth of a heartbeat.

possibly into a person. When 30 mA 'leaks' from a circuit, these CBs trip the power. They used to be called 'earth leakage protection'; now they are Residual Current Interrupt switches.

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.

short circuit

when the current is allowed to flow from one conductor to another with little or no resistance



Figure 8.44 A short circuit can cause a fire.

Tasers

Law enforcement officers around the world are using alternative weapons, such as pepper sprays and rubber bullets, instead of traditional firearms (for example, guns and rifles) to minimise serious injuries and deaths. One new weapon is the Taser, which uses electricity (a small battery) and simple science to immobilise a suspect.

But what does a 50000 V shock do to a person's brain? Research has found that this electric shock can impair a person's ability to process and remember information. Cognitive function greatly declines immediately after being tasered, which can pose problems for those who are being questioned or interrogated by law enforcement shortly after being subjected to the electric shock. This newfound knowledge may change the protocols surrounding Taser use and it is now heavily regulated.

Science as a human endeavour 8.3



Figure 8.45 A Taser is used by law enforcement.

- 1 Recall the reason why alternating current is supplied by power stations.
- 2 Recall how much voltage mains electricity is in Australia.
- 3 State the purpose of the third socket of a power plug.
- 4 Explain why some appliances do not have the earth socket.

Quick check 8.9

Section 8.4 questions



QUIZ

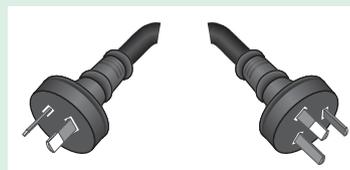
Remembering

- 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 Using the labels 2-pin, 3-pin, earth, active and neutral, redraw and then correctly label the electrical plugs shown below.
- 3 Describe the differences between series and parallel circuits.



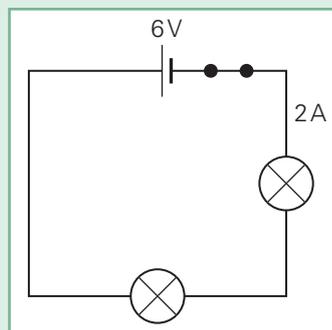
Understanding

- 4
 - a Describe the main disadvantage of a series circuit.
 - b Describe two advantages of a parallel circuit.
- 5 Explain why some electrical appliances are earthed.
- 6 Explain why some electrical appliances are not earthed.



Applying

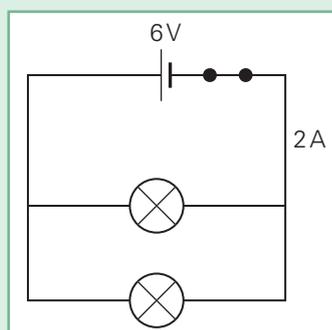
- 7 Draw a diagram to show how four 1.5 V batteries can be connected in parallel. What is the total voltage provided by this battery circuit? Label the positive and negative terminals of each battery.
- 8
 - a What happens to your muscles when you experience a current of 20 mA from a live wire from the mains electricity? Draw a simple diagram modelling this scenario and label the components.
 - b Identify reasons why you should not grab a person who is being electrocuted by a current of 20 mA.
- 9 Explain the function of an RCI circuit breaker in an electrical circuit.



Circuit 1

Analysing

- 10 A student constructs circuit 1 as shown above right using a 6 V battery and two identical globes and measures the current through the circuit as 2.0 A.
 - a Distinguish whether this is a series or parallel circuit. Explain your answer.
 - b What is the voltage drop across each globe?
 - c Calculate the resistance of one globe.
- 11 A student constructs circuit 2 as shown at right. The circuit contains a 6 V battery and two identical globes of higher resistance than in question 10.
 - a Is this a series or parallel circuit? Explain your answer.
 - b What is the voltage drop across each globe?
 - c Calculate the resistance of one globe.



Circuit 2

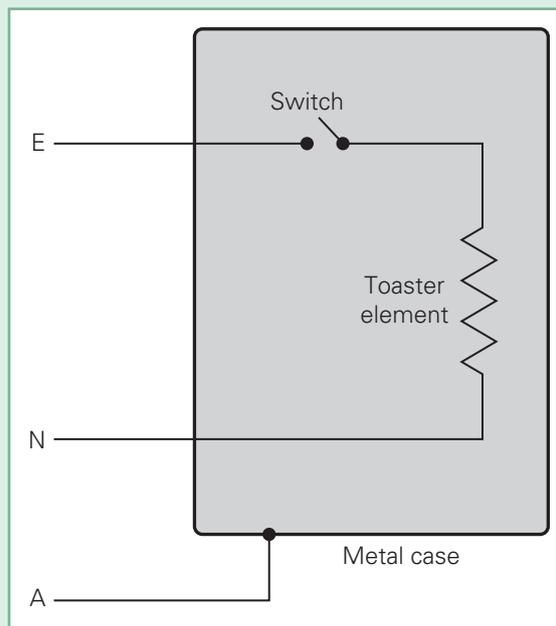
continued...

...continued

- 12** A circuit breaker in your home fuse box continually trips OFF when you are using your toaster. Explain what this means and what you should do next.
- 13** Explain what would happen if a red-green colourblind electrician using the old colour code for electrical wiring had connected the metal case of the toaster to the active – **A** (old colour red), and the toaster element to the neutral – **N** (old colour black) and the earth – **E** (old colour green).

Evaluating

- 14** Decide whether or not the use of Tasers in Australia is justified. Write down three arguments supporting and three arguments against, the adoption and use of Tasers by the police in Australia.
- 15** 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. Explain.



Incorrectly wired toaster diagram

Review questions



SCORCHER

Remembering

- State whether the following are true or false, and if false, explain why.
 - Static electricity can be produced by rubbing amber on fur.
 - The nucleus of an atom contains protons, neutrons and electrons.
 - The unit of charge is the volt.
 - Six thousand tonnes of disposable batteries are sent to landfill annually in Australia.
 - Tasers can be very dangerous.
- Name the two types of current electricity.
- List the three components that an electricity circuit needs.
- Draw these electrical components: switch open, switch closed, ammeter, voltmeter, battery, incandescent light globe, LED, photodiode.

Understanding

- Describe the energy transfers that occur in a working electrical circuit containing a battery and a light globe.
- Contrast how an ammeter and a voltmeter would be connected in a circuit.
- Explain how an RCI circuit breaker can protect you from stray current.
- Describe how electrical faults can cause house fires.

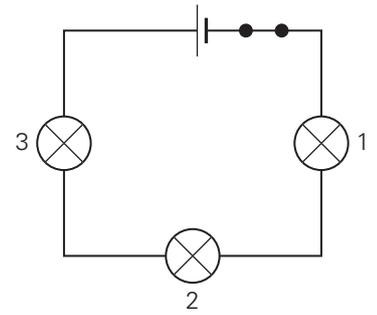
Applying

- For a certain electrical circuit, 20 coulomb of charge flows past a point in 5 seconds. Define the term 'current' and calculate the current in ampere.
 - For a certain electrical circuit, there is 20 joules of electrical energy per coulomb of charge. Define voltage and calculate the voltage of this circuit in volts.
- Explain what a good electrical insulator is and give an example of where it may be used.
- Explain why electrical wires made from gold and/or silver are not used for sending power from the La Trobe Valley to Melbourne.

Analysing

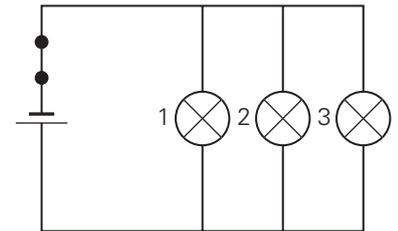
12 a If one or more of the globes were broken in the circuit at right, how would it affect the other globes? Copy and complete the following table regarding the circuit.

Globe broken	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
Globe 1			
Globe 2			
Globe 2 and 3			



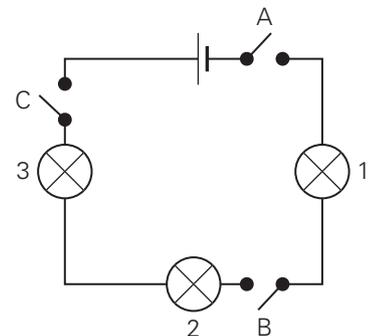
b If one or more of the globes were broken in the circuit at right, how would it affect the other globes? Copy and complete the following table regarding the circuit.

Globe broken	Globe 1 (on/off)	Globe 2 (on/off)	Globe 3 (on/off)
Globe 1			
Globe 2			
Globe 3			
Globe 2 and 3			



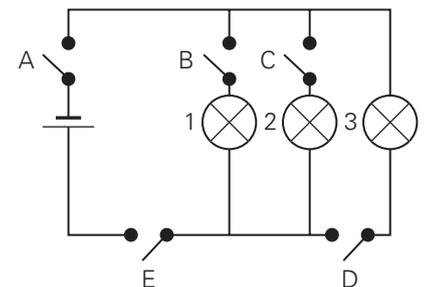
13 a Copy and complete the following table regarding the circuit shown at right.

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 at right.

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, E			



Evaluating

14 Propose reasons why:

- a** household electrical wires are coated in plastic
- b** many household appliances are double insulated.

15 a Identify whether solar energy is a suitable source of electrical power for domestic use.

- b** Suggest reasons why installation and use of domestic solar electrical units in Australia has been lower than expected.

STEM activity: Can you see the renewables?

Background information

In this chapter, you learnt how circuits work and some applications for them in your household. Technology has significantly advanced over the past 30 years and now circuits are becoming minute and more powerful to drive smaller devices. Have you ever thought about the amount of carbon emissions produced when you perform a search using your favourite search engine? Experts have estimated that a simple search consumes enough energy to release 0.2 g of carbon dioxide into the atmosphere. The number might seem small, however, imagine the emission from today's nearly 5 billion connected devices!

People and governments have recently started to invest in renewable and sustainable energy sources because our planet has gone through

VCSSU130

VCSIS113

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environmental change over centuries. Still, some people in our society need help in understanding that the energy resources of our planet are finite. Now more than ever, it is important that we all do our very best to change our current practices into more sustainable ones.

There are many ways to showcase this message to the world, one of the most powerful of them all involves storytelling. Good stories have the power to bring us together, encourage us to understand and empathise with many causes. Recently, digital storytelling has been used by many professionals (including famous YouTubers) to tell/sell their ideas, opinions and/or products.



Figure 8.46 Even tablets and smartphones contribute to the carbon dioxide levels in the atmosphere.

Design brief: Design and create a 60-second infomercial promoting the use of renewable energy.

Activity instructions

In teams (maximum of 4 people per group), 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.

Scenario

Your local council has just informed its residents that they wish to invest some capital to secure the energy needs for its residents for the next 20 years. One local company, Coal Co., has lobbied heavily for funds to expand an old open-cut coal mine in the region. On the other hand, a new start-up business, Argus Renewables, has hired your team to create a 60-second video to gain support from residents for the development of a large solar farm in the region.

Suggested materials

- mobile device, camera to record footage
- laptop or tablet with a video editor
- paper to create a storyboard
- your imagination!

Evaluate and modify

- 1** Create a mind map of the advantages of renewable energy over non-renewable energy that should be communicated to your audience through the infomercial.
- 2** Discuss with at least three of your colleagues the challenges you encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.
- 3** Have you finished your video? Congratulations! Now it is time to show it to someone in your family or someone in another year level and ask them for their opinion on it.
- 4** How effective is your infomercial? Based on the feedback from your family member, how will the target market respond?
- 5** Create a range of evaluative questions to use to gauge the success of your infomercial. Show your infomercial to a target audience and use the question to test its effectiveness.

Chapter 9 Electromagnetism

Chapter introduction

This chapter is all about magnetism and electromagnetism. You will explore how magnetism and electromagnetism impact on our everyday lives. You will look at how to build electric motors, generators and transformers. You will also learn the stories of how scientists and electrical engineers contributed to our current understanding of magnetism and electromagnetism.

Curriculum

The interaction of magnets can be explained by a field model; magnets are used in the generation of electricity and the operation of motors (VCSSU131)

- | | |
|--|----------|
| • investigating the action at a distance or the field model around magnets of different shapes | 9.1 |
| • investigating the effect of a magnet on a current from a battery to produce movement | 9.1, 9.2 |
| • investigating the movement of a magnet and a wire to produce electricity | 9.3 |

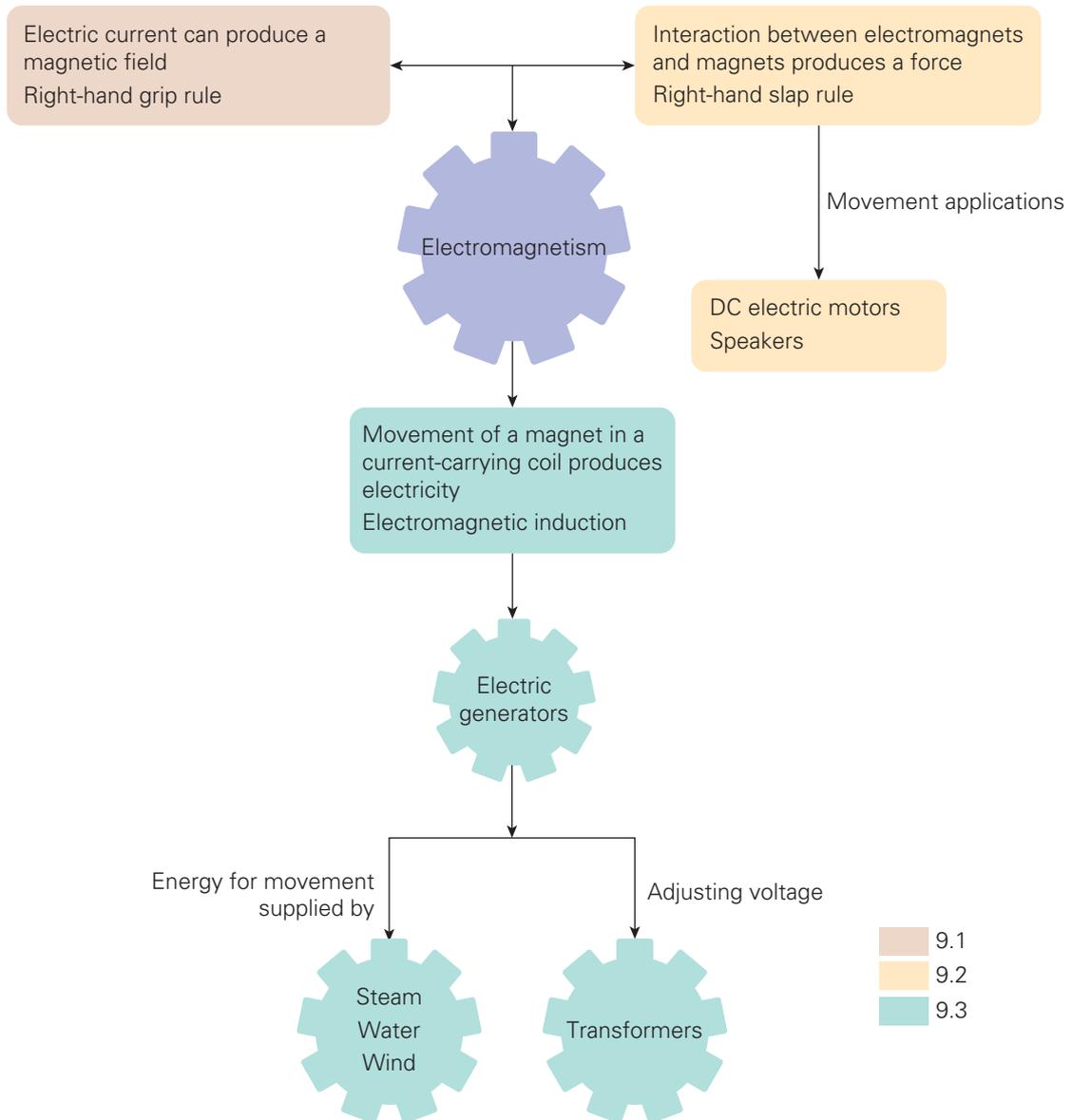
Victorian Curriculum F-10 © VCAA (2016)

Glossary terms

armature	generator	pole
brush	kinetic energy	right-hand grip rule
commutator	magnet	right-hand slap rule
conductor	magnetic field	solenoid
current	magnetic field line	temporary magnet
electric motor	magnetic induction	torque
electricity	magnetism	transformer
electromagnet	nuclear fission reaction	turbine
electromagnetism	permanent magnet	



Concept map





9.1 Magnets and electricity

Magnets

The discovery of magnetism begins, it is believed, with the ancient civilisations in Asia Minor around 600 BC. In a region known as Magnesia, stones were found that could attract each other! These stones were named **magnets** after their place of discovery. The

magnet

a material that attracts other iron-containing materials or aligns with an external magnetic field

word 'magnet' comes from the Greek language, *magnētis lithos*, literally meaning 'the stones of Magnesia'.



Figure 9.1 A piece of magnetic rock (magnetite) attracting an iron cube

The most magnetic of all the naturally occurring minerals on Earth is magnetite, an oxide of iron. Naturally magnetised chunks of magnetite are called lodestone – literally meaning 'the stone that leads'. The magnetic properties of lodestone were known to humans since the sixth century BCE at least, with the Greek philosopher Thales of Miletus (you might remember him or his student, Pythagoras, from your Mathematics course) making one of the earliest known references to it.

Young Albert Einstein's surprise present

In 1884 when Albert Einstein was five years old, his father Hermann Einstein bought him a magnetic compass. As Albert was sick in bed at the time, he fiddled around with it,

Did you know? 9.1

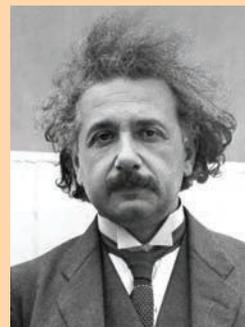


Figure 9.2 Albert Einstein – arguably the greatest physicist ever – inspired by a compass

but no matter how hard he tried to trick it to point elsewhere, the compass needle would always point to the same direction (magnetic north). He later wrote there was 'something behind things, something deeply hidden'. This was the beginning of Albert Einstein's lifelong scientific exploration. He was quoted saying, 'I have no special gift, I am only passionately curious'.

Other civilisations (the Chinese and the Anglo-Saxons, for example) noticed that these magnetic stones always pointed in the same direction when suspended from a fine piece of silk or cotton thread. These people had accidentally discovered the compass and, inadvertently, the fact that Earth has a **magnetic field**. They created the first land compasses and they later used these lodestones to create compasses to navigate in ocean exploration.

magnetic field

the region in which a magnet or electromagnet can exert a force on other magnets



WORKSHEET



VIDEO

How do magnets work?



Figure 9.3 A working model of the first instrument known to be a compass. The spoon is carved from magnetic lodestone, and the plate it sits on is bronze, a non-magnetic metal. It is believed that the Chinese used such compasses as earth-based direction pointers over 2400 years ago.

An even more useful property of lodestones was that they could, simply by stroking, turn an iron needle or steel needle into a magnet – you have made a compass before using this method in Practical 7.1. This process is called **magnetic induction**. These magnetised needles were

then placed in non-magnetic containers and were used by mariners to navigate and explore the world.

magnetic induction

the process by which an object is magnetised by an external magnetic field



Figure 9.4 A magnetic compass will always align with Earth's magnetic field and point north.

Of course, as the name suggests, **temporary magnets** are temporary; that is, they only stay magnetic while they are in the presence of a magnetic field. You will be familiar with the fact that a **permanent magnet** attracts paperclips, steel nails and other objects made of iron. Magnets can also attract nickel and cobalt, which have magnetic properties. Shape does not matter, and all magnets have two ends, which are

temporary magnet

magnet that does not retain its magnetism outside of an external magnetic field

permanent magnet

a magnet that retains its magnetic properties outside of a magnetic field

called the north (N) and south (S) **poles** by convention.

pole

the end point of a magnet; also the points near the ends of Earth's axis of rotation.

The forces between magnets can be attractive (when unlike poles are placed near each other) or repulsive (when like poles are placed near each other).

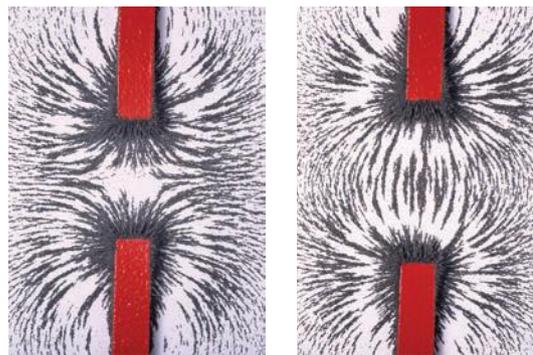


Figure 9.5 Iron filings show the magnetic field attraction between unlike poles and magnetic repulsion between like poles.

These magnetic forces can be put to good effect; for example, they keep the door seal on the fridge closed (attractive) or propel maglev trains (repulsive), which you will look at later in this chapter.

- 1 What inspired Einstein to become a physicist?
- 2 Explain magnetic induction.
- 3 Why did magnetic compasses come in brass containers?

Quick check 9.1

In 1846, to understand how magnets could attract and repel each other, the English physicist Michael Faraday (1791–1867) introduced the concept of **magnetic field lines**. The region around a magnet where

magnetic field line

a visual tool to represent the direction of magnetic fields

magnetic effects can be experienced, Faraday called the magnetic field. Using Faraday's ideas, the magnetic field surrounding a bar magnet can be shown as in the following diagram. The arrows on the field lines indicate the direction of the magnetic field.

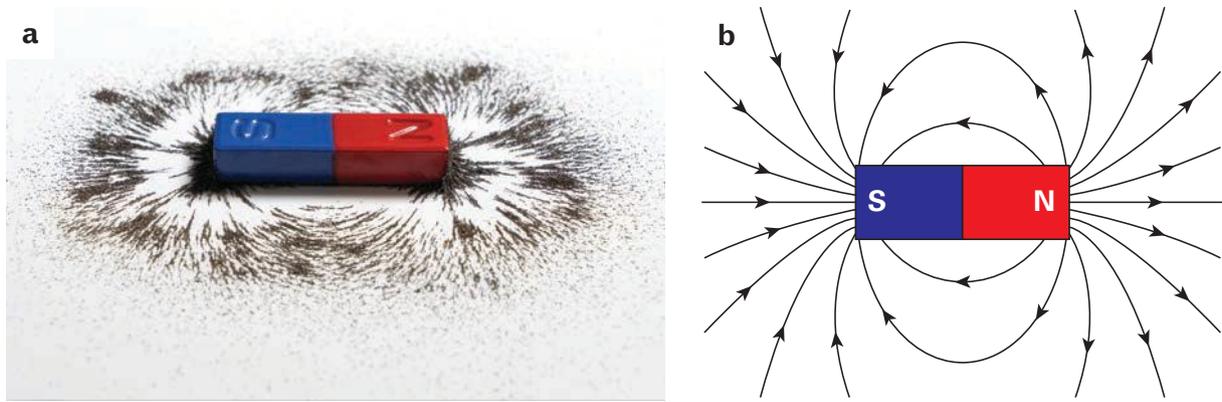


Figure 9.6 All permanent magnets have a north and south pole. The magnetic field surrounding a magnet can be: **(a)** visualised with iron filings and **(b)** represented using arrows.

In reality, the magnetic field exists in three dimensions. Figure 9.7 is a close-up photograph of the iron filings pattern between the north and south poles of a magnet and shows the three-dimensional nature of the magnetic field.



Figure 9.7 Three-dimensional magnetic field lines become visible when iron filings are gathered between the north and south poles of a magnet.

Faraday’s rules for magnetic field lines are listed below.

- 1 Each magnetic field line is a continuous loop that leaves the north end of the magnet, enters at the south end and passes through the magnet back to the north end.
- 2 Field lines do not intersect.
- 3 The closeness of the magnetic field lines represents the strength of the magnetic field.

Magnetic field diagrams can be used to explain why magnets attract each other and repel each other. When magnets attract each other the magnetic field lines join the two magnets, as shown in Figure 9.8a. When magnets repel each other the magnetic field lines push each other away, as shown in Figure 9.8b.

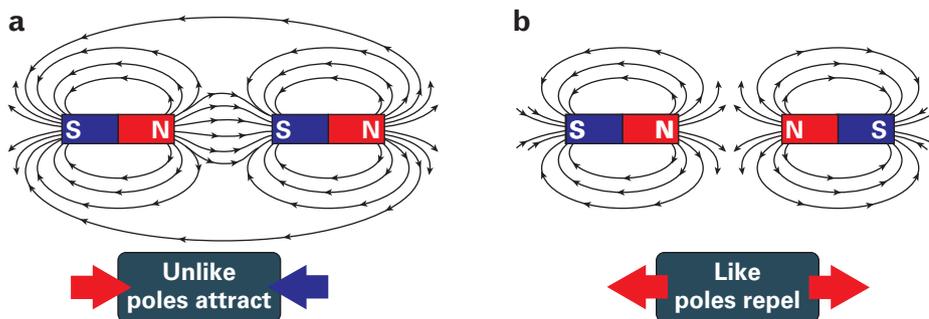


Figure 9.8 Magnetic field diagrams for **(a)** attraction: north–south magnets and **(b)** repulsion: north–north magnets

Even our planet acts like a giant bar magnet, as shown in Figure 9.9. The physical origin of Earth's magnetic field is not completely understood yet. Scientists think it is due to electrical currents in the conductive materials of Earth's core (iron and nickel). This magnetic field protects Earth from dangerous space radiation. The most striking evidence of Earth's magnetic field are probably aurorae (aurora borealis and

aurora australis), which are produced around the Arctic and Antarctic respectively, when charged particles in solar winds interact with Earth's magnetic field. Humans are not the only animals to use Earth's magnetic field to navigate (using magnetic compasses that naturally align themselves with Earth's magnetic field). Some migratory animals are known to also depend on it to guide themselves.

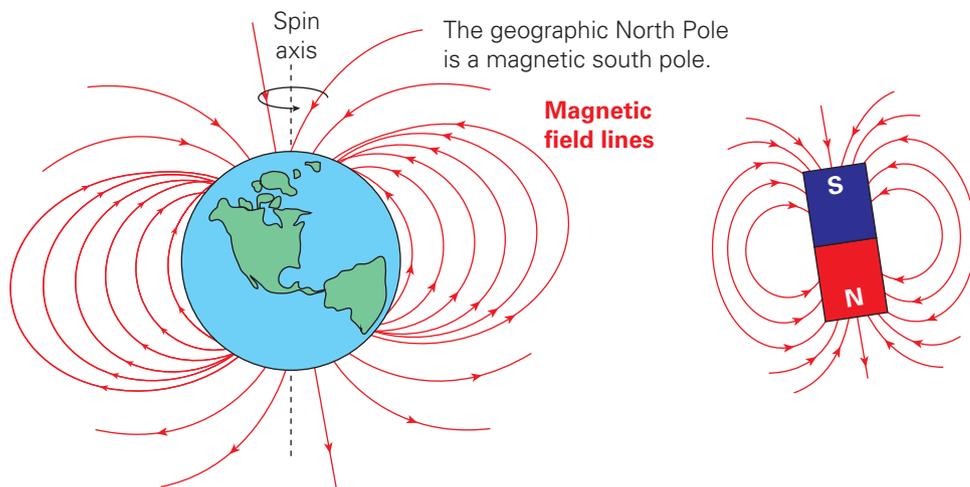


Figure 9.9 Earth's magnetic field acts like a giant bar magnet. The south pole of a magnet resides at the geographic North Magnetic Pole of the Earth, which is close to the geographic North Pole. You know this because a compass always points north, and opposites attract, so the north of a compass is attracted to the south pole of a magnet.

- 1** What happens when you place the north poles of two magnets next to each other?
- 2** Describe the magnetic lines inside and outside a magnet.
- 3** Will the magnetic field experienced by a paperclip become stronger or weaker as you approach it to one of the poles of a permanent magnet? Why?
- 4** What is the probable origin of Earth's magnetic field?
- 5** Name two positive effects of Earth's magnetic field.
- 6** Which magnetic pole is the closest to the geographic North Pole of Earth?

Quick check 9.2



Figure 9.10 Antarctic penguin gazing up at the southern lights (aurora australis)

- 1** Get two bar magnets, a horseshoe magnet, some iron filings and a sheet of A4 paper.
- 2** Place one of the bar magnets under the middle of the sheet of paper and sprinkle the iron filings on the paper. Try not to get filings on the magnets – they are difficult to remove. (Wrapping the magnets in cling wrap can reduce the removal problem.)
- 3** Observe how the filings position themselves around the magnet.
- 4** Repeat the experience with the horseshoe magnet. Do you notice any differences in the way the iron filings position themselves? Can you explain why the filings assume these distributions?
- 5** To go further, place the two bar magnets face-to-face and 2–3 cm away from each other then sprinkle the filings. Observe the distribution of the filings.
- 6** Now turn one of the magnets over. How does the distribution of iron filings change? Can you guess, from the filings distribution, when two unlike poles face each other and when two like poles face each other?

Try this 9.1

Magnetic wand saves wildlife in oil spills

In 2014, Australian scientists invented a tool that can save penguins and other wildlife caught in oil spills.

Science as a human endeavour 9.1



Figure 9.11 A member of an animal rescue team holds a swan affected by an oil slick after the hull of an oil freighter was punctured. The slick resulted in more than 200 tonnes of oil being spilled.

A team from Victoria University, led by Professor John Orbell, developed a handheld portable wand that removes oil from animals. The device applies magnetic micro-particles which absorb oil when applied to fur, feathers and rocks. The wand then harvests the particles that are bound to the oil.



Figure 9.12 Dr Peter Dann and Professor John Orbell using their magnetic wand to remove oil from a penguin. Oil not only poisons the penguin when ingested, it also reduces the insulation of the bird's plumage, making it susceptible to hypothermia (dangerously below normal body temperature).

Practical 9.1

Magnetic field direction around a magnet

Aim

To investigate the shape and direction of a magnetic field.

Materials

- bar magnet
- compass
- Blu-Tack

Method

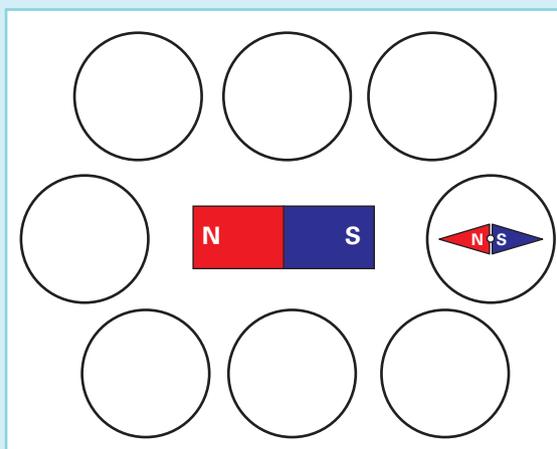
- 1 Predict the direction the compass north needle will point at each of the locations shown in the results diagram. The first one has been done for you.
- 2 Blu-Tack the bar magnet onto a flat surface so it does not move.
- 3 Place the compass at each location shown in the diagram as circles and draw your results.

Results

Copy and complete this diagram to show the direction the needle will point.

Evaluation

- 1 Evaluate whether the results were what you predicted and explain what happened.
- 2 Does a compass needle always point straight to the north pole of a magnet?
- 3 Draw what the magnetic field would look like in 3D.
- 4 From your experiment you can see that between the north and south poles, the needle is parallel to the pole orientation rather than continually pointing to the north pole. You also know that the geographic North Pole is Earth's magnetic south. Describe what would happen if the north part of a compass needle always pointed directly to the pole.



Conclusion

- 1 Make a claim from this experiment regarding the shape and direction of magnetic fields.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Electromagnetism

current
the flow of electric charge

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

magnetism
the ability to attract or repel objects that are magnetic

electromagnetism
the interaction between magnetic fields and electric currents

In 1820, the Danish physicist Hans Christian Ørsted noticed that the needle of a compass, placed next to an electrical wire carrying a **current**, turned so that the needle was perpendicular to the wire. Ørsted had discovered a connection between **electricity** and **magnetism** – **electromagnetism**. He found that a wire carrying a current created a magnetic field, as shown in Figure 9.13.

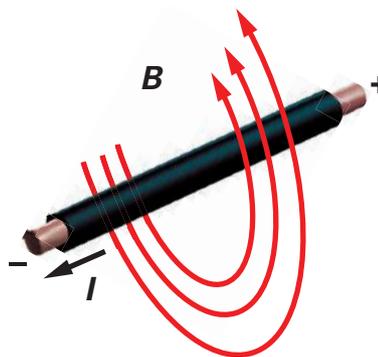


Figure 9.13 Ørsted's discovery of the existence of magnetic field B (red lines) around a wire carrying an electric current (I). Recall the convention for current direction is from the positive to negative terminal.

Right-hand grip rule

The direction of the magnetic field produced by the wire can be remembered with the **right-hand grip**, as Figure 9.14 demonstrates. If your thumb represents the

direction of the current, then your right-hand fingers curl in the direction of the magnetic field generated.

right-hand grip rule shows the direction of the magnetic field of a current-carrying wire

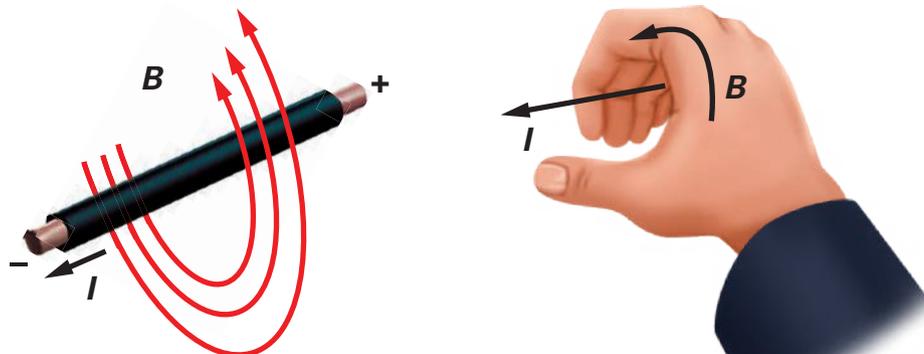


Figure 9.14 Diagram showing the right-hand grip rule where I is the current-carrying wire and B is the magnetic field. Recall the convention for current direction is from the positive to negative terminal.

Amazingly, if you already know the direction of the magnetic field, and your current-carrying wire is in a coil, you can do the opposite of this rule to figure out the direction

of the current in the wire. In this case, you would point your thumb in the direction of the magnetic field and then curl your fingers around to determine the current's direction.

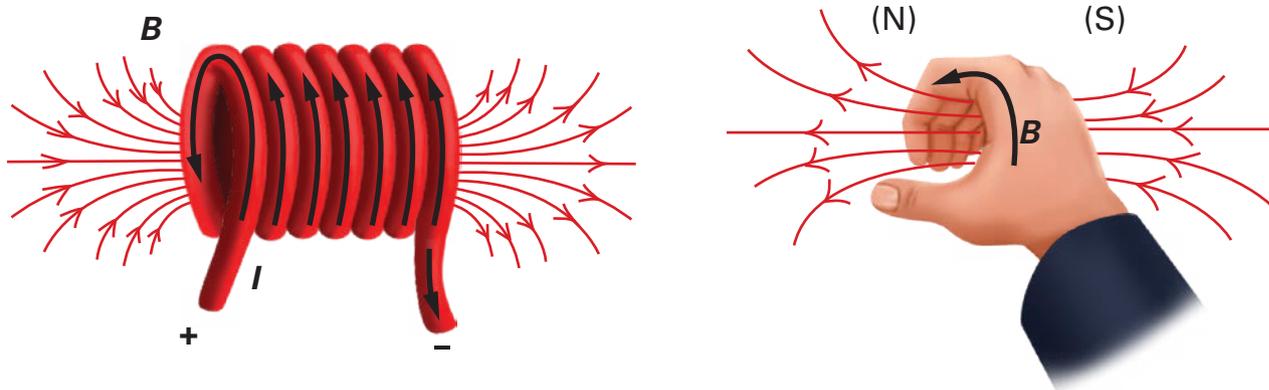


Figure 9.15 Diagram showing the right-hand grip rule where I is the current-carrying wire and B is the magnetic field

'Erasable' MRI contrast agents

Magnetic resonance imaging (MRI) is a medical imaging device that allows doctors to see inside the body without surgery. To make MRI scans easier to read, contrast agents (magnetic dyes) are generally used. Given to patients (either by injection or orally), they travel to tissues and organs, which are therefore easier to see. Medical research in this field recently concentrated on nanoparticles, which can target specific sites, like tumours. However, nanoparticles and magnetic dyes present the same issue: they are difficult to distinguish from body tissue.

Science as a human endeavour 9.2

continued...

...continued

In 2018, American scientists developed what they call 'erasable' MRI contrast agents to reduce this problem. In a study performed on mice, they showed that gas vesicles (a nano-sized protein shell with a hollow interior) could be used as contrast agents, because the air in their chambers reacts differently to magnetic fields compared to the patient body's aqueous tissues around them.

What is different, and interesting with this new type of contrast agent, is that it can be 'turned off' on command, simply with ultrasound waves that make them collapse, making their magnetic signals disappear at the same time. This makes MRI scans easier to read. For example, a dark patch on a MRI might be due to a contrast agent binding to a tumour, or it might be an unrelated signal from the surrounding tissue. Being able to simply erase the signals caused by MRI agents subsequently makes it easier to determine the nature of what is seen on an MRI scan.



Figure 9.16 Doctors preparing a patient for an MRI scan

The arrow convention is often used to indicate the direction of the current if the wires go into or come out of the page. A cross represents the tail feather of an arrow, a

while the dot represents the tip of an arrow. Applying the right-hand grip rule creates magnetic fields surrounding the currents, as shown in Figure 9.17.

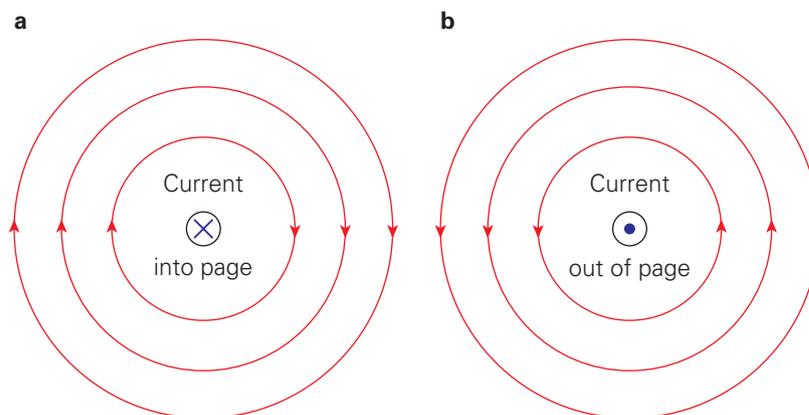


Figure 9.17 Diagrams showing magnetic field for current-carrying wires with (a) current going into the page or (b) current coming out of the page

The arrow convention is also used for the magnetic field going into or coming out of the page, as shown in Figure 9.18.

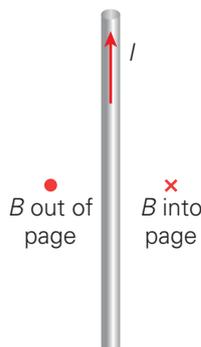
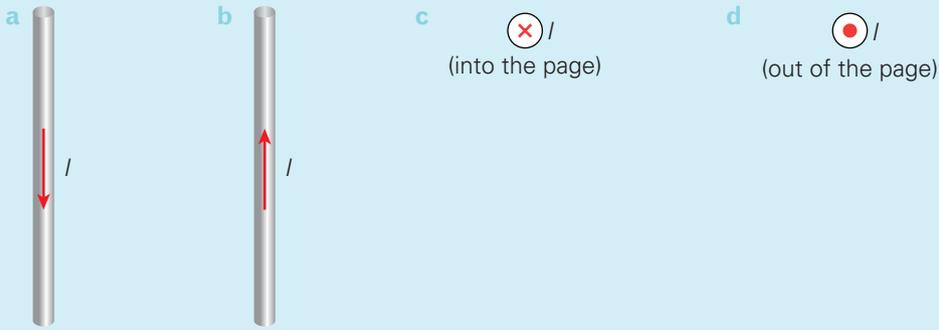


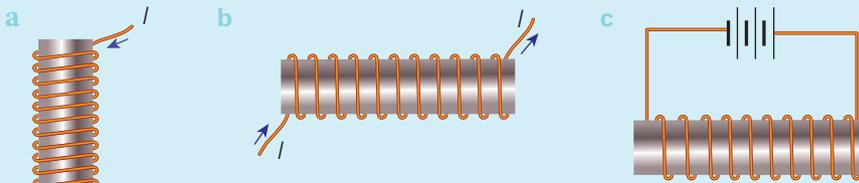
Figure 9.18 Diagram showing direction of magnetic fields for a current-carrying wire where I is the current and B is the magnetic field

1 Determine the direction of the magnetic field for each of the following wires.

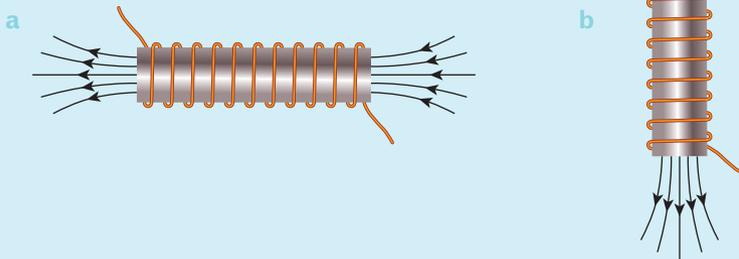
Try this 9.2



2 Determine the direction of the magnetic field for each of the following coils.

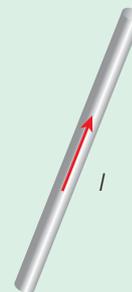


3 Determine the direction of the current in each of the following coils.



- 1 What is an electromagnet? How is it different from a permanent magnet?
- 2 How can the magnetic field created by an electromagnet be varied?
- 3 What does MRI stand for? What is it used for?
- 4 Determine the direction of the magnetic field in this wire.

Quick check 9.3



Electromagnets

You can take advantage of electromagnetism by using electromagnets. An **electromagnet** consists of a wire coiled around a piece of metal, usually iron.

electromagnet
a magnet consisting of a current-carrying coil surrounding a piece of iron

When a current is passed through a wire, a magnetic field is created. The metal in

the core of the electromagnet strengthens the magnetic field.

The reason why a coil of wire is best is because if the wire is made into the shape of a loop, then the right-hand grip rule shows that the magnetic field is more concentrated in the centre of the loop of wire (see Figure 9.19).



VIDEO
How do electromagnets work?



WIDGET
Electromagnet properties.

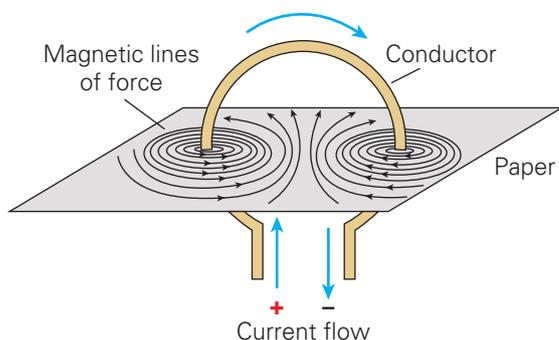


Figure 9.19 A single loop of wire concentrates the magnetic field.

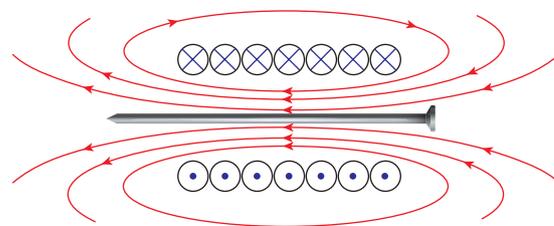


Figure 9.21 The magnetic field surrounding an electromagnet is similar to that of a bar magnet.

solenoid
a wire wrapped in the shape
of a cylinder

By making a coil of wire with lots of loops in it, called a **solenoid**, it is possible to create an intense magnetic field. When an electric current is applied to the solenoid, a magnetic field is produced around the coil (Figure 9.20). One end of the solenoid is the north pole while the other end is a south pole.

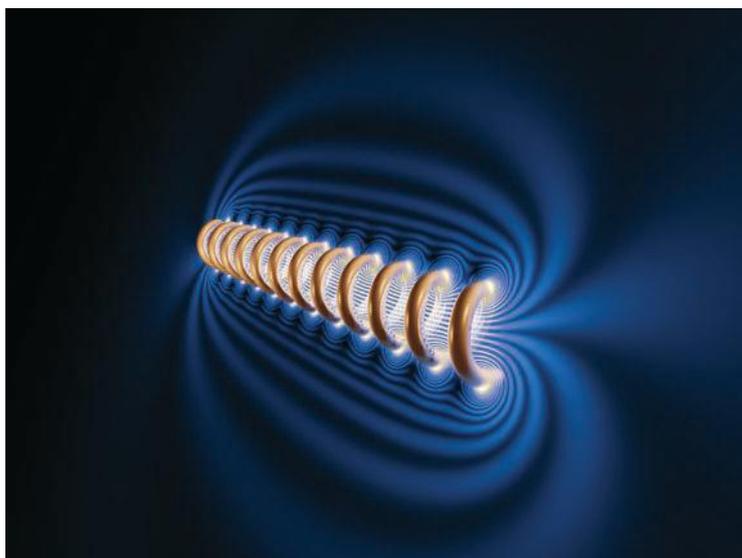


Figure 9.20 The magnetic field of a solenoid

An electromagnet can be created by inserting an iron core into the solenoid. The iron core increases the strength of the magnetic field. A magnetic field can still be created without the iron core, however it will not be as strong. Similar to the solenoid without an iron core, one end of the electromagnet is a north pole, the other end is a south pole (Figure 9.21).

A simple electromagnet can be made using a coil of wire, an iron nail and a battery.

Try this 9.3



Figure 9.22 A simple electromagnet

See if your nail is magnetised by holding it near some paperclips.

One advantage of using electromagnets rather than permanent magnets is that the magnetic properties can be switched on or off. The magnetic field strength can also be altered by changing the number of turns in the coil: more coils creates a stronger field.



Figure 9.23 This electromagnet lifting 500 kg of iron ore can be switched on or off.

- 1 What did Ørsted discover?
- 2 What is a solenoid?
- 3 What is the purpose of using an iron core in a solenoid?
- 4 List two advantages an electromagnet has over a permanent magnet.

Quick check 9.4

You might not see them, but electromagnets are ever-present. From doorbells and electric buzzers to MRI machines and particle accelerators – they are everywhere.

They are in your TVs, computers, cars, microwaves, washing machines, DVD players, in microphones, speakers and headphones, in cars and elevators, in copy machines, in anti-shoplifting systems, in electric motors and generators, in magnetic lifters, in maglev trains and electromagnetic aircraft launch systems, from everyday life objects to cutting-edge technology applications. Everywhere. Look around you, see how many objects using electromagnets you can spot.

Did you know? 9.2**Practical 9.2****Electromagnets****Aim**

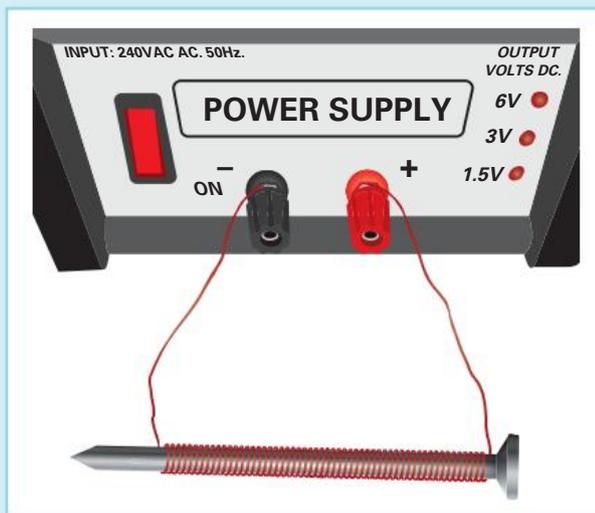
To investigate the magnetic fields produced by an electromagnet.

Materials

- 1 m of PVC-covered copper wire with the ends stripped and bare
- large iron nail
- iron filings
- paperclips
- wire stripper
- low-voltage DC power supply
- A4-size plastic sheet
- plastic compass

Method

- 1 Wind the insulated copper wire around an iron nail as shown.



- 2 Connect the ends of the wire to the low-voltage DC power supply while it is switched off. Once the ends are connected, switch it on.

continued...

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

...continued

- 3 Bring up a small plastic magnetic compass and record a map of the field around the nail. To do so, place the compass at different positions around the nail and record the direction and sense of the field line in this point using the compass needle.
- 4 Place an A4 plastic sheet over the electromagnet. Sprinkle iron filings over the sheet. Turn on power to the electromagnet and note what happens to the iron filings. Draw the pattern in your results section. Discuss what happens to the pattern of iron filings if you turn off the current.
- 5 Collect and recycle iron filings and remove plastic sheet from the electromagnet.
- 6 Use your electromagnet pick up paper clips. How many can you pick up? Record this number in your results.
- 7 Investigate two factors affecting the strength of the electromagnet: the number of coils and the current flowing in the wire. Use the number of paper clips that the electromagnet can pick up as an indication of the strength of the electromagnet.

Results

- 1 Draw a diagram of the pattern of iron filings created by the electromagnet.
- 2 Create a table and note how many paperclips your electromagnet could pick up.

Evaluation

- 1 What is the purpose of the iron nail in your electromagnet?
- 2 Explain why your electromagnet gets warm when you turn it on.
- 3 From your field map, work out which end of the electromagnet is north. Draw this on your recorded magnetic field map.
- 4 Explain the pattern of iron filings created by the electromagnet when you use the A4 plastic sheet.
- 5 Explain what happens to the pattern when you turn the electromagnet off.
- 6 Explain how the electromagnet can pick up paperclips.
- 7 What sources of error might there be for this experiment and how could they be resolved?

Conclusion

- 1 Make a claim from this experiment regarding the magnetic field of electromagnets.
- 2 Support the statement by using your observations (include potential faults in the experiment).
- 3 Explain how your observations support your claim.

Maglev trains

As discussed earlier in the chapter, unlike poles of magnets attract, while like poles repel. These magnetic forces can be put to good effect in magnetic levitation (maglev) trains.

Research on the internet to answer the following questions.

- 1 What is the main difference between the engine of a conventional train and a maglev train?
- 2 What is electromagnetic suspension?
- 3 How do maglev trains compare to conventional trains in terms of efficiency, noise, pollution, speed and maintenance?
- 4 Are there any maglev trains in Australia? Are there projects to develop maglev trains in Australia?

Explore! 9.1



Figure 9.24 Shanghai magnetic levitation (maglev) train to Pudong airport (top speed 430 km/h). Maglev trains can travel at speeds of up to 500 km/h riding on a 'magnetic cushion'.

Section 9.1 questions



QUIZ

Remembering

- 1 What material makes magnetic rocks magnetic?
- 2 What is magnetic induction?
- 3 What are Faraday's three rules for magnetic field lines?
- 4 What does the right-hand grip rule tell you?
- 5 What is the arrow convention for current and magnetic fields?
- 6 How does a compass work?

Understanding

- 7 What concept is used to explain magnetic attraction and repulsion between magnetic poles?
- 8 What is a solenoid?
- 9 How does an electromagnet work?
- 10 Why are iron cores added at the centre of solenoids?

Applying

- 11 Draw the magnetic field lines for the following two configurations. Use arrows to indicate the direction of the magnetic field.

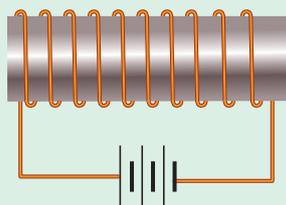


- 12 Draw the magnetic field generated by the following wires.



Analysing

- 13 How does a magnetic screwdriver work?
- 14 Determine the direction of the current and draw the magnetic field lines for the following solenoid. Which side is the north pole?



Evaluating

- 15 What is a magnetic wand? How does it work? How does it help wildlife in oil spills?
- 16 Deduce why increasing the number of coils in a solenoid increases the intensity of the magnetic field generated.



9.2 Generating movement



WORKSHEET

electric motor
a device that converts electrical energy to mechanical (movement) energy

Electric motors

As discussed previously, repulsive and attractive forces are generated between electromagnets and permanent magnets. In 1821, Michael Faraday used this effect to create the world's first **electric motor**.

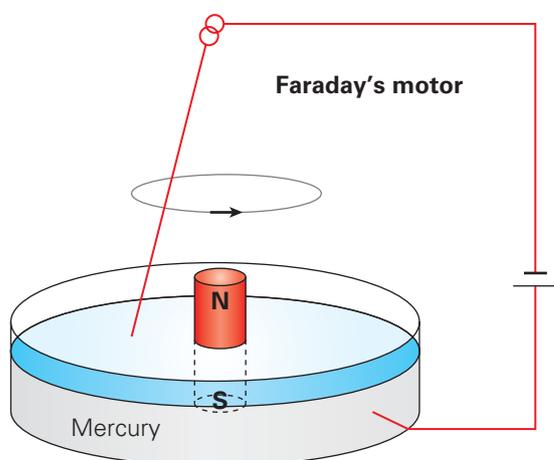


Figure 9.25 A schematic diagram of Faraday's electric motor

Faraday used a wire, a battery and a dish of mercury (a good electrical **conductor**). One end of the wire hung free in the mercury. When current was applied to the circuit, a circular magnetic field was generated. The wire's magnetic field interacted with the magnetic field of the permanent magnet. This caused the wire to rotate around the magnet. Faraday had converted electrical energy into rotational **kinetic energy** (movement).

conductor
a material that allows electric current to flow easily

kinetic energy
the energy of an object in motion

Just like two magnets that experience a force of attraction or repulsion when their magnetic fields interact, a magnet can exert a force on a current carrying wire. This is the basis of how electric motors work.

When a current carrying wire is placed in an external magnetic field, both magnetic fields will interact and this results in a force being exerted on the wire. If the wire is coiled, these forces can create **torque**.

torque
a force that causes something to rotate

The direction of this force can be predicted using the **right-hand slap rule**. If you hold your hand as shown in the Figure 9.26, your thumb points in the direction of the conventional current (I) and your fingers point in the direction of the external magnetic field (B). The wire will move in the direction that your palm faces (F).

right-hand slap rule
shows the direction of the force when a conductor moves in a magnetic field

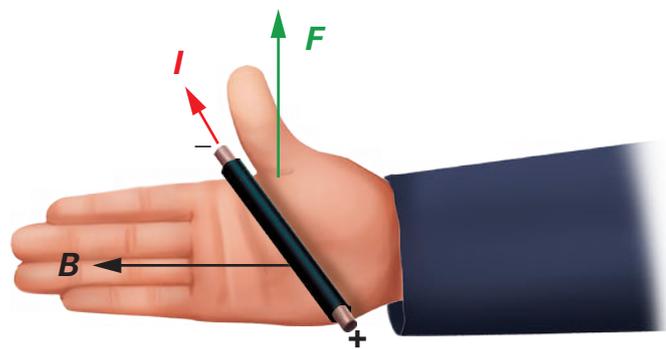


Figure 9.26 The right-hand slap rule is where your thumb is aligned with the direction of conventional current, your fingers are aligned with the magnetic field and your palm faces the direction of the force on the wire.

Practical 9.3

A simple electric motor

Aim

To build your own motor.

Materials

- D-cell battery
- insulated copper wire
- 2 long sewing needles (with the eyes large enough to fit the copper wire through) or 2 big paperclips
- sand paper or emery board
- modelling clay or Blu-Tack
- electrical (duct) tape
- small circular magnet
- marker pen

Method

- 1 Make a loop by wrapping the insulated copper wire several times (start with 5 or 10 times) around your D-cell battery, remove the loop and wrap the ends of the wire around the loop, leaving them sticking out, as shown in the diagram at right.
- 2 Using the sandpaper or an emery board remove 2 cm of insulation on ONE SIDE of the wire. Thread each end through the eye of a needle.
- 3 Lay the D-cell battery sideways on a flat surface and stick it in place with the modelling clay.
- 4 Make two small balls of modelling clay and impale them on the sharp end of each needle.
- 5 Place the needles upright near each of the terminals of the battery so that each needle touches one terminal of the battery and fix them in place with the electrical tape.
- 6 Your coil should be hanging above the battery. Place the small magnet on the battery, underneath the coil.
- 7 Give your coil a spin.
- 8 Does your coil spin? If not, try to spin it in the other direction. Redo your coil with more loops. What changes when you spin the coil? Record your observations in your results.

Results

Insert a picture or diagram of your construction and record your observations regarding how your motor operates.

Evaluation

- 1 Using the right-hand slap rule, could you have predicted the way the coil turns?
- 2 Deduce what might happen if you used a smaller or larger battery.
- 3 Deduce what might happen if you use a larger magnet.
- 4 Can you explain how the number of loops or the intensity of the current delivered by the battery affects your motor?
- 5 What faults might there be for this experiment and how could they be resolved?

Conclusion

- 1 Make a claim from this experiment regarding the requirements for a functioning motor.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Be careful

Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

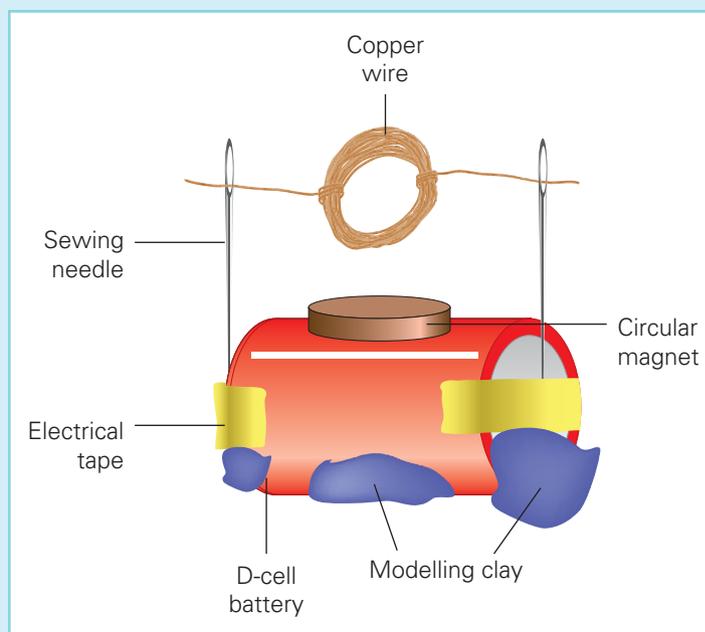


Figure 9.27 The simple coil that will be the spinning part of the motor

- 1 Why was Faraday's 1821 electrical motor experiment dangerous?
- 2 Explain how a permanent magnet can cause a current carrying wire loop to rotate.
- 3 Explain the right-hand slap rule and describe what it is used for.

Quick check 9.5

DC electric motors

Today, electric motors are everywhere. Electric fans, electric drills, washing machines, hairdryers, trains, electric cars and much more, all use electric motors.



Figure 9.28 Cross-section showing the electric motor in a drill

The simplified diagram in Figure 9.29 shows the magnetic forces (F) acting on the coil of wire in a simple direct current (DC) motor. Recall from Chapter 8 that DC current means the current flows in one direction around the circuit. Check using the right-hand slap rule that you understand why the force on the wire on the left (F) goes up, and the force on the wire on the right (F) goes down.

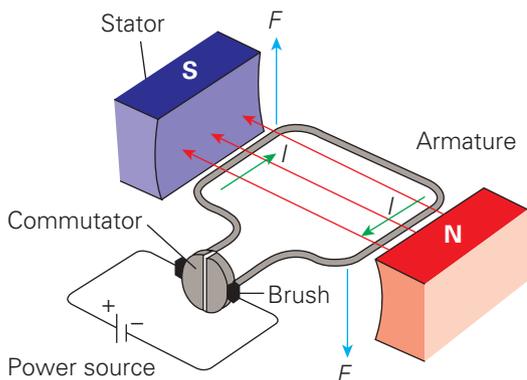


Figure 9.29 A simplified diagram of a simple DC motor

When electric current (I) flows through the **armature** coils, a magnetic field is produced. The magnetic field produced by these coils interacts with the magnetic field produced by the permanent magnets on either side of the armature coils. The magnetic forces of the two sides of the loop cause a torque, making the coil turn.

armature
the rotating coil which is part of an electric motor

The **brushes** connected to the power source lightly touch the commutator. This allows current to continue being supplied to the armature coils. The **commutator** ensures that the current supplied to the coil keeps the coil rotating in the same direction. It does this by turning with the armature and then after a 180° rotation, when exposed to the opposite pole of the permanent magnets, the commutator makes the current change direction, allowing the armature to continue rotating in the same direction rather than oscillating back and forth between the two magnets.

brush
the part of a motor that conducts current between stationary and moving parts

commutator
a split ring that reverses current at a point in a motor

- 1 What does DC stand for?
- 2 Which parts of a simple DC electric motor are moving and which parts are stationary?
- 3 Write down a list of five electric motors that you have around your home. Explain what each electric motor does and what the general purpose is of the motor.
- 4 Explain the role of the brushes and commutator in a simple DC motor.

Quick check 9.6

Electric motors in everyday life

The number of electric motors used in consumer-oriented products (such as electronic devices and cars) is estimated to have reached 12 billion units in 2018.

You will find them everywhere in your home appliances (from the ventilation fans in your laptop or desk computer to your refrigerator or washing machine).

Electric motors are also largely used in cars (not just electric cars). A modern car can contain a hundred electric motors (to lift windows, lock the doors, use the wipers, spool the air ventilation fans, activate the automatic parking brake and more.)

Can you think of other uses of electric motors in a car?

Did you know? 9.3



Figure 9.30 The world speed record in an electric wheelchair is held by Jason Liversidge, who has motor neurone disease.



Figure 9.31 A DC motor

There are many different designs for simple DC motors. One common design used in some schools for practical work is shown in Figure 9.31. Note the motor has three sets

of armature coil windings and also a triple segmented commutator (a commutator with three splits rather than two). This means that at any point in the rotation, two of the three commutator segments are in contact with the brushes. This design ensures that the DC motor does not have a 'dead spot', where the motor does not turn and which could cause the coils to burn out. This absence of a 'dead spot' is a handy feature as it prolongs the longevity of these motors!

Simple DC motor

Look at a permanent magnet DC electric motor set up for you.

Using **only 2 V DC** for the DC electric motor, turn it on and answer the following.

- 1 Which way is your motor turning – clockwise or anticlockwise? What effect does the reversing of the current through the coils have on this DC motor? Try it.
- 2 The current is put back to its original direction. What effect would the swapping of the permanent magnets have on this DC motor? Try it.
- 3 You may have noticed some electrical sparking where the brushes made contact with the commutator. Why is there electrical sparking?
- 4 When the DC current is replaced with an AC current, the motor probably does not rotate but vibrates instead. Explain carefully what is happening there.

Try this 9.4

Be careful

Hot wires can burn if there are short circuits. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

Speakers

Recall that a coil of wire with an electric current running through it produces a magnetic field. This magnetic field can interact with other magnetic fields, such as that of a permanent magnet and experience attraction or repulsion. The speakers in headphones use the forces generated by the interaction between the electromagnets and the permanent magnets to produce sound.



Figure 9.32 Fido's headphones use the interaction between permanent magnets and electromagnetic coils to produce the heavy metal music, which Fido loves hearing in his headphones.

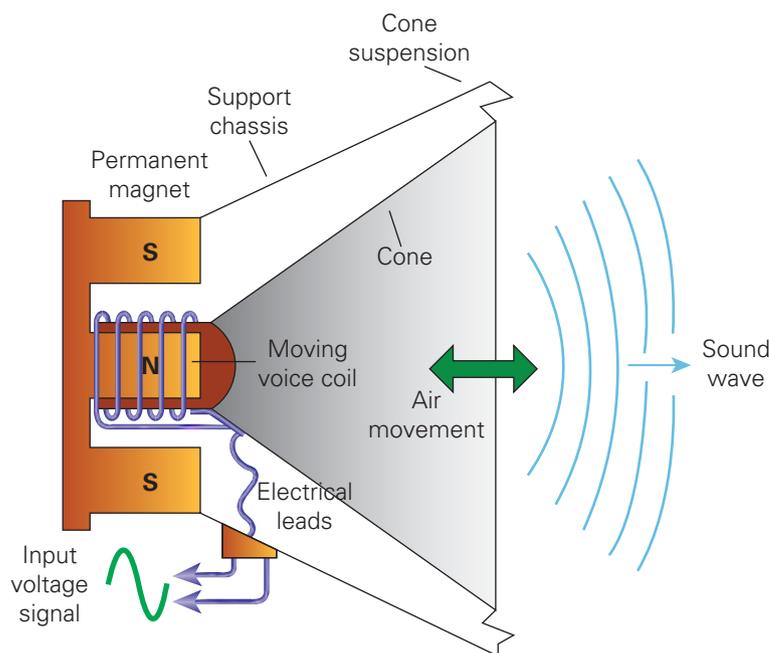


Figure 9.33 Cross-section of a typical headphone moving-coil style loudspeaker

Inside the speaker, electric current flows through the coil around the base of the speaker cone. This base sits inside a cylindrical permanent magnet. The coil, also called a moving voice coil, moves the whole cone back and forth. The coil of wire shown in Figure 9.33 creates a changing magnetic field caused by the changing electric current produced by the audio source (music). This coil, which is attached to the cone of the speaker, therefore interacts with the permanent magnet either being momentarily attracted or repelled. This causes the speaker cone to vibrate, which then creates the heavy metal music, which Fido loves hearing in his headphones.

Build your own loudspeaker from scratch

Look up on the internet tutorials on how to make your own loudspeaker with items you might already have in your home (like a polystyrene cup or an empty yoghurt cup, a small magnet, a broken pair of headphones, some copper wire, a battery, sticky tape, Alfoil etc.).

Try this 9.5

Follow the tutorial you found and try your new home-made loudspeaker on a radio for example.

- 1 Does your loudspeaker work as you would have expected? If it does not work, try to find what might be the problem. Can you figure out how to make it work?
- 2 Suggest some improvements, for example, how can you make your loudspeaker louder?
- 3 With this experiment, can you explain how a loudspeaker transforms electric energy into mechanical energy?

Magnetic cellulose loudspeakers

If you have ever been to a HiFi shop, you might have noticed that a wide range of speakers is available, and that new ones, with ingenious technology, keep being developed, in a never-ending search for the perfect sound rendition associated with the smartest design.

Science as a human endeavour 9.3

continued...

...continued

In 2013, a Swedish team developed speakers made from a new material derived from wood pulp that do not even need permanent magnets to work. Instead, magnetic particles are incorporated directly to the cellulose membrane of the speaker, making it possible to design ultra-thin, great-sounding and environmentally friendly speakers.

Talking on the phone

Explore! 9.2

The first telephones were developed in the nineteenth century and nowadays, it is estimated that 75% of the world's population has a smartphone, but did you ever wonder how telephones transform soundwaves to electric signals and electric signals to soundwaves?

The mouthpiece of a telephone is the part doing the sound collecting, and the earpiece is the part doing the sound emission, but how?

Research on the internet and answer the following questions.

- 1 Identify the earpiece part that is used to convert an electric signal to soundwaves.
- 2 Identify the mouthpiece part that is used to convert soundwaves to electric signals.
- 3 Explain piezoelectricity. Are piezoelectric materials used in the earpieces and mouthpieces of telephones?

Section 9.2 questions



QUIZ

Remembering

- 1 What are the energy changes associated with an electric motor?
- 2 Recall what forces Michael Faraday used to create the world's first electric motor.
- 3 Describe Faraday's motor.
- 4 Recall which parts of a telephone do the sound collecting, and which do the sound emission.
- 5 List some common devices that use electromagnets.

Understanding

- 6 Explain why the permanent magnets are curved in some DC motors.
- 7 Explain how a DC motor works.
- 8 Explain what happens at any point in the rotation if a simple DC motor has three sets of armature coil windings and also a triple segmented commutator.

Applying

- 9 Explain what it means if a DC motor has a 'dead spot' and why it is a problem.
- 10 What are the design parameters (aspects that are needed such as cost, design, materials and risk) for creating headphone speakers?
- 11 Describe what happens to both magnetic fields when a current carrying wire is placed in an external magnetic field.

Analysing

- 12 Describe how the speakers in headphones use the forces generated by the interaction between the electromagnets and the permanent magnets to produce sound.

Evaluating

- 13 Imagine a world where they had not discovered electromagnets. Propose some ideas on what this would be like and give reasons why you would not be able to use a number of appliances.
- 14 Headphone speakers are different from ordinary loudspeakers. Decide on the design aspects which contribute to the function of headphone speakers, for example, cost, material etc. Explain your choices.



9.3 Generating electricity



Electromagnetic induction

Ten years after Michael Faraday created the electric motor, he returned to his electrical research and discovered how to create electricity using a magnet and a coil of wire. Faraday connected his apparatus to a galvanometer (an instrument that detects electrical current). He discovered that when he passed the magnet back and forth through the coil of wire, which remained stationary, a current was created. Moving the magnet to the left into the coil created a current in one direction and moving the magnet right out of the coil created a current in the opposite direction. The magnetic field of the magnet exerted a force on the electrons in the wire, causing them to move, generating current. This was the world's first alternating current (AC) **generator**. The

generator
a device that converts mechanical (movement) energy into electricity

production of a current in a wire by changing the magnetic field is called electromagnetic induction.

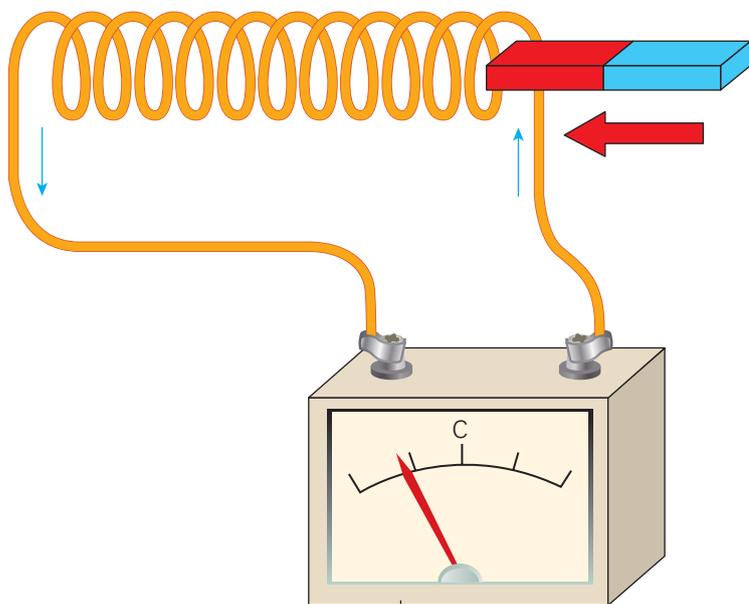


Figure 9.34 Using a magnet and a coil to create electricity

A current is generated if there is relative movement between the the coil and the magnetic field in relation to each other. The movement could be from the just the magnet, just the coil or both. To generate sufficient electrical energy to run domestic appliances, tram and train networks, street lighting, hospitals, factories and so on, electrical energy must be produced on a massive scale.

Electric guitars and Faraday

Did you know? 9.4

Electric guitars use Faraday's principle for generating electricity to create sound. Made of a solid body and various magnetic pick-ups, they are literally mini-generators generating in the order of 20–200 millivolts.

A vibrating steel string interacts with a bar magnet to generate a small electric current in the magnetic pickups, which are magnets wound with coils of very fine wire. The signal passes through the tone and volume circuits to the output jack, and through a cable to an amplifier where the electrical signal is then converted into sound via amplifiers and loudspeakers.



Figure 9.35 Lindsay Ell performing with her Fender Stratocaster

- 1 Explain the term 'electromagnetic induction'.
- 2 Describe the first AC generator.
- 3 Explain the outcome of moving a magnet in one direction then the other through a wire coil.

Quick check 9.7**Practical 9.4****Magnets can generate current****Aim**

To generate current with a magnet.

Materials

- bar magnet
- insulated copper wire
- galvanometer
- cardboard tube
- wire stripper

Method

- 1 Make your own solenoid by neatly wrapping the insulated copper wire around the cardboard tube.
- 2 Using the wire stripper, remove around 2 cm of insulation on each of the free ends of the wire.
- 3 Connect the free ends of the wire to the positive and negative terminals of the galvanometer.
- 4 Predict what you think will happen when you put the magnet bar inside your coil. Do it and observe the galvanometer needle.
- 5 Move the magnet back and forth inside the coil, what happens to the galvanometer's needle? Move the bar magnet faster or slower. Does it have an effect?
- 6 Now move the magnet bar back and forth outside the coil. How does this affect the galvanometer's needle?
- 7 Add more turns to your solenoid. What happens?

Results

Insert a picture or diagram of your construction and record your observations regarding how your current generator works.

Evaluation

- 1 Could you have predicted the way the galvanometer's needle would move, depending on the movement of the bar magnet?
- 2 Can you explain why and how the speed of movement of the bar magnet affects the intensity of the current generated?
- 3 Is the current generated more intense if you add more coils to your coil?

Conclusion

- 1 Make a claim from this experiment regarding generators, current and magnets.
- 2 Support the statement by using your observations.
- 3 Explain how your observations support your claim.

Generators

To generate massive amounts of electricity, a long piece of wire is coiled up and rotated inside a large magnet. Most large-scale production of electrical power uses

turbines to turn the coil or wire.

These turbines can be turned by steam (similar to the turbine in Figure 9.36), by falling water (hydroelectricity) or by wind (wind farms).

turbine
a type of machine that turns wheel with blades to produce power

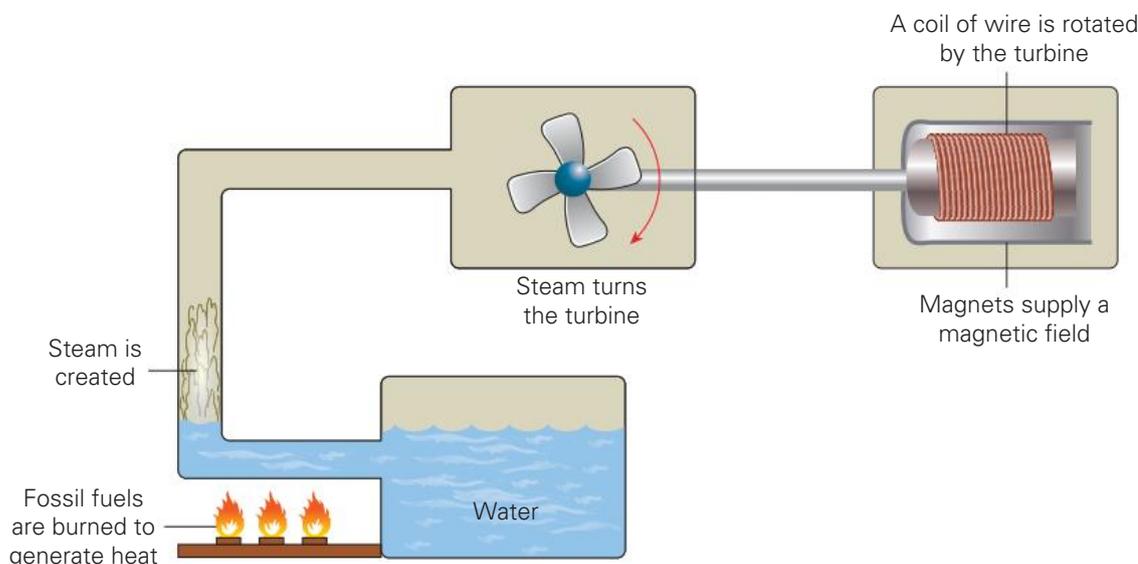


Figure 9.36 A typical steam turbine generator

The turbine blades turn due to the considerable force on them which then rotates coils of wire inside very large electromagnets. The rotation of the coils in the magnetic field produces a large electric current and a high voltage.

Steam-driven turbines

For steam turbines the steam can be generated using various methods, for example, burning coal, burning gas and harnessing nuclear energy.

In Australia, about 60% of our electrical energy is generated by coal-fired power stations. Coal-fired power stations transform the chemical energy stored in coal into electrical energy. Burning the coal produces intense heat, which is used to boil water to create very high temperature (500°C) and high-pressure steam. The superhot steam applies force on the turbine blades which then rotate coils of wire at 3000 revolutions per minute (3000 rpm) inside very large electromagnets. A typical coal-fired steam generator can generate 300 million watts (300 MW) of electric power. The average of the 21 coal fired power stations in Australia is 900 MW.

In nuclear power stations, the energy required to boil water to produce the steam that turns the turbine blades is released in **nuclear fission reactions**. Australia does not have any nuclear power generation stations.

nuclear fission reaction
the process by which an atom splits into two parts

Water-driven turbines

In hydroelectric power stations, the energy used to turn the turbines is obtained from gravitational potential energy. Water falling from a great height turns the turbines directly with no need for high-pressure steam.



Figure 9.37 Turbines in Murray 1 power station. Murray 1 is the second-largest power station in the Snowy Mountains hydroelectric scheme. It has 10 turbine generators, each producing 95 megawatts of power (95 MW). Each turbine generates enough electricity to power 95 000 homes.

This is how Australia's Snowy Mountains hydroelectric scheme generates approximately 7.5% (in 2018) of Australia's total electricity demands.

The energy of waves can also be harnessed by placing generators on the surface of the ocean. Waves are caused by wind and in some places on Earth, there are consistent amounts of wind that produce continuous waves. These waves contain tremendous amounts of energy

that can be used to spin turbines and create large amounts of electricity.

Similarly, tidal energy is a reliable source of energy. Huge amounts of water move around the Earth as tides go in and out. The movement of this water can be used to turn turbines. It is the interaction of gravitational forces between the Earth, Moon, and Sun that cause tides. So, as long as the Moon continues to orbit Earth and Earth orbits the Sun, there will be tides to generate electricity.

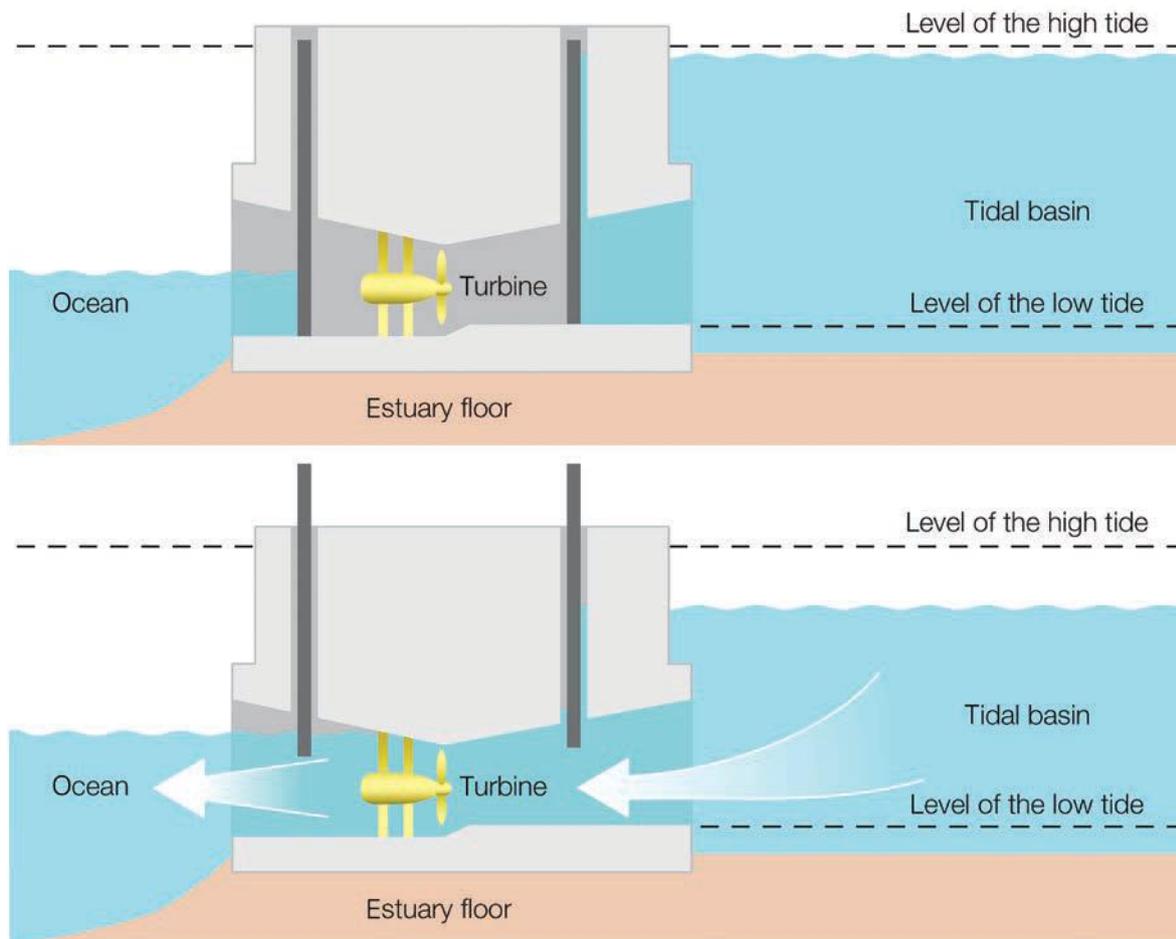


Figure 9.38 Movement of the water during tides turns the turbines to generate electricity.

Wind energy

Wind energy is gaining popularity around the world. Australia is perfectly placed to construct and use wind farms to create electricity as there are extensive areas where wind harvesting is a viable option. Currently, Australia relies heavily on coal-fired power stations for most of its electricity and this comes at a large

environmental cost. Australians produce massive amounts of greenhouse gases per head of population and are contributing to climate change. Figure 9.39 shows a modern wind turbine used to generate electricity. These typically produce 2 MW of electricity and, currently, the cost is estimated at approximately \$4 million to manufacture, construct and install.

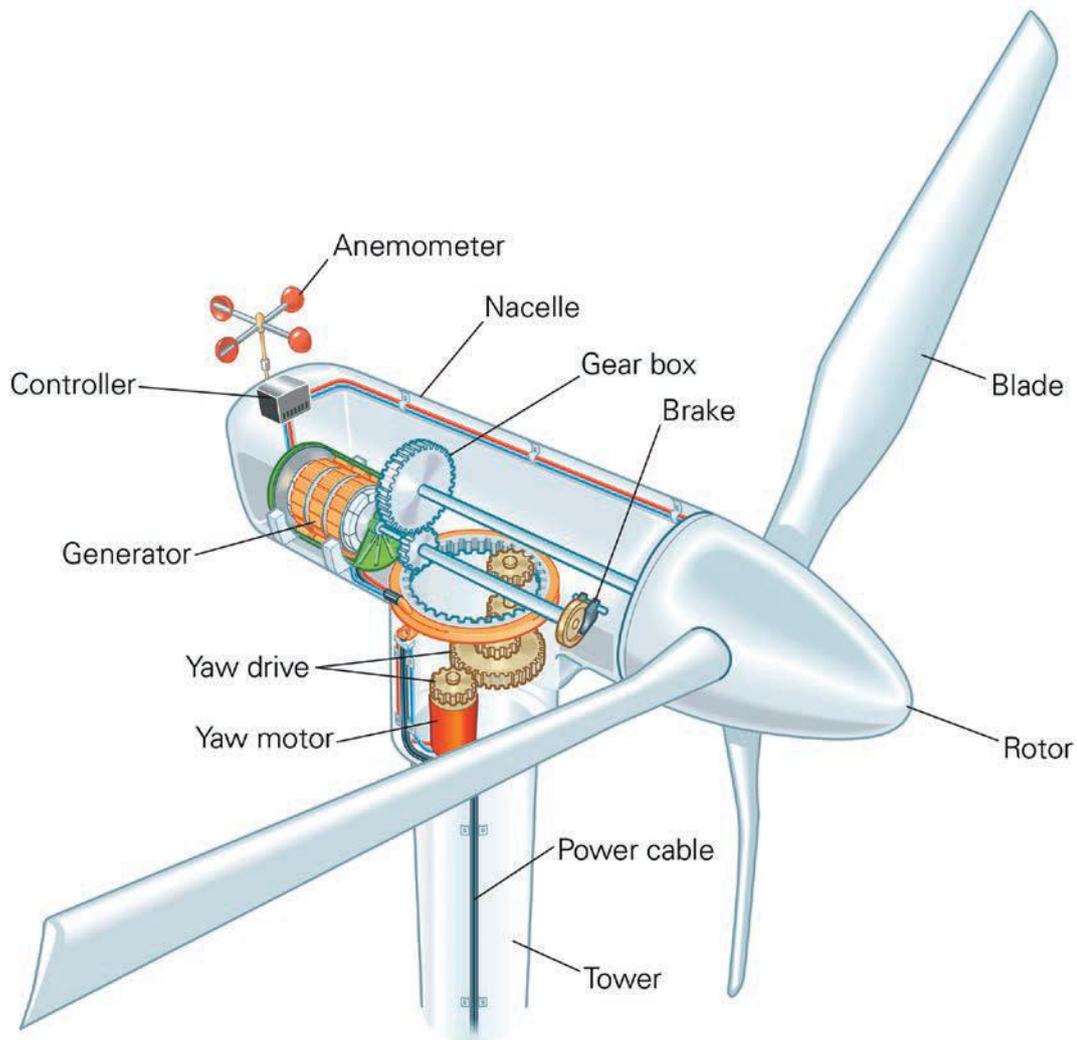


Figure 9.39 Modern wind turbine used to generate electricity. The wind power turbine housing box sits 70 metres above the ground, while each of the three blades is 35 metres long. Each aerodynamically constructed blade has a mass of about 20 tonnes.

Although the blades on a wind turbine appear to rotate fairly slowly (about 20 revolutions per minute, 20 rpm),

gearing inside the housing box enables an appropriate high enough rotational speed (1800 rpm) for the electric generator.

Generating electricity

Explore! 9.3

Section 1: Energy sources: coal, solar, nuclear

For each energy source, investigate and report on the following.

- 1 How is electricity generated?
- 2 What are the advantages and disadvantages of each method of electricity generation?
- 3 What are the environmental issues (good and bad) associated with each method of electricity generation?

Section 2: Australian states

- 1 Research and compare each Australian state to the national electricity production method percentages. Record this in a table or graph.
- 2 Which state in Australia is the biggest consumer of electricity? What percentage of the nation's electricity production does it consume and in which sector of this state's society is most of the electricity consumed?

continued...

...continued

Section 3: Australia and the world

- 1 Make a table to compare the methods of electricity generation and their percentage of total generation for each of the following countries: Australia, USA, India, China and France.
- 2 Comment on the Global electricity generation by source pie chart (Figure 9.40) with regard to the world's dependence on fossil fuels and the implications for climate change.

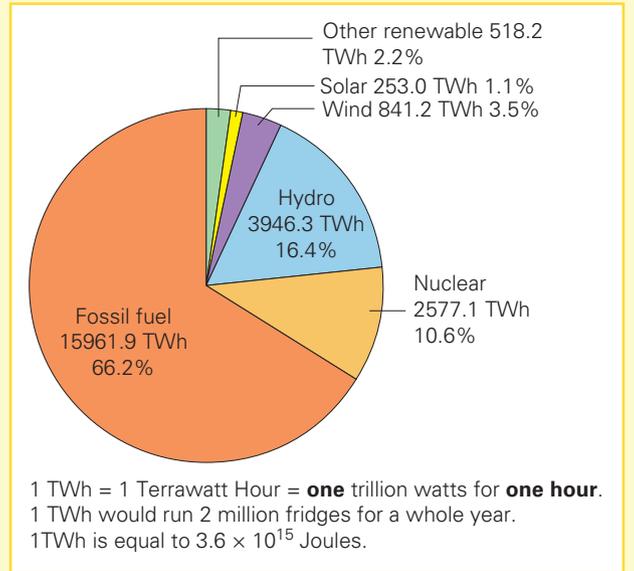


Figure 9.40 Global electricity generation by source

New electricity generators

Science as a human endeavour 9.4

Life on Earth is mainly dependent on the renewable energy of the Sun but we humans have been relying heavily on fossil fuels since the Industrial Revolution. However, since the beginning of this century, with growing levels of environmental awareness, renewable energies have started to gain traction. The production of electricity through wind power, for example, with the use of wind turbines, has dramatically increased over the last two decades but for an average person, having a wind turbine in the backyard is impractical. Fortunately, microgeneration technologies enabling small businesses and communities to meet their needs are being developed. The search for new ways to produce energy is a continuous endeavour and sometimes, researchers draw inspiration from nature.

Imagine a biomimetic tree that produces electricity as its artificial leaves sway in the wind. Does it seem far-fetched? This is nonetheless what a team of American scientists is developing, striving to allow small scale, off-grid, energy harvesting with aesthetic devices.

But small-scale energy production can take many forms, as with wearable thermoelectric generators, where a temperature difference is converted into electricity. Recently, a team of South Korean scientists has been working on new ways to boost wearable thermoelectric generators. In the near future, it might be possible to self-power small electronic devices using only our body heat.

Transformers

In 1831, Michael Faraday was investigating electromagnetism and conducted an experiment with an iron ring, some copper wire and a battery. Figure 9.41 shows the basic set-up of Faraday's experiment.

Quick check 9.8

- 1 Explain the various ways in which electricity is currently generated.
- 2 Explain the new ways in which scientists and engineers are trying to generate electricity.

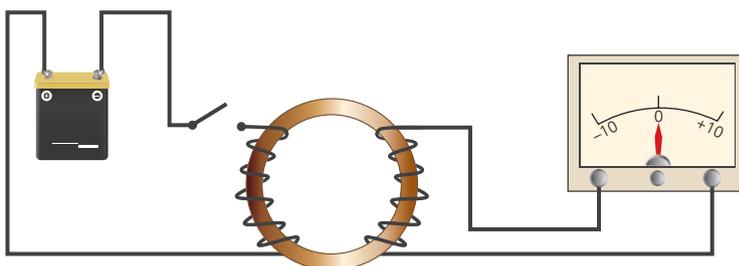


Figure 9.41 Michael Faraday's experiment that transformed the world of electricity

In the middle is a continuous ring made of solid soft iron. It is wrapped on opposite sides in two sets of unconnected copper wires. The left-hand side (LHS) coil and the right-hand side (RHS) coil are insulated and do not touch each other at any point.

Now this is the surprising part that even surprised Faraday! When the circuit is closed and current flows through the LHS, the galvanometer connected to the RHS registers a current. However it quickly fades, despite the current still flowing through the LHS coil.

When the battery is disconnected, another current is registered on the RHS in the opposite direction to the original current. Again it quickly fades.

By switching the battery on and off repeatedly, the effect can be reproduced, creating 'alternating current' in the RHS coil. This can be done as rapidly as you like. Faraday discovered it only works with AC and not with a constant direct current (DC).

Faraday noticed another very interesting thing with his experiment. If the number of turns on the RHS coil is half the number of turns on the LHS coil, then the current in the RHS coil doubles and the voltage in the RHS coil halves!

transformer

a device that changes the AC voltage as it moves from one circuit to another

Modern **transformers** take advantage of this particular discovery of Faraday's set-up. A transformer is a device that increases or decreases AC voltage. You can transform voltages up or down simply by adjusting the ratio of the turns of the two coils. For example, you may have a smartphone that only requires 18 V to operate, but 240 V comes out of the wall socket. So a transformer usually comes as a part of the power cord and it converts the 240 V down to 18 V so you can safely charge your phone.

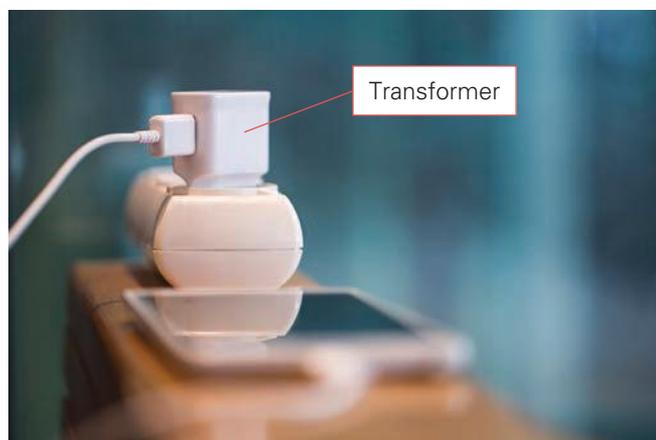


Figure 9.42 Smartphone charging – notice the transformer is part of the plug.

Faraday's discovery proved crucial for the public supply of AC electricity on a large scale, since power stations generate at high voltages (10 kV) that need transforming to very high voltages (500 kV) for efficient transmission through the high-voltage transmission wires in the electrical distribution system. Further transformers are then used to bring the voltages down to various other levels (240 V for houses).



Figure 9.43 You may have seen transformers on power poles in the street.

Section 9.3 questions

QUIZ

Remembering

- 1 What are the energy changes associated with an electric generator?
- 2 Consider if it is possible to have a device which is both an electric motor and electric generator. Give an example.

Understanding

- 3 Faraday passed a magnet through a coil to generate electricity. Is it possible to have the magnet stationary and have the coil move to make electricity? Explain.
- 4 Explain where or how a turbine can be made to rotate.
- 5 Explain how the rotation of a turbine produces electricity.

Applying

- 6 Explain how electric guitars are mini-generators of electricity.
- 7 Identify what happens to the current and voltage in the LHS coil in Figure 9.41, if the number of turns on the RHS coil is half the number of turns on the LHS coil.

Analysing

- 8 Discuss how the energy of waves can be harnessed.



- 9 In Australia about 60% of our electrical energy is generated by coal-fired power stations. Describe how coal-fired power stations transform the chemical energy stored in coal into electrical energy.

Evaluating

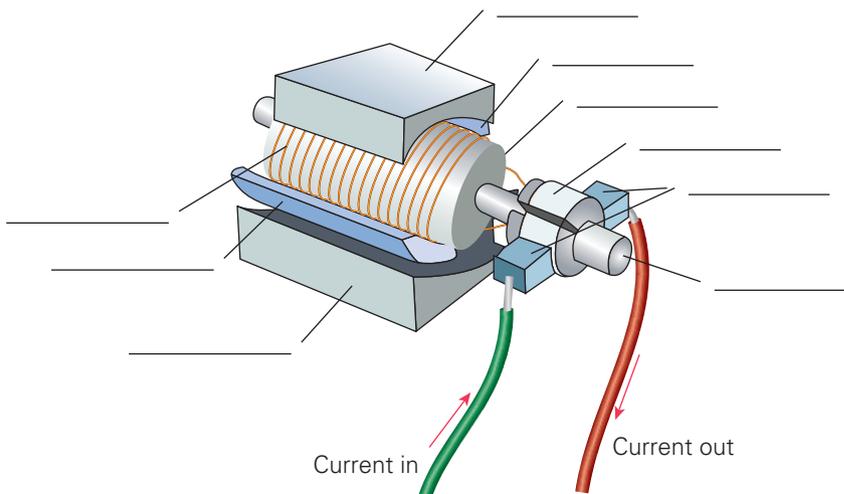
- 10 Evaluate the level of take up of solar and wind power generation given our considerable solar and wind power potential.
- 11 Evaluate whether hydroelectric power is renewable and list the advantages and disadvantages of creating and using hydroelectric power.



Review questions

Remembering

- 1 **a** Define the term 'magnetic induction'.
- b** Describe one practical use of magnetic induction.
- 2 Discuss the difference between a solenoid and an electromagnet.
- 3 **a** Identify and label each of the components of the DC motor below from the following list: permanent magnets, armatures, armature windings, shaft, split-ring commutator, brushes.



- b** Complete the table below to indicate the role of these parts of a DC motor.

Component	Purpose
Permanent magnets	
Armature windings	
Brushes	
Split-ring commutator	
Shaft	

Understanding

- 4 Magnets are said to be dipolar. Explain what this means.
- 5 Many electrical devices use electromagnets.
 - a** Name three devices that use electromagnets.
 - b** Are electromagnets permanent or temporary magnets? Explain your answer.
 - c** Explain the roles of the solenoid and the iron core in an electromagnet.

Applying

- 6 Explain how a magnetic wand works in cleaning up oil spills.
- 7 Why do commercial DC motors have multiple split rings and multiple armature windings?
- 8 What is the function of the solenoid on the cone of a loudspeaker?

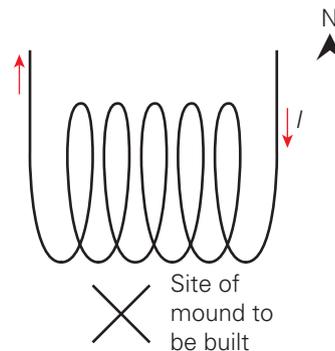
- 9 The extra energy demand when two million households on the eastern states turn on their air-conditioning units, each of which uses 2.5 kW of power, is 5000 MW.
- Suggest what may happen if this occurred.
 - What measures could householders take as a group to prevent blackouts on very hot days?
- 10 Explain how an electric guitar does not use electricity but actually makes electricity.

Analysing

- 11 Electric generators are sometimes described as electric motors in reverse. Explain what this means.
- 12 Explain why AC power has become the mainstay of electrical transmission and distribution systems. Refer to how transformers work and the role of high-voltage transmission in reducing power losses over long distances.

Evaluating

- 13 Evaluate the level of Australian government action on the development of renewable energy sources such as domestic solar electrical energy and commercial wind farms.
- 14 *Amitermes meridionalis* is a species of termite found in northern Australia. It is also known as the 'compass termite' or 'magnetic termite' because their wedge-shaped mounds are aligned north–south to control and stabilise temperature and humidity inside the towers as shown below. Predict what would happen if a colony of these termites was to start building a mound next to a current-carrying wire, as shown on the right, along with the repercussions.



STEM activity: The simplest maglev system

Background information

The magnetic train does not use wheels, axles or mechanical transmissions, but a magnetic levitation system on a special rail. That is, without there being contact with the rails, the train floats and moves.

Maglev (abbreviation for magnetic levitation) is used in trains that operate in countries such as Japan and South Korea with trains that can exceed 500 km/h! They have many advantages, for example: the trains do not experience any friction with the ground, they need less energy, are quieter and do not require much maintenance. Although advantageous in many fronts, maglevs are expensive to build, require an expert skilled labour force to operate and considerably large investment needed to install brand new lines, while regular trains can take advantage of existing railways.

Design brief: Construct the fastest model maglev system.

Activity instructions

In this task, you will use all the knowledge constructed on magnetism to construct a simple (and inexpensive) magnetic levitation (maglev) train system model. This activity has been developed



to give you the opportunity to investigate how a number of important concepts on magnetism combine to allow engineers to create very fast trains that levitate above the rail! Ideally, you should work in pairs, get a set of materials listed below and follow the step-by-step guide. Have fun! Once you have a working model, evaluate its function and modify your model to achieve the fastest possible speed.

Materials required

- 2 strong N35 neodymium magnets (11 mm diameter × 2 mm thick)
- Cu wire or tin solder wire – 1 mm diameter
- cylinder to coil wire (11.5–12 mm outside diameter)
- AAA battery (10.5 mm in diameter and 44.5 mm long)

Procedure

- 1 First, you should coil some tin solder wire to create the track for your train. The process of coiling is simple, as shown in Figure 9.44a. You should aim to create a coil (track) around 20 cm long that remains in a straight line, as shown in Figure 9.44b.

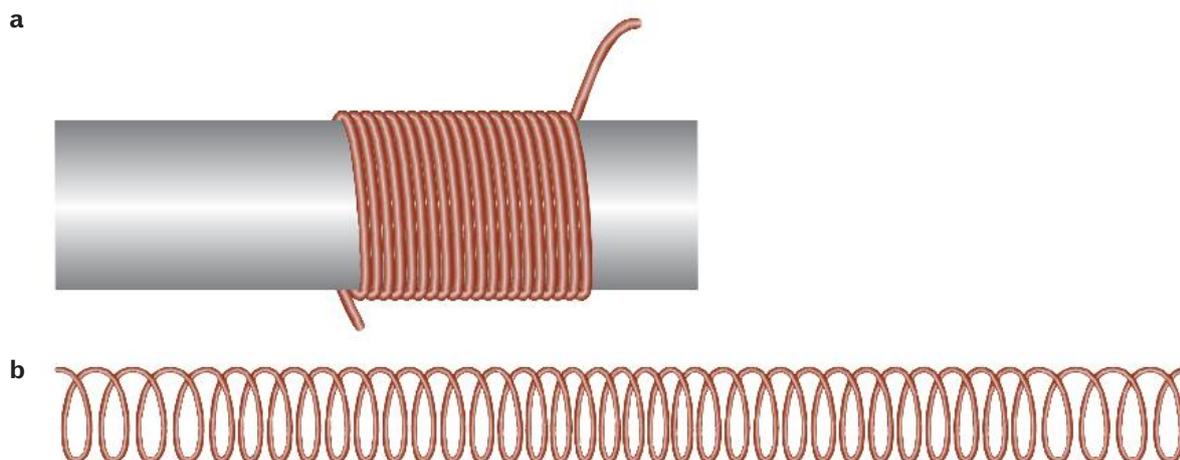


Figure 9.44 (a) Coiling the copper wire. **(b)** Finished result.

The second step is the most straightforward (and important) of them all.

- Take your AAA battery, two strong N35 neodymium magnets and place the magnets on either end of the battery as shown in Figure 9.45, making sure that the magnets are repelling. In other words, both magnets must be facing out (north).

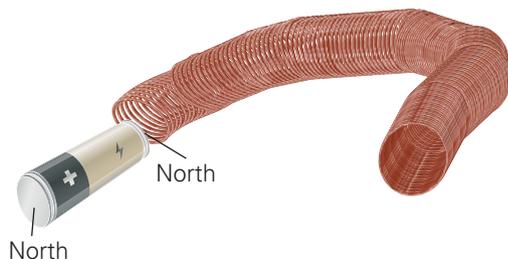


Figure 9.45 Magnets placed and ready to go (repelling!)

- Place your battery (train) inside the copper wire as shown in Figure 9.46 and observe what happens.

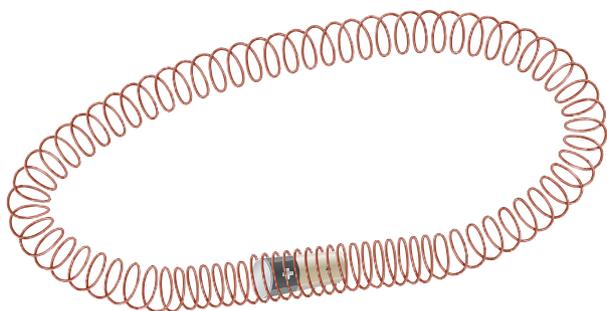


Figure 9.46 Your small train system is ready to go.

Evaluate and modify

- How would you estimate the length of copper wire required to create a train track measuring around 50 cm in length?
- Discuss with at least three of your peers the challenges you have encountered throughout this project. Identify ways of increasing the speed of the model. List the strategies or actions that allowed you to overcome the challenges.
- Reflection on your project is integral and vital for problem-solving in the real world. Create a list of suggested improvements that could be applied to this project.
- Time to explore! List your predictions and observations for the following scenarios.
 - Predict how your train would behave if you decided not to follow the instruction to place the magnets on the battery as suggested.
 - Predict what would happen to your train if you decided to place both batteries repelling as requested but facing south instead.
- You know that trains can move long distances, however, your group has only a little 20 cm strip of track. How could you create a closed looped circuit (look around) that is around 1 m long and capable of moving constantly? Scientists can use extensive testing to improve the efficiency of products, machines and so on. Now, it is time to measure the efficiency (speed) of our mini maglev!
- List your data and observations for the following.
 - Record five measurements of the time taken for a train to travel 1 metre.
 - List your data using a table and determine the average time for a train using two magnets.
 - Determine the group that has the fastest model.
- Now, it is time to investigate the efficiency of a train that uses four magnets.
 - Add two magnets to each side of a battery, with north facing out on each pair, and repeat steps **6a** and **b** above.
 - Present your data and explain to your peers whether adding two extra magnets improves the efficiency of your train.

Glossary

Chapter 1

continuous data quantitative data that can be measured

control condition the condition where the independent variable is absent, used as a baseline to measure results against

controlled variable any variables that may influence the outcome of an experiment, that are kept constant

dependent variable (DV) the variable that is measured during the experiment to see if the independent variable has had an effect

descriptive statistics tools used to summarise and describe data sets, e.g. measures of centre and spread

discrete data quantitative data that can be counted

experiment a scientific procedure used to test a hypothesis or test a cause-and-effect relationship between two variables

experimental condition the different conditions where the independent variable changes

extraneous variable any variable that may influence the outcome of an experiment that has been failed to be controlled for

hypothesis a prediction or explanation for something that is based on known facts, but has not yet been proved

independent variable (IV) the variable that is systematically manipulated or changed during an experiment

inferential statistics tool that allows scientists to establish cause and effect relationships between variables by analysing the changes in data sets

line graph a type of graph with *x* and *y* axes, used to display numerical data

line of best fit a line through a scatter plot of data points that best expresses the relationship between those points

mean often referred to as the 'average', this measure of centre is found by adding all the values and then dividing this sum by the number of values

measure of variability the use of mathematical calculations that describes how spread the set of data or scores are from each other; for example, range or standard deviation

median a measure of centre of a data set, found by ordering the values from smallest to largest and finding the middle point

mode a measure of centre of a data set, found by identifying the most frequently occurring data value

objective data data that can be directly observed or measured, not open to interpretation

observational the skill of closely watching an experiment, using all five senses or specialised tools to detect changes

outlier an extreme data point

potable clean and safe to drink

primary data data that is sourced for/during the experiment

***p*-value** a statistic that gauges the level of probability that the difference between the control and experimental groups are due to chance factors, and determines the statistical significance of the results

range a measure of spread, found by subtracting the minimum value from the maximum value

reliability the consistency, stability or dependability of data or results

secondary data data that is sourced from someone else's research or a database

standard deviation a measure of spread that shows, on average, how far the scores differ from the mean

subjective data data that relies on personal experiences, interpretation or responses

trend the overall pattern of movement in the data, e.g. increasing or decreasing

validity a valid experiment or procedure measures what is intended to be measured; when extraneous variables are not recognised and controlled this may not be the case.

variable any factor that can change during an experiment

Chapter 2

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 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 or a self-antigen

antiseptic a substance that stops or slows down the growth of microorganisms, 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, such as bacteria, and occurs when the cell divides, giving rise to two identical cells

budding an asexual reproduction process where the new individual is a clone of the parent organism

capillary the smallest vessels which contain oxygenated blood and enable red blood cells to deliver oxygen to the tissues on a cellular level

carbohydrate biological molecules made of carbon, with hydrogen and oxygen in the same ratio as in water, and which can be broken down with the release of energy in the body

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

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 release glucose into the bloodstream, raising the blood glucose levels

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 the liver and muscle cells to take up glucose from the bloodstream, lowering the 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 an organism that is composed of more than one cell

nephron the functional unit of the kidney, involved in filtering the blood to produce urine

non-specific immunity the branch of the immune system that does not depend 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 a small organism, such as a bacterium, virus, prion or parasite that can cause disease

phagocytosis a cellular process where a white cell wraps around 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, with structural and regulatory functions, and can also be used as an energy source. Food sources of protein include meat, legumes, dairy, eggs

receptor a sense organ (or cell/group of cells) that detects stimulus

septic describes a wound infected with bacteria

stimulus any object or event that elicits a sensory or behavioural response in an organism

unicellular a single-celled organism

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 non-cellular pathogen comprised of infectious particles that are inactive outside a living host cell

Chapter 3

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

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

homunculus a representation of the body parts in the brain where size shows level of sensitivity

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 a specialised nerve cell

neurotransmitter the chemical messenger that is released from one neuron and travels across the synapse to bind to the next neuron

plasticity the ability of the brain to change its neuron structure and function over time, in response to experiences

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

sensory neuron a nerve cell that transmits messages from the sensory receptors to the central nervous system

synapse the gap between two neurons

target cell a cell affected by a specific hormone

Chapter 4

abiotic non-living factors, such as temperature, pH, salinity, rocks, water

apex predator the highest level consumer in a food chain

autotroph otherwise known as a producer, an organism capable of making its own food

biome a region of Earth's surface and 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 animal

carrying capacity the maximum population size a particular environment can support

cellular respiration a chemical process where glucose is burnt with oxygen, producing carbon dioxide and water and releasing energy

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

ecologic niche the role an organism fulfils in an ecosystem, e.g. its habitat, nutrition, interactions with other organisms

ecosystem a biological unit made up of the community of living organisms, the non-living components and the interactions between them

emigration the movement of individuals out of the population

eutrophication killing of life in a lake as a result of excessive growth of algae

exponential growth a rapidly accelerating increase in population size

food chain the flow of energy from organism to organism, in an ecosystem

habitat the environment an organism lives within

heterotroph also known as a consumer; an organism that must eat or 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

limiting factor biotic or abiotic factor that prevent a population from growing

logistic growth population growth that increases initially, but then plateaus (flattens out) once it reached a certain point

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 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

prey living animal that is captured and eaten by a predator

primary consumer the first consumer who eats the producer in a food chain

producer otherwise known as an autotroph, an organism capable of making its own food

quadrat a tool used to measure species abundance

secondary consumer the consumer who eats the primary consumer

symbiotic relationship a relationship between two types of living things that help at least one of them survive

tertiary consumer the consumer who eats the secondary consumer

trophic level the feeding level of an organism within a food chain

vector an agent (either a human, animal or microorganism) that carries and transmits a pathogen (disease-causing agent) from an infected organism to a non-infected organism

Chapter 5

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 that denotes the number of protons in an atom of an element

beta particles a charged particle that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom.

compounds chemical combination of two or more elements combined in a fixed and definite proportion by weight.

electromagnetic spectrum the range of all possible forms that light can take, plotted out in terms of lowest to highest frequency of the light wave

electron a subatomic particle with a negative charge found in all atoms

gamma rays are electromagnetic radiation with an energy level above a specified amount / wavelength shorter than a specified amount

ion a charged version of an atom that has either gained or lost electrons

isotope form of the same element with the same number of protons but different number of neutrons

mass number also known as relative atomic mass; it gives the mass of the atom (usually thought of as the number of protons and neutrons in the nucleus)

molecule a group of two or more atoms

neutron a subatomic particle with a neutral charge in the nucleus of an atom

nucleus the central part of the atom containing its protons and neutrons (nuclei is the plural)

proton a subatomic particle with a positive charge 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

subatomic particles the particles that make up an atom

Chapter 6

acid a substance that has a pH of less than 7

activation energy energy required for a non-spontaneous chemical reaction to occur

base a substance that has a pH greater than 7

chemical change a rearrangement of atoms which is often irreversible

combustion the reaction of a fuel with oxygen usually producing heat and light

conservation of mass a law that states that matter and energy can neither be created nor destroyed

endothermic an absorption of heat characterised by a decrease in surrounding temperature

exothermic heat is released from a reaction characterised by an increase in surrounding temperature

neutralisation a reaction between an acid and a base, forming a solution that has a neutral pH

photosynthesis the chemical reaction by which organisms make their own food

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

rearranged the process of moving 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 and comprises of a metal and a non-metal

spontaneous reaction reaction that does not require any energy input to get started

Chapter 7

constructive (divergent) a type of plate boundary that occurs when plates move away from one another

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

convection currents a form of heat transfer which works due to different densities of materials

core the inner part of Earth's structure

crust the top layer of the Earth which supports all of life on Earth and is split into giant slabs called tectonic plates

destructive (convergent) a type of plate boundary that occurs when plates move towards one another

epicentre the part of Earth's surface directly above the focus of an earthquake

focus the exact point under Earth where the earthquake occurs

geoid a model of the Earth surface which defines zero elevation

GPS a radio navigation system that allows land, sea, and airborne users to determine their exact location, velocity, and time

hotspot a pocket of magma that sits just underneath the crust

lag time the time between the arrival of the P and S waves

lava molten rock that has reached the surface

lithosphere the solid outer layer of Earth consisting of the crust and upper mantle

magma molten rock below the surface of Earth

mantle the layer of the Earth underneath the crust which is made up of solid rock and is where convection currents take place

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

plate boundaries three types: divergent, convergent, and transform.

plate tectonics the theory that the Earth's crust is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

pyroclastic consisting of or relating to small pieces of rock from a volcano

Richter scale a system used to measure the strength of an earthquake

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 crust sinks underneath less dense continental crust

tectonic plates Earth's crust is split into gigantic slabs of rigid rock which float on top of Earth's mantle

transform a type of plate boundary that occurs when plates move parallel to one another

tsunami a great wave produced by earthquakes in the ocean

Chapter 8

alternating current a form of electricity where the current reverses direction in regular cycles

ammeter a device for measuring the strength of an electric current

ampere one coulomb per second

battery a portable source of power

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 a material that allows electric current to flow easily

coulomb the amount of charge transferred in one second with a current of one amp

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

direct current a form of electricity when the current flows in one direction

double-insulated appliances that have two levels of insulating materials between the electrical parts of the appliance and any parts on the outside that you touch

dry cell a battery in which the electrolyte is absorbed in a solid to form a paste

earthed a pin in a plug through which the electric current will flow via the earth pin 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 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 is given

voltage drop the difference in energy the charges carry before and after the load

voltmeter a device for measuring voltage between two points on an electric circuit

Chapter 9

armature the rotating coil which is part of an electric motor

brush the part of a motor that conducts current between stationary and moving parts

commutator a split ring that reverses current at a point in a motor

conductor a material that allows electric current to flow easily

current the flow of electric charge

electric motor a device that converts electrical energy to mechanical (movement) energy

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

electromagnet a magnet consisting of a current-carrying coil surrounding a piece of iron

electromagnetism the interaction between magnetic fields and electric currents

generator a device that converts mechanical (movement) energy into electricity

kinetic energy the energy of an object in motion

magnet a material that attracts other iron-containing materials or aligns with an external magnetic field

magnetic field the region in which a magnet or electromagnet can exert a force on other magnets

magnetic field line a visual tool to represent the direction of magnetic fields

magnetic induction the process by which an object is magnetised by an external magnetic field

magnetism the ability to attract or repel objects that are magnetic

nuclear fission reaction the process by which an atom splits into two parts

permanent magnet a magnet that retains its magnetic properties outside of a magnetic field

pole the end point of a magnet; also the points near the ends of Earth's axis of rotation.

right-hand grip rule shows the direction of the magnetic field of a current-carrying wire

right-hand slap rule shows the direction of the force when a conductor moves in a magnetic field

solenoid a wire wrapped in the shape of a cylinder

temporary magnet magnet that does not retain its magnetism outside of an external magnetic field

torque a force that causes something to rotate

transformer a device that changes the AC voltage as it moves from one circuit to another

turbine a type of machine that turns wheel with blades to produce power

Index

- abiotic factors 128, 130, 141, 145, 153
 interdependence with biotic 129
 Aboriginal and Torres Strait Islander
 peoples 141
 acceleration 39
 accuracy 9
 acid rain 231
 acid reactions 230–8
 acid–base reactions 233–5
 word equations for 234
 acid–carbonate reactions 236–8
 acidic conditions 130, 242
 see also basic conditions
 acid–metal reactions 231–3
 word equations for 231
 acids 222, 233–5
 defined 230
 explosive? 230
 action potential 91–3
 activation energy 218–19
 active sockets 316, 319
 addiction, adolescent brain and 117–18
 adenosine triphosphate (ATP) 138
 adolescent brain addiction and 117–18
 adolescents
 addiction and the brain 117–18
 sleep patterns 86
 adrenal gland 84–5
 aerobic respiration 227–8
 agar plates 60, 70–2
 age 37
 air 31–2, 127, 185
 air chamber levitating houses 281
 see also oxygen
 air pollution 296
 airborne 64
 alcohol 62–3, 117
 algae 147
 overgrowth 138–9
 alkali metals 182
 alkaline conditions *see* basic conditions
 alkaline earth metals 182
 ‘all or none’ principle 91
 alpha decay 194–5
 alpha radiation 196–8
 alternating current (AC) 296, 354
 alternating current (AC) generators
 348
 aluminium 172
 alveoli 51–2
 Alzheimer’s disease 114–15
 ambient temperature 33, 205
 amino acids 34, 43
 ammeters 304
 amperes 303
 amygdala 109, 117
 amyloid plaques 115
 anaerobic respiration 228
 analysis of data *see* data analysis
 Andes 286
 animals 128, 166
 navigation by Earth’s magnetic field
 332
 respiration 227
 smaller body size 160–1
 Antarctica 127
 antibiotic resistance 70
 antibiotics 70–2
 versus antiseptics 70–1
 unnecessary 70
 antibodies 33, 68–9
 binding sites 68
 antidiuretic hormone (ADH) 50
 antigens 68–9
 antimicrobial resistance (AMR) 70
 antiseptics 70–2
 anxiety 92
 apex predators 132
 Aristotle 185
 armatures 344
 arrow convention 336
 arrows in chemical reactions–‘yields’
 205
 assumptions 115
 Athel pine 159
 atomic mass units (amu) 179
 atomic models
 comparison between 187
 development 184–91
 modern 176–7, 191
 atomic number 180–2, 192
 atomic theory, modern 185
 atoms 173–98, 200
 balanced equations 214–15
 defined 171–2
 mostly empty space? 187–8
 rearrangement 205
 structure of 175–9
 attitudes 9
 attraction 178, 330–2, 340, 342, 344,
 346
 Aurora Australis/Borealis 332
 Australasia ‘ecozone’ 286–7
 Australian plate 277
 automatic involuntary action 97
 autotrophs (self-feeding) 132
 average(s) 16
 ‘finding the average’ 20
 significance of difference between
 two average scores *see*
 statistical significance
 axon terminals 89–91, 93
 axons 89–90
 unmyelinated 91
 B cells 68–9
 bacillus 59
 bacteria 58–63, 128, 153, 207
 diseases caused by 58
 types of 59
 balance 91, 118
 bar charts 17
 bar magnets 332
 base isolation 281
 bases 222, 233–5
 basic conditions 130, 207
 see also acidic conditions
 batteries 294, 297, 300, 354, 359
 used 295
 beats per minute (bpm) 53
 behaviour 84, 92
 risk-taking 117
 beliefs 9
 bell-shaped curves 21
 best fit, line of 17
 beta decay 195
 beta radiation 196–8
 bias 9–10
 unbiased data 8
 bile 65
 binary fission 58, 153
 biodegradation 200, 207
 biodiversity 148
 bioluminescence 252
 biomes 127
 bioplastics 200–1
 bioprinting (3D) 56
 biotic factors 128–9, 141, 153
 interdependence with abiotic 129
 birth rates 152
 ‘black lights’ 196
 Black Plague 64
 ‘Black Saturday’ 141–2
 bladder 49
 blood 52–3, 64–5
 flow of 52
 blood glucose levels
 insulin and glucagon release 48
 regulating 47–8
 blood pressure 39, 84
 maintaining 53
 blood sugar 47
 blood vessels 53
 bloodletting 64
 bloodstream 49, 52, 68
 bodily functions, self-regulating 83
 body cells 47
 body parts

- brain, communication with 83–7
 - sensitivity of 112–13
 - see also* human body, the
- body systems 43–56
- body temperature 52, 67
- Bohr, Niels 189
- Bohr atomic model 291
- Bohr diagrams 177
- bonds/bonding 205, 219
- bone marrow 68
- bones 116
- brain, the 50, 88, 106–18, 122
 - of the adolescent 117–18
 - communication with and control of body 83–7
 - cross-sectional view 84
 - functioning 93
 - plasticity of 115–16
 - structures within 109–11
- 'brain freeze' 110
- brain imaging 95
- brain shrinkage 114–15
- brain stem 109, 118
- branchings (circuit) 314
- breathing 31–2, 38–9, 51
- breathing rate 54–5, 227
- Broca's area 108
- brushes 344
- budding 62–3
- Bunsen burners 219
- burns 237
- bushfires 141
 - see also* fire
- calories (Cal) 37
- camels 159–60
- capillaries 52
- capture–mark–recapture method 157
- carbohydrates 32–4, 37, 43, 47
 - break-down of 34, 45
 - types of 33
- carbon 32, 181–2, 200, 205, 223–4
 - isotopes of 192
- carbon dioxide 32, 43, 49, 51–2, 62–3, 135–6, 138, 205, 225, 227–8
 - conversion from fat 38
 - emissions 201
- carbon emissions 324–5
- carbon monoxide 223–4, 259
- carbon-14 (C-14) 197
- carbonates 236–8
 - explosive? 230
- cardiovascular system 52–3
- carelessness 319
- carotid artery 53
- carrying capacity 153
 - versus* limiting factors 154
- categories 10
- cathode ray tubes 185–6
- causal relationships 8, 19
- cause-and-effect relationships 5, 19
 - spinal cord damage, causes and effects 101–5
- cell body (neuron) 89–90
- cells 31, 138
 - body 47
 - chemical instructions to 68–9
 - diffusion across membranes 45
 - specialised 45, 83, 88
- cellular pathogens 58
- cellular respiration 31–2, 43, 45, 51–2, 138
 - process 138
- central nervous system (CNS) 50, 83, 88, 91–2
 - integration 99
- central tendency, measures of 20
- cerebellum 109, 118
- cerebral cortex 106–8
- cerebrum 106
- cervical cancer 69
- cervical spine 102
- Chadwick, James 189–90, 192
- chance 19–20
- charge 177–8
 - accumulation or flow 291, 296
 - build-up 291
 - static electricity and 291–3
 - see also* negative charge; positive charge
- charged particles 182
- charts/charting 17
 - also under* specific charts
 - see also* graphs/graphing
- chemical change
 - indicators 207–9
 - irreversible 209
- chemical energy 225, 350
- chemical equations 209–11
 - law of conservation of mass relation to 214–15
 - types of 211
- chemical messengers 86–7, 91
 - see also* hormones
- chemical properties 33
- chemical reactions 33, 135, 138, 205–38
 - in the body 31, 34–5
 - defined 205
 - energy and 218–24
 - exothermic and endothermic reactions 219–23
 - spontaneous *versus* non-spontaneous reactions 218–19
- chemical secretions 67
- chemicals
 - endocrine disrupting 85
 - see also* hormones
- Chile Triple Junction 263
- chitin 62
- chlorides 230
- chlorophyll 136, 225
- chloroplasts 135–6, 225
- circuit breakers 319–20
- circuit diagrams 299–303
 - drawing 302–3
- circuits 294–6, 324–5, 345
 - applications 313–20
 - circuit symbols 295–6
 - closed 354
 - components 294
 - simple 299–311
 - symbols 300–1
- circulatory system 43
- climate change 351
- climatic features 127
- closed circuits 354
- closed systems 213
- clownfish 147
- coagulation 242
- coal-fired power stations 350–1
- cobalt 330
- Cobalt-60 (Co-60) 197
- coccus 59
- coccyx 102
- coffee 242–3
- coils 348, 350, 354
- colour 207
- columns 14–15
- combustion reactions 223–4
- commensalism 145, 147
- communication 118
 - wireless 196
 - within and between neurons 91–7
- community 127
 - inter-organism relationships benefiting 129
 - plus habitat *see* ecosystems
- commutators 344–5
- comparison 10
 - between atomic models 187
 - of experimental and control groups 19
 - of liquid's viscosity 272–3
 - of photosynthesis and respiration 229
 - of rock density 265–6
 - of values across series/parallel circuits 315–16
- compasses 254–5, 329–30
- competition 145–6, 150, 153
- complex carbohydrates 33
- components (circuits) 293–4
 - symbols of 300–1
 - troubleshooting 313
- compounds 173, 205–6
 - defined 172–3
 - forming from elements 174–5, 206
- computer modelling 279–80
- concentration 39, 92

- conclusions 10
drawing 4, 19–20
drawing from 22
observations to 12–22
valid 4, 19, 22
- concrete 207
- conductors 305–6, 342
- connecting wires 294, 296
- conscious responses 101
- consciousness, loss of 53
- conservation of mass 212–17
- conservation of matter law 38
- conservative plate boundaries 267
- constancy 6
body's constant internal
environment maintenance *see*
homeostasis
variables, keeping constant 8
- constructive (divergent) boundary
262–3, 266–8
on land 267
in the ocean 267
- consumers 132, 135, 138
- continent movement theories 247–55
- continental crust 264
two continental plates meeting 265
- continental drift 247–50
evidentiary support 248–50
- continental outlines (match) 248
- continuous data 9–10, 17
- contralateral organisation 107
- control centre 44
- control condition 6, 22
- control groups 19–20
- controlled variables 6–7
that haven't been controlled for *see*
extraneous variables
- convection currents 259–62, 267
- conventional current 342
- conventions
arrow convention 336
of current 296
for current direction 334–6
for writing mass number 193
- coordinates 17
- coordination 39, 83–118
of body systems 86–7
see also response and coordination
- copper wire 339
- cores, outer and inner 257
- corpus callosum 106
- correlation 19
- correspondence 18
- coulombs 303
- cows **moo** softly (Change, Measure,
keep the Same) 6
- crude oil 200
- crust 257
- crystal circuits 300
- current 303–5, 320, 338, 342, 354
current–resistance relationship 310
direction—from positive to negative
terminals 334–5
effect on body 319
generation 349
proportionality with applied voltage
307–8
split current at branchings 314
- current carrying wires 342
- current electricity 293–7
- dairy legumes 34
- Dalton, John 185
- data 17
central points 20
describing 19
gathering *see* data collection
organising/summarising 4, 19, 78
primary–secondary comparison 9
raw 19
recording 243
representing on graphs 4, 17–18,
123
tabulated 4, 14–16
types of 8–10, 17
used for experiments *see*
experimental data
- data analysis 4, 19–22
outlier exclusion from 21
- data collection 4, 158–9
during experiments 8–11
- data points 20–1
extreme *see* outliers
- data sets 20
- DC electric motors 344–5
- death rates 141–2, 152
- defibrillators 306
- deforestation 148
- degradation (land) 143, 150
- dehydration 39, 53
- Democritus 185
- demography 152
- dendrites 89–90, 93
- dependent variables (DVs) 6–7, 17–19
- depression 92
- descriptive statistics 4
versus inferential 19–20
- destructive (convergent) boundary
262–6, 268
- detergents 139–40
- diabetes 48
- diagrams 177, 220–1, 299–303, 331
- diaphragm 51
- diet 31–2
fad 38
healthy and varied 35
see also food
- diffusion 45–7, 52
- digestion 31, 34, 84
- digestive system 32–4, 43, 45–8
- digital multimeters 306
- direct contact 64
- direct current (DC) 296, 339, 354
- direct current (DC) motors 344–5
- disasters, natural 141–2, 279–82
- discrete data 9–10
- disease
disease-causing bacteria 59
infectious 78–9
vectors 148–9
from vitamin deficiency 34
- disease transmission 64–6
simulating 78–9
- dissection 104–5, 109–10
- diuretics 50–1
- divergent plate boundaries 266
- DIY (Do It Yourself) electrical work
319
- documentation
reporting results *see* scientific
reporting
- dopamine 92, 95, 117
- double insulation 316–18
- double-insulated plugs 316–17
- drones 158–9, 280
- droughts 141, 143–4
- drug-resistant bacteria 70
- drugs 50, 94, 117
- dry cells 295
- ear wax 67
- Earth 351
four elements 185
grounding to 292
layers 257
magnetic field of 332
our changing Earth 247–82
polarity 253
structure of 276
surface gravity 279
see also plate tectonics; tectonic plate
movement
- earth sockets 316, 319
- earthing 292, 316–18
- earthquake-proof buildings 281, 286–7
designing 282
- earthquakes 264, 268, 274–7
Australia at risk? 277
detection means 274–5
effects of 276–7
occurrence, sites of 274
- ecological niche 145
- ecosystems 127–61
clumped patterns in 128
components 128–30
defined 127–44
energy flow within 13–40

- environmental changes affecting
 - 141–4
- living and non-living components
 - 127–8
- population dynamics within 152–61
- seasonal changes, effects on 141–4
- self-designed 134
- size 127–8
- ectoparasites 148
- effectors 44, 94, 99
- Einstein, Albert 329
- electric cars 296–7
- electric current *see* current
- electric motors 342–3, 345
- electric shock 320
- electrical circuits 302
- electrical energy 350
 - transforming 316
- electrical engineering 307
- electrical hazards 319
- electrical impulses 91
- electrical shocks 339
- electrical signals 83
- electricity 293–320, 324–5, 329–40
 - defined 291–7
 - generating 348–54
 - generating large amounts of 348–53
- electrochemical messengers 87
- electrocution 319
- electroencephalograms (EEG) 115
- electromagnetic induction 348
- electromagnetic radiation 195–6
- electromagnetic spectrum 195
- electromagnetism 329–36, 353
- electromagnets 337–40
 - versus* permanent magnets 338
- electron cloud model 177, 189
- electrons 176, 178, 186, 291, 294
 - fast-moving 195
 - flow (neg to pos) on imbalances 294
 - number of 181–2
 - relative mass 179
 - in shells 189
- electrostatic charge 291–2
- elements 173, 180, 192, 197
 - defined 172
 - formation of 194
 - forming compounds from 174–5, 206
 - on periodic table 171–2
- elimination (of waste) 45
- emigration rates 152
- emotions 84, 92, 117–18
- endangered species 166–7
- endocrine glands 84–5
- endocrine system 43–4, 48, 83–5
 - actions 86–7
 - see also* homeostasis
- endoparasites 148
- endothermic reactions 219–23
 - ‘endothermic’ = internal heat 221
- energy 10–11, 31–2, 54–5
 - chemical reactions and 218–24
 - conservation of 83
 - conversion/transfer 293–5
 - cycling of 135
 - expenditure–burning off 37, 39
 - flow through ecosystems 131–4
 - food energy 36–7
 - forms of 291–7, 316
 - levels 177, 189
 - non-destruction 213
 - production 51–2
 - release in body 32
 - requirements and pathways 132
 - shared across load 313
 - useable 32
 - wind energy 351–3
 - within ecosystems 135–40
 - see also* kinetic energy
- energy level diagrams 220–1
- energy pyramid 133
- energy sources 32–4, 36–7, 352
 - renewable and sustainable 324–5
- energy storage 33, 45
 - as fat 37
- engineers 166–7
- environment
 - effect on photosynthesis 136
 - organisms, interactions with
 - 145–51
 - problems 143
- environmental change 43–4, 324
 - affecting ecosystems 141–4
- environmental protection 158
- enzymes 33–4, 45
 - digestive 46
- epicentre (of earthquake) 274
- epidemics 64–5
- equations 225
 - balanced 214–15, 225
 - word equations 231, 234
 - worded equation for cellular
 - respiration 32
 - see also* chemical equations
- equipment
 - failure 21
 - protective 206, 230
- Ernest Rutherford 186–7
- erosion 159
- error 21
- estimation 5, 18, 157
 - formulas 155, 157
 - see also* prediction
- Eurasian plate 277
- European settlement 159
- eutrophication 138–9
- evaluation, of hypotheses 4
- excretion 49
- excretory system 43, 49–50
- exercise 37–41, 54–5, 227
 - hydration and 39
- exhalation 38, 52
- exothermic reactions 219–23
 - ‘exothermic’ = external heat 220
- experimental data 4, 19–21
 - during experiments 8–11
- experimental groups 19–20
- experiments 4, 186, 219, 353–4
 - defining experimental variables 5–6
 - designing a sound experiment 5–8
 - experimental errors 21
 - replicating 5, 16
 - see also* *Practicals*
- exploitation 166
- exponential growth 153
- extinction 161, 166–7
- extraneous variables (EVs) 8
- Eyjafjallajökull volcanic eruption 274
- faeces 128, 133
- fairness 6
- Faraday, Michael 330, 342, 348, 353–4
- fats
 - conversion to carbon dioxide and
 - water 38
 - energy storage as 37
 - fat (protective) layers and deposits
 - 33
 - see also* lipids
- feedback 167
- feral camels 159–60
- feral rabbits 150–1
- fermentation 62–3
- fertilisers 139–40
- fever 67
- fight–flight response 83–4
- fire 141–3, 185, 206, 320
- fish/fishing 34, 160
- flash floods 143
- fleas 148
- floods 141, 143–4, 159
- fluorine 182, 200
- focus (of earthquake) 274
- fontanelles 116
- food 31, 37–41, 154, 227
 - packaged food nutritional labels 37
 - sources 142
 - for vitamins 35
- food chains 131–2, 135
 - land-based 132
- food webs 132
- force 330–1, 344, 351
 - sideways or horizontal 281
- fossil fuels 353
- fossils 248–9
- fourth order consumers 132
- Fracastoro, Girolamo 65
- frequency 21, 195
- friction 267, 270

- frontal lobe 107–8, 118
 fuels 223
 functional proteins 34
 fungi 62, 128
 diseases caused by 58
 fuses 319–20
- galvanometers 348
 gamma decay 195
 gamma radiation 196–8
 gamma rays 195
 gaseous exchange 51–2
 gases 181–2, 205, 273, 296, 351
 gender 37
 generalising 22
 generators 348–51, 353
 genes 33
 genetic material 63
 geoids 279
 geological patterns 280
 germ theory 65–6
 germination (seeds) 142–3
 glaciers 249
 glands 84
 global positioning satellites/system
 (GPS) 262, 279
 global warming 160, 166
 glucagon 47–8
 glucose 31–2, 43, 45, 132, 135–7, 225,
 227–8
 blood concentration *see* blood
 glucose levels
 glutamate 92
 gold foil experiment 186–7
 government
 natural disaster response 279
 renewable and sustainable energy
 sources 324–5
 graphs/graphing 78, 123
 reading values from 18
 representing data on 4, 17–18
 also under specific graph
 see also charts/charting
 gravitational forces 351
 gravity 279
 gravity mapping 279
 Great Barrier Reef 147
 greenhouse gases 166, 351
 grey matter 101
 grounding (to Earth) 292
 groups
 experimental/control groups
 comparisons 19–20
 of nutrients 32–6
 of organism populations *see*
 community
 growth 31, 84, 118
 exponential 153
 logistic 153–4
 population's growth rate 153
 growth models, for population 153–4
- habitats 127, 142, 145
 destruction 166
 plus community *see* ecosystems
 habits 117
 halogens 182
 handwashing 60
 hazards 319
 hearing 88
 heart 52
 heart rate 39, 53–5
 heat 33, 133, 258, 270, 293
 cautions 201–2, 206
 external 220
 heat loss 295
 heavy metals 257
 height 37
 helium 171, 194–5
 helper T cells 68
 hemispheres (brain) 106–7
 hemispheric specialisation 107
 herbivores 132
 Hess, Harry 250–1, 257
 heterotrophs (varied feeding) 132
 Higgs boson 190
 high-energy waves 195
 Himalayas 265
 hippocampus 109, 117–18
 Hippocrates 65
 homeostasis 31–72, 78–9, 83, 86–7
 homunculus 112
 hormones 43, 51–2, 83–5, 92
 release in body 84
 host cells 64
 hotspots 271
 household electricity 316–17
 devices and appliances 318
 human body, the 31
 biological clock 86
 bodily functions 83
 body systems 43–56
 brain, role of controlling 83–7
 chemical reactions in 31, 33
 current sensitivity 319
 energy source *see* food
 first line of defence 67
 the fuel source for organs 32–3
 hormone-production sites 85
 interactions 31–44, 78–9, 86–7
 longest neuron 93
 neurotransmitter production 93
 receptor site responses to change 44
 reflex action protection 97
 systems interaction *see* homeostasis
 see also body parts
 human error 21
 human impact 159–61, 166–7
 human papillomavirus (HPV) 69
 humidity 127–8
 hunting 160
 hydration 39
 see also dehydration; water
- hydrochloric acid 230–1
 hydroelectricity 349–50
 hydrogen 32, 171, 173, 176, 187–8,
 200, 210, 223, 231
 isotopes of 193
 hypothalamus 50, 84–5, 109, 117
 hypothermia 333
 hypotheses 4, 71, 78, 112–13
 constructing 7
 supporting 20
 template 7
- igneous rock 267
 illness 37, 58
 immigration rates 152
 immune response 68–9
 faster, stronger second response 69
 immune system 43
 lines of defence in 67–9
 immunisation 69
 immunity-specific and non-specific 67
 inaccuracy 9
 independent variables (IVs) 6–7, 17–19
 Industrial Revolution 353
 infection 69, 78–9
 infectious disease transmission 64
 inference 19
 inferential statistics 4
 versus descriptive 19–20
 inflammatory response 67
 infographics 243
 infomercial 325
 information
 interpretation of 9
 processing 320
 infrared (IR) radiation 195
 inhalation 52
 injury 319
 see also spinal cord injury
 inquiry
 see also scientific method
 insulation 316–18
 insulators 306–7
 insulin 47–8
 integumentary system 43
 interactions
 among organisms 145
 biotic–abiotic surroundings 128
 body systems interactions 31–44,
 78–9, 86–7
 community-surroundings 127, 129
 interdependence 129
 internal combustion engines 224
 internet 196
 interneurons 88–9, 96, 99
 intraspecific/interspecific competition
 146
 invasive organisms 159
 investigations 40–1
 planning and conducting 4–12
 see also *Practicals*

- ionisation 196
- ions 49, 181–2
 - formation 181–2
- iron 330, 332, 338
 - filings 331
 - oxides of 329
- island arcs 270
- isotopes 182, 192–4
 - discovery and definition 192
 - naming 192–3
 - stable and unstable 194
 - uses for 197–8
- Juan de Fuca plate 258
- kidneys 49, 53, 85
- killer T cells 68
- kilojoules (kJ) 37
- kinetic energy 10–11, 219, 342
- knee jerk reflex 99
- Koch, Robert 66
- 'Koch's postulates' 66
- labelling (food) 37
- land bridges 249
- landfill 22, 295
- landmass 247–50
- language 107, 116, 118
 - formal language for reporting 7
- Large Hadron Collider (CERN) 176
- large intestine 49
- lava 272
- Lavoisier's law *see* law of conservation of mass
- law of conservation of mass 212–17
 - observing 214–17
 - in practice 213–14
 - relation to chemical equations 214–15
- law of conservation of matter 38
- learning 92, 107, 115
- left-hand side (LHS) coil 354
- lemon batteries 297
- letters 10
- life
 - building blocks of *see* cells
 - reactions of 225–9
 - requirements 31–2
- light 189, 196, 208, 293, 295
 - forms of 195
 - speed of 176
- light emitting diodes (LEDs) 295–6
- light energy 225
- light intensity 128
- lightning 141, 291
- limiting factors 154
- line graphs 17
 - features 18
- lines of defence – first, second, third 67–9
- lipids 33–4, 37, 43
- liquids 33
 - viscosity of 272–3
- literature (scientific) 4
- lithosphere 257
- liver 47, 49
- load 294–5, 313–14
- lobes 107–8
- lodestone 329–30
- logistic growth 153–4
- loudspeakers 346–7
- lumbar spine 102
- lymphocytes 68–9
- macrophages 67–8
- maglev system, simplest 358–9
- maglev trains 340
- magma 258, 264, 267, 270–1
- magnesium 174–5, 210, 231
- magnetic field lines 330–1, 334, 337
 - Faraday's rules for 331
 - see also* current
- magnetic fields 329, 342, 346
 - attraction and repulsion forces in 330–2
 - concentrated 338
 - diagrams 331
 - direction of *see* magnetic field lines of Earth 253–4, 332
 - going into/coming out of page 336
 - three-dimensional nature of 331
- magnetic forces 330–1, 344
- magnetic induction 330
- magnetic properties 338
- magnetic resonance imaging (MRI) 117
 - erasable 335–6
- magnetic striping 253–5
- magnetism 253, 329, 334
- magnetite 253, 329
- magnets 329–34, 348, 359
 - current generation 349
- Maillard reaction 210
- malaria 148
- mantle 257
- mapping 112, 262, 279–80
 - ocean floor 251
 - using gravitational measurements 279
- Marina Trench 252
- mass 179
 - conservation of 212–17
 - history 212–13
 - non-destruction 213
 - the universe and 212–13
- mass number 182–3, 192
 - in brackets 194
 - unusual 193
- materials 4
- matter 38, 185
- Matthews, Drummond 253–5, 257
- mean 20
- measures/measurements 219
 - of central tendency 20
 - equipment/tool failure leading to error 21
 - gravitational measurements–geoids 279
 - measurement of food energy content 36
 - plate movement measuring and mapping 279–80
 - unit symbols 15
 - of variability 20–1
- meat 34
- median 20
- medulla 109
- melatonin 86
- melting points 33
- memory 92, 107, 118, 122
- memory cells 69
- memory loss 91
- Mendeleev, Dmitri 175
- messages 97
- metabolic rate 38
- metabolism 38, 84
- metals 231–3
- Metchnikoff, Elie 66
- method/methodology 5–8
 - missing steps leading to error 21
 - see also* scientific method
- microbiology 66
- microgeneration technologies 353
- microorganisms 65
 - response to 58–72
- microscopes 58, 60, 63–4, 171–2, 225
- microwaves 195–6
- Mid-Atlantic Ridge 267
- milk curdling 242–3
- minerals 31, 34–5, 43
 - absorption 45
- mitochondria 31, 62, 138, 227
- mode 20
- models/modelling 46–7, 90, 153–4
 - atomic models 176–7, 184–91, 291
 - computer modelling 279–80
 - predator–prey cycle 150–1
 - stimulus–response model 44
 - see also* simulation
- molecules 171, 173, 200
 - splitting into atoms 173–4
- Moon 351
- Morley, Lawrence 253–5
- mosquitoes 148–9
 - factories 149
- motor function 102
- motor neurons 83, 88–9
- motors
 - DC electric 344–5
 - 'dead spots' 345

- electric 342–3
- moulds 62, 70
- Mount Everest 266
- mountain ranges 251
- mountains 264
- movement 31, 92, 118, 219, 293, 342
 - of Earth 286–7
 - generating 342–7
 - of negatively charged electrons 291
 - tectonic plate movement 257–68
 - voluntary muscle movements 83
- mucous membranes 67
- mucus 67
- multicellular organisms 31, 43
- millimeters 306
- multiple sclerosis 91
- muscle system 43
- muscles 38, 47
 - contractions 319
 - voluntary muscle movements 83
- mushrooms 62
- music 346, 348
- mutualism 145–7
- myelin sheaths 89–91
 - myelinated nerve fibre bundles/ tracts 101
- myrtle rust 159

- NASA Volcanobots 280
- natural disasters 279–82
 - predicting and responding to 279–81
- natural pest control 159
- negative charge 178, 181, 186–7, 291–2, 296
- negative terminals 294
- negligence 319
- nephrons 49
- nerves 89, 101–2, 106
- nervous system 43–4, 83, 88–97, 122
 - actions 86–7
 - see also* homeostasis
- neural impulses 91
- neurodegenerative disease 114–15
- neurofibrillary tangles 115
- neurons 88–97, 106, 115–16
 - brain shrinkage and 114–15
 - communication within and between 91–7
 - networks of *see* nervous system
 - pre- and post-synaptic 92
 - reflex action involvement 97
 - 'at rest' 91
 - structures of 89–90
 - threshold 91
 - types of 86–9
- neurotransmitters 83, 89, 92–4
 - excitatory or inhibitory 94
 - naturally occurring 94
 - roles of 92–3
- types of 93
- neutral sockets 316, 319
- neutralisation reactions 234
- neutrons 176, 178–9, 190, 192
 - calculating number of 182
 - relative mass 179
- neutrophils 67
- nickel 330, 332
- nitrate 230
- nitric acid 230
- nitrogen 181, 200
- nitrogen-14 (N-14) 197
- noble gases 182
- nomenclature 192–3, 231, 234
- non-cellular pathogens 58
- non-spontaneous reactions 218–19
- north pole 253, 330–2, 338
- northern hairy-nosed wombat 158
- nuclear energy 350
- nuclear fission reactions 350
- nucleus 177, 182
 - splitting of *see* radioactive decay
- numbers 10, 16
- nutrient agar plates 60, 70–2
- nutrients 32–6, 51–2, 130–1
 - absorption 45
 - essential micronutrients 34–5
 - groups 32–6
 - overabundance of 138
 - in soil 166
- nutrition 145
- nutritional labels 37
- nuts 34

- obesity 39
- objective data 8
- observation 4, 12–18, 109–10
 - to conclusions 12–22
 - of convection currents 260–1
 - recording rules 13
 - of tectonic plate boundary 279
 - see also* recording
- occipital lobe 107–8, 118
- oceanic crust 264, 267
 - oceanic meets continental plate 264
 - two oceanic plates meeting 265
- oceanography 252
- Ørsted, Hans Christian 334
- ohms 305
- Ohm's law 307–11
- oil spills 333
- oils *see* lipids
- open systems 213
- opinion 9–10
- orbits 177
- organ transplant 56
- organelles 62
- organic matter 128
- organisation
 - of data 4, 19
 - ecosystem levels 127
- organisms 70, 159
 - abundance of 145
 - in a community *see* ecosystems
 - complex 31
 - energy flow of *see* food chains
 - hormone coordination of 85
 - individual 129
 - interactions with environment 129, 145–51
 - multicellular *versus* unicellular 31
 - see also* microorganisms
- organs 56
 - fuel source for 32–3, 37
 - protection by fat layers 33
- osmoregulation 50
- outliers 21
- ovaries 84–5
- overhunting/overfishing 160
- oxygen 31–3, 43, 51–2, 135, 172, 174–5, 200, 205, 225, 227
- oxygen demand 54–5

- Pacific ring of fire 286
- pain 118
- pancreas 84–5
- Pangaea 247–50
- parallax error 21
- parallel circuits 314–16
 - split current at branchings 314
- paraplegia 102
- parasites 58
- parasitism 145, 148
- parathyroid gland 85
- parentheses 194
- parietal lobe 107–8, 118
- Parkinson's disease 92, 94
- participants 4
- particles 182
- Pasteur, Louis 65
- pathogens 58–64, 67
 - clumping 69
- patterns 4
 - of data movement *see* trends
 - geological patterns 280
 - 'pyramid of energy' pattern 133
 - sleep patterns 86
 - spaced, clumped or random (population) 128
 - see also* relationships; trends
- penetration (of radiation) 196
- people 128
 - energy requirement differences 37
 - human impact on population dynamics 159–61
 - right-handedness 111
- periodic table 171–2, 180, 192–3
- peripheral nervous system (PNS) 83, 88

- permanent magnets 330–1, 346
 versus electromagnets 338
 personality 118
 personality traits 107
 pH 128, 130, 233, 242–3
 phagocytosis 67, 69
 phlegm 65
 phlogiston 213
 phosphorus 200
 photosynthesis 132, 135–7, 220, 225–7
 chemical and word equations for 135
 comparison with respiration 229
 relationship with respiration 138
 word and formula equations for 225
 physical activity 37
 physical properties 208, 280
 pictures 10
 pie charts 17
 pineal gland 84–5
 pituitary gland 50, 84–5
 planetary model 189
 plants 128, 132, 166
 effect of light on 136–7
 effects of detergent on 139–40
 respiration 227
 plasticity 115–16
 plastics 22, 85, 200–1
 plate tectonics 257–68
 plotting 17
 plum pudding model 186
 poles/polarity 253, 330–2, 338, 340
 pollinators 146–7
 pollution 296
 polyethylene 200
 polymers 200
 ponds 109
 population 128, 141–2, 152
 generalised conclusions application 22
 as group of individuals 129
 growth models 153–4
 growth rate 153
 size changes 152–3
 size determination methods 154–9
 S-shaped curve (growth *versus* time) 153
 population dynamics
 human impact on 159–61
 within ecosystems 152–61
 positive charge 177–8, 181, 186–7, 291–2, 296
 positive terminals 294
 positron emission tomography (PET)
 scans 114–15
 post-synaptic neurons 92
 potential energy 10–11, 219
 power points 316
 power poles 354
 power sources 294, 302, 313
Practicals
 comparison 265–6, 272–3, 315–16
 demonstrations 60, 174–5, 183, 197–8, 206, 221–2, 259–60
 design/self-design 134, 197–8, 216–17, 254–5, 275, 282, 343, 349
 experiments 10–11, 142–3, 187–8
 investigations 40–1, 54–5, 104–5, 111, 136–7, 139–40, 156–7, 178, 183, 193–4, 197–8, 226–7, 297, 308–10, 334, 339–40
 measuring 36, 304–5
 modelling 46–7
 observation 13–14, 109–10, 173–4, 215–17, 232–3, 235, 237–8, 315–16
 testing 60–3, 71–2, 100–1, 112–13, 130, 222–3
 predator–prey cycle 150–1
 modelling cycle using feral rabbit 150–1
 predators 132, 159–60
 prediction 4–5
 of electron location 189
 of natural disasters 280–1
 see also estimation
 pre-frontal cortex 118
 pressure 267, 272
 pre-synaptic neurons 92
 prey 150–1
 primary (P) waves 275–6
 primary consumers 132
 primary *versus* secondary data 9
 prisms 58
 probability 19–20
 problem solving 107
 procedural error 21
 procedure 4
 appropriateness of 22
 producers 132, 138
 products 209–10, 214
 prokaryotes 58
 properties 33, 78–9, 177–9, 181, 205, 207, 338
 protective equipment 206
 proteins 33–4, 37, 49
 to amino acids 34
 break-down of 34
 building 43
 coagulation 242
 protons 176, 178–9, 187, 192, 291
 number of 180–1
 relative mass 179
 puberty 87
 pulse 53
p-value 19–20
 pyramid of energy pattern 133
 pyroclastic flows 273
 quadrats 154–5
 quadriplegia 102
 qualitative data 9–10
 quantitative data 9–10
 quaternary ammonium compounds (QACs) 71
 questioning 4
 rabbit control 150
 rabbits 150–1
 radial artery 53
 radiant energy 132, 135
 radiation 196
 dangerous space radiation 332
 ionising *versus* penetrating 196
 radio signals 279
 radio waves 195
 radioactive decay 194–6
 radioisotopes 194, 197
 radiotherapy 197
 rainfall 128
 random sampling 155
 range 20
 rational thought process 118
 ‘rays’ 185–6
 reactants 209–10, 214
 reaction conditions 210
 receptor sites 44
 receptors 44, 92–3, 99
 neurotransmitter ‘key–lock’ binding 93
 recording 12–18
 of data 14–16, 243
 in tables 14–16
 see also observation
 recycling 22
 reflex actions 97–101, 122–3
 reflex arcs 97–8
 regeneration (land) 150
 ‘regenerative’ braking system 296–7
 regulatory proteins 33
 rehabilitation 103–4
 relationships
 among organisms 129, 145
 current–resistance relationship 310
 between photosynthesis and respiration 138
 types of 5, 8, 101–5, 146–8
 between variables 4
 see also Ohm’s law; patterns; trends
 release energy 219
 reliability (of data) 5, 16
 renewable resources 296–7, 324–5, 353
 replication 2, 5, 16
 of bacterium 58
 of T and B cells 69

- of viruses 64
- reporting (scientifically) *see* scientific reporting
- reproductive processes 84, 151, 154
- reproductive system 43
- repulsion 178, 292, 330–1, 340, 342, 344, 346
- research, reliability of 5
- research hypotheses *see* hypotheses
- research questions 4–8
- research statistics 4, 22
 - drawing valid conclusions from 22
- resistance 305–9
 - current–resistance relationship 310
- resources
 - infinite 153
 - limited/finite 146, 200, 324
 - renewable 296–7
- respiration 138, 225, 227–8
 - comparison with photosynthesis 229
- respiratory system 43, 51–2
- response 99
 - conscious and unconscious 101
 - immune response 68–9
 - of neurotransmitters at effector sites 94
 - predicting/responding to natural disasters 279–81
 - response times 100–1
- response and coordination 44, 83–118
- results
 - raw 16
 - reliability of 5, 16
 - replicable 22
 - reporting *see* scientific reporting
 - valid and consistent 5
 - see also* scores
- Richter scale 276–7
- rift zone 267
- right-hand grip rule 335–6
- right-hand side (RHS) coil 354
- right-hand slap rule 342
- right-handedness 111
- robotic sensors 311
- robots 280
- rocks 127–8
 - density comparison 265–6
 - matching types across continents 248
 - molten 251, 253
- rods 59
- rotation 344, 350
- rotational kinetic energy *see* movement
- sacrum 102
- safety precautions 60, 71, 105, 142, 157, 173–4, 197, 201–2, 206, 221–2, 235, 237, 259, 304, 310, 315, 317–20, 339, 343, 345
- Sagan, Carl 212–13
- salamanders 147
- salinity 127–8
- salts 49, 230–1
 - excess salts in soil 144
- sampling 154–9
- San Andreas Fault 267–8
- sand 128
- satellites 279
- scanning electron microscopes 225
- scanning tunnelling microscopes 171–2
- scatterplots 17
- Schrödinger, Erwin 189
- sciatic nerve 93
- science (as human endeavour) 56, 94–5, 114–15, 147, 158–61, 172, 190, 207, 252, 281, 296–7, 300, 320, 333, 335–6, 346–7, 353
- science applications 242
- scientific method
 - rigorous 22
 - steps 4–5
- scientific reporting 4
 - formal write-up 7
- scientific thinking 4–22
- scores 20–1
 - average scores 19
- scurvy 35
- seafloor spreading 250–1, 254
- seasonal change 65, 141–4
- secondary (S) waves 275–6
- secondary consumers 132
- secondary data *versus* primary 9
- seeds 34, 150
 - post-fire germination 142–3
- seismic resistance 281
- seismic waves 274
 - types of 275–6
- seismograms 275
- seismometers 274–5
- seizure 116
- sensations 118
- senses 12, 88
 - also under* specific sense
- sensitivity of body parts 112–13
- sensors 95, 122, 311
- sensory function 102
- sensory neurons 83, 87–9
- sensory receptors 87–8
- septic (tissue) 71
- series circuits 313, 315–16
- shock 320
 - see also* electric shock
- short circuit condition 320
- sight 12
- signals 122, 279
- significance *see* statistical significance
- silica 272
- silicon 200
- SIM (Sensory, Inter, Motor) [neuron mnemonic] 89
- simple carbohydrates 33
- simple circuits 299–311
- simulation 78–9, 280
- single-organisms 31
- skeletal system 43
- skin 49, 67
 - fat deposits under 33
- skull 116
- sleep 47, 84, 86
- smartphones 347, 354
- smell 12, 88
- Snowy Mountains hydroelectric scheme 350
- social media 122–3
- sockets 316
- Soddy, Fredrick 192
- sodium-24 (Na-24) 197
- soil 166
 - bacteria in 71–2
 - soil pH 130
 - solar energy 296–7, 325
 - solar system 176–7
- solenoids 338
- solids 33, 172, 181, 205
- somatosensory cortex 112
- sonar 250
- sound 12, 118, 208, 250, 346, 348
- south pole 330–2, 338
- speakers 346–7
- species 128, 145, 166
 - dominant 146
 - sampling 154–5
- speech 118
- speed 345
 - of action potential 91
 - of light 176
- spheres 59
- spinal cord 83, 88, 97–105
 - CNS integration 99
- spinal cord damage 101–5
- spinal cord injury
 - prognosis 103–4
 - rehabilitation potential 103–4
 - symptoms 103
- spinal reflex 97
- spirals 59
- spirillum 59
- ‘spontaneous generation’ 65
- spontaneous reactions 218–19
- standard deviation 20–1
- starch 135
- ‘starstuff’ 212–13
- starvation 154
- static electricity
 - charge and 291–3
 - history 292
- statistical significance 19–20, 22
- steam 213, 350
- steam-driven turbines 349–50, 352
- STEM 78–9, 122–3, 166–7, 200–1, 242–3, 286–7, 324–5, 358–9
- stem cells 104

- stimuli/stimulus 44, 87, 89, 97, 99
 reaction times 122–3
- stimulus–response model 44, 48, 50, 53, 96, 98
- stomach acid 67
- storytelling 324
- stress 84
- structural proteins 33–4
- subatomic particles 175–6, 193–4
 properties of 177–9
- subduction 251, 264–5
- subduction zones 270
- subjective data 8–9
- sugar(s) 39–41, 45, 132
 blood sugar 47
 break-down of 62–3
- sulfates 231
- sulfur 200
- sulfuric acid 230
- summary/summarising 4, 19
- Sun 131–2, 135, 176–7, 351
- sunlight 135–6, 225
- ‘superbugs’ 70
- supernova 171
- superplume 267
- sustainability, sustainable practices 324
- sutures 116
- sweat 38–9, 49, 67
- symbiotic relationships 145–8
- symbols 180, 214, 295–6, 300–2
 Latin names for 172
- synapses 89–90, 92–4, 116
- synaptic gap 92
- ‘synaptic pruning’ 117
- T cells 68–9
- tables
 recording data in 4, 14–16
 set-up rules 14–16
- Taipei World Financial Centre 281
- target cells 84, 87
- tasers 320
- Tasmanian tigers 161
- taste 12, 88
- tears 67
- technology 56, 166, 287, 324–5, 353
 natural disasters and 279–82
- tectonic plate movement 257–9, 279–80
 Australia’s movement 262
 effects of movement 270–7
- tectonic plates 257–8
 plate boundaries 262
- temperature 44, 127–8, 209, 222–3, 242, 258
 body 39
 control 49
 room *see* ambient temperature
 of surroundings 220
- temporal lobe 107–8, 118
- temporary magnets 330
- tendency *see* trends
- tertiary consumers 132
- testes 84–5
- testing
 fair 6
 soil pH 130
 testable hypotheses 7, 78
 trials 243
- testosterone 87
- thalamus 117
- thermal insulation 33
- thinking 107, 118
- Thomson, Joseph John 185–6
- thoracic spine 102
- thymus 68, 84–5
- thyroid 84–5
- ticks 148
- tidal energy 351
- tide pools 127–8
- toadstools 62
- torch circuits 313
- torque 342, 344
- touch 12, 88, 112, 118
- toxic substances 35, 58, 92, 200, 232, 295
- transform boundary 262–3, 267–8
- transformers 353–4
- trenches 264
- trenches (ocean) 251–2
- trends 4, 14–15, 17, 19
see also patterns; relationships
- trepanning 64
- triplegia 102
- trophic levels 132–3
- tropics 249
- tsunamis 264, 274–7
- turbines 349–52
- ultraviolet (UV) radiation 195–6
- unconscious responses 101
- unicellular organisms 31
- units/unit symbols 15
 for energy measurement 37
 energy units 133
- ureter 49
- urine 38–9, 49
 production, storage and excretion
 by organs 50
- vaccines 69
- validity
 valid and consistent results 5
 valid conclusions 4, 19, 22
- values 9
 place values 15
 reading from graphs 18
 shown in columns 14–16
- Van de Graaff generators 291–2
- vapours 49, 65
- variability, measures of 20–1
- variable resistors 309–10
- variables 9–10
 changes to 5–6
 correlation between 19
 defining experimental variables 5–6
 relationships between 4
 types of 6–8
see also hypotheses
- vectors 64, 148–9
- vegetation 127, 141, 150
- vertebrae 102
- vesicles 92–3
- vibration control 281
- Vine, Frederick 257
- Vine, Fredrick 253–5
- viroids 58
- viruses 63–4
 diseases caused by 58
- viscosity 272–3
- visible light 195–6
- vision 88, 118
- vitamins 31, 34–5, 43
 absorption 45
 wheel 35
- volcanoes 251, 264, 267, 280
 eruption events 272–4
 formation sites 270–1
- voltage 291–2, 303, 350
 AC 354
 output not exceeded 339, 345
 proportionality with current 307–8
 shared across load 313
 transforming 354
- voltage drop 303, 314
- waste products 32, 38, 43, 45, 49, 51, 133, 135, 138
- waste systems 148
- water 31–2, 39, 43, 49, 51–2, 135–6, 173, 185, 227–8, 233
 absorption 45
 conversion from fat 38
 diffusion of 46–7
 invisible spaces in 183
 losses 39
 regulating levels 50
- water systems 148
- water vapour 49
- waterborne 64
- water-driven turbines 350–1
- waterways 22, 200
- wavelengths 195
- waves 351
 of energy *see* seismic waves
 sound waves 250
- weathering 238
- Wegener, Alfred 247–51
- weight 37
- weight loss 38–9

- Wernicke's area 108
- wetlands 127
- white blood cells 67–8
- white matter 101
- wildlife 141, 333
- wind energy 351–3
- wind farms 349, 351
- wind speed 128
- wind turbines 352
- windings 345
- wires/wiring 359
 - coiled with loops *see* solenoids
 - copper wire 339
 - current carrying 342
 - going into/coming out of page–
arrow convention 336
- words 10
- World Health Organization (WHO)
149
- X-rays 195–6
- yeasts 62–3
- yields 205
- zero charge 181
- zero error 21
- Zika virus 78, 148