CAMBRIDGE

INTERACTIVE TEXTBOOK INCLUDED



Brodie Reid
Kerrie Ardley
Emma Bone
Gemma Dale
Eddy de Jong
Christopher Humphreys

Cambridge science 9

for Western Australia

CAMBRIDGE UNIVERSITY PRESS

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How to use this resource

Elements in the print book

You will see the following types of boxes throughout this book.

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

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

Explore!

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

Did you know?

These are short facts that contain interesting information.

Quick check

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

Science as a human endeavour

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

Section questions

Question sets at the ends of sections are categorised under the following headings: Remembering, Understanding, Applying, Analysing and Evaluating. Action verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

Hands-on activities

Try this

Classroom activities help explore concepts that are currently being covered.

Practicals

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

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End-of-chapter features

Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria		Linked question	Check
2.1	I can recall the essential requirements for life.	3, 6	
2.2	I can state the definition of homeostasis.	4	
2.2	I can construct the stimulus–response model.	17a	
2.2	I can describe how blood glucose levels are controlled in the body.	17b	
2.2	I can describe how water levels are controlled in the body.	17c	
2.2	I recognise how the circulatory and respiratory system work together.	8	
2.3	I can recall different types of pathogen.	12	
2.3	I can describe the way we classify bacteria.	7	
2.3	I can discuss the different lines of defence in the body.	5	
2.3	I can discuss the use of vaccination and antibiotics in protecting against pathogens.	10	

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

Chapter review question sets are under the following headings: Remembering, Understanding, Applying, Analysing and Evaluating. Action verbs have been bolded. These questions are also available as Word document downloads in the Interactive Textbook.

Data questions

A Year 9 student with diabetes measures their blood sugar level hourly and the data is plotted in blue in Figure 2.56. Another student, who does not have diabetes, also measures their blood sugar as a comparison, and this is plotted in orange. The students are careful to eat the same three meals on this day – breakfast, lunch and dinner at the same time – and the student with diabetes injects insulin after each meal.

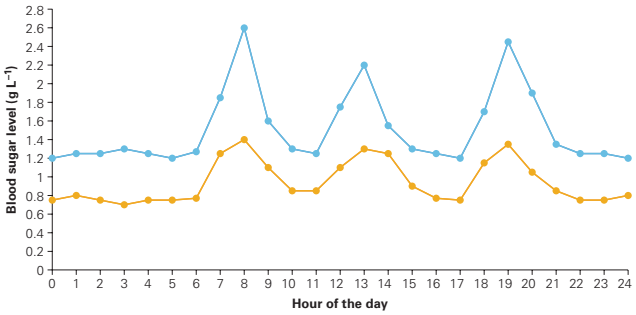
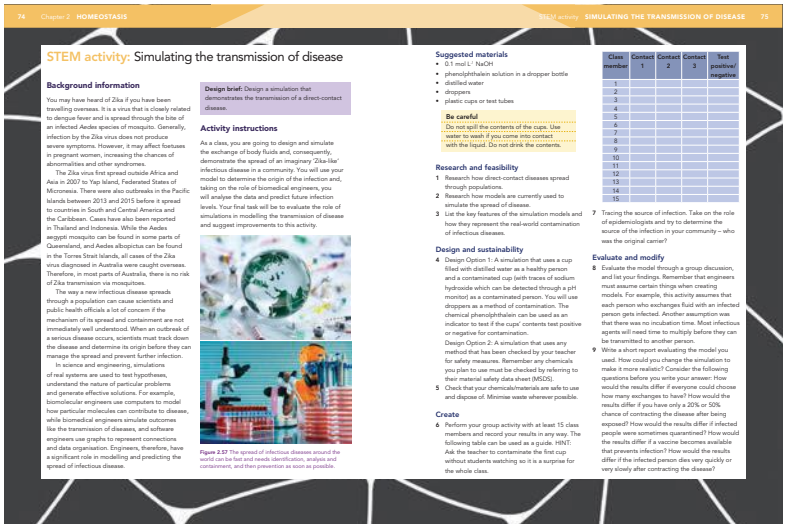


Figure 2.56 Relative blood sugar level over a 24-hour period. Orange line – student without diabetes, Blue line – student with diabetes

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


74 Chapter 2 HOMEOSTASIS

STEM activity SIMULATING THE TRANSMISSION OF DISEASE 75

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 foetuses in pregnant women, increasing the chances of abnormalities and other syndromes.

The Zika virus first spread outside 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.

The way a new infectious disease spreads through a population can cause scientists and public health officials a lot of concern if the mechanism of its spread and containment are not immediately 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, 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: Design a simulation that demonstrates the transmission of a direct-contact disease.

Activity instructions

As a class, you are going to design and simulate the exchange of body fluids and, consequently, demonstrate the spread of an imaginary 'Zika-like' infectious disease in a community. You will use your model to 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.

Figure 2.57 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 mol L⁻¹ NaOH
- phenolphthalein solution in a dropper bottle
- distilled water
- droppers
- plastic cups or test tubes

Be careful

Do not spill the contents of the cups. Use water to wash if you come into contact with the liquid. Do not drink the contents.

Research and feasibility

1 Research how direct-contact diseases spread through populations.

2 Research how models are currently used to simulate the spread of disease.

3 List the key features of the simulation models and how they represent the real-world contamination of infectious diseases.

Design and sustainability

4 Design Option 1: A simulation that uses a cup filled with distilled water as a healthy person and a contaminated cup (with traces of sodium hydroxide which can be detected through a pH monitor) as a contaminated person. You will use droppers as a method of contamination. The chemical phenolphthalein can be used as an indicator to test if the cups' contents test positive or negative for contamination.
Design Option 2: A simulation that uses any method that has been checked by your teacher for safety measures. Remember any chemicals you plan to use must be checked by referring to their material safety data sheet (MSDS).

5 Check that your chemicals/materials are safe to use and dispose of. Minimise waste wherever possible.

Create

6 Perform your group activity with at least 15 class members and record your results in any way. The following table can be used as a guide. HINT: Ask the teacher to contaminate the first cup without students watching so it is a surprise for the whole class.

Class member	Contact 1	Contact 2	Contact 3	Test positive/ negative
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

7 Tracing the source of infection. Take on the role of epidemiologists and try to determine the source of the infection in your community – who was the original carrier?

Evaluate and modify

8 Evaluate the model through a group discussion, and list your findings. Remember that engineers must assume certain things when creating models. For example, this activity assumes that each person who exchanges fluid with an infected person gets infected. Another assumption was that there was no incubation time. Most infectious agents will need time to multiply before they can be transmitted to another person.

9 Write a short report evaluating the model you used. How could you change the simulation to make it more realistic? Consider the following questions before you write your answer: How would the results differ if everyone could choose how many exchanges to have? How would the results differ if you have only a 20% or 50% chance of contracting the disease after being exposed? How would the results differ if infected people were sometimes quarantined? How would the results differ if a vaccine becomes available that prevents infection? How would the results differ if the infected person dies very quickly or very slowly after contracting the disease?

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

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Links to the Interactive Textbook

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

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

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

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

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

Overview of the Interactive Textbook (ITB)

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

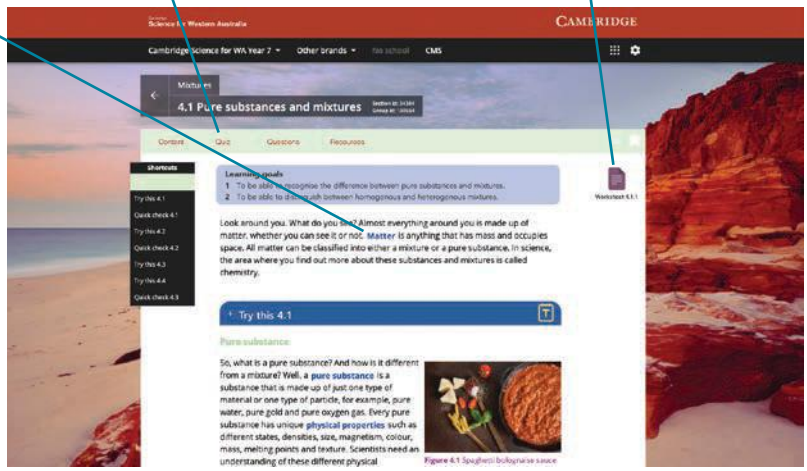
Definitions pop up for key terms in the text.

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

Worksheets are provided as downloadable Word documents.

Videos summarise, clarify or extend student knowledge.

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



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

Practical 2.1: Investigation

Measuring the energy content in food

Aim
To investigate the amount of chemical energy stored in various foods.

Be careful
No food items are to be consumed.

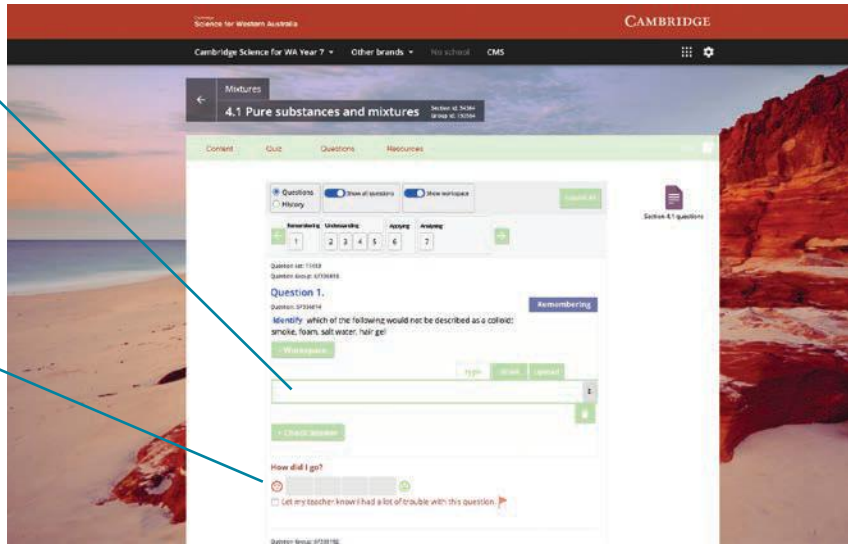
Materials
- large test tube
- test-tube rack
- test-tube holder (wooden peg)
- heatproof mat
- bottle cork with a needle inserted into the top
- thermometer
- tin can open at both ends (to act as a chimney)
- 25 millilitres (mL) measuring cylinder
- assorted food samples, e.g. Twisties (do not use nuts)
- measuring scale

Planning
1. Write a rationale about the chemical energy stored in food and the different components of food that provide energy.
2. Develop a hypothesis to predict which food sample/s will transfer the most energy.
3. Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
4. Complete a risk assessment for this investigation, describing how any risks will be controlled.

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

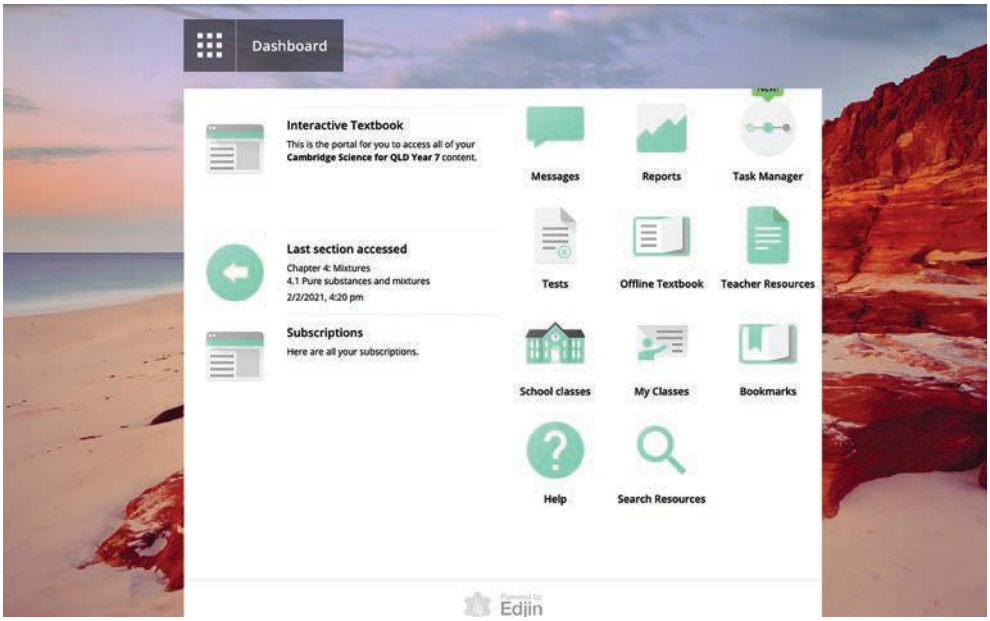
Self-assessment tools enable students to check answers, mark their own work and rate their confidence level in their work. This helps develop responsibility for learning and communicates progress and performance to the teacher. Student accounts can be linked to the learning management system used by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



Overview of the Online Teaching Suite (OTS)

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

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



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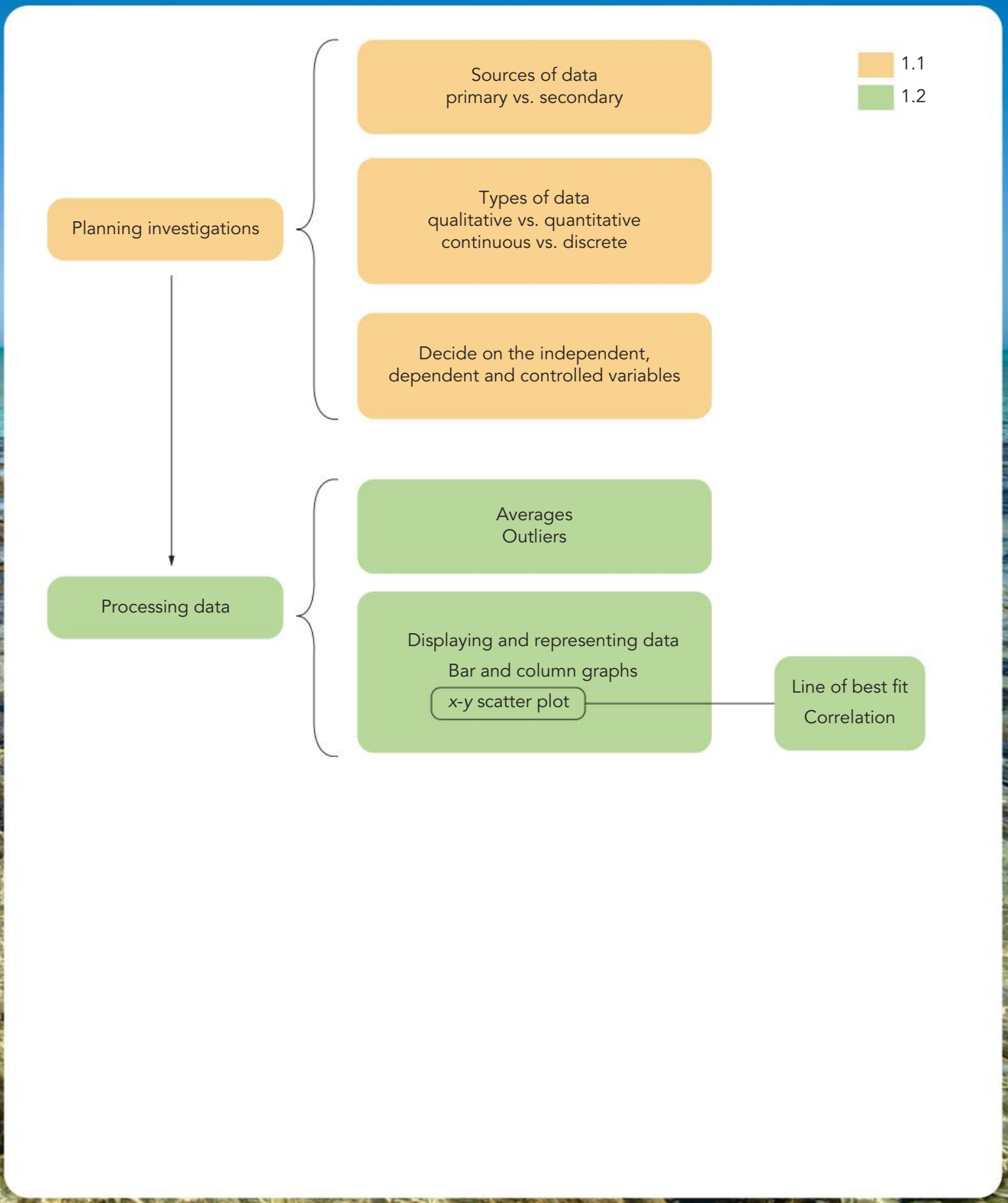
Chapter 1
Science and data

Chapter introduction

Data is information that comes in the form of measurements, counts, observations, descriptions and other research findings. In this chapter, you will learn about the different types of data that can be collected and presented in an investigation.

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Chapter map



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1.1 Planning data collection

WORKSHEET

Learning goals

1 To be able to define primary and secondary sources of information.
2 To be able to distinguish qualitative and quantitative data types.
3 To be able to identify the independent, dependent and controlled variables in a scientific experiment.

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

Sources of data

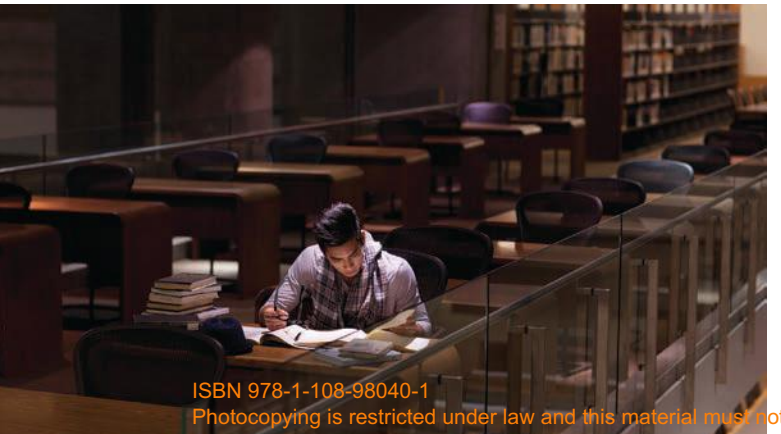
Primary data is data that researchers collect themselves for a specific purpose. This kind of data can be obtained from observations, experiments, surveys or interviews.

Secondary data is data collected by other people. A scientist can analyse this type of data. This kind of data can be obtained from scientific journals, the Australian Bureau of Statistics, or investigations that other people have conducted. Secondary data can be useful during the rationale phase of an investigation. You can learn from the experiments or studies that other people have conducted to better understand how to answer your research question.

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

secondary data
data that has been previously collected for another purpose

Figure 1.1 Both primary and secondary sources of data are important during various stages of scientific investigations. Secondary data can be helpful during the planning stage, while primary data is collected during an investigation.





Quick check 1.1

1 Classify these scenarios as primary or secondary data:
   a Gathering student data from the Australian Bureau of Statistics
   b Recording the running speed of classmates
   c Observing the time taken for traffic lights to turn green
   d Using data that you gathered as a class and analysing it individually
   e Referencing data from a project you did in the past

Types of data

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

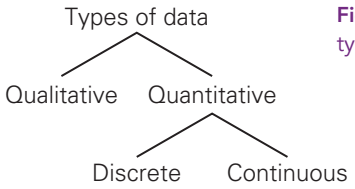


Figure 1.2 Different types of data

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Quantitative vs. qualitative data

You can collect two types of data from an investigation.

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

Not all investigations involve taking measurements. The data you collect from some investigations is **qualitative data**. This means that the data is non-numerical. Qualitative data could be descriptive or some other type of written observation, for example, the shape of leaves, how something tastes or open-ended interview transcripts.

Quick check 1.2

1 Explain how qualitative data is different to quantitative data.
2 Have a look at the image below. What kinds of data could be derived from it? Categorise them as qualitative or quantitative.



Continuous vs. discrete data

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

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

quantitative data
data values that are numerical

qualitative data
data that is descriptive and non-numerical

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

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

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

Quick check 1.3

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

Recording data

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

Variables

Whenever you are performing an investigation, three different types of variables will be involved. It is important to know what these variables are. If they are to be measured, you need to know the units, too.

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independent variable
the variable that is purposely changed (manipulated) during an experiment

dependent variable
the variable that is measured to see whether it is affected by the independent variable

controlled variable
any variable that may influence the outcome of an experiment and is therefore kept constant

The **independent variable** is the variable (or factor) that you are changing (manipulating) in the investigation. It is not affected by, or does not depend on, other variables. For example, if you are measuring how the volume of water affects plant growth, the independent variable is the volume of water. In this case, you need to decide whether millilitres (mL) or litres (L) are the appropriate units to use. If you change more than one variable at a time, it will be hard to determine which variable is causing any change you observe.

The **dependent variable** is the variable or factor that you are measuring or observing. You are assessing how this factor responds to changes in the independent variable. For example, when you are measuring how the volume of water affects plant growth over a period of time, the dependent variable is the amount of plant growth. In this case, you need to decide whether millimetres (mm), centimetres (cm) or metres (m) is the appropriate unit to use.

The third type of variable is the **controlled variable**. These are factors that are held constant throughout the investigation to ensure it is only the independent variable that is affecting the dependent variable. Examples of controlled variables in the plant growth experiment include keeping all your plants in the same location so the plants get the same amount of light and keeping them at the same temperature throughout the investigation.

Worked example 1.1

Naveen wants to investigate how fast his plant grows over a few weeks. Identify the independent variable, dependent variable and controlled variables. Decide on appropriate units for the independent and dependent variables.



Figure 1.3 A series of photos showing the plant's growth over a period of several weeks

Working	Explanation
Independent variable: Time period, measured in days	If the plant is being observed for several weeks, then measuring it every day or every few days would be an appropriate frequency for data collection.

continued…

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…continued

Working	Explanation
Dependent variable: Height of the plant, measured in centimetres	Depending on the type of plant, some research may be required to estimate the rate of growth. Typically, plants grow several millimetres per day, so centimetres with one decimal point may be an appropriate measurement. It also depends on the ruler you have available.
Controlled variables: The plant needs to be watered at the same times and with the same volume of water every day. The amount of sunlight also needs to be consistent. This may involve ensuring that it is not moved from its position for the duration of the investigation. The temperature of the room also needs to be kept consistent.	All external influences apart from the independent variable must be kept constant to ensure the independent variable is the only factor affecting the dependent variable.

Table of results

When recording collected data in a table, the independent variable data is recorded in the first (left-hand) column, while the dependent variable data is recorded in the columns to the right. Results should also be recorded to the same number of decimal places to assist with accuracy and avoid ambiguity. For the example above, Naveen may decide to record data from two other plants of the same species to assess whether the data is consistent. That way, a **mean** (average) can be calculated. Figure 1.4 shows what the results table would look like. An appropriate title for the table includes the independent and dependent variable, for example, is 'Plant height recorded over 25 days'.

mean
the result you get by adding two or more values together and dividing the total by the number of values

The dependent variable is placed in the top row, and results for each trial are shown and are shown to the same number of decimal places.

Plant height recorded over 25 days

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

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

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

Figure 1.4 How to set up a table of results for the worked example of Naveen's plant

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Quick check 1.4

1 Olive loves drinking hot chocolate. She wants to find out at which temperature of milk the chocolate powder dissolves the quickest. For Olive's investigation, identify the independent, dependent and controlled variables.

2 Olive records her results in the table below. Determine how many mistakes can be found in the table. Copy the table below into your workbook and correct the mistakes.

Dependent variable: Time (days)	Independent variable: Temperature (cm)			
	Trial 3	Trial 2	Trial 1	Total
20	5.5	5.5	6	17.0
30	4.5	4.5	5	14.0
40	2.5	3.5	3	9
50	1.5	2	1.5	5
60	0.5	1	1	2.5

Section 1.1 questions

QUIZ

Remembering

1 **Identify** the different types and descriptions of data missing in the table below.

Type of data	Description
Quantitative	
	Data values that are worded or descriptive
	Quantitative (numerical) data that is whole numbers
Continuous	

2 **Identify** the independent, dependent and controlled variables in the following investigations.
- a Phoenix wants to investigate whether music helps plants grow quicker.
- b Ishan is going to investigate if mass affects the time it takes for an object to fall.

Understanding

3 Leo conducts a simple investigation into how long different brands of kettle take to boil water. He chooses three different kettles: an electric metal kettle, an electric plastic kettle and a metal kettle for putting on the stovetop. Leo boils half a litre of water in each and waits for each kettle to be cool before he starts the next trial. **Identify** the controlled variables in Leo's investigation.

Applying

4 **Explain** how primary data is different to secondary data.

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Analysing

5 Give examples of the data you have collected in your science class over the last year. Then **classify** each as primary or secondary data.

6 Using your own example of an investigation, **distinguish** between the independent and dependent variables.

Evaluating

7 From his investigation in Question 3, Leo records the following results for the time taken for water to boil:
Electric metal kettle: 3 minutes 30 seconds, 3 minutes 42 seconds, 3 minutes 44 seconds
Electric plastic kettle: 4 minutes 2 seconds, 3 minutes 52 seconds, 3 minutes 57 seconds
Stovetop kettle: 5 minutes 5 seconds, 4 minutes 47 seconds, 4 minutes 54 seconds
Create an appropriate results table, carefully including the names for the variables and their units.

8 Saria and Jake are investigating three aspects of the students in their class:
- hair colour – number of students with each hair colour
- eye colour – number of students with each eye colour
- height – the height of each student.

They are arguing over whether the quantitative data they need to collect for their series of investigations is continuous or discrete. Saria says all the data is discrete while Jake disagrees and says all the data is continuous. **Discuss** who is right and who is wrong. Give reasons for your answer.

9 Collecting both primary and secondary data has advantages and disadvantages. **Determine** one advantage and one disadvantage for each, and then give reasons why this is an advantage or disadvantage. You may choose to organise your answer in a table like the one shown below.

	Advantages	Disadvantages
Primary data		
Secondary data		

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1.2 Processing data

WORKSHEET

Learning goals

1. To be able to calculate the mean and identify outliers of a set of data.
2. To be able to represent data in bar and column graphs as well as *x*–*y* scatter plots.
3. To be able to draw a line of best fit to identify a trend in plotted data.

Making sense of the information and data after they have been collected is the next phase of conducting experiments. This requires a number of steps, including ensuring the data is valid, sorting it into sequences, and representing it so it is more easily viewed and summarised. These steps in processing data may be conducted manually, but big experiments and data sets may also involve digital processing methods.

Averages and outliers

When experiments result in many numbers from repeated trials, it makes sense to find one number that represents all the trials. This is an average and it is easiest to use the mean. Finding the mean requires simple mathematics, maybe a calculator, and a few simple steps: add up all the numbers you have and divide the total by how many numbers you added up.

Figure 1.5 The ability to represent data in a visual form is an important part of modern culture in many day-to-day endeavours.



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Worked example 1.2

A scientist caught 5 fish, measured the length of each and wanted to know the mean of the lengths. The lengths (cm) of the fish were 20.2, 21.6, 23.4, 20.0 and 22.2.

Working	Explanation
Step 1: 20.2 + 21.6 + 23.4 + 20.0 + 22.2 = 107.4 cm	First add up all the lengths.
Step 2: 107.4 cm ÷ 5 = 21.5 cm The mean fish length is 21.5 cm.	Then divide the result by 5 as that is how many fish there were.

Sometimes the data collected may contain one or more numbers that seem very different to the other observations made. These numbers are called **outliers**, and might be due to faulty procedures or chance errors in collecting the measurements.

outlier
an extreme data point – a number that is very different to the other numbers collected

When outliers are identified, and be aware not every set of measurements contains them, some decisions need to be made.

Should the trial be performed again? Or, if that is not possible, could the outlier numbers be deleted from the data and an average calculated from the rest? Both options could be acceptable depending on the situation. If the outliers are not handled properly, then the mean is not a true representative of the measurements collected.

Displaying and representing data

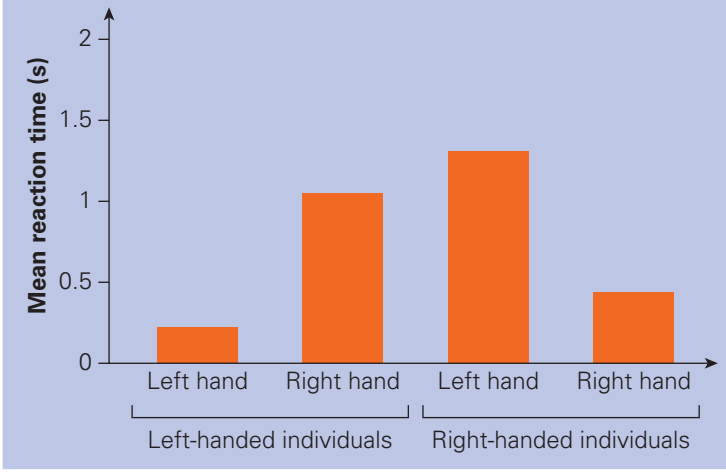
Data representation	Reason for use
Column graph  	Column graphs are used for comparing qualitative data between different categories or groups. They are suitable for medium to large sets of data.

Table 1.1 Different types of graphs suit different types of data and variables.

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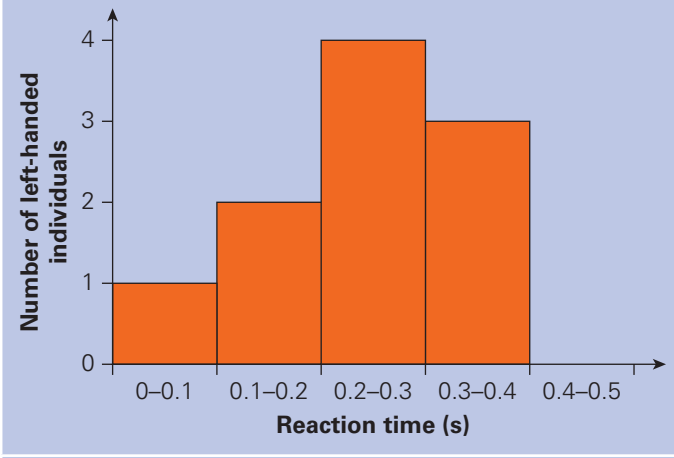
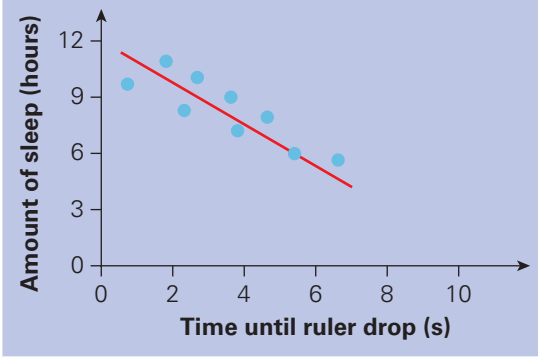
Data representation	Reason for use
Histogram 	Histograms are used to plot the frequency of continuous data that is divided into intervals. They are suitable for medium to large sets of data.
x–*y* scatter plot 	Scatter plots are used to determine the relationship between variables. They are suitable for medium to large sets of data.

Table 1.1 *(Continued)*

Bar graphs and column graphs

Bar graphs use rectangular bars that are proportional to the values that they represent. A vertical bar graph may be called a column graph. Bar graphs are made up of four parts:

- a title that explains the information being graphed; titles for graphs should be written above the graph
- labels on axes that explain what each side of the graph is showing, including units
- a scale of numbers that increases evenly from bottom to top (or left to right if the bars are horizontal)
- category labels that explain what each bar is showing.

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

Figure 1.6 shows an example of a vertical bar graph (column graph) and a horizontal bar graph presenting the same information.

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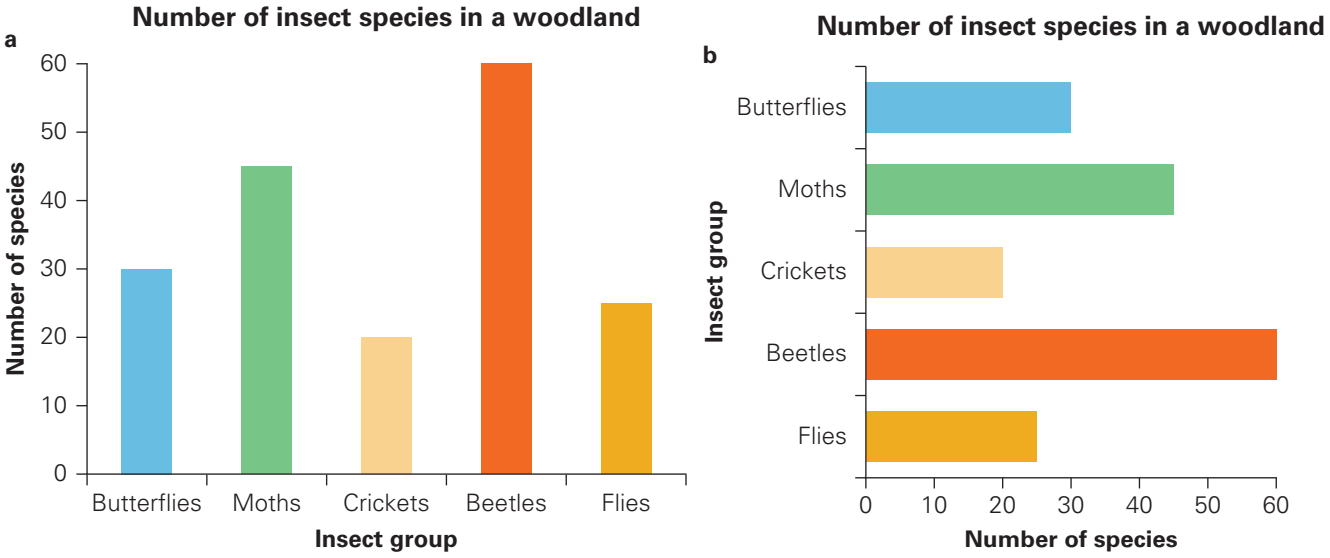


Figure 1.6 The same data presented in (a) a vertical bar graph (column graph) and (b) horizontal bar graph

Quick check 1.5

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

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

Scatter plot

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

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

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

A simple method of remembering this is to recall the acronym DRY MIX.

D – **D**ependent variable
R – **R**esponds to changes in other variables
Y – Is placed on the ***y***-axis

M – The **m**anipulated variable is the one that is deliberately changed
I – **I**ndependent variable
X – Is placed on the ***x***-axis

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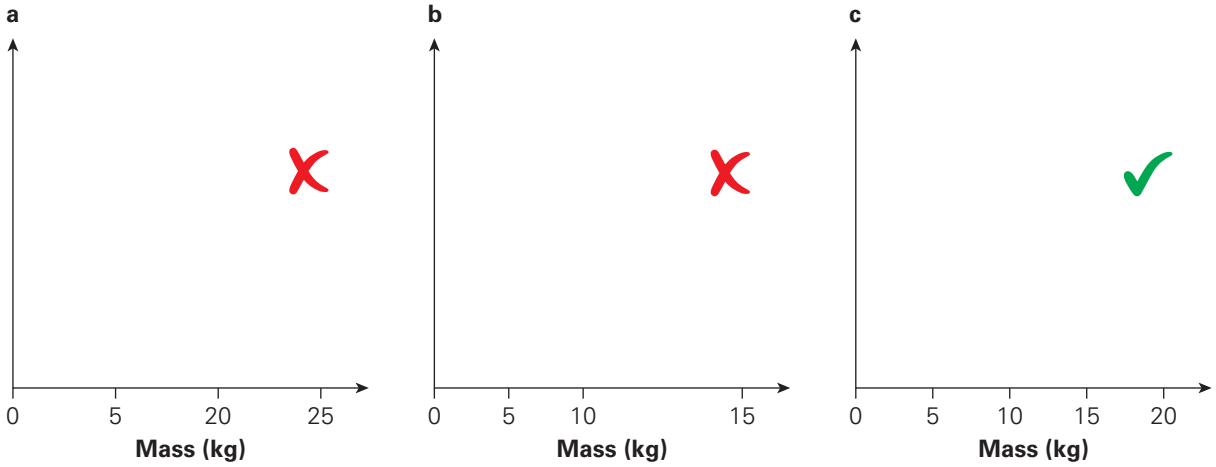


Figure 1.7 Graph (a) does not increase evenly along the *x*-axis. Graph (b) is not spaced evenly. Graph (c) has the correct spacing and numbering for the *x*-axis.

When preparing the *x*-axis and *y*-axis, it is important to place the numbers on the axis in a way that shows the correct relationship. The numbers on both axes need to increase evenly, starting at zero as the corner point (**origin**). Each distance of the line needs to represent the same value of the data. For example, if the first unit of the graph represents 5 kilograms (kg), every increment of the graph also has to be 5 kg (see Figure 1.7).

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

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

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

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

The results in Table 1.2 are taken from the investigation in Section 1.1 of plant height over 25 days. Only the average information is shown.

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

Table 1.2 Mean plant height over time

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Plotting the data correctly on a Cartesian plane makes it much easier to analyse.

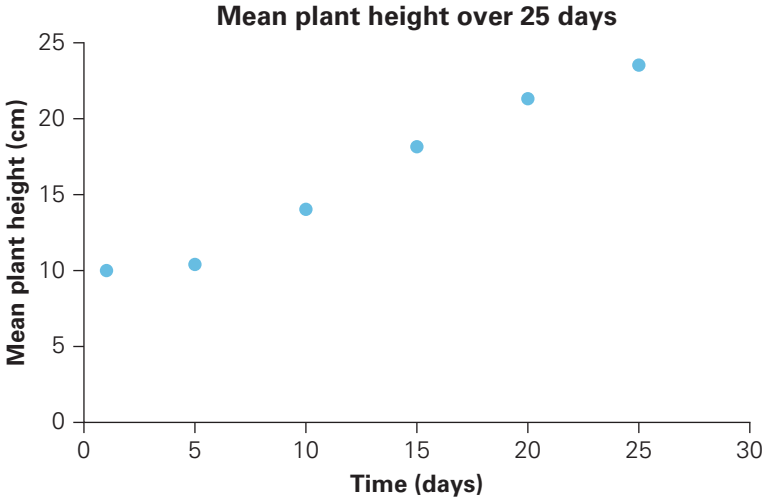


Figure 1.8 Graph of mean plant height against time

Quick check 1.6

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

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

a Identify the independent variable in this experiment.
b Identify the dependent variable in this experiment.
c Use this information to draw a complete *x*–*y* scatter plot graph of this data.

Line of best fit

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

linear
a straight line plotted on a graph

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

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

- Do not include outliers.
- Make the line as close to as many points as possible.
- There should be a consistent number of data points above and below the line.

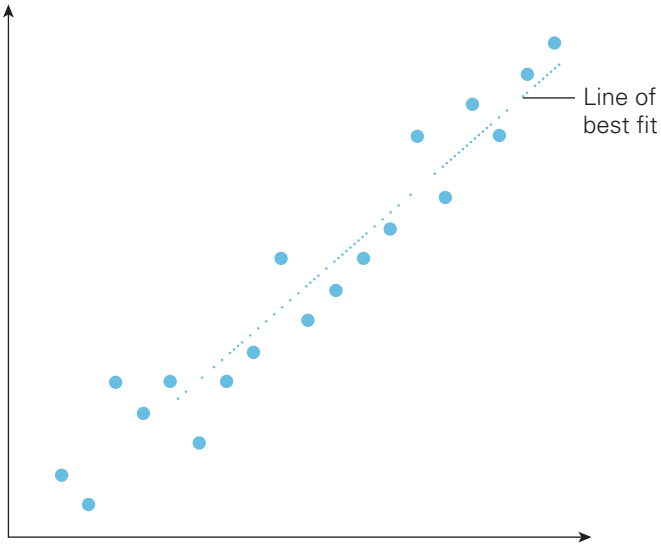


Figure 1.9 A scatter plot with a line of best fit. Even though the line is not touching any of the points, it is drawn as a close approximate to the average of all the points.

Figure 1.10 is an example of when a non-linear line fits the data points better than a straight line. In these cases, you can use a software program like Excel to find the line of best fit.

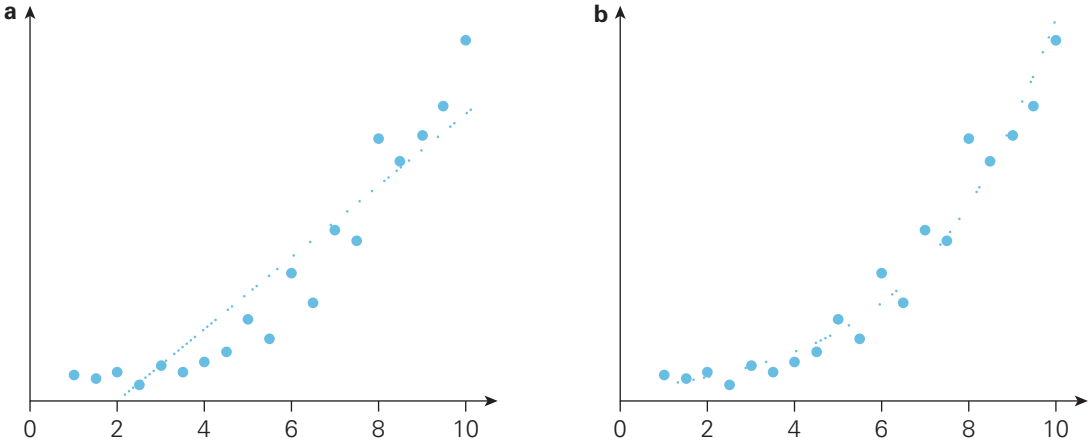


Figure 1.10 The data points here suggest that the relationship between the *x* and *y* variables is non-linear, meaning that the line that best fits the data is curved (graph b) rather than straight (graph a).

Correlation

Scientists often seek to understand whether a relationship exists between experimental variables, and to do this they analyse the data. Numbers might be correlated positively or negatively, or they may have no correlation. This relationship can usually be discovered with a simple glance at an *x*–*y* plot. When interpreting a correlation between variables, it is important not to assume that one variable affects the other. A correlation may actually be caused by another factor that isn't one of the variables. That is why it is important to use the word 'suggests' or 'provides evidence' rather than 'proves' or 'causes' if you think there might be a relationship.

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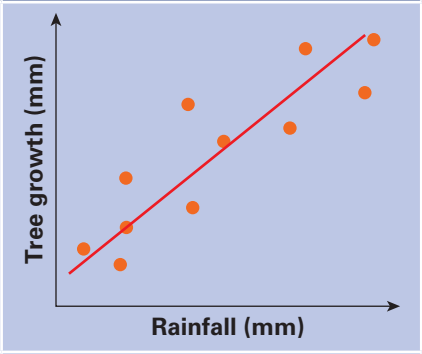
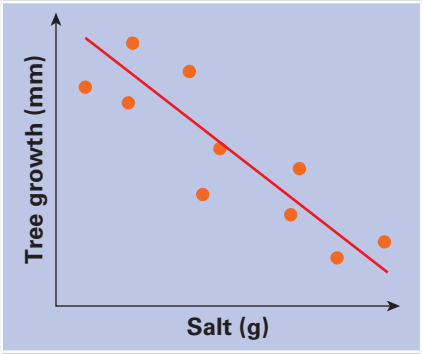
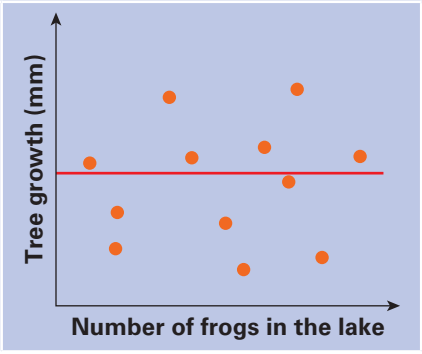
Correlation	Example graph	Interpretation
Positive (one variable increases as the other variable increases)		The results suggest that more rainfall may contribute to an increase in tree growth in a specific area.
Negative (one variable decreases as the other variable increases)		The results suggest that increased salt added to the soil in the specified area inhibits (hinders) tree growth.
No correlation (no pattern in the way the variables increase or decrease)		The results suggest that the number of frogs in the lake situated 1 kilometre away does not affect tree growth.

Table 1.3 An *x*–*y* scatter plot can show the degree of correlation of two factors.

Remember, if two variables show a correlation, it does not necessarily mean that one has an effect on the other; it only provides evidence that there might be a relationship between the two variables. However, the correlation may be caused by other factors.

Quick check 1.7

1 State whether you would expect a positive, negative or no correlation for each of the following examples.
   a The volume of a set of headphones on hearing damage
   b A high temperature forecast on the expectation of bushfires
   c Eating fatty foods on having healthy cholesterol levels
   d Students' absences on grades
2 Refer back to the previous Quick check 1.6.
   a Predict whether the trend line for the graph you drew will be linear or non-linear.
   b Identify whether there is a positive, negative or no correlation.
   c Describe what the data suggests would happen if you reduce the amount of food added.

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Section 1.2 questions

QUIZ

Remembering

1 Name four items that must appear on an x–y plot.

Understanding

2 **Explain** how the mean is calculated.

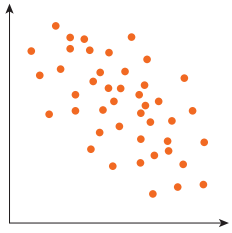
Applying

3 Erica left six avocado seeds suspended, each in the same volume of water, for two weeks. At the end of the trial she measured the height of the sprout from the base of the seed. The results were as follows:
3 cm, 2.5 cm, 2.5 cm, 3 cm, 1.5 cm, 1.5 cm
Calculate the mean height of the sprout after two weeks.

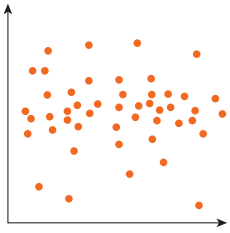
Analysing

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

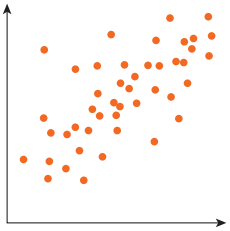
a



b



c



Evaluating

5 **Construct** an x–y scatter plot of the following data from an experiment measuring the stretch in a spring with increasing masses added. Include a line of best fit to evaluate any trend in the data.

Mass added (g)	Spring stretch (mm)
0	0
10	5
20	12
30	15
40	20
50	21
60	24
70	30
80	35
90	41

6 **Construct** the appropriate graph for the following data of a heating curve for the temperature of water measured after every minute of heating. Include a line of best fit to evaluate any trend in the data.

Time (min)	Temperature (°C)
0	0
1	3
2	3
3	15
4	17
5	18
6	18
7	20
8	22
9	30

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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria		Linked question	Check
1.1	I can define primary and secondary data.	3	
1.1	I can distinguish between quantitative and qualitative data.	2	
1.1	I recognise the difference between discrete and continuous data.	5	
1.1	I can identify independent, dependent and controlled variables.	4	
1.2	I can calculate the mean of scientific data.	1	
1.2	I can identify outliers in a dataset.	1	
1.2	I can represent data in different graphs.	6	
1.2	I can state the correlation between data on a graph.	8	

Review questions

SCORCHER

Remembering

1 **Identify** any potential outliers in the following data set and **calculate** the mean: 2, 2, 2, 3, 1, 3, 12.

2 **State** two examples of qualitative data and two examples of quantitative data you have used during your science lessons.

Understanding

3 **Contrast** primary data and secondary data, giving an example for each.

Applying

4 **Identify** the independent, dependent and controlled variables in the following investigation: Miriam wants to investigate if having a TV on increases the air temperature in her bedroom.

Analysing

5 **Classify** the following as either discrete or continuous data.

a The number of days on which it hailed in a year
b The diameter of hailstones
c The speed of a car
d How many cracks appear on a wall after an earthquake
e The length of cracks in different materials

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Evaluating

6 **Decide** on the appropriate graph to use, and construct one for the following data obtained from a survey of the methods used to heat houses in a neighbourhood.

Heating type	Number of households
Gas	25
Electric	20
Wood	8
Reverse cycle air-conditioning	22
Kerosene	5
Heat pumps	5

7 **Deduce** when a scientist might use a column graph rather than a scatter plot.

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

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

a **Construct** a graph of the following points of data and then draw in a line of best fit for each set of data.

b **Describe** the two results in terms of correlation.

c **Determine** the relationship between substance X and bacterial colony growth.

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Data questions

A Western Australian scientist designed an experiment to show how the temperature at which water boils changes as the water is placed at different heights above sea level. The scientist did this by boiling water while on a hike up Mount Meharry (also known as Wirlbiwirlbi to the local Indigenous peoples) in Western Australia's Karijini National Park. The mountain's peak is 1249 m high and is Western Australia's highest peak above sea level. The scientist used the same volume of water in the same beaker, the same heating apparatus and the same thermometer to measure the temperature. The results are presented in Figure 1.11.

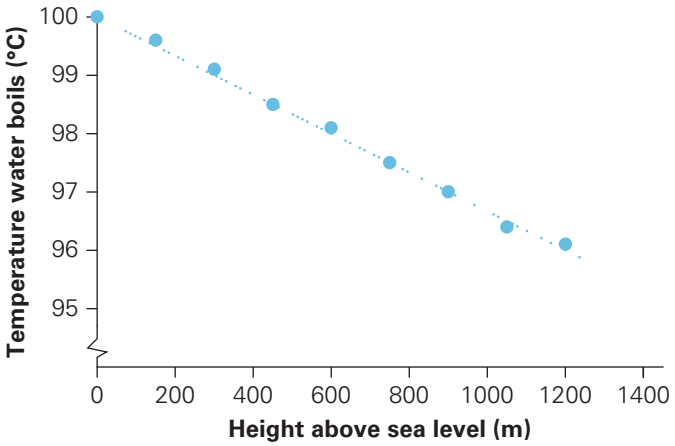


Figure 1.11 The temperature that water boils at different heights above sea level on Mount Meharry (Wirlbiwirlbi).

1. **Identify** two controlled variables in this experiment.
2. Use the graph to **determine** the independent variable in the experiment.
3. **Identify** the trend in water boiling temperature as height above sea level changes.
4. **Analyse** the data points and identify any outliers that should be removed from the trend line.
5. From the trend line, **infer** the temperature of boiling water at 700 m above sea level on Mount Meharry (Wirlbiwirlbi).
6. **Justify** that the linear trend line is a reliable fit for the data.
7. **Extrapolate** the data to estimate the height above sea level that would allow water to boil at 95°C.
8. Mountains in the Alps in Europe reach a height above sea level that is double that of Mount Meharry (Wirlbiwirlbi). **Predict** the temperature that water would boil at on a 2400 m peak in the Alps.

Figure 1.12 Mount Meharry (Wirlbiwirlbi) in the Karijini National Park, Western Australia



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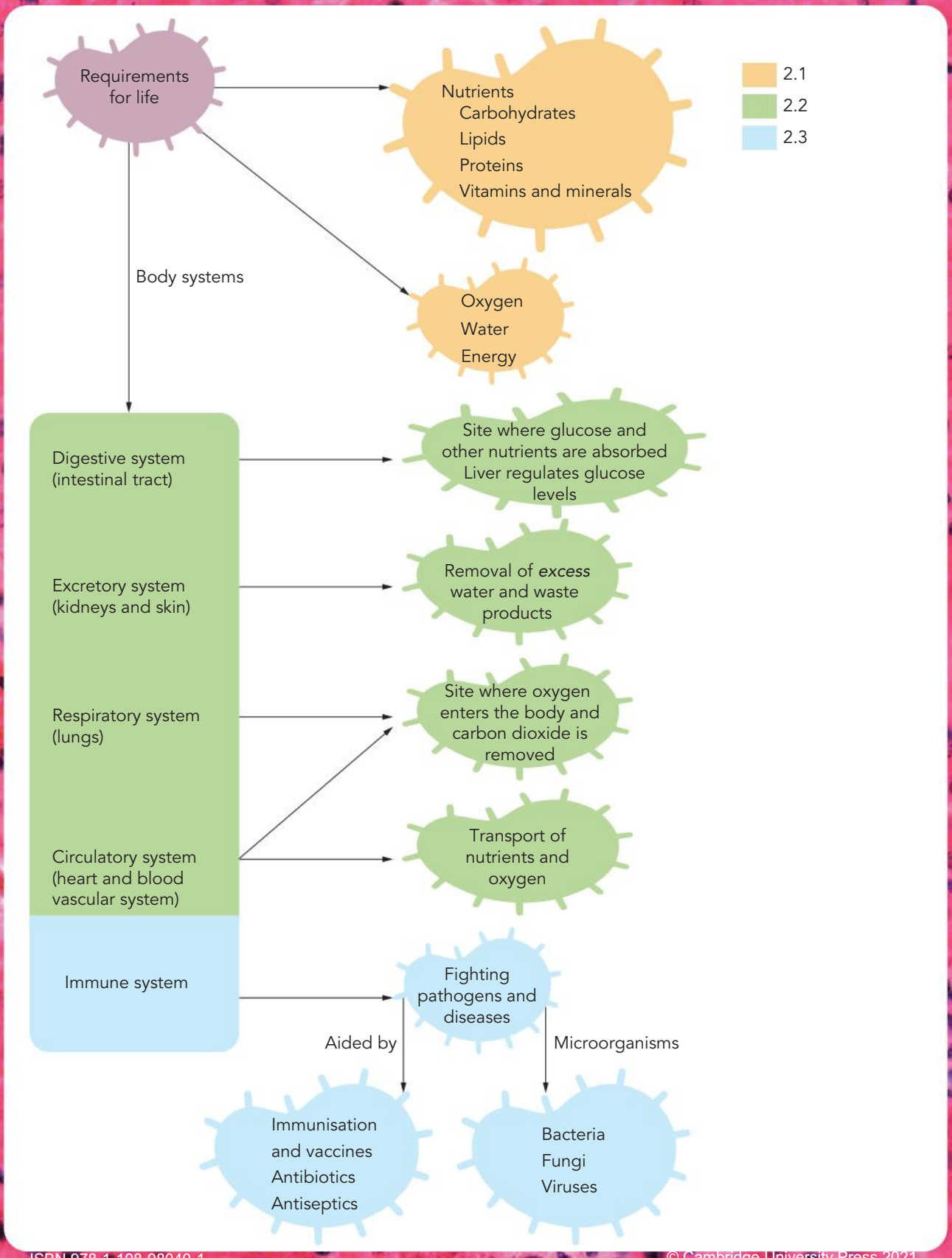
Chapter 2
Homeostasis

Chapter introduction

The human body is a fascinating, yet complex, biological machine. All body systems work in an inter-related way to contribute to the health of the entire organism. The word *homeostasis* originates from the Greek words for 'same' and 'steady'. It refers to the processes living things use to maintain a relatively stable internal environment, in spite of external changes. All cells within the body depend upon the internal body environment to survive and function, and some are very fussy about the conditions they are prepared to tolerate! This chapter will focus on the role of feedback systems in the human body that detect and respond to change, including the damage made by invading pathogens and the body's ability to defend itself against that damage.

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Chapter map



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2.1 The requirements for life

WORKSHEET

VIDEO
Components of cellular respiration

Learning goal

1 To be able to recall the essential nutrients required for life.

Multicellular versus unicellular organisms

All living organisms consist of cells. Cells are commonly known as the 'building blocks of life' and most are so small that you cannot see them without a microscope. Complex organisms, such as fish, humans and other mammals, consist of many cells and are called multicellular organisms. For example, the human body is made up of trillions of cells. **Multicellular** organisms are complex and require specialised systems to carry out specific functions. They contain various levels of organisation. Individual cells within a multicellular organism perform specific functions, but they also work together for the good of the whole organism. Simple organisms like bacteria, amoebas and paramecium consist of just one cell and are called 'unicellular' or 'single-celled' organisms. In **unicellular** organisms, the single cell functions on its own and performs all required life functions. However, this chapter will focus on multicellular organisms that rely on highly organised and interdependent internal body systems to respond to changes in their environment.

multicellular
composed of more than one cell

unicellular
composed of a single cell

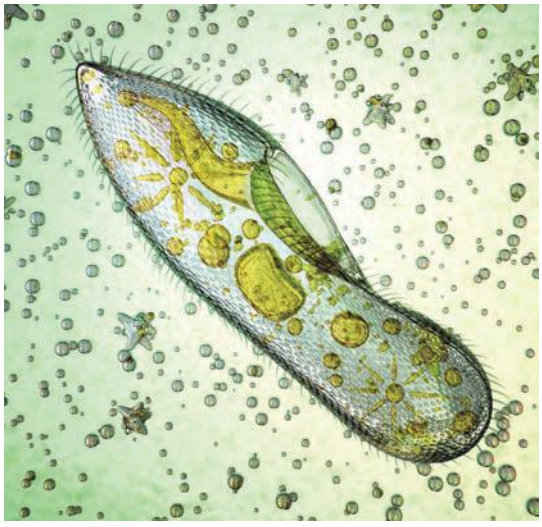


Figure 2.1 A unicellular organism known as *Paramecium caudatum*

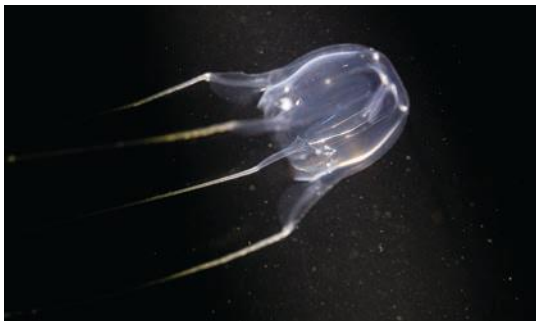


Figure 2.2 This box jellyfish (*Carybdea rastoni*) is an example of a multicellular organism. It has no respiratory system, an incomplete digestive system, no skeletal system, no muscular system and a basic nervous system, but it still contains specialised cells such as cnidocytes. These cells contain a secretory organelle responsible for stings.

Essential requirements for life

Animals, such as humans, can live for several weeks without the nutrients obtained from food and survive a few days without water, yet can only live a few minutes without oxygen. Humans clearly need 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. Many of the chemicals that maintain your body's proper functioning (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

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in the chemical bonds of glucose is released as useable chemical energy. This process occurs in organelles called mitochondria that are found in body cells. Cellular respiration provides cells with the energy required for their specialised functions. The other reactant needed for cellular respiration is oxygen, and you obtain this by breathing in the oxygen from the air. 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.

glucose + oxygen ⟶ carbon dioxide + water + energy

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 to release enough energy for use within the cells.

cellular respiration
an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy

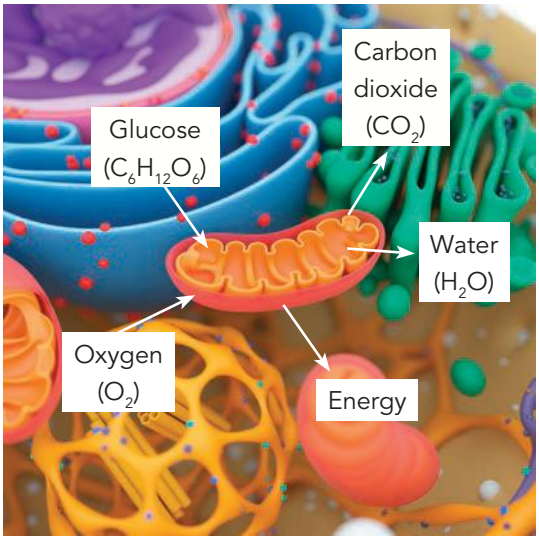


Figure 2.4 Cellular respiration occurs in the mitochondria of animal and plant cells to provide energy for cellular work.

Try this 2.1

Make a revision poster!

Orient your paper in landscape mode and draw the word equation for cellular respiration across the page. Underneath each word, draw a diagram of the substance. Also annotate the equation to show where the reactants come from and how the products are removed from the body.

CELLULAR RESPIRATION REVISION POSTER

glucose + oxygen ⟶ carbon dioxide + water + energy

Quick check 2.1

1. State the main difference between a unicellular and a multicellular organism.
2. Recall the essential requirements for life.
3. State the reactants and products from the process of cellular respiration.
4. Recall why cellular respiration is an essential requirement for life.



Figure 2.5 Water is an essential requirement for life, and humans need about 2 litres (L) of water per day to remain healthy. This includes the water obtained from food.

Nutrients

Nutrients are the chemicals obtained from a healthy diet that provide you with the energy and building blocks your body needs to grow and repair.

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

- carbohydrates
- lipids (fats and oils)
- proteins
- vitamins and minerals.

VIDEO
Nutrient groups

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Carbohydrates

Carbohydrates are the quickest source of energy for the body. Simple carbohydrates, as found in sugar, white flour and pasta, can be digested and used for energy immediately (see Table 2.1). Complex carbohydrates, proteins and fats are digested by the body over a longer period of time to provide energy and other nutrients.

When someone eats more carbohydrates than the body can use right away, these will be stored by the body as glycogen in the muscles, and then the excess will be stored as body fat.

Types of carbohydrates	
Simple	**Complex**
Examples include fructose, glucose and lactose (also referred to as sugars or monosaccharides)	Examples include starch and cellulose (also referred to as polysaccharides)
	
Found in foods such as fruit (fructose), honey (glucose) and milk (lactose)	Found in foods such as potatoes, rice, pasta, oatmeal, bread and vegetables

Table 2.1 Types of carbohydrates

carbohydrate
biological molecule made of carbon, hydrogen and oxygen, which can be broken down with the release of energy in the body

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; can also be used as an energy source

enzyme
a biological catalyst that increases the rate of a chemical reaction without itself being changed by the reaction

antibody
also called immunoglobulin; a protective protein produced by the immune system in response to the presence of a foreign substance (called an antigen)

Lipids

Fats and oils, also called **lipids**, are greasy substances that also provide the body with energy. A gram of fat provides at least twice as much energy as a gram (g) of carbohydrate, but the energy stored in fats and oils cannot be obtained as quickly as the energy in carbohydrates. The body also uses fat for long-term energy storage.



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

When carbohydrates are not available for energy, such as when you do not eat for a while when you are ill, or when people choose to fast or go on a ketogenic diet, the human metabolism will switch to fat-burning mode for energy. 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. For example, haemoglobin carries oxygen around in the bloodstream.
- Some proteins are used to make **antibodies**, which enable your body to resist infectious diseases.

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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). The amino acids can then be reassembled to make structural and functional proteins. Major dietary sources of protein include meat, fish, dairy, legumes, nuts and seeds.

amino acid
an organic molecule that forms the basic building block of a protein

While amino acids from protein can be used as a source of energy, this usually only happens when there is a surplus of protein 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.

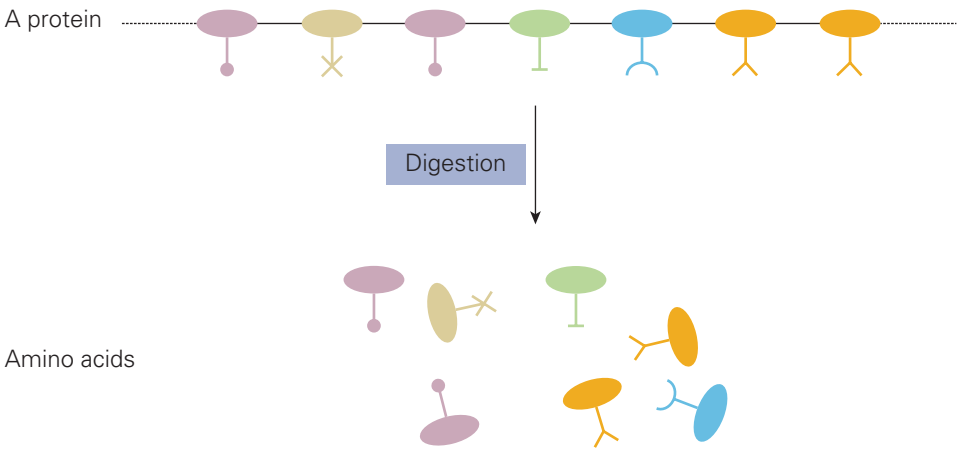


Figure 2.8 During digestion, proteins are broken down into individual amino acids. Your body cannot absorb protein molecules, but amino acids can be absorbed and reassembled within the body to build new proteins.

Vitamins and minerals

Your body needs tiny amounts of essential micronutrients known as vitamins and minerals. These chemical compounds assist in thousands of chemical reactions in the body: some work with enzymes as catalysts; others play a role in strengthening your bones, healing wounds and helping nerve cells conduct electrical impulses; and others assist in the breakdown of carbohydrates and proteins. A deficiency of vitamins can lead to disease, such as scurvy or rickets. Most people

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can get all of the necessary vitamins and minerals by eating a healthy, varied diet and do not need to routinely take supplements in tablet form. Some vitamins and minerals are toxic when taken in excess of the body's requirements.



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

Explore! 2.1

Scurvy

Throughout the thirteenth to sixteenth centuries, thousands of sailors and explorers on long journeys died from what is now known to be a preventable disease: scurvy. Research some of the gruesome symptoms that were observed aboard the sailing ships, and what treatments people used for this disease at the time.

Quick check 2.2

1 State the four main groups of nutrients that your body needs.
2 Draw up a table to describe the function of each of the four nutrient groups in the body. You may use this text or use your preferred search engine to do further research.

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Practical 2.1: Investigation

Measuring the energy content in food

Be careful
No food items are to be consumed.

Aim
To investigate the amount of chemical energy stored in various foods.

Planning
1 Write a rationale about the chemical energy stored in food and the different components of food that provide energy.
2 Based on your knowledge of the investigation, write a hypothesis on which food sample/s will transfer the most energy.
3 Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
4 Complete a risk assessment for this investigation, describing how any risks will be controlled.

Materials
- large test tube
- test-tube rack
- test-tube holder (wooden peg)
- heatproof mat
- bottle cork with a needle inserted into the top
- thermometer
- tin can open at both ends (to act as a chimney)
- 25 millilitres (mL) measuring cylinder
- assorted food samples, e.g. Twisties (do not use nuts)
- measuring scale

Method
1 Draw the results table below.
2 Place the tin can, Bunsen burner and cork on the heatproof mat. Ensure the room is well ventilated to avoid a build-up of smoke.
3 Use the measuring cylinder to pour 10 mL of water into the test tube.
4 Measure the starting temperature of the water and record it in the results table.
5 Measure the mass of the food sample and record it in the results table.
6 Place the food sample on the needle.
7 Have the test tube in its holder, ready to be placed over the flame.
8 Use the Bunsen burner to light the food sample. Immediately place the tin can over the top and hold the bottom of the test tube in the flame.

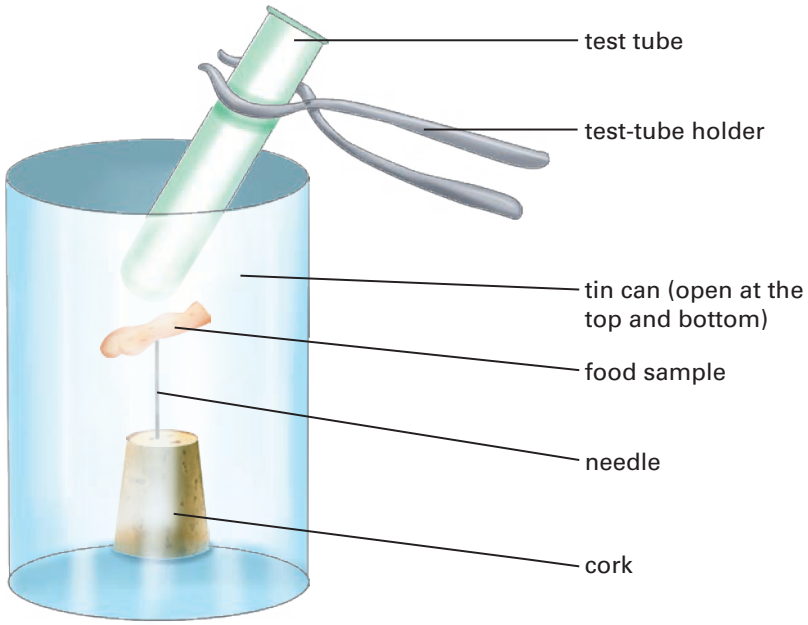


Figure 2.10 Experimental set-up

9 Measure the final temperature of the water as soon as the food sample is completely burned out and record it in the results table. (If it doesn't burn completely, relight it from the Bunsen burner and continue immediately.)

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…continued

10 Repeat with other food samples.

11 It takes 42 joules to raise the temperature of 10 mL of water by 1°C. Multiply the temperature change for each sample by 42 to find the energy content of the sample.

Results

Type of food	Energy content per 100 g (J)	Mass (g)	Starting temperature (°C)	Final temperature (°C)	Temperature change (final – starting temperature) (°C)	Energy content (temperature change × 42 joules) (J)

Discussion

1 Describe any trends, patterns or relationships in your results.

2 When the food was burned, the chemical energy was released as heat energy which was measured by how much it heated up the water. Deduce whether any energy was lost, and if so, how.

3 Identify the foods that contained the most and least energy per gram. Was your hypothesis supported?

4 Identify any unusual results that you found.

5 Compare the actual energy content per 100 g of food (found on the nutritional label) with the energy content that you calculated.

6 Identify any potential sources of error in this experiment.

7 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

Draw a conclusion from this experiment regarding foods and energy content. Justify your answer with data.

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. Some athletes and others now choose to use fat instead of carbohydrates as their main energy source most of the time. The internationally accepted unit for measuring the energy contained in food is kilojoules (kJ). This unit is used in Australia although labels sometimes show kilocalories (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 (2079 Cal), and you will see this used as the average value on nutritional labels. However, keep in mind that everyone's energy requirements are different, and they vary widely according to age, gender, height, weight and level of physical activity. People with certain illnesses, or who are pregnant, will also have additional energy requirements.

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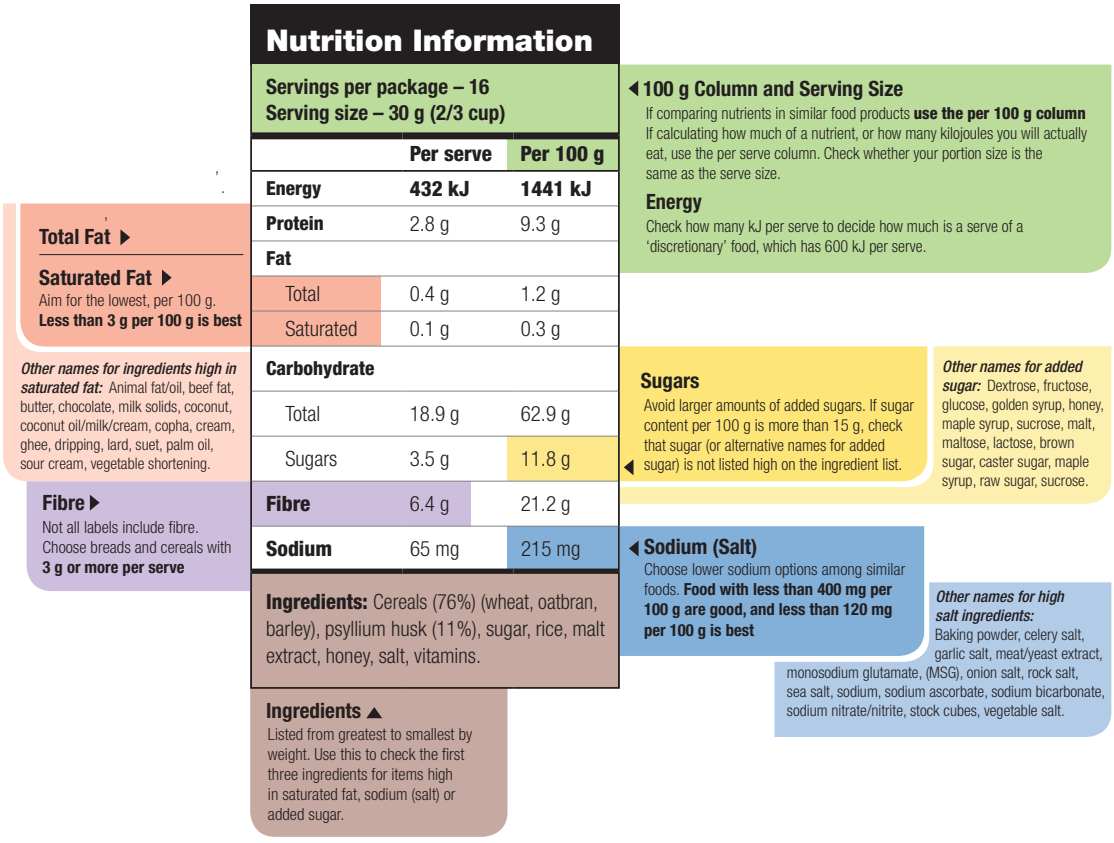


Figure 2.11 Nutrition labels shown on food packages provide the nutritional facts of the food. Note that certain types of fat are healthy, and everyone has different nutritional needs.

Try this 2.2

Bring in a food wrapper with the nutritional content supplied on it to analyse in class.
The following table summarises the energy content of the different components of food.

Food	Energy content
1 g of protein	17 kJ or 4 Cal
1 g of fat	37 kJ or 9 Cal
1 g of carbohydrate	17 kJ or 4 Cal

Calories are an old unit for measuring food energy (1 kilocalorie – usually written as 1 Cal – is 1000 calories). In science the kilojoule (kJ) is used.

- 1 Cal = 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 kJ per 100 g		
Protein (kJ) per 100 g		
Fat (kJ) per 100 g		
Carbohydrate (kJ) per 100 g		

Summarise the findings from the table above in a paragraph.

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Science as a human endeavour 2.1

Hydration

More than half of your body by mass is water; it is found in your blood, inside your cells and between your cells. You use water to maintain your blood pressure and your body temperature and for many other day-to-day functions. It is recommended that you drink 2 L of water per day, as fluids are readily lost through sweating, passing urine and even breathing! This fluid loss is heightened when you are exposed to high temperatures and during high-intensity exercise, so you need to increase your fluid intake to match the loss to prevent your body from becoming dehydrated.

Physiologically, dehydration leads to decreased blood pressure, increased heart rate and temperature, and a loss of physical coordination, meaning you are not performing at your best. A lot of energy is expended trying to regulate the internal conditions. As dehydration progresses, you can experience muscle cramping, nausea, vomiting and diarrhoea, as well as accompanying psychological symptoms such as a decrease in concentration and mental functioning.



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

Most elite athletes playing Australian Rules football can expect to lose, on average, approximately 1 L of fluid per hour, and in hot, humid weather 2–3 L per hour. One way they combat this is by drinking sports drinks, which contain water, carbohydrates and salts that are claimed to result in improved hydration. Sports drinks often contain high levels of sugar, and scientific studies have shown they contribute to childhood obesity (as teenagers drink them when not engaging in sports) and tooth decay in elite footballers.

Did you know? 2.1

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 L 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 kilometres per hour! A driver could weigh 3 kilograms (kg) less at the end of a race than at the start simply because of water loss, but this is readily regained as they replenish their bodies with fluids and food.



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

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Practical 2.2

How much sugar do different types of soft drink contain?

Be careful
No food items are to be consumed.

Aim

To determine how much sugar is in different soft drinks. Because it is difficult to extract the sugar from the drinks and weigh it, you must use a different method. The more sugar that is dissolved in water, the denser the liquid will be (that is, the same volume will weigh more). You will graph the density of different concentrations of sugar in water – this will be your reference graph. Then you will measure the density of the soft drinks and estimate the concentration of sugar they contain from your reference graph. This assumes that it is only the sugar content of the soft drinks, and no other dissolved substance, that affects the density.



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

Materials

- Three different types of regular (not diet) soft drink, for example, cola, lemonade, ginger beer. These should be poured out into jugs or large containers and labelled 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 (that is, there are no bubbles in the liquid).
- sugar
- water
- 500 mL measuring cylinder
- scale
- stirrer

Method

Sugar solution reference graph

1 Draw the results table below.
2 Record the mass of the empty measuring cylinder in column A in each row of the results table.
3 Add 20 g of sugar to the measuring cylinder.
4 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.
5 Measure and record the mass of the measuring cylinder and sugar solution in column B in the first row of the results table.
6 Subtract the mass of the measuring cylinder (column A) from its mass with the sugar solution (column B). Record this measurement in column C in the first row of the table. It is the mass of 200 mL of the sugar solution.
7 Empty the measuring cylinder, rinse and shake to remove drops of water from it.
8 Add 40 g of sugar to the measuring cylinder, and repeat steps **4–7**, recording the results in the second row of the table.
9 Add 60 g of sugar to the measuring cylinder, and repeat steps **4–7**, recording the results in the third row of the table.
10 Calculate the density of the sugar solutions for the three rows of the results table by dividing the mass in column C by the volume of the solution (that is, 200 mL), and record the results in column D.

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

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11 Draw a line graph showing the density of the sugar solution (*y*-axis, g mL^{-1}) 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 solution (g)	A Mass of measuring cylinder (g)	B Mass of measuring cylinder + sugar solution (g)	C (= B – A) Mass of sugar solution alone (g)	D (= C/200) Density of sugar solution (g mL^{-1})
20 g sugar				
40 g sugar				
60 g sugar				

Soft drink

1 Draw the results table below.
2 Record the mass of the empty measuring cyclinder in column A in each row of the results table.
3 Add 200 mL of flat soft drink to the measuring cylinder, and record the name of the soft drink in the first column of the table below.
4 Measure and record the mass of the measuring cylinder with the soft drink and record the weight in column B of the results table.
5 Subtract the mass of the measuring cylinder (column A) from the mass of the measuring cylinder and the soft drink (column B). Record this measurement in column C. It is the mass of the soft drink alone.
6 Empty the measuring cylinder, and rinse and shake the cylinder to remove drops of water.
7 Repeat steps **3–6** using the other two soft drinks.
8 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.

Name of the soft drink	A Mass of measuring cylinder (g)	B Mass of measuring cylinder + soft drink (g)	C (= B – A) Mass of soft drink alone (g)	D (= C/200) Density of soft drink (g mL^{-1})

Results

1 On the *y*-axis of the reference graph, mark and label the density of the first soft drink. 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.
2 Repeat for the two other soft drinks.

Discussion

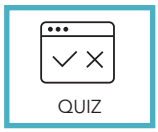
1 Compare the actual sugar content per 100 mL of soft drink (found on the nutritional label) with the mass of sugar that you calculated.
2 Identify any potential sources of error in this experiment.
3 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

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Quick check 2.3

1 State the standard measured unit for energy in food.
2 Recall the approximate daily energy requirements for a healthy adult.
3 Define the term 'dehydration' and explain why it is so important to keep hydrated.

Section 2.1 questions



Remembering

1 **Recall** one major difference between a unicellular and a multicellular organism.
2 **State** three requirements for healthy human life.
3 **State** two ways that water is lost through the body.
4 **State** four essential nutrients that a healthy diet should include.

Understanding

5 **Identify** two possible places or ways that excess carbohydrates can be stored in the body.
6 **Calculate** the energy in kilojoules from the following food types: (Remember that kilojoules and Calories both measure energy: 1 Calorie (Cal) = 1 kilocalorie = 1000 calories = 4.184 kJ.)
   a One 600 g jar of homemade tomato sauce contains 172 Cal energy.
   b Two tablespoons (30 g) of peanut butter contain 185 Cal.
   c Four Weetbix contain 107 Cal.
   d One red apple, raw and with the skin on, contains approximately 60 Cal.

Applying

7 **Explain** what occurs during the process of cellular respiration.
8 **Describe** three different functions of proteins in the human body.

Analysing

9 **Classify** the following organisms as either unicellular or multicellular.
   a Bacteria
   b Horses
   c Jellyfish
   d Amoebas
   e Paramecia
   f Platypuses
   g Archaea
   h Yeast
   i Crocodiles

Evaluating

10 An athlete is contemplating going on a diet to lose some weight and decides to minimise their carbohydrate intake. **Propose** some potential consequences or considerations for the athlete.
11 Women generally 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 per gram than carbohydrates. **Propose** why athletes don't eat lots of fatty food just before they compete.
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, one in four Australian children was overweight or obese in 2017–18. **Decide** whether childhood obesity is a problem in Australia. Recommend several strategies to reduce childhood obesity rates.
15 If the Western Australian Government banned all sugary foods and drinks in schools, would this solve obesity in children? **Discuss** the pros and cons of this rule.

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2.2 Body systems working together

WORKSHEET

Learning goals

1. To be able to define homeostasis.
2. To be able to construct a stimulus-response model.
3. To explore how blood sugar and water levels are regulated by the human body.
4. To be able to explain how the respiratory and circulatory systems work together to regulate oxygen in the bloodstream.

Coordination: it's a team effort!

Within the human body, 11 major organ systems interact with each other to enable humans to grow, maintain life and reproduce. Each system depends upon other systems to keep the body functioning at an optimal level, and each is made up of organs with highly specific functions. The systems are:

- circulatory
- endocrine
- skeletal
- reproductive
- digestive
- excretory
- nervous
- muscular
- immune
- integumentary (skin and outer body coverings)
- respiratory.

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

All multicellular organisms depend upon their body systems working together to maintain homeostasis. The body does an amazing job to maintain a stable internal environment, despite considerable changes within the external environment. This process is known as **homeostasis**. When a change occurs in an animal's external environment, such as an increase in temperature, an adjustment must be made so that the internal environment of the body and cells remains stable.

The nervous system plays the primary role in controlling and coordinating most actions of the human body. It works in partnership with the endocrine system, which produces

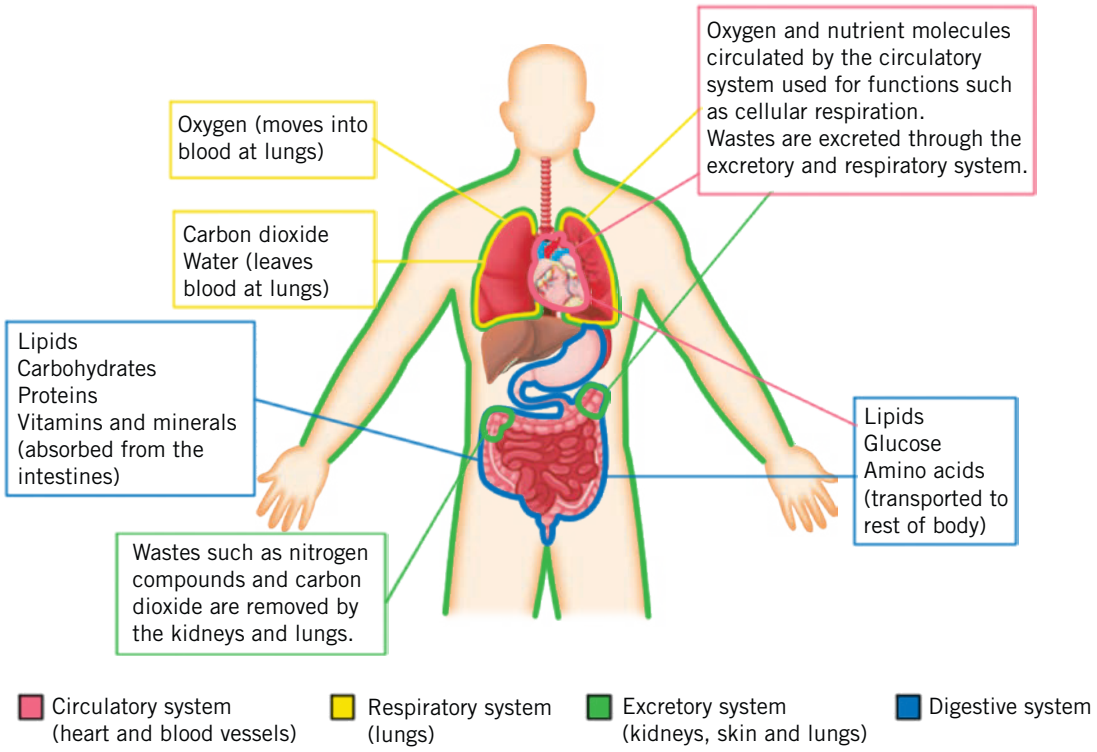


Figure 2.15 An example of how 4 of the 11 body systems work together with other systems

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particular hormones that are released into the blood stream in response to external or internal changes. Together they form a team: the nervous system provides fast-acting, short-lasting effects and the endocrine system triggers slow-acting, long-lasting effects.

Stimulus–response model

To achieve homeostasis, the body needs to respond to changes within the body's internal and external environment as the result of **stimuli**. Changes are detected by **receptor** sites within the body, and if a response is required, then certain actions are brought about by **effectors** within the body to bring the body back to its 'normal' or optimum level. This can be described using the five-step stimulus–response model, shown in Figure 2.16 and Table 2.2.

VIDEO
Describe how negative feedback works

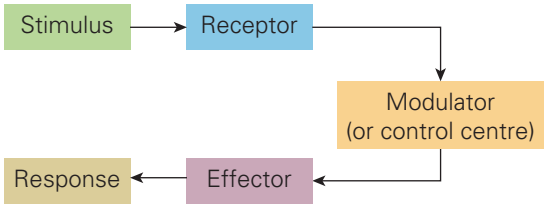


Figure 2.16 A flow chart outlining the stimulus–response model

Stage	Description	Example
Stimulus	The thing that has changed in the external or internal environment	External temperature drops drastically
Receptor	Specialised cells that detect the change and send a stimulus signal to the modulator	Temperature receptors (thermoreceptors) in the skin
Modulator	Receives the signal from the receptors and coordinates the response, sending a response signal to the effector	Hypothalamus in the brain receives the information regarding the drop in temperature and sends an electrochemical signal to the effector
Effector	The muscles or organs that are signalled to cause the response	Muscles begin to contract and relax quickly (shivering) to generate heat
Response	The body returns to a state of balance so the receptors are no longer active	Body core temperature is raised back to within normal range

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

stimulus (plural: stimuli) any object or event that elicits a sensory or behavioural response in an organism

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

effector a muscle, gland or organ capable of responding to a response signal from the modulator

Explore! 2.2

X-ray art

X-ray art is an artistic style used by the Aboriginal peoples of Arnhem Land to draw native animals. This style of painting using the cross-hatch design is known as 'rrark'. Animals are painted showing some internal anatomical features. Use the internet to find some more examples of paintings, sculptures or headdresses produced by Aboriginal and Torres Strait Islander peoples that show internal features of animals.



Figure 2.17 Aboriginal paintings depicting X-ray figures stand on Nourlangie rock in Arnhem Land, Northern Territory.

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Quick check 2.4

1 Define the term 'homeostasis'.
2 Explain why homeostasis is so important to your survival.
3 State the part/s of the body that are involved in maintaining homeostasis.
4 Create a stimulus–response model in your notes or on A4 paper and annotate it with information about each of the five parts, similar to Figure 2.18.

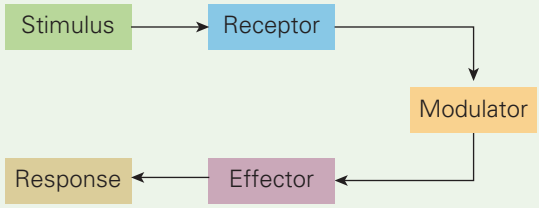


Figure 2.18 A flow chart outlining the stimulus–response model

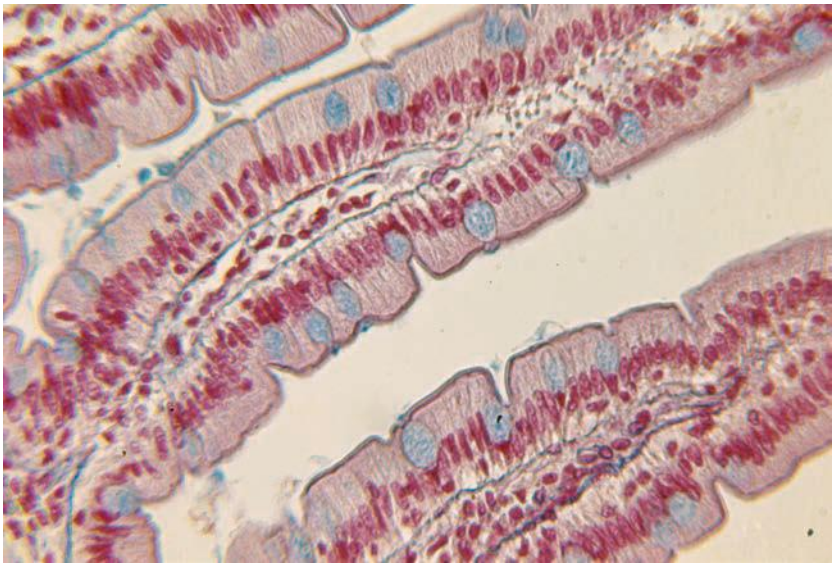
Body systems maintain homeostasis

The digestive system

The food you eat contains a variety of nutrients that are necessary for building new body tissue, repairing damaged tissues and providing energy to power your cellular processes. The digestive system enables you to break down the food you eat and absorb the nutrients along with all their stored energy. It also enables you to absorb water, vitamins and minerals, and to eliminate wastes from the body.

For example, recall that your body needs glucose for cellular respiration. When you consume carbohydrates, enzymes begin to break them down from the moment they enter your mouth: even a savoury cracker begins to taste sweet when left on the tongue for a few minutes as enzymes in saliva begin to break the complex carbohydrates down into sugars. This partially digested food is then broken down physically (by the teeth), before it progresses through the digestive system and continues to be broken down chemically (by enzymes). The smaller molecules, such as glucose, will diffuse across the cell membranes in your intestines and be absorbed into the bloodstream, ready to be circulated around the body to where they are needed.

Figure 2.19 Specialised cells, called villi, in the intestines have a high surface area to aid the absorption of nutrients into the bloodstream.



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Diffusion is the movement of a substance from an area of high concentration to an area of low concentration. If a drop of dye is added to a glass of water, without stirring, the dye will gradually spread and colour the entire contents – this is an example of diffusion. It is an important process for moving substances within cells as well as into and out of them. When glucose-rich blood flows near actively respiring cells (which are using glucose), glucose will diffuse from the blood into those cells.

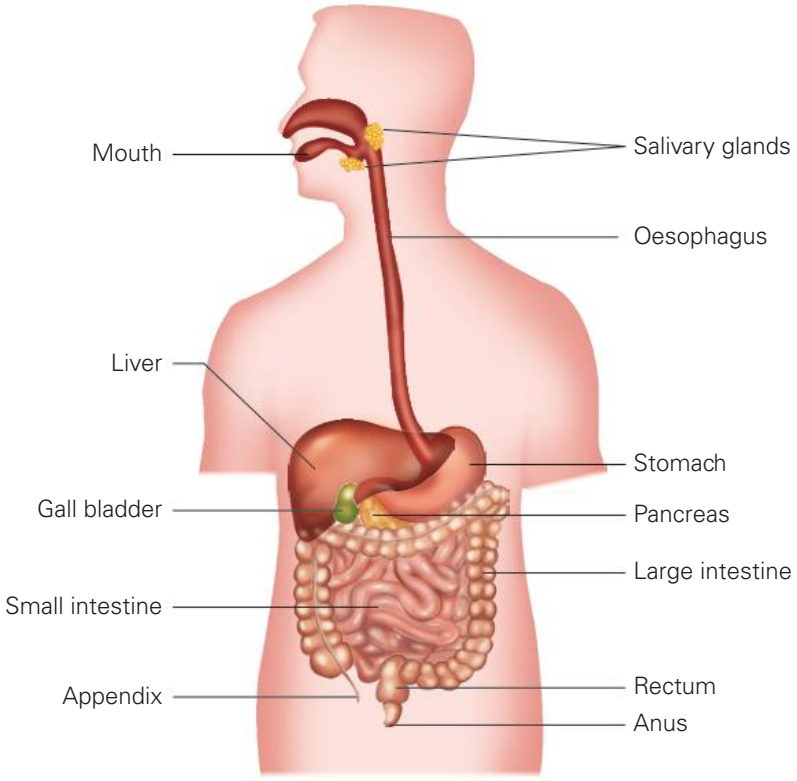


Figure 2.20 The human digestive system

Did you know? 2.2

No stomach

The platypus and echidna, both egg-laying mammals (monotremes), do not have stomachs. With the use of DNA sequencing, scientists discovered that the genes responsible for making important digestive enzymes are missing and that the platypus and echidna evolved without a stomach.



Figure 2.21 Both the platypus and echidna do not have a stomach.

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WIDGET
Maintaining homeostasis

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 doughnuts in a row, your body is swamped with glucose and your blood sugar levels surge. Similarly, your body must also cope with prolonged periods of time when you do not ingest any glucose – like when you are asleep! Such drastic swings must be managed and the glucose level must be kept constant.

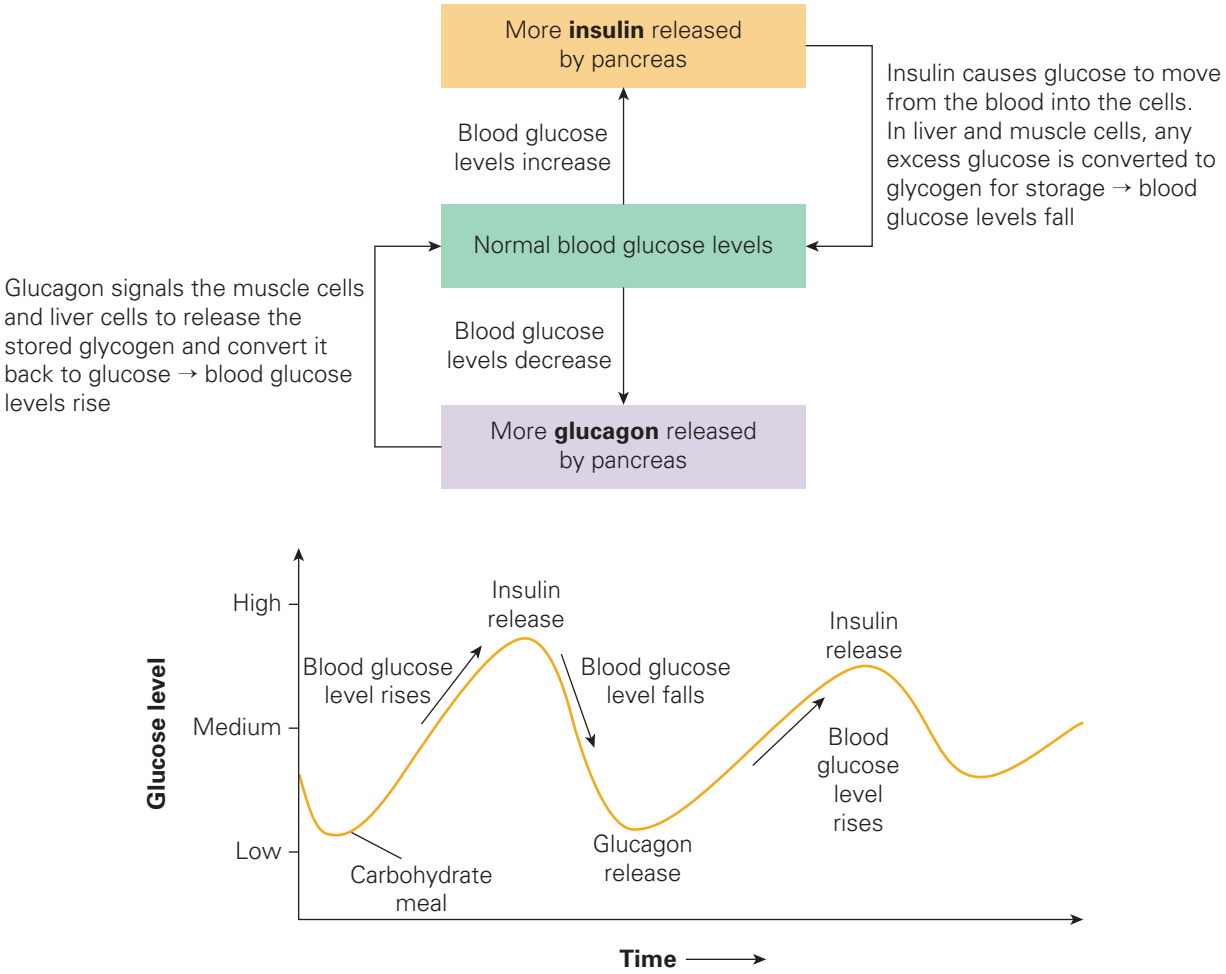


Figure 2.22 After a carbohydrate-rich meal, insulin levels in the bloodstream increase as the body needs to decrease the blood glucose levels.

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

glucagon
a hormone secreted by the pancreas that triggers the liver and muscle cells to convert glycogen into glucose, raising blood glucose levels

Homeostasis of blood glucose levels is controlled by two hormones that are secreted by the pancreas: **insulin** and **glucagon**. Both hormones are slow-acting products of your endocrine system and they act upon effectors (which are usually glands or organs) to bring about opposite changes to regulate the blood sugar level. They are released in different amounts, according to your blood glucose levels (see Figure 2.22).

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Try this 2.3

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, modulator, effector and response.
Extension: Try to draw a double loop that shows both scenarios!

Explore! 2.3

Diabetes

Diabetes is a medical condition where the body does not produce enough insulin or the body cells become resistant to insulin over time. It has become increasingly common in Australian society, due in part to some lifestyle factors. Research the following questions:

1 What is the difference between type 1 and type 2 diabetes?
2 Who is normally affected by each type of diabetes and at what age is it typically diagnosed?
3 How is each type of diabetes treated?
4 What are some of the factors that predispose people to developing diabetes?



Figure 2.23 Insulin is injected into the body by a person with diabetes.

Quick check 2.5

1 Recall the primary role of the human digestive system.
2 Describe the role that digestive enzymes play in providing energy to your cells.
3 After a meal rich in simple carbohydrates, your blood glucose levels rise sharply. Recall the hormone that is released by the pancreas to decrease the levels.

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The excretory system

The digestive system works very closely with the excretory system, of which the main responsibility is the removal (excretion) of wastes and excess water from the body. The excretory system includes the liver, kidneys, and associated organs such as the ureters and bladder. However, other organs such as the large intestine, skin and lungs also play a role in the excretion of certain substances. The major excretory organs are summarised in Table 2.3.

nephron
the functional unit of the kidney, involved in filtering the blood to produce urine

Organ	Role in excretion
Kidneys	Filter the blood and form urine which allows removal of urea, excess salts and water
Large intestine	Stores waste material not absorbed after digestion, forming faeces which are passed from the body
Liver	Breaks down alcohol, toxins and excess amino acids (from proteins) that are in the bloodstream
Lungs	Exhale water vapour and carbon dioxide
Skin	Secretes sweat (which contains some waste materials) for temperature control

Table 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 1 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 lets them work 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 such as urea, poisons, and excess water and ions [salts] taken in through your diet). The waste fluid then leaves the nephrons, moves along tubes called ureters and enters the bladder where it will eventually be passed out as urine (see Figure 2.24). The nephrons of the kidney filter 100 mL of fluid every minute, but only 1 mL of this finds its way into the bladder.

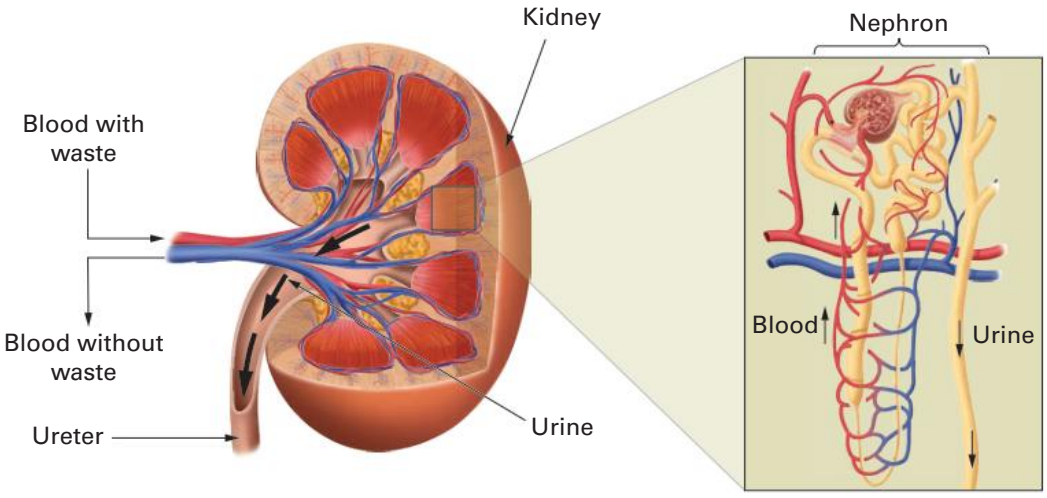


Figure 2.24 The structure of the kidney and one nephron: the functional unit of the kidney

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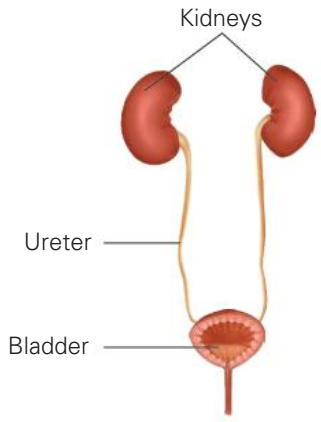


Figure 2.25 A simple overview of the organs involved in urine production, storage and excretion

Regulating water levels

Regulation of the amount of water in the blood is a very important example of homeostasis. It is often referred to as **osmoregulation**. The amount of water in the blood is measured continuously by a group of osmoreceptors in the hypothalamus of the brain. 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 in response to dehydration is controlled by antidiuretic hormone (ADH), which is formed in the hypothalamus but stored in the pituitary gland. Many body systems are involved in the process.

1 Osmoreceptors in the hypothalamus (central nervous system) detect low blood water levels.
2 The hypothalamus triggers the pituitary gland (central nervous system) to release antidiuretic hormone (ADH).
3 ADH is carried by the blood (circulatory system) to the kidneys.
4 ADH increases the ability of the kidney tubules (excretory system) to reabsorb water and return it to the blood.
5 Water levels in the blood increase to their normal level.

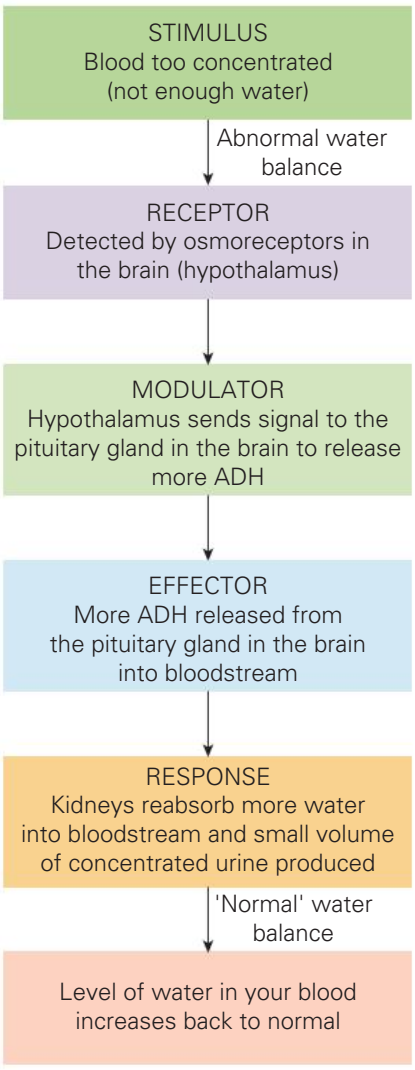


Figure 2.26 The stimulus–response flow chart for when water levels are low

osmoregulation
the regulation of water levels in the blood/body

Try this 2.4

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, modulator effector and response.

Quick check 2.6

1 Recall the organs that are involved in excretion of wastes.
2 State two functions of the excretory system.
3 Identify the part of the kidney that is responsible for filtering blood. Describe its role.
4 Recall what ADH stands for and its role in osmoregulation.
5 State the part of the brain that monitors blood water concentration.

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Did you know? 2.3

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 them out of the athlete's system.

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



Figure 2.27 Athletes may be banned for taking diuretics.

The respiratory and circulatory systems

The respiratory system and the circulatory (also called cardiovascular) system work together to keep up a constant supply of oxygen to the cells of the body. The systems work together to ensure that the cells obtain the required amount of oxygen to perform cellular respiration to release energy, and that they can also get rid of the waste product – carbon dioxide. The respiratory system (lungs and diaphragm) is responsible for breathing which drives the exchange of gases. The circulatory system, as the name suggests, is responsible for circulating the respiratory gases, but also transporting nutrients, water and hormones.

The respiratory system

The respiratory system facilitates the exchange of gas inside the lungs. To breathe in, a large muscle called the diaphragm contracts, moves downwards and draws air into your lungs. The air (which is approximately 21% oxygen) travels into the nose and mouth, down the trachea (windpipe) and to branching tubes called bronchi (singular: bronchus) and smaller bronchioles into the left and right lungs.

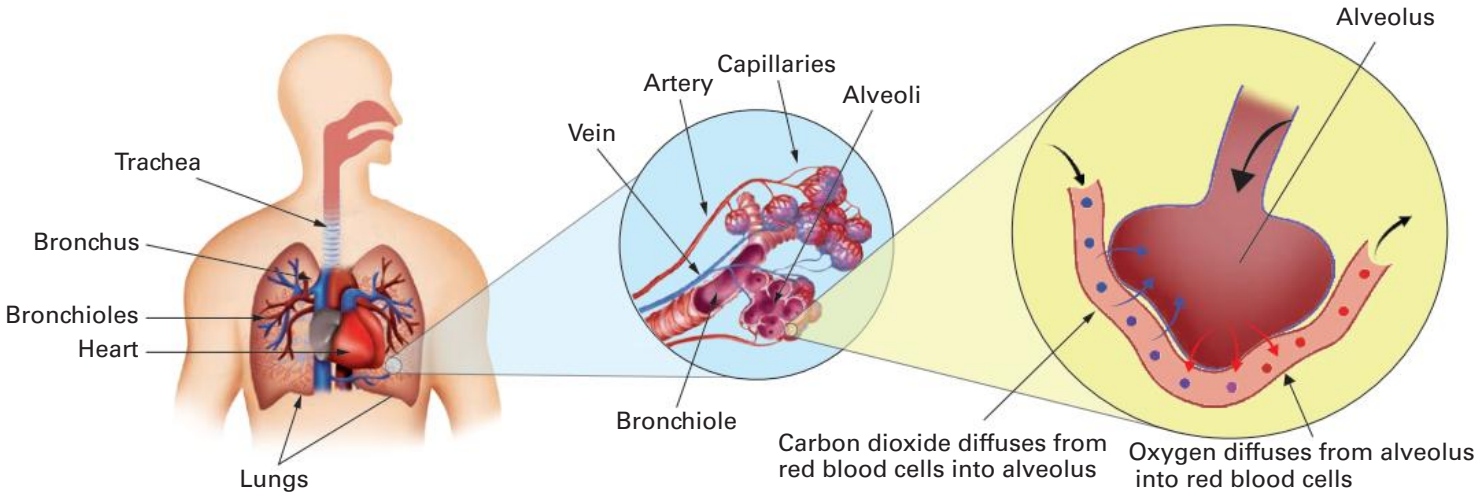


Figure 2.28 Zooming in on the respiratory system

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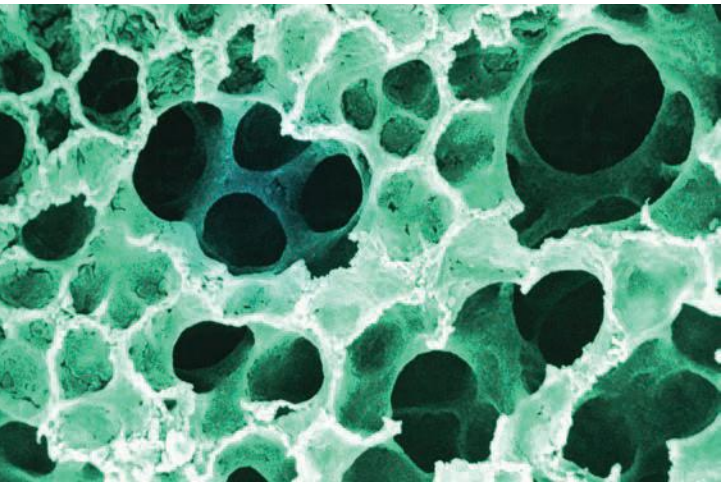


Figure 2.29 Alveoli in the lungs

These tubes terminate in microscopic air sacs called **alveoli** (singular: 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! 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, which 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).

The circulatory system

The circulatory system is the transport system of the body. It has four main functions, which are to:

- transport nutrients, gases, hormones and waste products around the body
- protect the body from infection by transporting antibodies
- help maintain body temperature
- help maintain fluid balance within the body.

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.

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 can take a continuous reading of your pulse in bpm.

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

capillaries
(singular: capillary) the smallest vessels that contain oxygenated blood and enable red blood cells to deliver oxygen to the tissues on a cellular level

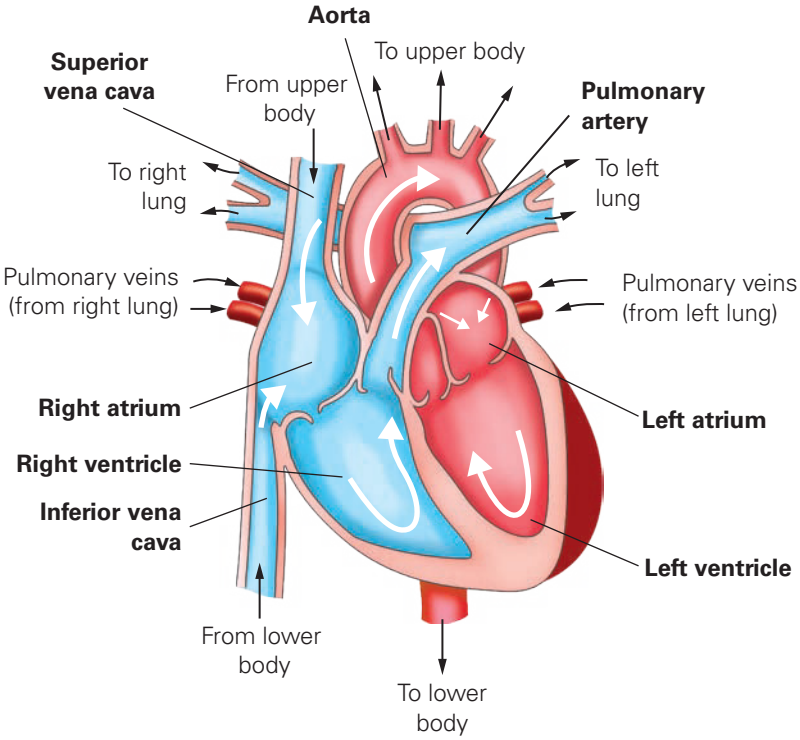


Figure 2.30 Human heart anatomy diagram showing blood flow with main parts

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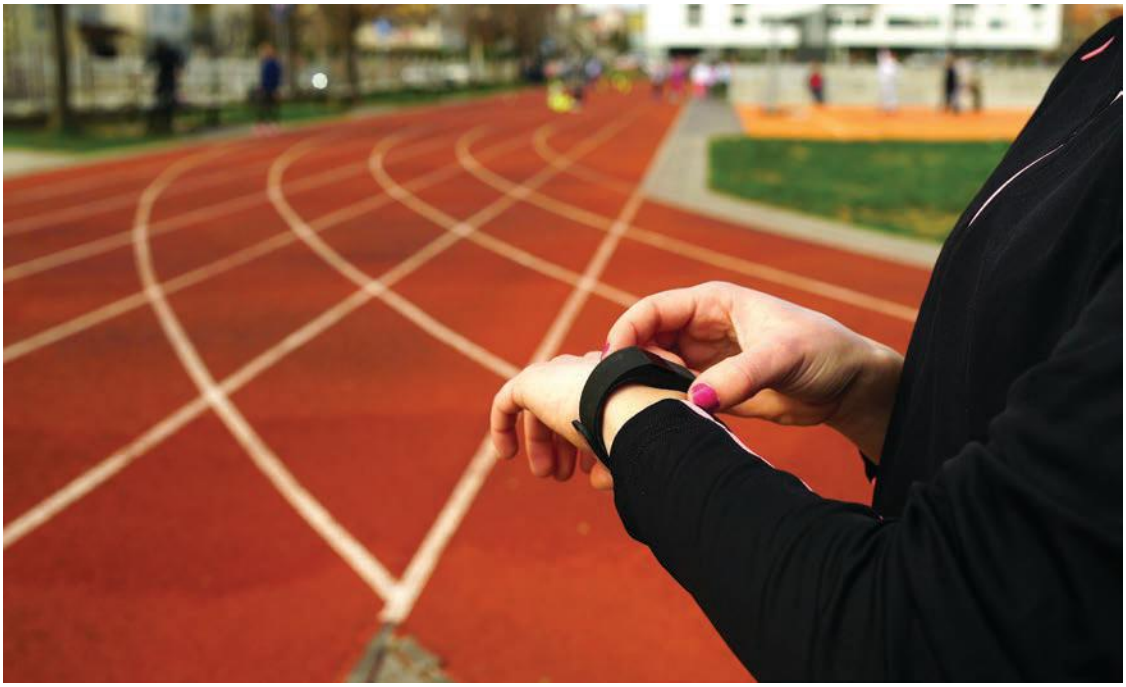


Figure 2.31 Modern sports watches allow you to continuously monitor your heart rate over the course of a day.

Try this 2.5

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.

Maintaining blood pressure

Homeostatic control of blood pressure is critical to your survival. If your blood pressure is too high, it can result in damage to internal organs, and if your blood pressure is too low, you can lose consciousness. The heart and blood vessels contain special pressure receptors (baroreceptors) that can detect the change in blood pressure. If the blood pressure decreases, signals are sent from the brain stem to the heart to allow for the blood vessels to constrict (get smaller) and the heart rate to increase, also increasing blood pressure.

As you know, the kidneys regulate the amount of water in the blood. In doing so, they also play a role in regulating blood pressure. Too much water and the blood pressure is high, too little water (as in dehydration) and the blood pressure is low. If blood pressure is too high, the brain stem sends signals to the heart to slow down and to the blood vessels to dilate, thus lowering blood pressure.

Try this 2.6

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.
Extension: Draw a double loop that shows both scenarios.

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Quick check 2.7

1 Compare the functions of the respiratory system with the functions of the circulatory system.
2 Explain why you need oxygen and why you need to get rid of carbon dioxide.
3 Recall the location of the receptor sites that detect changes in blood pressure.
4 Other than the heart, recall an organ that is involved in maintaining blood pressure.

Practical 2.3

Exercise, heart rate and breathing rate

The body's energy needs vary according to how active you are. When you are resting, less energy is required, so you consume less oxygen. However, your respiratory and circulatory systems must work together to meet your increased energy needs during exercise.

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

- increasing your respiratory rate (breaths per minute) – breathing harder and faster means more oxygen can diffuse into the bloodstream and you can also exhale more carbon dioxide
- increasing your heart rate and blood pressure – this pumps the oxygen faster to the cells.

Aim

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

Planning

Construct a specific and relevant research question for this activity.

Materials

- stopwatch
- calculator
- (optional) sporting watch/device that may record pulse in bpm or pulse oximeter

Method

1 Draw the results table below.
2 Measure your partner's resting heart rate by placing your index and middle fingers on the inside of their wrist. Using the stopwatch, count the number of beats in a 15-second period. (Optional: wear a heart rate monitor.)
3 Get your partner to count how many times they exhaled in this 15-second period.
4 Multiply both numbers by 4 to get beats per minute and breathing rate per minute. Record these in the table.
5 Instruct your partner to walk at their usual pace outside for a 2-minute period (low intensity). When the 2 minutes is up, immediately measure their heart rate and get them to count how many times they take a breath in a 15-second period.
6 Multiply both values by 4 and record in the table.
7 Measure the heart rate and breathing rate twice more: once 1 minute after they stopped walking and once 2 minutes after.

continued…

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…continued

8 Instruct your partner to run around outside and use the stopwatch to time them for a 2-minute period (high intensity). When the 2 minutes is up, immediately measure their heart rate and get them to count how many times they take a breath in a 15-second period.
9 Multiply both values by 4 and record these in the table.
10 Measure the heart rate and breathing rate twice more: once 1 minute after they stopped walking and once 2 minutes after.

Results

Time after exercise (minutes)	Heart beats in 15 seconds	Heart rate per minute (bpm)	Breathing rate in 15 seconds	Breathing rate per minute
At rest (resting)				
Low-intensity exercise (2-minute walk)				
0				
1				
2				
High-intensity exercise (2-minute run)				
0				
1				
2				

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

Discussion

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

Conclusion

Draw a conclusion from this experiment regarding the level of exercise intensity and heart rate and breathing rate. Justify your answer with data.

Extension

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

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Science as a human endeavour 2.2

Bioprinting and the creation of organs

People can live longer and healthier lives these days, 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 from 2016 to 2018 can expect to live an average of 80.7 years, and a girl would be expected to live an average of 84.9 years. This compares to average lifespans of 47.2 years for males and 50.8 years for females born from 1881 to 1890.

Approximately 1700 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, into a skin cell, lung cell or liver cell). These stem cells can be harvested from a patient who needs a new organ, 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. Now that it has been recognised for its biological applications, it is necessary to ensure sterile and tightly controlled conditions. Many challenges 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.

Explore! 2.4

Bioprinting

Research the 3D Print Exchange site, which is organised by the National Institute of Health (NIH) in the United States. 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.



Figure 2.32 This 3D bioprinter developed by the Russian company 3D Bioprinting Soltions is capable of printing live organs.

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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 **Identify** the correct word to complete the following sentence. The functional unit of the kidney is called a _____.
3 **Recall** the two structures where gas exchange occurs in the lung.
4 **Recall** the hormones that are secreted by the pancreas and what effect they have.

Understanding

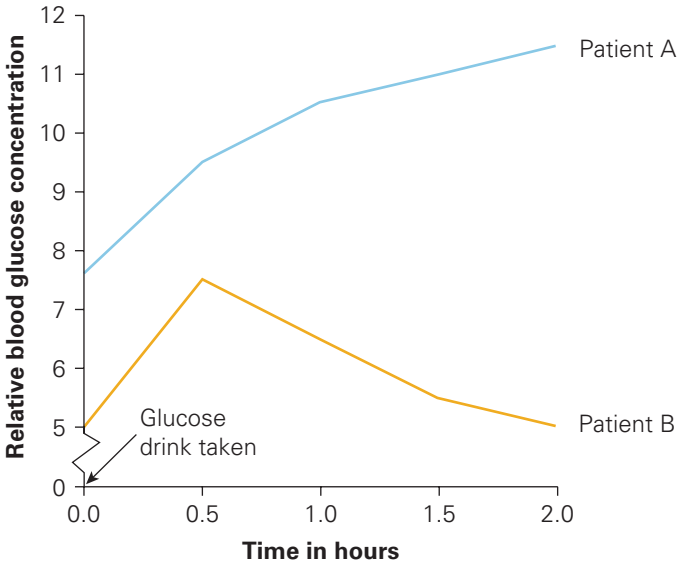
5 **Explain** how the body responds to the increased energy demands of exercise.
6 During long and frequent periods of exercise an athlete is likely to reduce muscle mass. **Explain** why.

Applying

7 A person who has undergone a serious and lengthy surgical operation stands up for the first time after the surgery. They lost a significant amount of blood during the procedure and their blood pressure is low, making them feel dizzy. **Construct** a stimulus–response model showing the steps the body would take to address this deviation from normal blood pressure.

Analysing

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



Evaluating

9 **Discuss** why both the lungs and kidneys are considered to be organs involved in excretion.
10 **Summarise** the ways in which the digestive, circulatory and respiratory systems overlap. You may choose to do so in a Venn diagram.
11 **Construct** a labelled diagram showing the stages of the stimulus–response model.

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2.3 Response to microorganisms

Learning goals

1. To be able to list the different types of pathogens.
2. To be able to describe different types of bacteria.
3. To explore the three lines of defense against infection.
4. To be able to explain how vaccination and antibiotics influence an immune response.

WORKSHEET

VIDEO
Three main pathogens

Pathogens

Disease results when an infectious agent, called a **pathogen**, invades living tissue. Some pathogens are cellular; that is, they are made of cells. Examples are bacteria, fungi and parasites. Some pathogens are non-cellular, for example, viruses, viroids and prions. Individual pathogens within an infected individual replicate 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	AIDS
Gonorrhoea	Thrush	Poliomyelitis
Syphilis	Tinea	Rubella
Tetanus		Influenza
'Strep throat'		Common cold
Gastroenteritis		COVID-19
Anthrax		Mumps

Table 2.4 Some common diseases caused by different pathogens

Bacteria

Bacteria (singular: bacterium) are simple unicellular organisms called **prokaryotes**, which have a cell wall but no membrane-bound organelles (such as a nucleus or mitochondria) inside (see Figure 2.33). Individual bacteria cannot be seen with the naked eye, but a bacterial colony (group of many bacteria) will be visible if it contains a sufficient number of bacteria. Scientists therefore need a microscope to study individual bacteria.

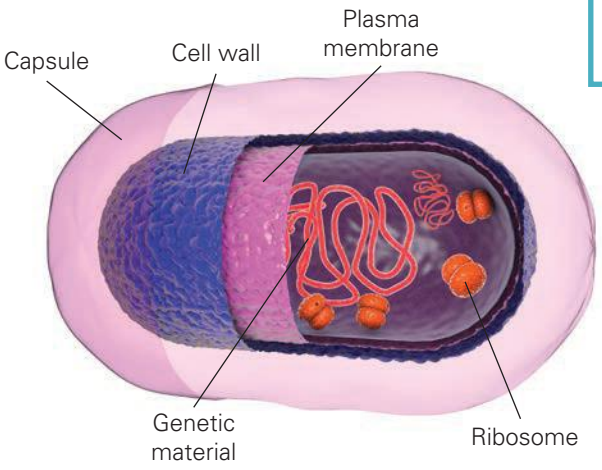


Figure 2.33 General structure of a bacterial cell

pathogen
an infectious agent, such as a bacterium, virus, prion or parasite, that can cause disease

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

prokaryote
a single-celled organism with no membrane-bound organelles (such as a nucleus), e.g. a bacterial cell

binary fission
a form of asexual reproduction; the most common form of reproduction in prokaryotes; it occurs when the cell divides, giving rise to two identical cells

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 1 bacterium, after 20 minutes, you will have 2 bacteria, then in another 20 minutes, 4 bacteria, and so on. After just 3 hours, you have had 9 cell divisions, equating to a growth from 1 bacterium to 512 bacteria. After 20 divisions, under suitable conditions, there would be over 1 million bacteria. That is why you can quickly become ill when harmful bacteria invade your body.

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Figure 2.34 Coloured scanning electron micrograph (SEM) of *Escherichia coli* bacteria (pink) on a gecko's tongue. The magnification is ×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. Recall why bacteria are considered prokaryotes.
3. Describe how bacteria reproduce, and why this is a problem if a pathogenic strain infects a person.
4. State the different names and shapes of bacteria.

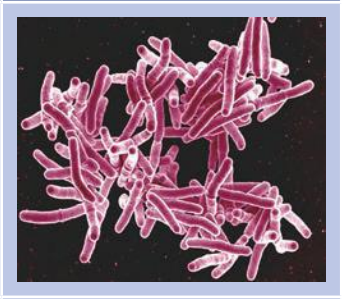
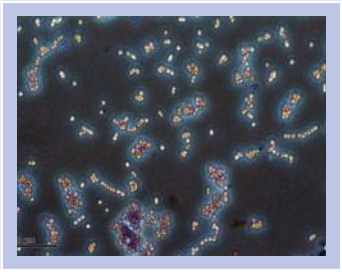
Shape	Biological name	Diseases	Magnified image
Rod	Bacillus (plural: bacilli)	Typhoid Tuberculosis	
Spiral	Spirillum (plural: spirilli)	Syphillis	
Spherical	Coccus (plural: cocci)	Streptococcus (causes tonsillitis)	

Table 2.5 Common types of disease-causing bacteria

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Did you know? 2.4

One of the first investigators of bacteria grew them on the jelly of the eye of an ox! Nowadays biologists use nutrient agar plates. Agar is a jelly derived from red algae, which some bacteria can use as food on its own. However, if a food like meat extract has been added, bacteria can readily grow on it and will divide to form colonies very quickly.




Figure 2.35 In the past, one scientist used the eye of an ox for growing bacteria. Nowadays, a nutrient agar dish is used. This one contains bacterial colonies.

Practical 2.4: Investigation

Using antibacterial agents to prevent the growth of bacteria

Aim

To determine the most effective antibacterial agent.

Planning

1. Write a rationale about antibacterial agents and their impact on bacteria.
2. Write a hypothesis about which antibacterial agents you expect to be most effective.
3. Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
4. Complete a risk assessment for this investigation, describing how any risks will be controlled.

Be careful

Ensure gloves are worn when handling nutrient agar plates. Do not sample from the body or expose the agar to any pathogenic organisms. Hands are to be washed with soap immediately after handling nutrient agar plates. All working surfaces are to be wiped down with disinfectant after all nutrient agar plates are collected. Once the plate is sealed, it is not to be reopened. Once the plate has been observed, it should be sterilised via autoclave.

Materials

- Petri dish containing sterile nutrient agar
- cotton buds
- marker pen
- masking tape
- tweezers
- filter paper
- hole punch
- different antibacterial products (e.g. cleaning products, manuka honey, hand sanitiser)
- disposable gloves
- disinfectant
- hand wash (soap)

Method

1. Using a cotton bud, wipe over an object of choice, such as a phone screen, computer keyboard, computer mouse or door handle.

continued…

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…continued

2 Using a marker, split the Petri dish into quarters by drawing on the plastic base of the dish. Label three of the quarters with three of the antibacterial products you will be testing. The fourth will be your control.
3 Open the Petri dish and swab the cotton bud gently over the nutrient agar.
4 Create some filter paper discs by using a hole punch.
5 Using the tweezers, dip one of the filter discs in one of the antibacterial products.
6 Place this disc in the centre of the appropriately labelled agar quarter.
7 Repeat steps **5–6** with two other antibacterial products.
8 Place a clean filter paper disc in the control quarter.

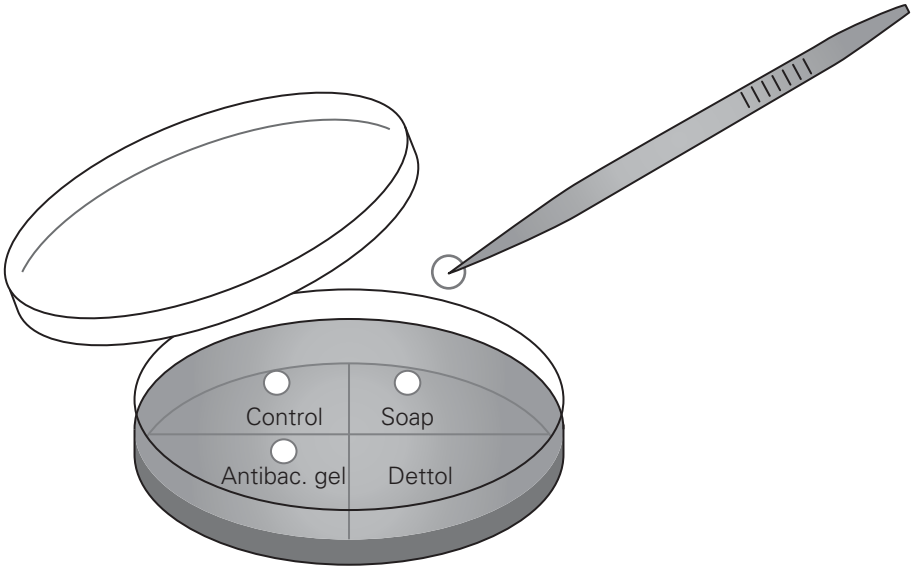


Figure 2.36 Make sure you label the outside base of the dish, not the actual agar!

9 Secure the lid with three pieces of tape.
10 Wipe down all work surfaces with disinfectant after all the nutrient agar plates have been collected.
11 The plates will be stored upside down (with the agar at the top) in an incubator at 37.6°C for 1–2 days.
12 Remove the plates from the incubator and observe the colonies of bacteria that have grown.

Warning: Microbes can produce harmful toxins, so it is very important to seal them securely. Taking careful precautions and minimising exposure to the microbes can protect us from dangerous infections. It is essential that the plates produced are sealed, collected and destroyed (incinerated or autoclaved). Ensure hands are washed after handling any plates.

Results

1 Calculate the zone of inhibition (ZOI) for each filter paper disc. The ZOI is the clear area around each disc where there is no bacterial growth. Measure the diameter of the ZOI by placing a ruler across the centre of the filter paper disc and measuring from one side of the ZOI to the other. Repeat this measurement at an angle of 90 degrees to the first to calculate the mean diameter.
2 Sketch the colonies and ZOIs that you can see on your agar plate.

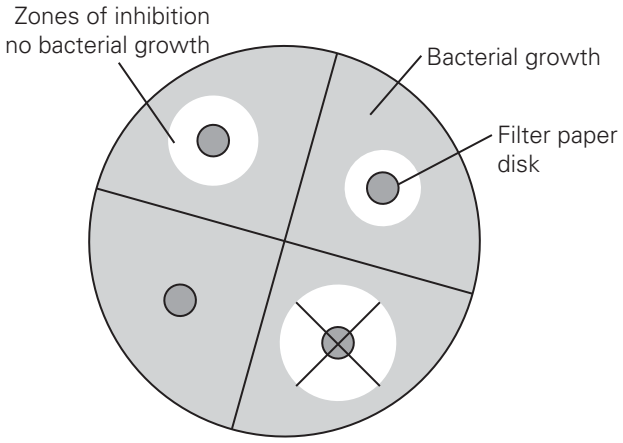


Figure 2.37 Take two measurements of each clear zone.

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Discussion

1 Compare the ZOIs of each antibacterial product and the control.
2 Sequence the products in order of the most to least effective at killing bacteria.
3 Compare your results with other products that your classmates have tested. Identify the most effective product at killing bacteria.
4 Discuss why certain products may be better than others at killing bacteria.
5 Discuss the purpose of the control quarter of your agar plate.
6 Identify any potential sources of error in this experiment.
7 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

Draw a conclusion from this experiment regarding bacterial growth and antibacterial products. Justify your answer with data.

Fungi

Fungi can be single-celled or multicellular organisms that contain a nucleus and have a cell wall made of chitin. They also have membrane-bound organelles, including mitochondria, which means they are **eukaryotic** organisms like plants and animals, including you! Familiar fungi include yeasts, moulds, and mushrooms. Unlike plants, fungi cannot photosynthesise their own food. Instead they use their long, fibrous cells to penetrate plants and animals, breaking them down and extracting their nutrients. You may have seen furry growth on decaying food – this is a type of fungus called mould.

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

eukaryote
an organism with a nucleus and membrane-bound organelles



Figure 2.38 The pink area between this person's toes is a localised tinea infection (commonly known as 'athlete's foot').

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

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Practical 2.5

Fermentation

Yeast is a type of fungus, one that is very useful in the production of many foods. You might have some baker's yeast in the cupboard at home – it is used when baking bread. Yeast exists as single cells and reproduces by a process called **budding**, where a yeast cell develops a small 'bud', which grows and eventually separates to form a new yeast cell.

Yeast feeds on sugar. This specialised process, known as **fermentation**, allows for sugar to be broken down by yeasts (in the absence of oxygen) to form alcohol and carbon dioxide.

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

$$\text{sugar} \rightarrow \text{alcohol} + \text{carbon dioxide}$$

Some alcoholic beverages (like champagne) are fizzy because the carbon dioxide is contained and not allowed to escape. A similar reaction causes bubbles in baked goods, which causes breads and cakes to rise.

Aim

To investigate the process of fermentation using yeast.

Materials

- 5 test tubes
- test-tube rack
- 200 mL beakers
- balloon
- limewater
- sugar
- yeast
- delivery tube with stopper
- teaspoon
- marker pen
- measuring cup for 10 mL

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 2.40).

2 Fill each test tube A–D according to the table below.

A	B	C	D
2 teaspoons sugar 10 mL warm water	1 small heaped teaspoon yeast 10 mL warm water	2 teaspoons sugar 1 small heaped teaspoon yeast 10 mL warm water	2 teaspoons sugar 1 small heaped teaspoon yeast 10 mL warm water

3 Place a balloon over the end of test tube C.

4 Attach a delivery tube to test tube D and place the outlet into some limewater in a fifth test tube as shown in the diagram.

5 Leave all test tubes for approximately 30 minutes. Observe the results after this time.

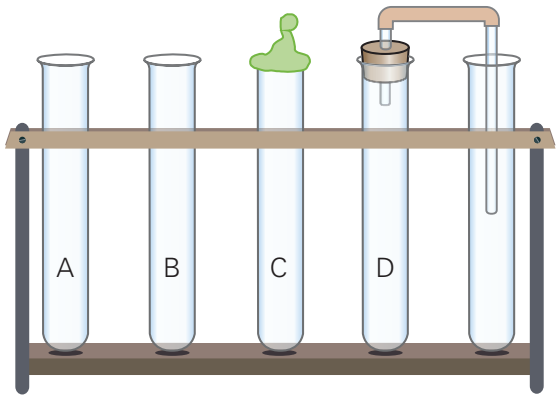


Figure 2.40 Experimental set-up

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Results

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

Discussion

1 Describe any trends, patterns or relationships in your results.
2 Suggest some reasons for the different results obtained in test tubes A, B and C, making reference to the contents of the test tubes.
3 Explain why it is important to use warm water and not to use water that is too hot.

Viruses

Viruses are tiny non-living pathogens. They cannot be seen with a light microscope but can be seen with an electron microscope. Viruses are made up of a core of genetic material surrounded by a protein coat. However, when they penetrate a suitable host cell, they take it over and turn it into a virus factory (see Figure 2.41).

One of the key requirements for life is the ability to reproduce. Since viruses are not a living organism, they depend upon invading other cells and using the invading cell to replicate. Viruses are an important part of all ecosystems, including the human body. In your body, viruses are known to infect not only your own cells, but also other pathogens that live inside you.

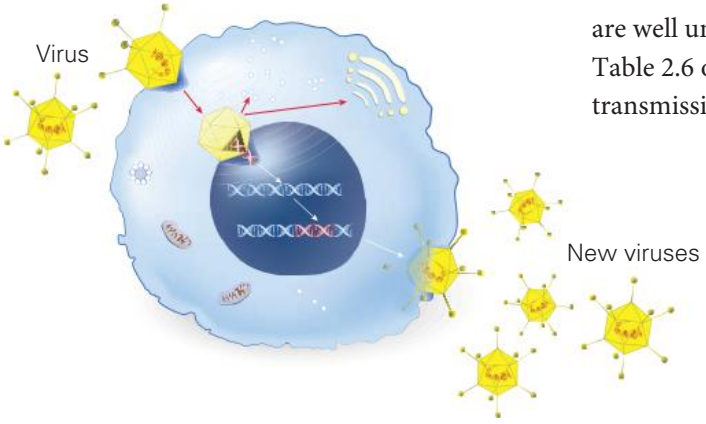


Figure 2.41 The replication of a virus via a host cell

Quick check 2.9

1 State three common types of fungi.
2 Describe how fungi are able to obtain the nutrients they need to survive.
3 Explain how yeast cells reproduce.
4 Describe the structure of viruses and how they reproduce.
5 Scientists argue that viruses are in fact non-living. Discuss why this may be the case.

VIDEO
How do I become infected?

Disease transmission

From the Black Death (also known as plague) in the fourteenth century to the COVID-19 pandemic, epidemics of infectious diseases (diseases caused by pathogens) have afflicted societies throughout history. In the modern world, the modes of transmission of infectious diseases are well understood. Figure 2.42 and Table 2.6 outline the main modes of transmission.

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

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Mode of transmission	Description	Examples
Direct contact	Spread is by skin-to-skin contact between people or via surfaces they have touched.	A student has tinea (fungal infection) and showers on a school camp without wearing thongs. Another student uses the same shower and develops the same fungal infection.
Airborne	Pathogens can be spread via droplets of saliva produced when you cough and sneeze, or by spores spread in the air.	A person infected with the common cold (rhinovirus) sneezes on the train, and the person next to them wakes up infected the next day.
Vectors	Disease-carrying organisms spread pathogens.	A tourist is bitten by a mosquito in Papua New Guinea and contracts malaria.
Waterborne	Pathogenic organisms live in water and can be passed on by drinking the water.	A person becomes infected with typhoid after drinking water that has not been chemically treated in a developing country.
Blood	Pathogens are spread by contaminated blood or other body fluids.	Human immunodeficiency virus (HIV) can be transmitted through shared needles from tattooing, piercings or medical procedures.

Table 2.6 Modes of infectious disease transmission

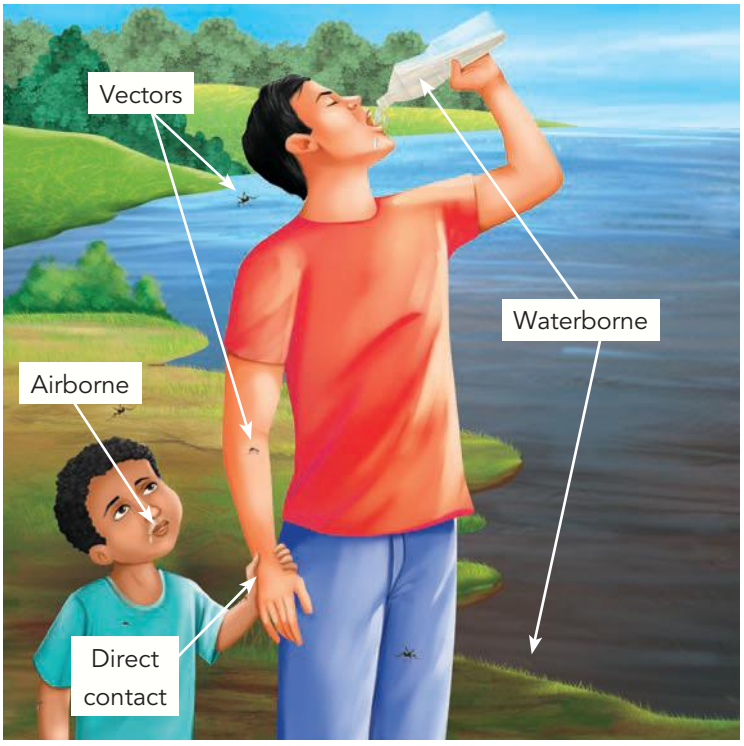


Figure 2.42 Modes of disease transmission

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Explore! 2.5

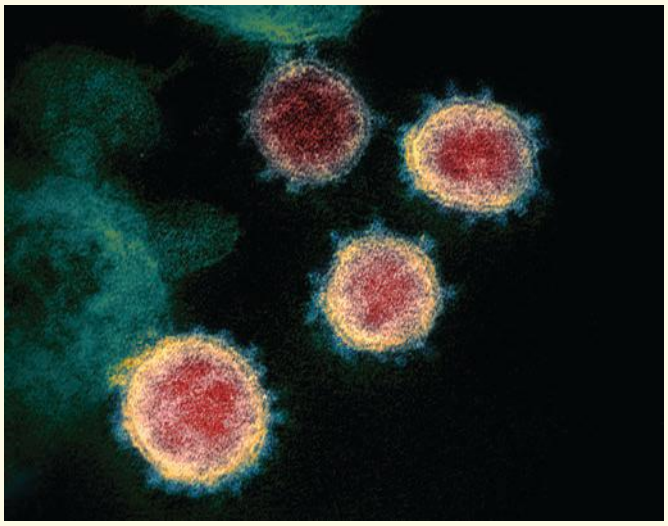


Figure 2.43 The virus that causes COVID-19

Governments and people around the world were taken by surprise when a flu-like infection was identified in Wuhan, China, in late 2019. The virus causing the disease was identified and classified on 7 January 2020, just days before the first death from the virus was recorded. By 20 January 2020, cases were being reported outside China, and the virus then spread exponentially around the world. By 7 March 2020, 100 000 cases were recorded worldwide, and on 11 March 2020 the World Health Organization announced that COVID-19 was a global pandemic. On the 27 January 2021, over 100 million cases had been recorded as well as over 2 million deaths.

As many countries did, Australia's national, state and territory governments instituted wide-ranging measures to minimise the spread of the virus through the community. This included restricting travel, closing businesses, banning gatherings and requiring people to work, study and remain at home except for essential tasks.

We will all remember the 'lockdown' periods and physical distancing measures for a long time – you have been living through history in the making. Use the internet to research the current status of, and knowledge about, COVID-19 to answer the following questions.

1. Differentiate between the terms 'coronavirus', 'SARS-CoV-2' and 'COVID-19'.
2. In what ways is COVID-19 similar to and different from the seasonal flu?
3. People who get seriously ill with COVID-19 often decline after a week of mild illness. Predict what is happening to their immune system.
4. Compare how effective different public health measures were in different countries.
5. Why was physical distancing an important public health measure for COVID-19?
6. Why is a vaccine considered a vital part of managing SARS-Cov-2?

Prior to the invention of the microscope, little was known about the causes of disease. Our understanding 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'.

germ theory
the theory that some diseases are caused by pathogens

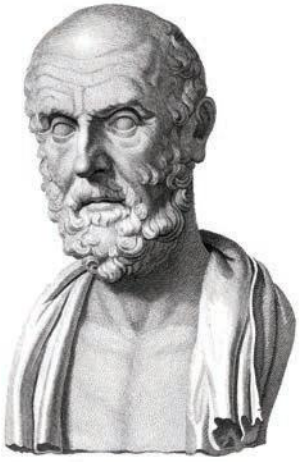
Today we understand a lot more about the causes of disease, and we know that many diseases are caused by infections from pathogens. This is known as the modern **germ theory** of disease.

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Development of the germ theory

If any one scientist has been visionary and seen further than others, it is because they stand on the shoulders of the 'giants' who went before.

Hippocrates (460–377 bce)



Hippocrates

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). This 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.

Fracastoro (1478–1553)



Girolamo Fracastoro

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 modern germ theory, later confirmed by the work of Louis Pasteur and Robert Koch.

Pasteur (1822–1895)



Louis Pasteur

Louis Pasteur experimented with microorganisms and disproved the theory of **spontaneous generation** that earlier scientists had subscribed to; this was the notion that disease could arise from non-living matter. His work proved that microorganisms were all around us.

spontaneous generation the idea that disease can arise from non-living matter

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'.

Figure 2.44 Timeline of development of germ theory

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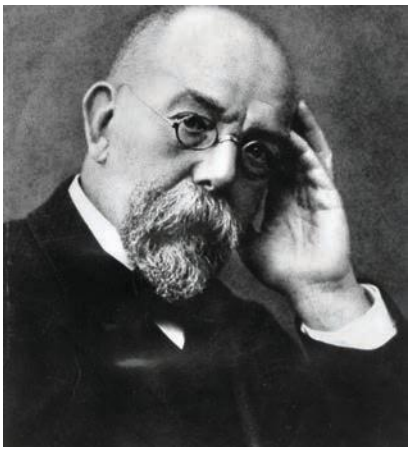
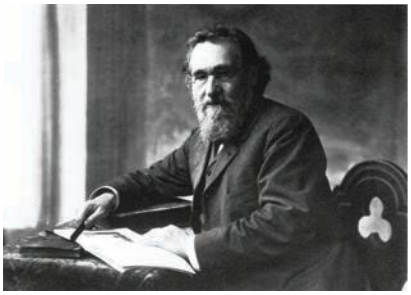
Koch (1843–1910)	 Robert Koch	Robert Koch developed a set of rules called 'Koch's postulates', which lay out four criteria that must be met before a microbe can be said to cause a disease.
Metchnikoff (1845–1916)	 Elie Metchnikoff	Elie Metchnikoff discovered antibacterial white blood cells, which together with Koch's work led to the modern germ theory of disease.

Figure 2.44 *(Continued)*

Explore! 2.6

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:

June Almeida
Ann Bishop
Elizabeth Bugie
Alexander Fleming
Howard Florey
Mary Hunt
Edward Jenner
Joseph Lister
Louis Pasteur
Marjory Stephenson



Figure 2.45 When Alexander Fleming accidentally discovered penicillin (an antibiotic), it could not be produced quickly enough for mass production. Mary Hunt, illustrated here with a cantaloupe melon, was a mould expert hired to find a better producer of penicillin. She would look for produce in the markets to grow the mould on and became the folk legend 'Mouldy Mary'.

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The immune system

The body's **immune system** is its defence against infectious diseases. To function properly, the immune system must be able to detect, distinguish and respond to a variety of pathogens and damaged or foreign cells. The immune system has three lines (or levels) of defence, which can be divided into two categories. The first and second lines of defence respond in the same way to all infections, so they provide **non-specific immunity**. The third line of defence provides **specific immunity** against a particular pathogen (see Table 2.7).

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

non-specific immunity immunity provided by the branch of the immune system that does not depend on recognition of the pathogen; includes the first and second lines of defence such as physical barriers, inflammation and fever

specific immunity immunity provided by the branch of the immune system that is specific to each particular pathogen; the third line of defence

First line of defence

The first line of defence aims to prevent infection: it is the first point of the human body that the pathogen comes into contact with. For example, it includes surface barriers like intact skin (protecting external boundaries) and mucous membranes (protecting internal boundaries, such as in the gut, mouth and nose). This line of defence is very useful, because if the pathogens cannot enter the host's body, they cannot disrupt normal physiological functions and cause disease. These barriers release chemical secretions, such as sweat, tears, ear wax, mucous and stomach acid, which restrict the growth of many pathogens on their surfaces and prevent the entry of pathogens into the body.

Non-specific immune system	Specific immune system
First and second lines of defence	Third line of defence
General defence that responds the same way for every infection	Targeted defence that produces antibodies to combat a specific pathogen
No 'memory' of prior infections; same intensity of response every time	Remembers a pathogen and responds harder and faster if it encounters it again (adaptive)

Table 2.7 Immune system lines of defence

Science as a human endeavour 2.3

Spray-on skin

Patients who sustain burn injuries are at high risk for developing infections as they have 'lost' their first line of defence. If patients survive the first 72 hours after their burn injury, infections are the most common cause of death. In 1993, Professor Fiona Wood and Marie Stoner developed a spray-on skin for burns patients that allows skin grafts to be applied much earlier, reducing both the risk of infection and the risk of scarring. This technique is now used worldwide.



Figure 2.46 Professor Fiona Wood was the recipient of the Australian of the Year Award in 2005.

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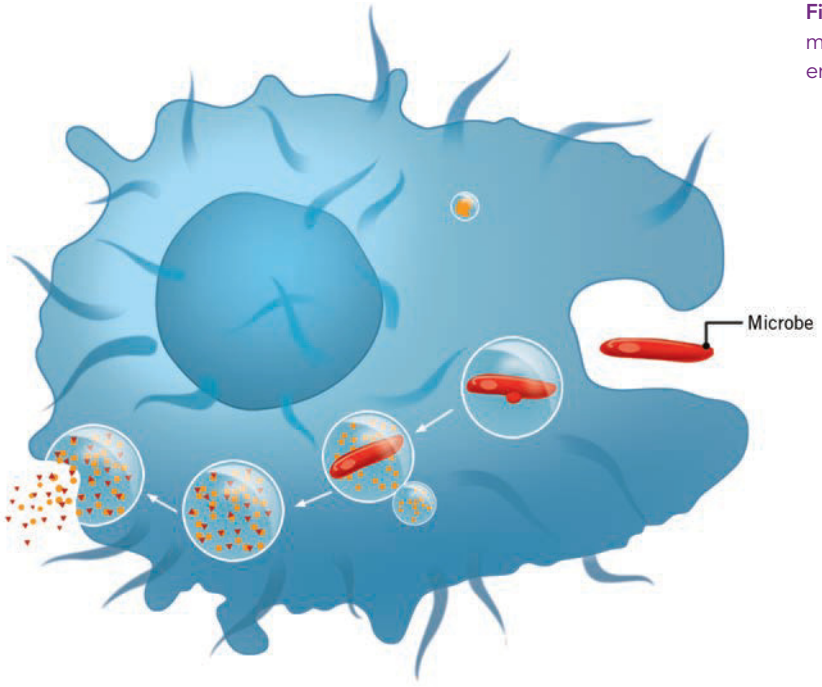


Figure 2.47 Phagocytes bind the target material, including bacteria, before engulfing and digesting them.

Second line of defence

If pathogens manage to cross the first line of defence, then internal defences are activated. An *immediate* response begins when special proteins come together to mark pathogens so they will be targeted for destruction. After a few hours, white blood cells of a type called phagocytes will start to engulf the pathogens in a process called **phagocytosis**. This triggers inflammation, which helps the immune response by increasing blood flow and the permeability of capillaries in the infected area, actively bringing more immune cells (white blood cells) to the site of an infection. These phagocytes engulf pathogens, causing some cells to explode and seep out as pus. The sight of pus in a wound is a sign of the second line of defense at work!

phagocytosis
a cellular process where a white blood cell engulfs and ingests a cell or large particle to break it down using enzymes

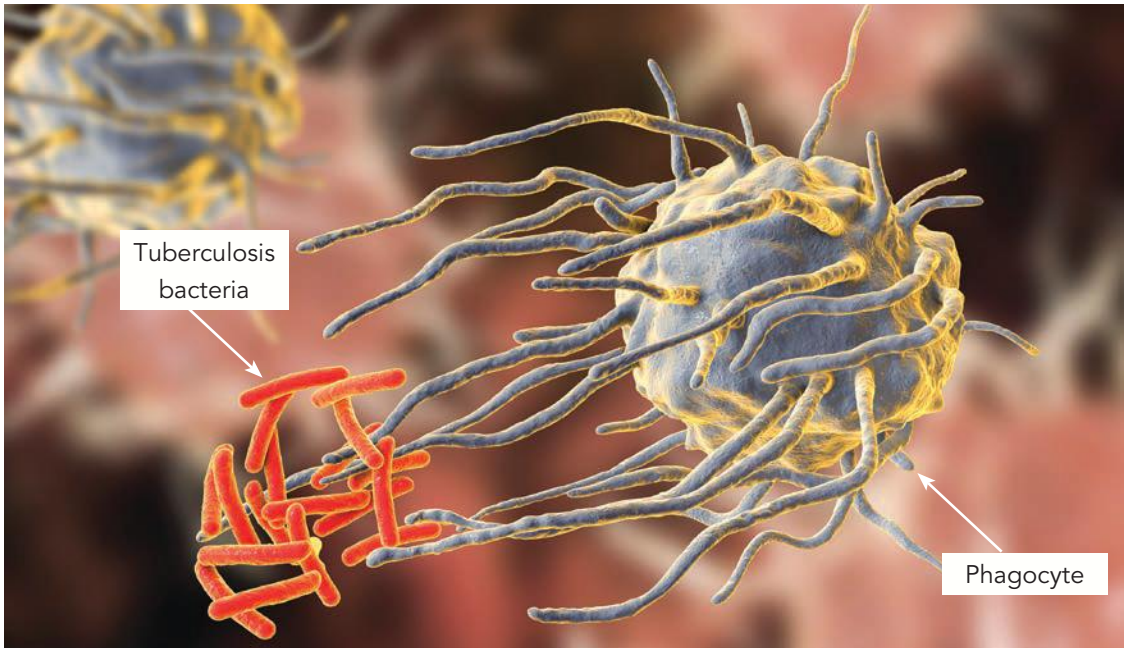


Figure 2.48 A phagocyte engulfing tuberculosis bacteria

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Third line of defence

The third line of defence in the body's immune response provides immunity that is specific to each particular pathogen. This specific immune system is adaptive, which means that it can 'learn' from an infection and respond more quickly if it encounters the same pathogen again. This immune response takes a few days to become protective.

antigen
a substance that induces an immune response in the body; can be foreign (non-self) or a self-antigen

lymphocyte
white blood cell that is involved with fighting disease; some produce antibodies

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

All immune cells need to differentiate between infected or foreign ('non-self') cells and non-infected 'self' cells. To do this, they identify a special molecule on the cell membrane called an **antigen**. Healthy cells have self-antigens that do not trigger a response. However, a pathogen will have foreign antigens on its surface – these are a sign to the immune system that the cell should be destroyed. The presence of foreign antigens activates two special types of white blood cells known as **lymphocytes**: B cells and T cells.

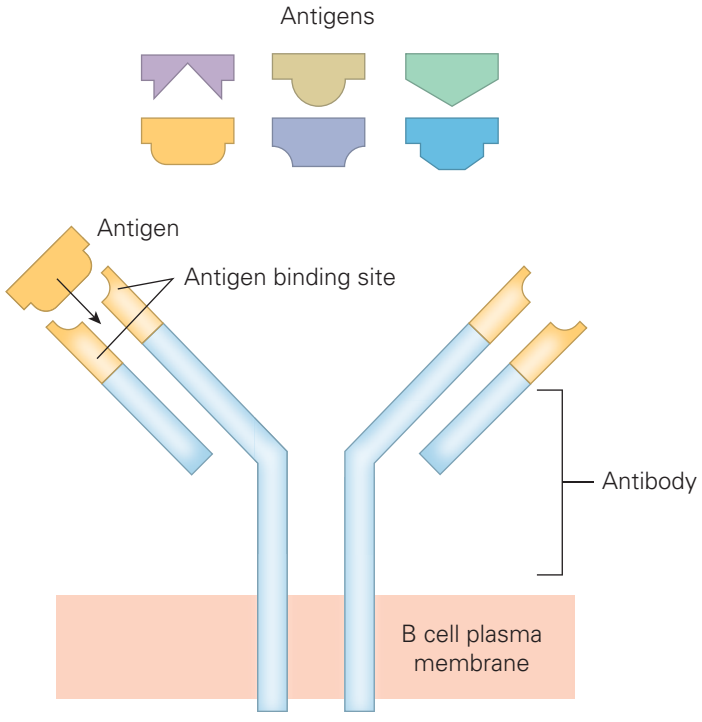


Figure 2.49 Like a lock and key, antibodies are designed with specific binding sites that can only attach to certain antigens with the right shape and size to match the binding site on the antibody. In this figure, only the yellow antigen would attach to the antibody as it matches the shape and size of the antibody's binding site. The other colours (antigens) are different shapes.

B cells are the part of the immune system that produce antibodies. Antibodies are Y-shaped proteins that recognise and bind to an antigen. Just like a lock and key that must match in size and shape, a specific antibody can only bind with one kind of antigen (see Figure 2.49). An antibody bound to an antigen is a signal for T cells to come and destroy the pathogen (see Figure 2.50). The type of T cell that takes this role is known as a killer T cell. Another type of T cell is the helper T cell. Helper T cells act like team leaders and provide chemical instructions to other T cells and B cells to replicate themselves and fight infection.

Both T cells and B cells can also form **memory cells**, which retain a 'memory' of a specific pathogen or antibody. Memory cells make the immune response much faster and stronger if the body encounters that specific pathogen again (see Figure 2.51). Sometimes, the second and subsequent responses are so effective you might not even feel unwell or know you have been infected! Being able to resist a pathogen in this way is called immunity. This is why you may have been told that you can only get chicken pox once; it is because you will have built up memory cells for the next encounter!

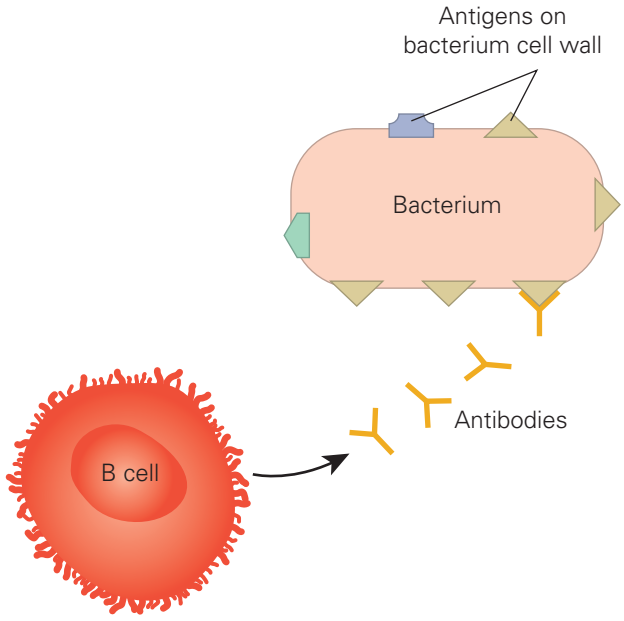


Figure 2.50 Antibodies bind to the antigens on a pathogenic bacterium. This bacterium does not have long to live!

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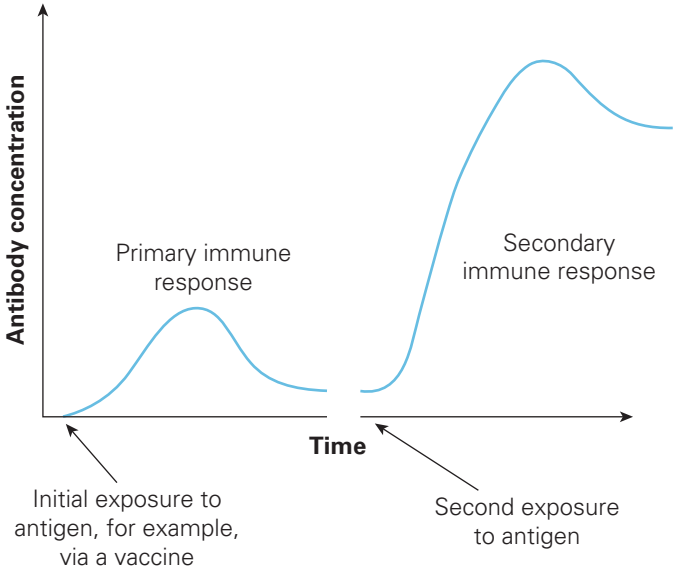


Figure 2.51 The second immune response to an antigen on the surface of a pathogen is faster and larger than the first response.

Quick check 2.10

1 Contrast non-specific and specific immunity.
2 Recall what is involved in each line of defence. You may choose to display your answer in a table as shown.

Non-specific immune response		Specific immune response
First line of defence	Second line of defence	Third line of defence

Immunisations 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 an inactivated pathogen or a weakened form or fragment of a pathogen (complete with all its identifying antigen flags) into your body. The antigenic material in a vaccine cannot cause an infection, but the immune system still recognises it as a threat (because of the antigens) and responds by producing antibodies. This **immunises** you against the disease caused by that pathogen.After the threat has passed, many of the antibodies will break down, but the memory cells remain in the body ready to act if you encounter that pathogen again. Immunisation acts like a first exposure to a pathogen, but without the risk of actually getting sick!

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

Quick check 2.11

1 Define the term 'vaccine'.
2 Compare vaccination with an infection from an actual pathogen.

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Did you know? 2.5

Human papillomavirus

Infection with certain types of the human papillomavirus (HPV) can lead to changes in the cells of a woman's cervix and has been shown to be a precursor for developing cervical cancer. Cervical cancer is the growth of these abnormal cells in the lining of the cervix. Globally, it is responsible for the death of one woman every 2 minutes. Research published by the International Papillomavirus Society has shown the rates of HPV infection in Australia have declined from 24% of Australian women aged 18 to 24 to 1% in the last decade. Researchers attribute this decline to the roll-out of the national immunisation program for HPV, which began in 2007.



Figure 2.52 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.

Science as a human endeavour 2.4

The fight against coronavirus

The following scientists are few among numerous scientists whose research and dedication have helped us understand COVID-19 and have led to vaccines.



Figure 2.53 Even though Katalin Karikó's work went unnoticed for years, it is now considered ground-breaking.

June Dalziel Almeida (1930–2007)

June Almeida was a Scottish virologist who pioneered ways to see, identify and diagnose viruses. Her innovations and insights included using the electron microscope in immunology. She was the first person to identify many types of viruses, including, in 1966, the group of viruses that became known as coronaviruses.

Katalin Karikó (1955–)

For many years, Hungarian immigrant Katalin Karikó struggled to get research grants for her work on messenger RNA (mRNA) to fight disease. The basis of this idea was that if mRNA gives the information for making proteins, then perhaps it could be used to make other proteins, even antibodies. One obstacle was that mRNA was prone to being destroyed before reaching target cells. The research was also considered far-fetched, however she continued to persist. Suddenly, at the age of 65, her dedicated work on this new kind of vaccine led to the Pfizer and Moderna vaccines.

Jennifer Doudna (1964–)

Jennifer Doudna and Emmanuelle Charpentier won the 2020 Nobel prize in Chemistry for their work on the CRISPR/Cas9 gene editing technology. Now, Professor Doudna is part of a team working on CRISPR/Cas13 to develop faster ways of detecting the COVID-19 virus. So far the device has been able to accurately detect the virus in samples in 5 minutes and 30 minutes in samples with low virus concentration. It is a much faster and potentially more portable method compared to the PCR tests in use.

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What are antibiotics?

Antibiotics are chemical substances produced by a living organism (usually a mould) that can stop the growth of bacteria. 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. Also, antibiotics will not work on viruses, as viruses are not living and do not have a cell membrane. 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 primary method of fighting bacterial infections in the human body. However, scientists are becoming increasingly concerned about drug-resistant bacteria, because infections due to these bacteria often last longer, cause more severe illnesses, require more doctor visits or longer hospital stays, and may even cause death. Antibiotic resistance occurs as a result of people not completing a required course of antibiotic medication. This might happen when the sensitive and weaker bacteria are killed quickly, so the person feels better and stops taking their medication. But that can leave alive some bacteria that, because of genetic mutations, are less susceptible (more resistant) to the antibiotic. As these bacteria reproduce, they produce a colony of antibiotic-resistant bacteria that can be passed on to other people!

antibiotic
a substance that inhibits the growth of bacteria inside the body

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

VIDEO
Australia's role in antibiotics



Figure 2.54 An agar plate that has been covered in bacteria. Each of the dots shows where an antibiotic disc was placed. The size of the surrounding clear section shows the effectiveness of the antibiotic at killing that type of bacteria.

Did you know? 2.6

Unnecessary antibiotics

At least 30% of antibiotic courses prescribed are unnecessary, meaning that no antibiotic is needed at all. For example, people often seek antibiotics when they are suffering from the common cold, but a cold is actually a viral infection and antibiotics will be useless.

Antimicrobial resistance

Antimicrobial resistance is a broader term that includes antibiotic resistance in bacteria plus resistance that develops in other microbes (such as viruses, parasites and fungi) against medicines that were 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

Figure 2.55 Antiseptic gels and hand sanitisers act to kill pathogens.



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septic
describes a wound infected with a harmful pathogen

necessarily killing them. They tend to work on a large variety of microbes and are most often used externally, for example, antiseptic hand washes. When harmful pathogens grow in living animal tissue, the tissue is said to be **septic**. Many of the antiseptics used in the past killed the bacteria in wounds but also damaged or killed the tissue around the wound. Modern antiseptics seldom injure the tissues.

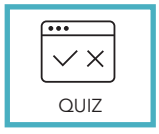
Explore! 2.7

Nanotechnology has the potential to help in medicine by improving the treatment of diseases. Nanomedicines are typically pharmaceutical compounds in tiny carrier materials. They can increase the therapeutic effect of a drug by allowing efficient delivery to target cells or tissues. Use the internet to research some recent developments of nanotechnology in medicine.

Quick check 2.12

1 Contrast antibiotics and antiseptics.
2 A patient in a hospital ward is isolated due to infection with a 'superbug'. Describe superbugs, including why the patient was isolated.

Section 2.3 questions



Remembering

1 **State** what is meant by a pathogen.
2 **State** if bacteria are classified as prokaryotes or eukaryotes, giving reasons for your answer.
3 A lymphocyte is a special type of white blood cell. **Recall** two different types of lymphocytes.

Understanding

4 **Describe** one difference between a bacterial cell and eukaryotic cell (for example, a plant or animal cell).
5 **Summarise** how immunisations can help fight disease.
6 **Explain** why a virus is considered to be non-living.
7 **Explain** why viruses cannot be treated with antibiotics.

Applying

8 '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.
9 Briefly **describe** how vaccines work.

Analysing

10 **Compare** the role of antibiotics and antiseptics.
11 **Contrast** non-specific immunity and specific immunity.

Evaluating

12 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, **evaluate** the compulsory vaccination of children.
13 The body's immune system may sometimes start to recognise 'self' antigens as foreign and 'non-self'. **Propose** what might happen in this case.

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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria		Linked question	Check
2.1	I can recall the essential requirements for life.	3, 6	
2.2	I can state the definition of homeostasis.	4	
2.2	I can construct the stimulus–response model.	17a	
2.2	I can describe how blood glucose levels are controlled in the body.	17b	
2.2	I can describe how water levels are controlled in the body.	17c	
2.2	I recognise how the circulatory and respiratory system work together.	8	
2.3	I can recall different types of pathogen.	12	
2.3	I can describe the way we classify bacteria.	7	
2.3	I can discuss the different lines of defence in the body.	5	
2.3	I can discuss the use of vaccination and antibiotics in protecting against pathogens.	10	

Review questions



Remembering

1 **Recall** what a disease-causing agent is called.
2 **Name** three diseases caused by viruses.
3 **State** the four categories of essential nutrients required for life.
4 **Define** the term 'homeostasis'.
5 **List** three examples of the first line of defense in humans.
6 A professional hockey player has an important match tomorrow.
   a **Recall** the nutrient that is the body's preferred source of fuel, suggesting a meal that would be suitable for her dinner the night before the game.
   b **State** the nutrients that this player might draw upon if this preferred source is depleted.
   c Glucose is burned to provide useable energy. **Recall** the name and equation for this reaction.
   d The player loses several litres of water during the game. **Recall** two homeostatic responses her body would use to retain water and maintain her blood pressure.

Understanding

7 **Describe** three different shapes of bacteria.
8 **Summarise** how the digestive, circulatory and respiratory systems interact with each other.

Applying

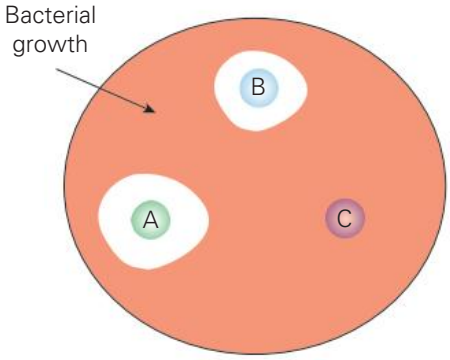
9 **Explain** why a highly active person who eats a low-kilojoule diet might lose weight.
10 **Describe** how vaccination can prevent individuals from being infected by a disease.
11 Upon checking his heart rate monitor, an AFL player sees his heart rate peaked at 185 bpm during the game. **Explain** why this occurred with reference to the body's energy requirements.

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Analysing

12 **Compare** bacteria and viruses.

13 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.

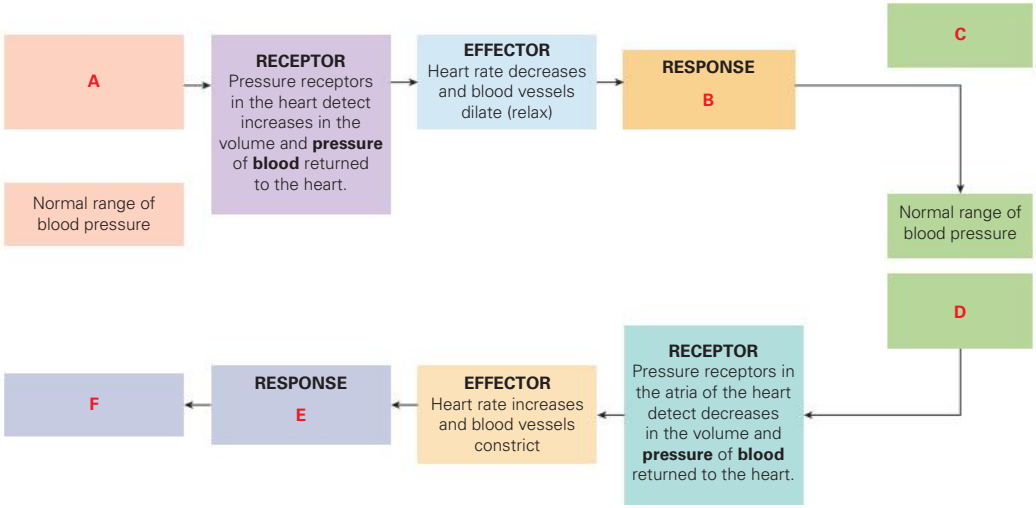


a Of the antimicrobial substances tested, **identify** which was the most effective, giving reasons for your answer.

b Of the antimicrobial substances tested, **identify** which was the least effective, giving reasons for your answer.

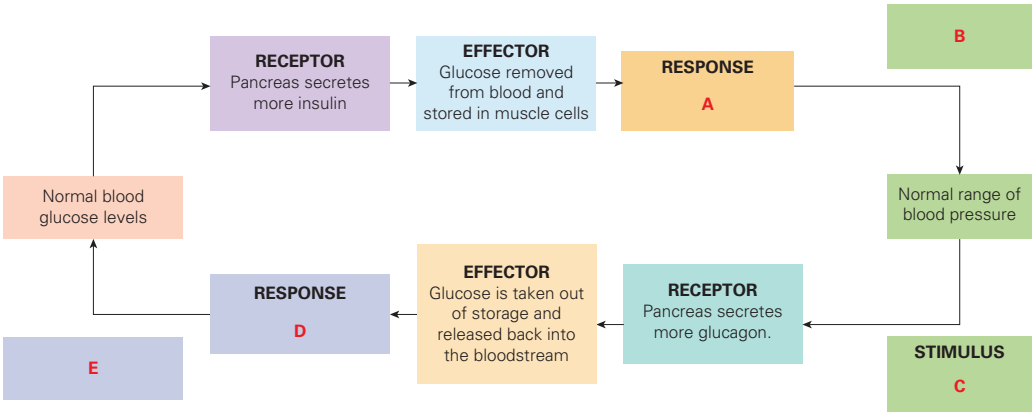
14 Complete the flow charts to **compare** the ways in which the body responds to each of the following scenarios. You can do this by identifying what the letters represent.

a High blood pressure versus low blood pressure

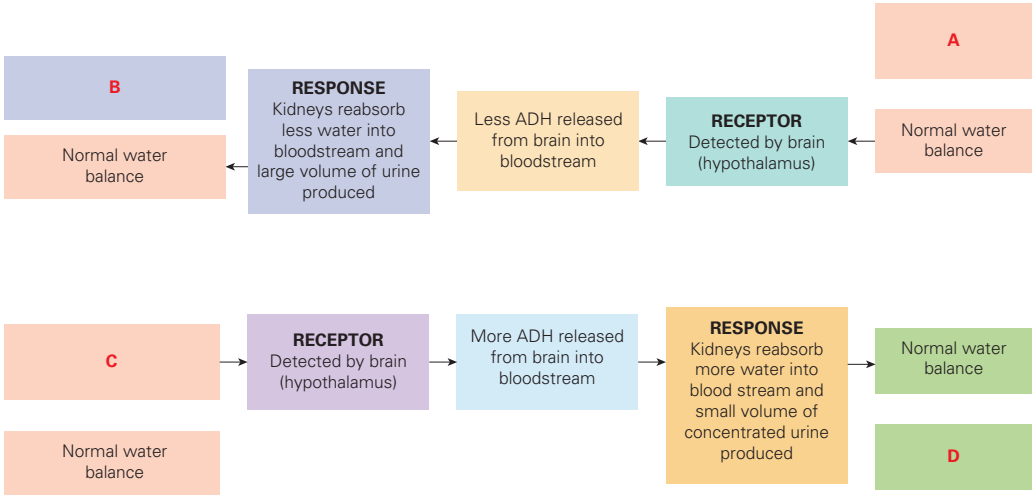


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b High blood glucose levels versus low blood glucose levels

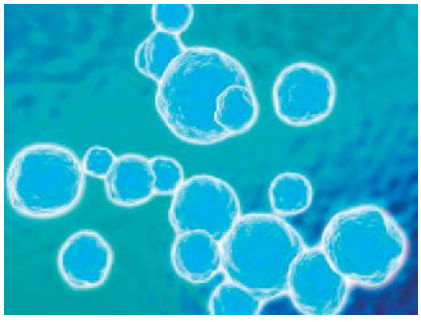


c High levels of water in the blood versus low levels of water (dehydration)



Evaluating

15 The image below shows MRSA bacteria (methicillin-resistant Staphylococcus aureus) that have developed resistance towards antibiotics. When they reproduce, the resistance is passed on to the resulting organisms.



Bacteria come in a variety of shapes, each with a specific name. **Justify** the scientific name for this type of bacterium.

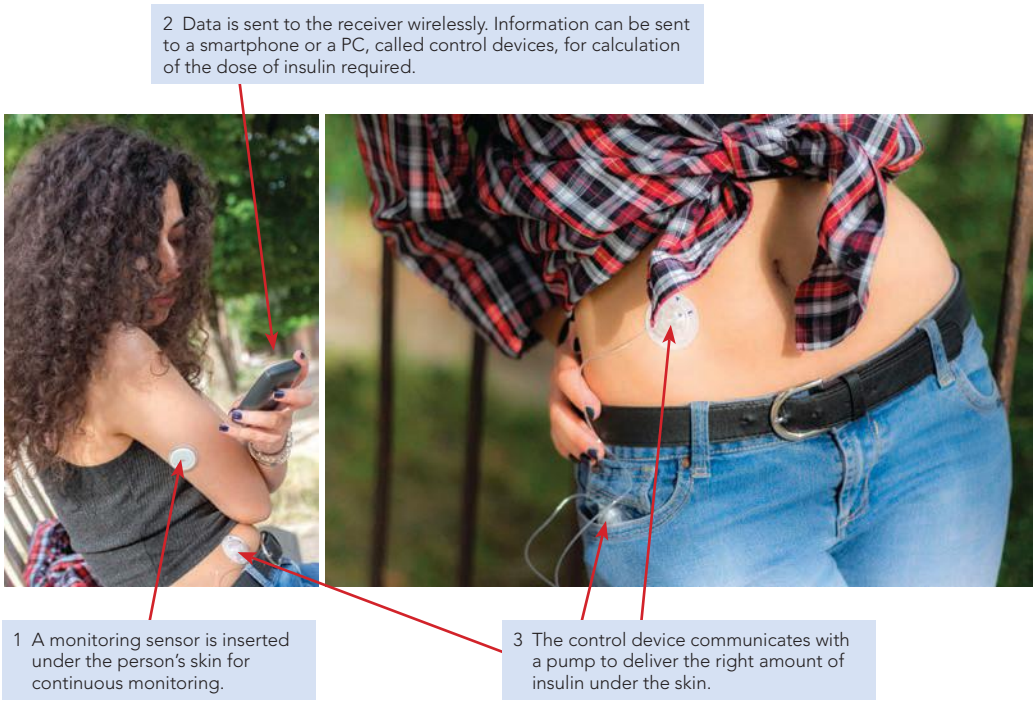
16 The SARS-CoV-2 virus can remain infectious on a healthy person's skin or lungs causing minor symptoms while in an immune-compromised person it can be life-threatening. **Propose** two ways it can spread from one individual to the next, along with examples of possible ways spread can be prevented.

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17 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 **Identify** which structures (on the transplanted organ) the body detects as being '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.



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 **Discuss** 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.

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Data questions

A Year 9 student with diabetes measures their blood sugar level hourly and the data is plotted in blue in Figure 2.56. Another student, who does not have diabetes, also measures their blood sugar as a comparison, and this is plotted in orange. The students are careful to eat the same three meals on this day – breakfast, lunch and dinner at the same time – and the student with diabetes injects insulin after each meal.

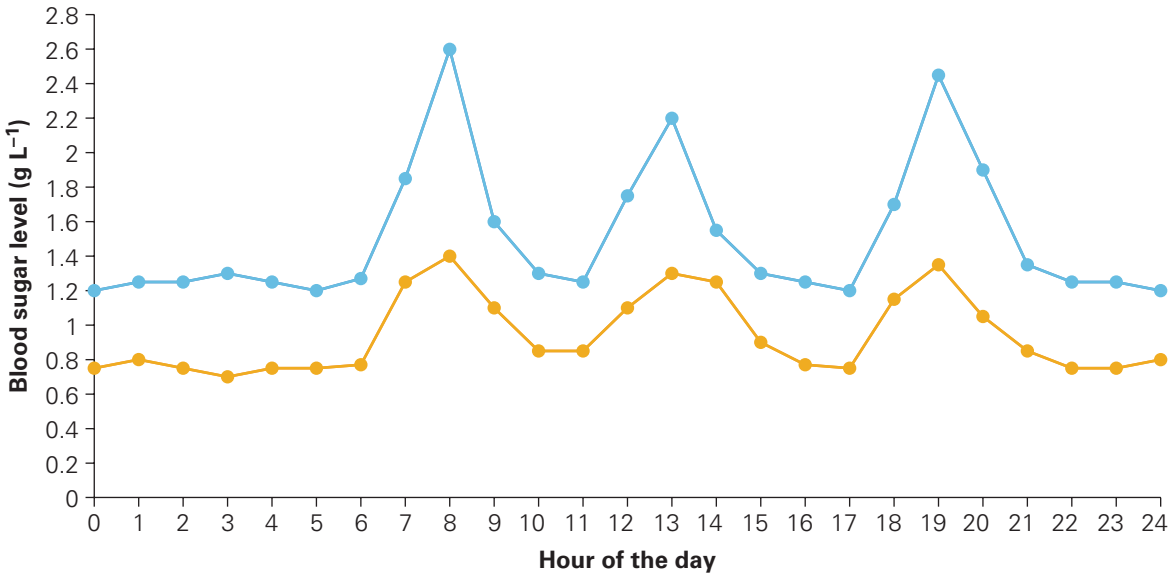


Figure 2.56 Relative blood sugar level over a 24-hour period. Orange line – student without diabetes, Blue line – student with diabetes

1 **Identify** the homeostatic (steady state) blood sugar level for each student.
2 **Determine** the times that the students ate breakfast, lunch and dinner.
3 **Identify** the peak blood sugar level for both students on this day.
4 **Identify** any patterns or trends that appear in the data.
5 **Contrast** the change in blood sugar level after each meal and provide a reason for the difference.
6 **Infer** a reason for the lower peak in blood sugar for the student with diabetes after eating lunch than after the other meals.
7 **Justify** whether the comparison of data would be valid if the students ate different meals on this day.
8 After the student with diabetes ate dinner, **deduce** the time that insulin was injected into the bloodstream.
9 **Predict** what would happen to the plotted data if the student with diabetes did not use insulin directly after the breakfast meal.

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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 foetuses in pregnant women, increasing the chances of abnormalities and other syndromes.

The Zika virus first spread outside 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.

The way a new infectious disease spreads through a population can cause scientists and public health officials a lot of concern if the mechanism of its spread and containment are not immediately 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, 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: Design a simulation that demonstrates the transmission of a direct-contact disease.

Activity instructions

As a class, you are going to design and simulate the exchange of body fluids and, consequently, demonstrate the spread of an imaginary 'Zika-like' infectious disease in a community. You will use your model to 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.



Figure 2.57 The spread of infectious diseases around the world can be fast and needs identification, analysis and containment, and then prevention as soon as possible.

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Suggested materials

- 0.1 mol L^{-1} NaOH
- phenolphthalein solution in a dropper bottle
- distilled water
- droppers
- plastic cups or test tubes

Be careful

Do not spill the contents of the cups. Use water to wash if you come into contact with the liquid. Do not drink the contents.

Research and feasibility

1 Research how direct-contact diseases spread through populations.

2 Research how models are currently used to simulate the spread of disease.

3 List the key features of the simulation models and how they represent the real-world contamination of infectious diseases.

Design and sustainability

4 Design Option 1: A simulation that uses a cup filled with distilled water as a healthy person and a contaminated cup (with traces of sodium hydroxide which can be detected through a pH monitor) as a contaminated person. You will use droppers as a method of contamination. The chemical phenolphthalein can be used as an indicator to test if the cups' contents test positive or negative for contamination.
Design Option 2: A simulation that uses any method that has been checked by your teacher for safety measures. Remember any chemicals you plan to use must be checked by referring to their material safety data sheet (MSDS).

5 Check that your chemicals/materials are safe to use and dispose of. Minimise waste wherever possible.

Create

6 Perform your group activity with at least 15 class members and record your results in any way. The following table can be used as a guide. HINT: Ask the teacher to contaminate the first cup without students watching so it is a surprise for the whole class.

Class member	Contact 1	Contact 2	Contact 3	Test positive/ negative
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

7 Tracing the source of infection. Take on the role of epidemiologists and try to determine the source of the infection in your community – who was the original carrier?

Evaluate and modify

8 Evaluate the model through a group discussion, and list your findings. Remember that engineers must assume certain things when creating models. For example, this activity assumes that each person who exchanges fluid with an infected person gets infected. Another assumption was that there was no incubation time. Most infectious agents will need time to multiply before they can be transmitted to another person.

9 Write a short report evaluating the model you used. How could you change the simulation to make it more realistic? Consider the following questions before you write your answer: How would the results differ if everyone could choose how many exchanges to have? How would the results differ if you have only a 20% or 50% chance of contracting the disease after being exposed? How would the results differ if infected people were sometimes quarantined? How would the results differ if a vaccine becomes available that prevents infection? How would the results differ if the infected person dies very quickly or very slowly after contracting the disease?

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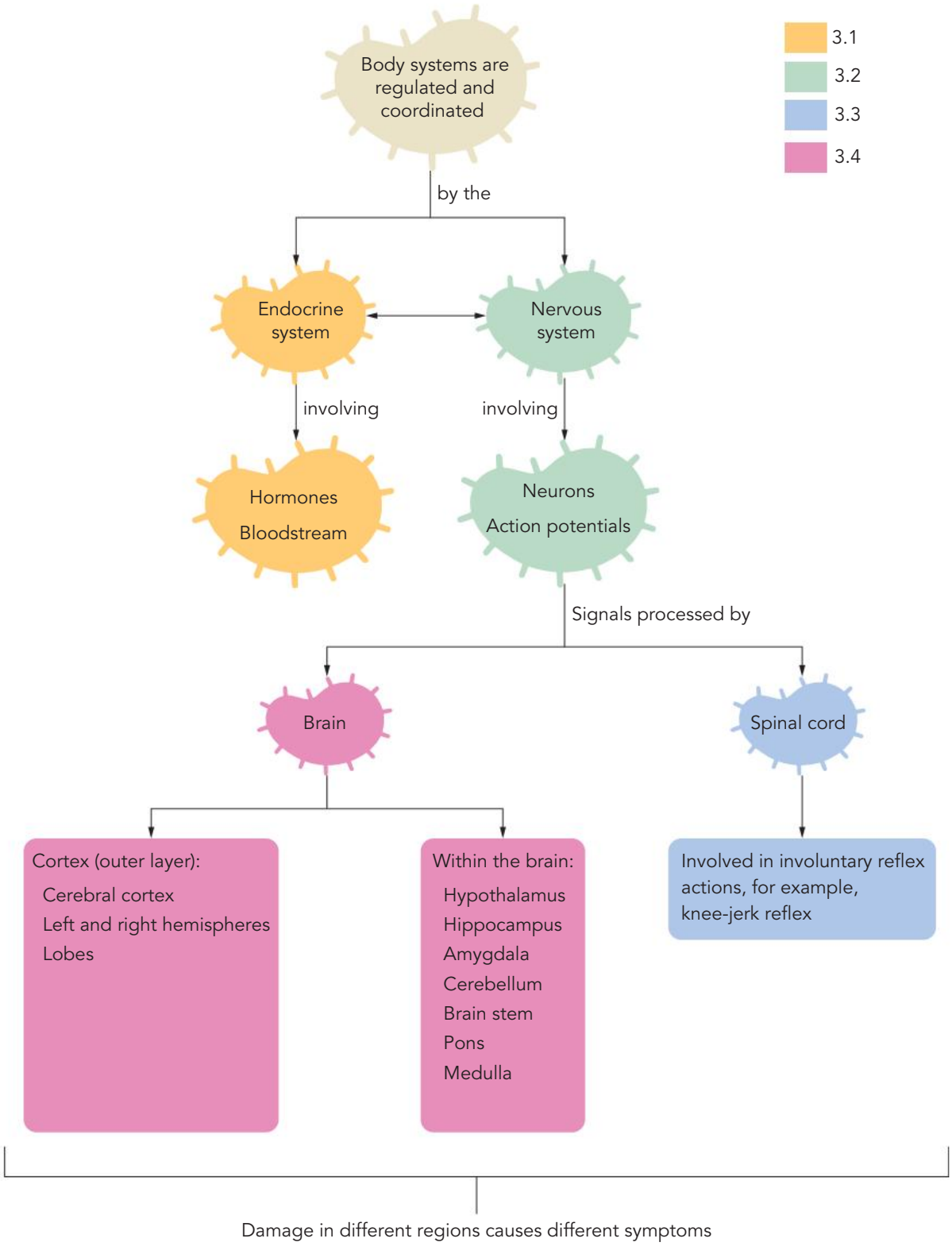
Chapter 3
Response and coordination

Chapter introduction

The brain is the master organ that, with few exceptions, controls the actions of nerves within the nervous system. It is also involved in the regulation of hormones within the endocrine system. Any thought, feeling or behaviour that you experience or undertake on a daily basis is ultimately controlled by the brain, even though you may not be aware of it. The brain continually reorganises itself by making new neural connections, 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. Then you will look in depth at the structure and function of the human nervous system.

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Chapter map



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3.1 Keeping control

WORKSHEET

Learning goals

1 To be able to recall the components of the central and peripheral nervous system.
2 To be able to label endocrine glands and the hormones produced at each.
3 To be able to compare the key features of the nervous and endocrine control systems.

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



Figure 3.1 A model of a neuron, the basic building block of the human nervous system

The nervous system

neuron
an individual nerve cell specialised to carry signals

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

somatic nervous system
the part of the peripheral nervous system involved with the voluntary control of body movements

autonomic nervous system
the part of the peripheral nervous system involved in involuntary physiological processes such as heart rate and digestion

The basic building blocks of the nervous system are our neurons (less commonly spelled 'neurones'). A **neuron** is essentially an individual nerve cell. Networks of these neurons allow signals to move between the brain and body. These organised networks, composed of up to 1 trillion neurons, help to make up what is known as the **nervous system.**

The human nervous system is composed of two main parts: the central nervous system (CNS), which includes the brain and spinal cord, and the peripheral nervous system (PNS), which is all of the neurons and nerve networks throughout the body that lie outside the CNS. The PNS is further divided into: the **somatic nervous system** which controls the voluntary and reflex movement of muscles and receives signals from sense organs, and the **autonomic nervous system** which controls involuntary body functions, such as digestion, tears and salivation. Figure 3.2 shows the key components of the human nervous system.

VIDEO
What do hormones do?

VIDEO
Parts of the nervous system

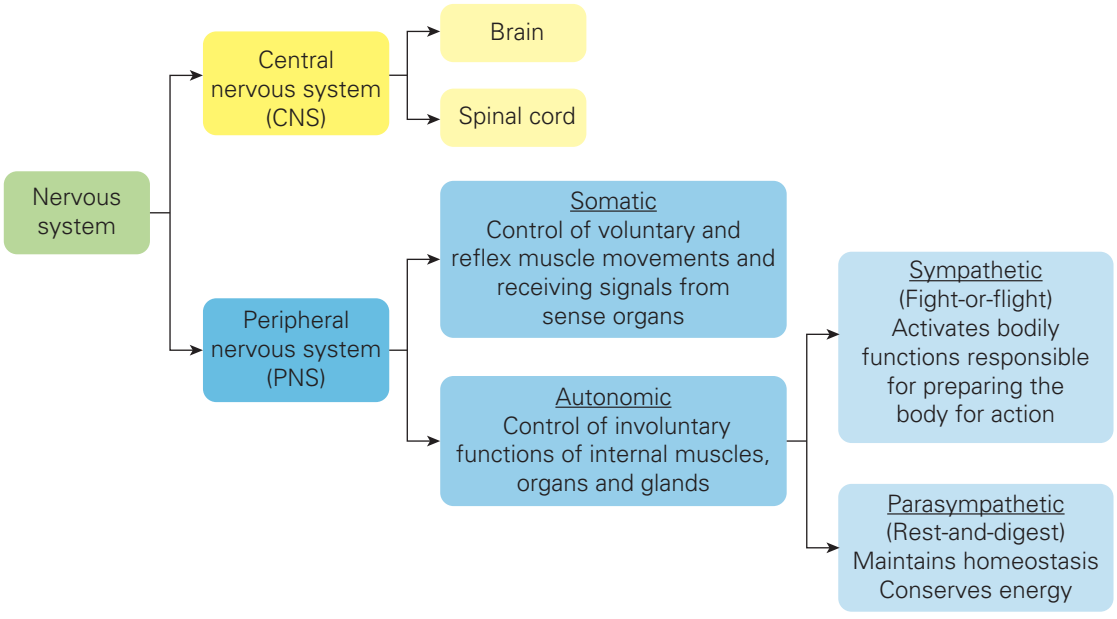


Figure 3.2 The components of the human nervous system

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Quick check 3.1

1 State another name for an individual nerve cell.
2 Recall the components that make up the CNS (central nervous system) and the PNS (peripheral nervous system).
3 Describe the role of the somatic nervous system, giving examples that illustrate the somatic nervous system in action.

The endocrine system

The nervous system does not work in isolation, it works with the **endocrine system**. The endocrine system uses glands located throughout the body which secrete **hormones** that regulate a variety of bodily processes, such as metabolism, digestion, blood pressure and growth. While many glands in the endocrine system are not directly linked to the nervous system, the two systems interact in many ways. Some of the most important endocrine glands are found within the brain; these include the pineal gland, the hypothalamus and the pituitary gland.

Located at the base of the forebrain is a tiny collection of neurons known as the hypothalamus. The hypothalamus links the nervous and endocrine systems. It is responsible for regulating an astonishing number of behaviours, such as sleep, hunger, thirst, sexual behaviour, and emotional and stress responses. The hypothalamus also controls the pituitary gland and the release of several different hormones.

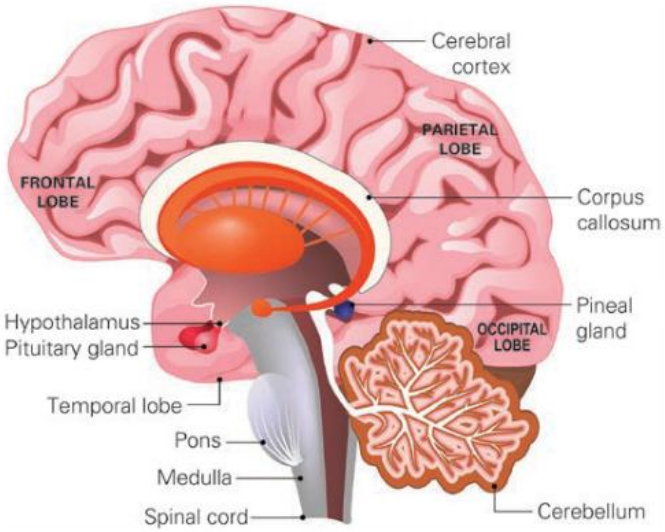


Figure 3.3 A cross-sectional view of the brain showing the location of the pineal gland, pituitary gland and the hypothalamus

VIDEO
Identify parts of the endocrine system

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

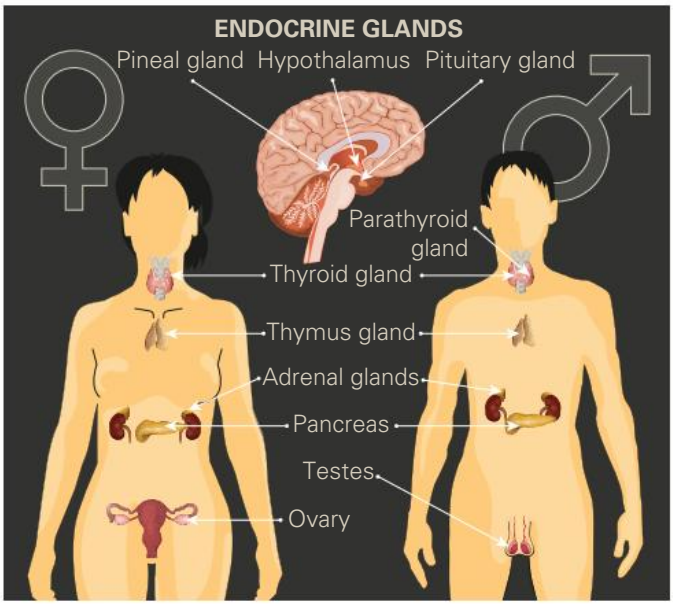


Figure 3.4 Endocrine glands in the female and male body

Hormones

Hormones are chemical messengers sent by the endocrine system to communicate with other parts of the body. They are made by endocrine glands which secrete the hormones directly into the circulatory or lymphatic systems. The blood or lymph carries the hormones around the body, so hormones are transported to, and cause an effect in, a totally different part of the body to where they were made. The cells they affect are called **target cells**.

Organisms are coordinated by many hormones and small amounts of these chemicals can have major effects. Table 3.1 shows where hormones are produced and what effect they have on the human body.

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

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Organ	Example of hormone secreted	Action of hormone
Pancreas	Insulin	Decreases blood glucose levels by increasing the uptake of glucose by cells and causing the conversion of excess glucose to glycogen in liver and muscle cells
	Glucagon	Increases blood glucose levels by stimulating the stored glycogen to be converted back into glucose and released into the bloodstream
Adrenal gland	Epinephrine (Adrenaline)	Secreted at moments of fear, stress or excitement, and has the effect of increasing the heart rate, constricting blood vessels close to skin, dilating blood vessels to some muscles, raising blood pressure and causing a rise in blood sugar. All these factors make the person ready for physical action during the fight-or-flight process.
Kidneys	Erythropoietin	Promotes the production of red blood cells by the bone marrow
Pituitary gland	Growth hormone (GH), antidiuretic hormone (ADH) and others	GH stimulates cell division, growth and repair of the body, and ADH regulates the amount of water in the blood.
Pineal gland	Melatonin	Responsible for regulating sleep patterns as it induces sleep. Melatonin is secreted in dark conditions and ceases to be released under light.
Hypothalamus	Various hormones	Sometimes referred to as the 'master switchboard', the hypothalamus is part of the brain and is the main control for the endocrine system. It operates with the pituitary gland (the 'master gland') as well as via neurons to other glands.
Testes	Testosterone	Promotes growth of bone, development of muscle, growth of facial hair and deepening of the voice in males during puberty
Ovaries	Oestrogen	Promotes development of breasts and pubic 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 and examples of their hormones, and the action of that hormone

Explore! 3.1

Endocrine-disrupting chemicals in plastics

How can the rising rates of cancer and metabolic conditions such as diabetes be explained? What about declining fertility rates? Well, one hypothesis is that exposure to endocrine-disrupting chemicals are affecting our body functions. The scientific research behind this hypothesis has mainly come from rat and mice studies, but some scientists believe it holds true for humans too. Endocrine-disrupting chemicals are commonly found in plastics and many other everyday household products, so what are the safe levels of exposure? Research the following questions.

1. Where might you find endocrine-disrupting chemicals in your house?
2. What everyday products might you find that contain BPA (bisphenol A)?
3. Discuss the stages of your life during which exposure to endocrine-disrupting hormones might be more harmful.
4. List some ways you could limit your exposure to endocrine-disrupting hormones.

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Did you know? 3.1

Melatonin and sleep

An adolescent typically requires 9.25 hours of sleep per night. However, an adolescent's body clock is shifted 1–3 hours later compared with people of other ages. That is, in adolescents, melatonin is released 1–3 hours later than in other people, which may cause adolescents to feel sleepy 1–3 hours later. Combined with digital technologies, social media and work, school or sporting commitments, this late body clock can cause irregular sleep patterns. Many adolescents accumulate sleep debt and have difficulty waking up in the morning.

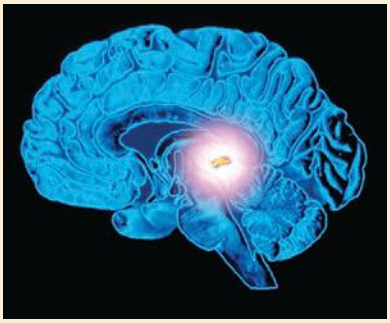


Figure 3.5 The pineal gland (highlighted) secretes the hormone melatonin, which controls the body's biological clock.

Try this 3.1

Step 1. Each morning for a 7-day period, record the amount of sleep you have had the previous night. Calculate your total sleep over the 7 days in hours.

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 sufficient 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 × 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 your classmates.

Quick check 3.2

1. Recall the part of the brain that is located at the base of the forebrain and controls many bodily functions such as sleep, hunger and thirst.
2. Describe how hormones are transported around the body.
3. Name the hormone that is responsible for regulating sleep patterns and inducing sleep.
4. Define target cells.
5. Discuss the effects of oestrogen and testosterone.

Two systems working together

As discussed in Chapter 2, the body maintains a relatively constant internal environment through a process called **homeostasis**. Homeostasis is maintained by the endocrine and nervous systems working together. They use chemical messengers and electrical impulses to communicate with cells and glands, but the speed of message transmission and the length of the effects differ between the two systems. The endocrine and nervous systems work in a coordinated way with all the other body systems to maintain a relatively stable internal environment and protect the body from harm.

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

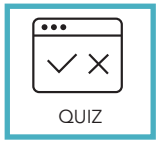
The key differences between the features of the endocrine and nervous systems are shown in Table 3.2.

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Feature	Nervous system	Endocrine system
Signals	Electrical and chemical messengers (via electrical impulses and neurotransmitters)	Chemical messengers (hormones)
Pathway	Transmission by neurons in the nervous system	Transported in the bloodstream (circulatory system) and lymph (lymphatic system)
Speed of information transfer	Fast	Comparatively slow
Duration of effect	Short-lived	Typically longer-lasting
Type of action and response	Voluntary or involuntary	Involuntary
Target cells	Adjacent cells	Often distant (many cells may be affected)
Example of action	Your friend throws a ball at you. Your sensory receptors detect the visual stimulus and the message is transmitted via neurons to your brain. Further messages are then sent down the spinal cord and via motor neurons and your skeletal muscles are stimulated to contact. 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



Remembering

1 **Name** the basic building block of the human nervous system.
2 **Name** two endocrine glands found within the brain.
3 **Recall** how hormones reach their target cells.

Understanding

4 **Explain** the difference in the speed of transmission within the nervous and endocrine systems.

Applying

5 **Compare** the somatic and autonomic divisions of the nervous system.

Analysing

6 **Classify** the following events as being under somatic or autonomic control.
   a Sweating
   b Walking
   c Pulling your hand away from a flame
   d Contractions of intestine to move food along

Evaluating

7 **Compare** the nervous and endocrine systems. You may choose to construct a Venn diagram for your answer.
8 The contraceptive pill contains a chemical which acts like the hormone oestrogen. It attempts to stop sperm reaching an egg in several ways, including:
   - suppressing ovulation so an egg is not released from the ovaries
   - making the cervical mucus thicker so that it becomes more difficult for sperm to reach an egg
   - decreasing the thickness of the lining of the womb so it is not thick enough for an egg to attach to it.

   Deduce some reasons why the contraceptive pill is *not* guaranteed to work 100% of the time.

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3.2 Neurons and the nervous system

Learning goals

1 To be able to distinguish between sensory neurons, interneurons and motor neurons.
2 To be able to label the structure of a neuron.
3 To be able to explain how nerve impulses travel through neurons.

WORKSHEET

Types of neurons

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

- **Sensory neurons** (also called sensory receptors) in the PNS transmit neural information from **receptors** to the CNS. The sensory information being transmitted could be from any of your five senses.
- **Interneurons** (also called relay neurons) transmit neural information within the spinal cord and brain. Interneurons connect the sensory and motor neurons and can only be found in the CNS.
- **Motor neurons** transmit neural information from the CNS to the PNS. This information is designed to initiate a response in the **effector**, which could be a muscle or gland.

sensory neuron
a nerve cell that detects and transmits sensory information to the central nervous system

receptor
something which detects and passes on a signal; a sensory receptor is a neuron or part of a neuron that detects a stimulus

interneuron
a nerve cell that transmits information within the brain and spinal cord (central nervous system) between sensory and motor neurons

motor neuron
a nerve cell that transmits messages from the central nervous system to the effectors

effector
something which produces an action in response to a signal

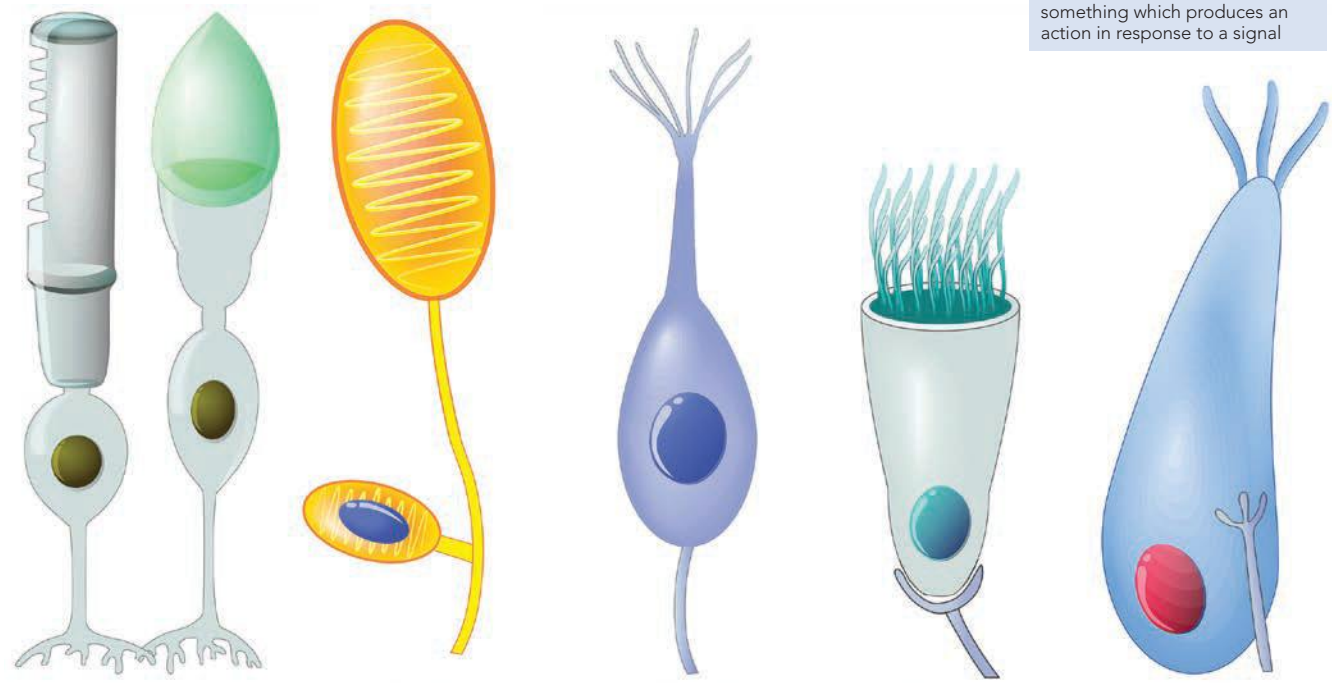


Figure 3.6 The different sensory neurons (sensory receptors) associated with your five senses. Their shape is closely associated with their specialised functions.

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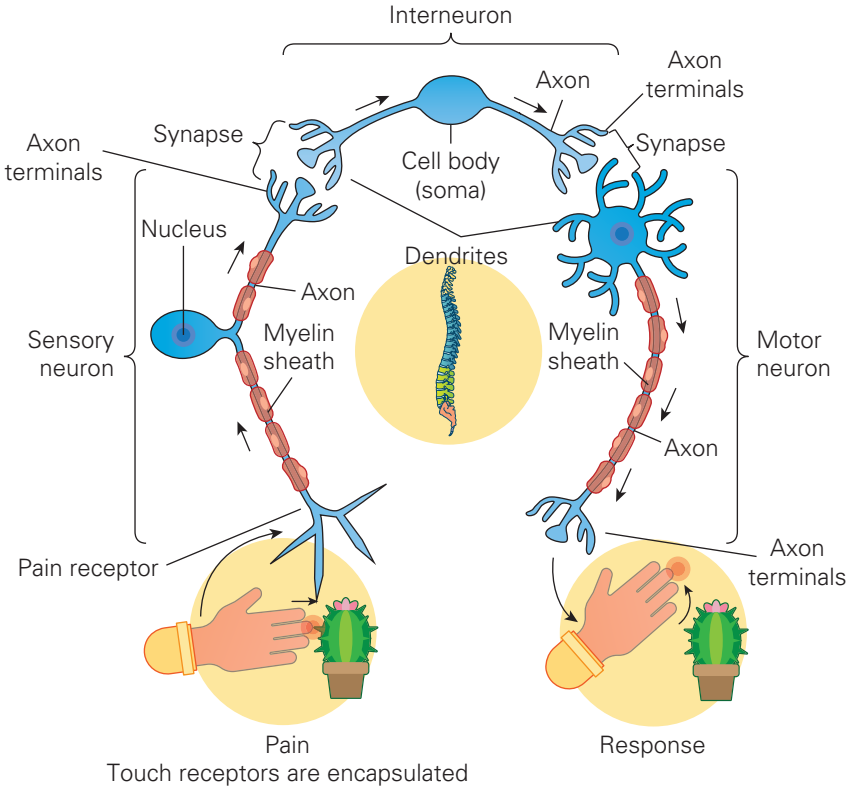


Figure 3.7 The three types of neuron (sensory, inter and motor) form an arc. Note how the sensory neuron has receptors to detect a stimulus and the motor neuron causes your response. This diagram shows a reflex arc so the interneuron in this case is in the spinal cord. In other cases of stimulus and response, there could be more than one interneuron in the arc and they could be routed through the brain.

dendrites
fine branching fibres which receive nerve impulses from synapses and conduct them to the body of a neuron

axon
long fine fibres that conduct nerve impulses from cell bodies to synapses, which form nerves when bundled

myelin sheath
insulating substance around axons to prevent nerve impulses from leaking out into the surroundings

synaptic cleft
a gap between the membranes of two neurons at a synapse, into which complex molecules project to facilitate and control the action of neurotransmitters

synapse
the junction between two neurons

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

Structures of a neuron

The key structures of the neuron include the **dendrites**, cell body (soma), **axon**, **myelin sheath**, axon terminals and the **synapse**. The synapse is the junction between neurons. The synapse includes the axon terminal (of the sending neuron), the gap between the neurons (**synaptic cleft**) and the dendrite (of the receiving neuron).

Structure of neuron	Function
Dendrite	Sensory receptors that receive stimuli in the case of sensory neurons or neurotransmitters from neighbouring neurons in the case of interneurons or motor neurons
Cell body (soma)	Contains most of the cell's organelles including the nucleus
Nucleus	Modulator (or control centre) of the cell and contains its genetic material
Axon	Transfers electrical impulses from the cell body to the synapse. It is the axons of neurons that are called nerves when they are grouped together in a bundle.
Axon terminal	Found at the end of the axon and contains neurotransmitters that are held in vesicles. Neurotransmitters are released once an electrical impulse is received.
Myelin sheath	An insulating layer consisting of Schwann cells that covers the axon. It helps keep the electrical signals inside the cell, allowing faster transmission.
Synapse	Electrical messages are passed along the neuron, but neurons do not touch one another. There is a junction between the neurons called a synapse. When an electrical impulse is received, the signal diffuses (travels) across the synaptic cleft in the form of chemical signals called **neurotransmitters**. The neurotransmitters then bind to the receptors on the dendrites of the neighbouring neurons.
Schwann cells	Form the myelin sheath

Table 3.3 Functions of structures of the neuron

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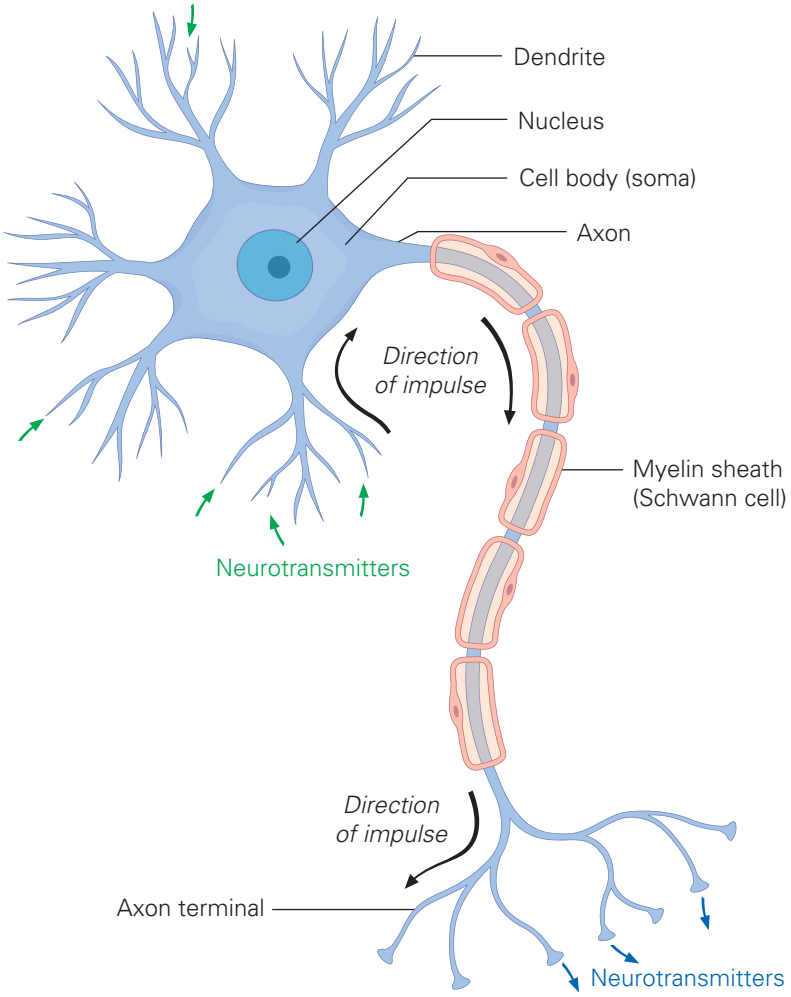


Figure 3.8 The key structures of a neuron showing the neural impulse travelling in one direction only along the neuron, from the dendrites to the axon terminals.

Quick check 3.3

1. Name the three different types of neurons.
2. Recall where interneurons are found in the body.
3. Interneurons are sometimes called relay neurons. Explain why you think that is an appropriate name.
4. State the function of the myelin sheath that covers the axon.
5. A fly lands on someone's face and they brush it off. Name the three types of neurons involved in the order they would be activated when the stimulus is detected.

Try this 3.2

Making model neurons

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

You will need a piece of A3 paper, and your teacher will provide you with a selection of materials to make the model neurons. 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 the end of another pipe cleaner around the soma, so you have a long piece coming down.
3. Around the axon is a fatty substance called the myelin sheath. To represent this, you are going to use a straw. Cut pieces of straw about 2.5 centimetres (cm) long each and thread them onto your axon with gaps between the lengths of straw. You should have a bit of pipe cleaner left at the end.
4. Take the end of the pipe cleaner near the bottom of the last myelin sheath, twist it to make a hoop and cut it so it splits – or add more small pipe cleaner pieces. You are beginning to make your axon terminals.
5. Repeat steps **1–4** for the next neuron.
6. Stick the neurons onto the sheet of paper and label the parts of one neuron with a dot point explaining the function of each structure (including the synapse).
7. Put up your posters in the classroom so that the axon terminals of one person's poster connect to the dendrites on the next poster. You should have a chain of neurons forming a nerve fibre!

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Communication within and between neurons

Communication within: action potential

An **action potential** is another name for the electrical impulse (neural impulse) that moves along a neuron. It travels only the length of the neuron, and once the action potential reaches the axon terminal, it relies on a chemical messenger (neurotransmitter) to pass the action potential on to the next neuron.

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 potential – to activate an action potential. When enough neurotransmitters arrive from other neurons, and the threshold is reached, an action potential will begin and 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; that is, it will continue to the end of the axon without further stimulation.

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

The speed of an action potential moving along an axon varies between neurons. The fastest travel over 100 metres per second, with the slowest travelling at about 1 metre per second. The speed depends upon two factors: the diameter (width) of the axon (the larger the diameter, the faster the impulse) and whether the axon has a myelin sheath (an action potential travels faster down an axon with a myelin sheath).

Explore! 3.2

Multiple sclerosis (MS)

Multiple sclerosis is a degenerative neurological condition characterised by the development of **scleroses** (Greek for 'scars') on neurons of the central nervous system. These scars result in damage to the myelin sheaths, which insulate the neurons, so the neurons do not transmit messages effectively. This can lead to a variety of symptoms, such as problems with motor (muscle) control, visual problems if the damage occurs in the optic nerves, problems with coordination and balance, and memory loss. Research multiple sclerosis and answer the following questions.

1. 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.

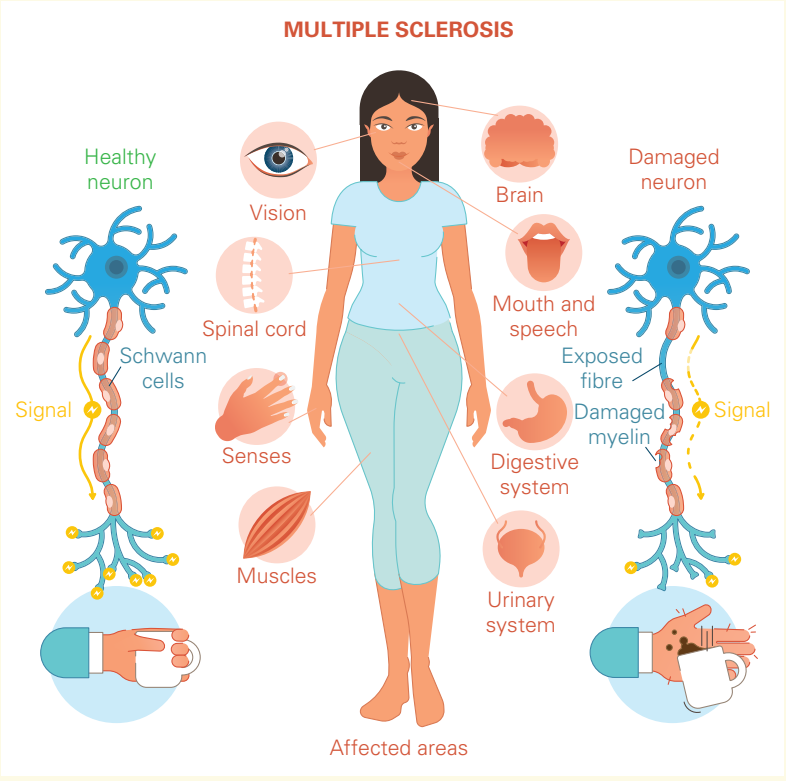


Figure 3.9 Multiple sclerosis affects many areas of the body.

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Communication between neurons: the synapse

When neurons communicate with each other, the action potential travelling down the axon to synapses at the ends of axon terminals causes neurotransmitters to be released from synaptic vesicles within the axon terminal. This part of the synapse is known as the presynaptic neuron. These specialised chemical messengers, the neurotransmitters, then move across the gap between neurons (the synaptic cleft). 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 First Nations peoples to paint 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; regulates appetite, mood, memory and behaviour	Some scientists theorise that low levels of serotonin are linked to depression.
Glutamate	A neurotransmitter in the CNS; involved with memory and learning	High glutamate levels are involved with depression, anxiety and symptoms typical of attention deficit hyperactivity disorder (ADHD), 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 cleft, they bind to special receptor sites on the dendrite of the next neuron – called the post-synaptic neuron. The receptor sites convert the information back into electrical signals which are then transmitted to the cell body of the post-synaptic neuron and along the axon. This process continues until the last neuron in the pathway connects to a muscle or gland, causing a response. This process is shown in Figures 3.10 and 3.11.

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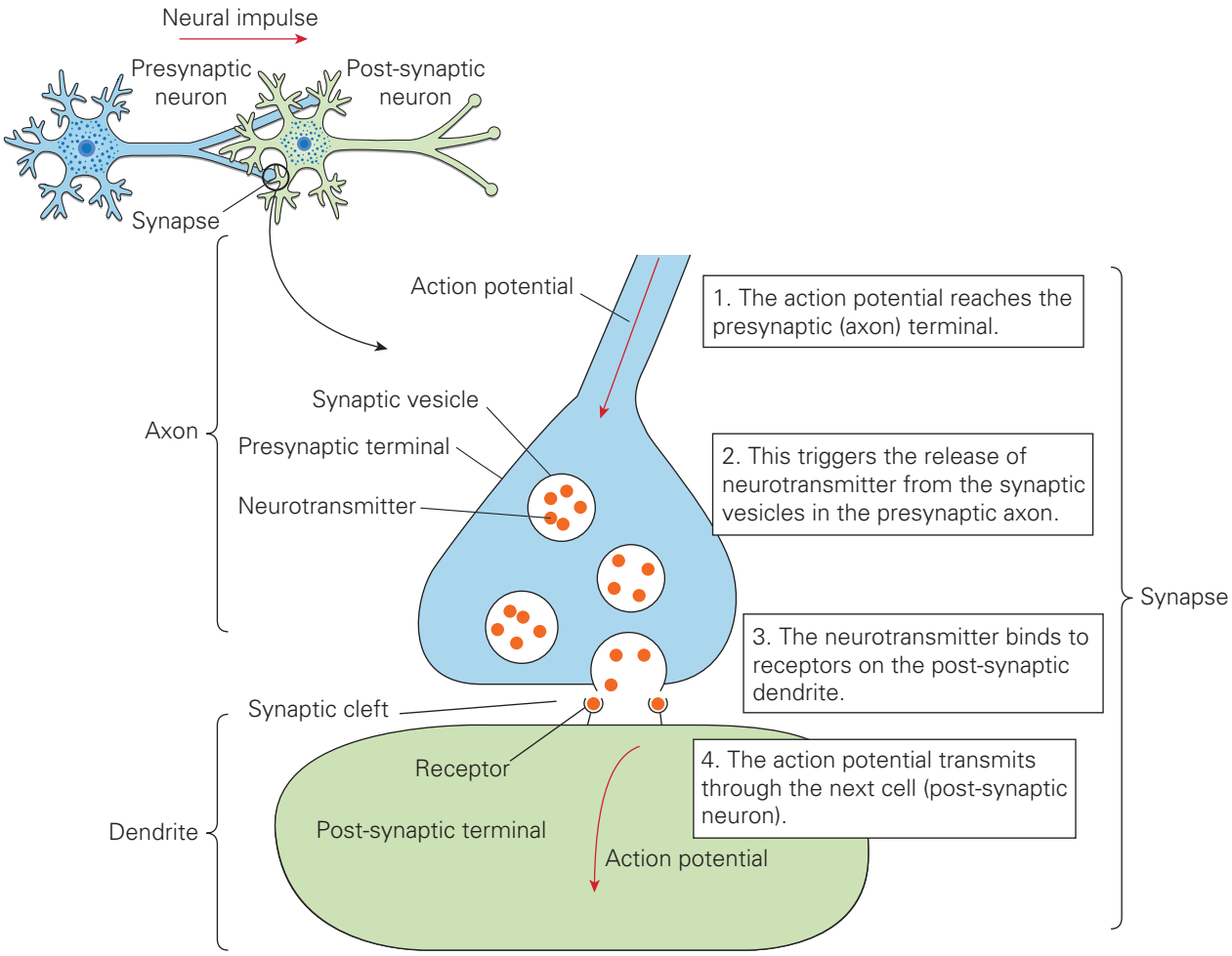
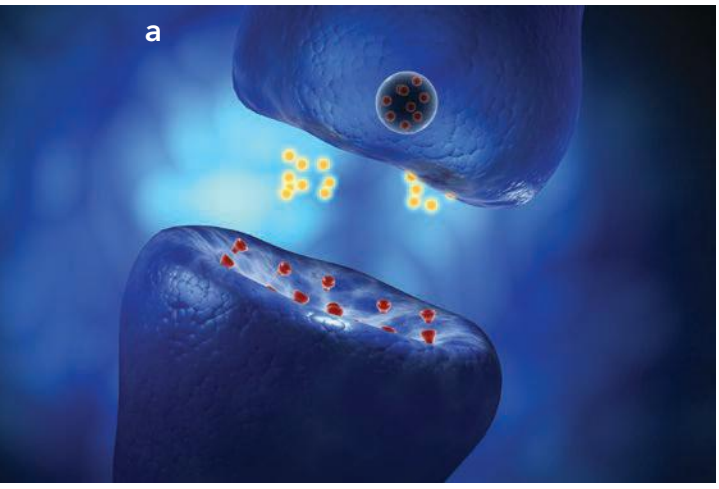


Figure 3.10 Communication between neurons involves the action potential triggering the release of neurotransmitters from their synaptic vesicles in the presynaptic neuron, moving across the gap and binding to receptors on the post-synaptic neuron.



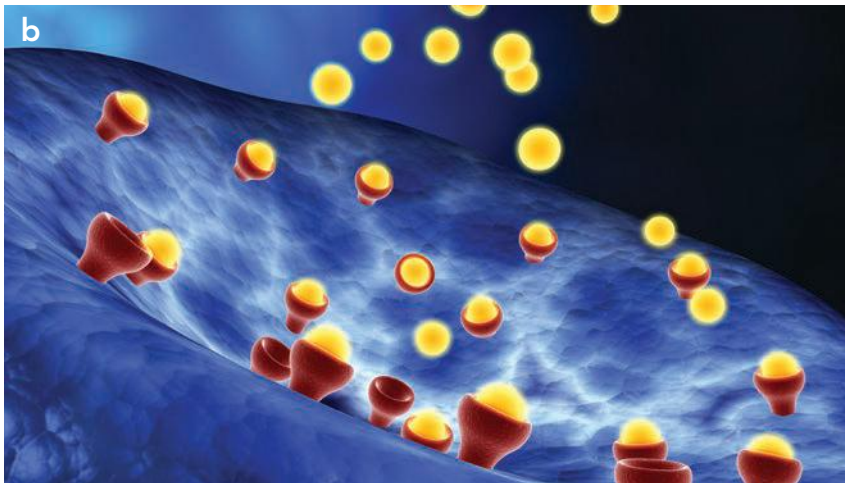


Figure 3.11 A synapse: **(a)** A synaptic vesicle in the axon terminal storing neurotransmitters, and the neurotransmitters (yellow) crossing the synapse to be received by the receptor sites (red) on the neighbouring neuron's dendrite. **(b)** Neurotransmitters (yellow) being released across the synaptic cleft and being received by the receptor sites (red) of the dendrite if they share the same distinct size and shape.

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Did you know? 3.2

The longest neuron

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 metre (m) in length. It is formed by the combination of five sets of paired nerve roots in the lumbar spine and has a diameter of about 2 cm!

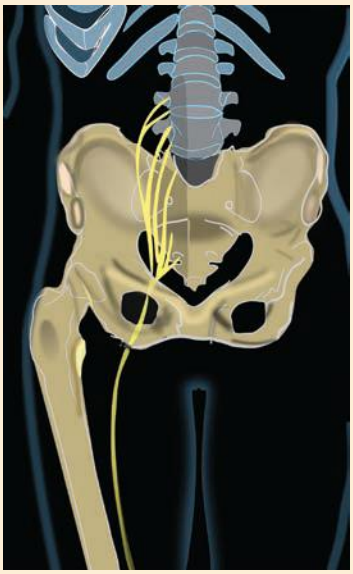


Figure 3.12 The sciatic nerve

Try this 3.3

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.

Quick check 3.4

1 State if an action potential is a signal between two neurons or along the axon of a neuron.
2 Recall what the 'all or none' principle means.
3 Define neurotransmitter.
4 Describe the role of the post-synaptic neuron.
5 Recall three common neurotransmitters, including their function.
6 Organise these stages into an flow chart in the correct order, showing how an action potential passes from one neuron to another.

Action potential stimulates synaptic vesicles to release neurotransmitters	Action potential is initiated once threshold is reached	Neurotransmitters released into synaptic cleft	Action potential travels along the presynaptic neuron's axon	Neurotransmitters bind to receptor sites on post-synaptic neuron's dendrites

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 3.13 shows.

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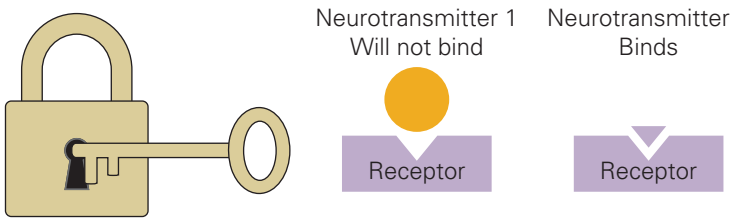


Figure 3.13 A specific neurotransmitter will bind only to its corresponding receptor, and in this way ensures it only causes the desired response. This is called the 'lock-and-key' model.

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.

Try this 3.4

Neurotransmission at the synapse

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 the following components.

- Presynaptic neuron (axon terminal)
- Synaptic vesicles
- Neurotransmitters
- Post-synaptic neuron (dendrites)
- Receptor sites
- Synapse
- Action potential
- Synaptic cleft

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 model.

Did you know? 3.3

Drugs

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.

Science as a human endeavour 3.1

Parkinson's disease

Neurodegenerative disease is an umbrella term for a range of conditions that primarily affect the neurons in the human brain. Examples of neurodegenerative diseases include Parkinson's disease, Alzheimer's disease and multiple sclerosis.

Parkinson's disease is a progressive, degenerative neurological condition that affects a person's control of their body movements, resulting in motor and non-motor symptoms. Parkinson's disease results from the loss of cells in various parts of the brain, including a region called the substantia nigra. This is a part of the brain where the production of the neurotransmitter dopamine is very common. When dopamine production is depleted, the motor system nerves are unable to control movement and coordination. The dopamine-producing cells are lost over a period of years resulting in the appearance of motor symptoms, such as tremors and rigidity.

Currently, there is no known cure for Parkinson's disease, but motor symptoms may be relieved by

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medications that increase the level of dopamine or mimic dopamine in the brain. The future of diagnosis and treatment of neurodegenerative disease depends upon technological advances in brain imaging and diagnostic tools. For example, a British company has recently produced a special pen, called a NeuroMotor Pen, that can help diagnose nerve disorders such as Parkinson's disease. The pen is connected to a tablet on which patients complete several handwriting and drawing tasks. Any abnormalities are quickly detected and can be used as 'digital biomarkers' to monitor patient progress. A number of low-cost wearable sensors and mobile phone applications have been developed that allow the symptoms of the patient to be continuously detected and quantified. The information can then be sent to a hospital to generate a daily report that will alert the doctor if there is any unusual data.

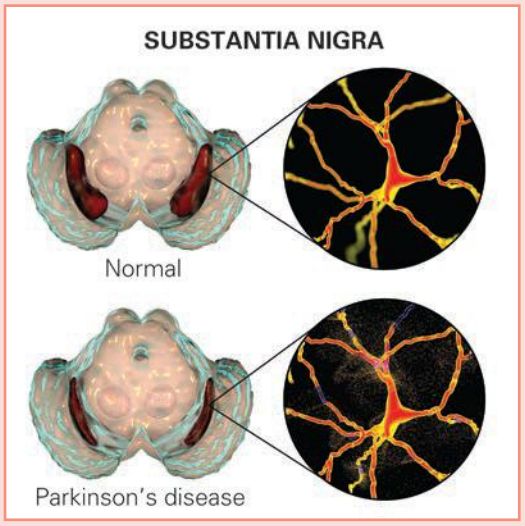


Figure 3.14 Computer illustration showing a healthy substantia nigra (top) and degenerated substantia nigra (bottom) of human brains

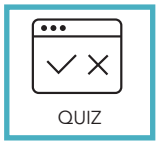
Explore! 3.3

Parkinson's disease

Research one of the following topics. Summarise your findings by explaining how technologies have improved knowledge and understanding of Parkinson's disease, or have helped people with Parkinson's live better lives.

- An imaging technique that allows us to identify and learn about Parkinson's disease (for example, PET scans or DaT/SPECT imaging)
  OR
- A technology developed to aid people with Parkinson's disease to have 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 **Name** the three different types of neurons found within the human nervous system.
2 **State** the function of dendrites.

Understanding

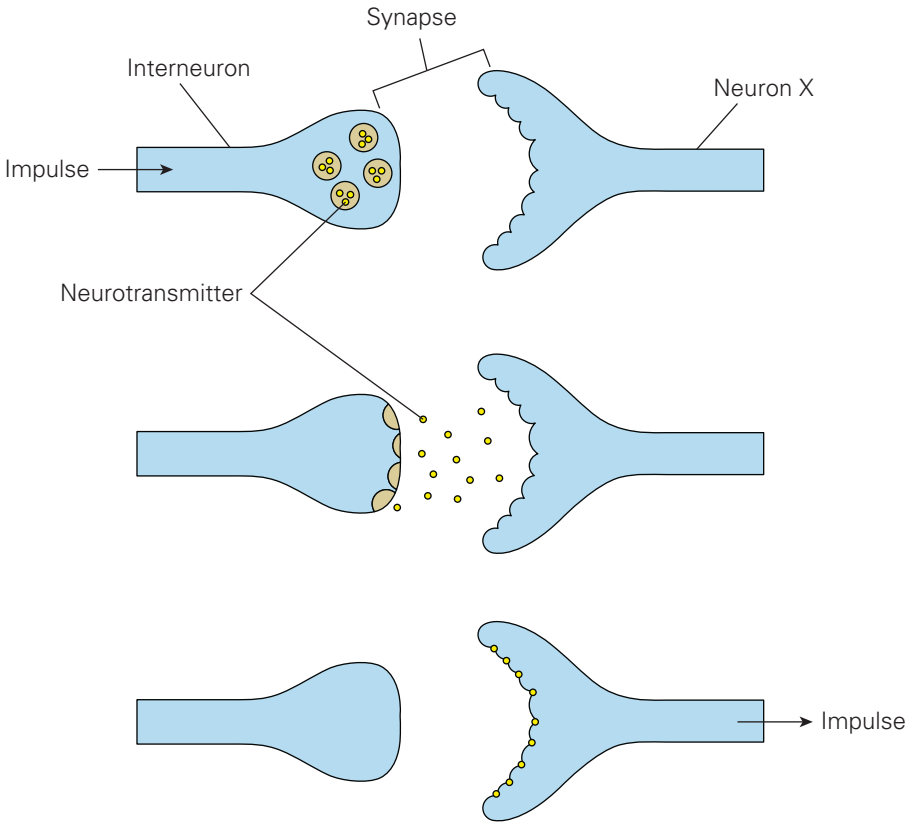
3 **Illustrate** a motor neuron, labelling all the key structures.

Applying

4 **Describe** how an action potential is triggered and transmitted from one neuron to the next.
5 **Describe** the synapse.
6 Using the 'lock and key' analogy, **explain** how neurotransmitters cross the synapse.
7 If a drug blocks the receptor sites, **explain** the effect it could have on neurotransmission across the synapse.

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



a **Identify** the name given to neuron X.
b **Describe** how information passes from the interneuron to neuron X. Use the diagram to help you.

Analysing

9 **Contrast** the function of the motor neuron with the sensory neuron.
10 **Compare** the role of two important neurotransmitters found within the brain – serotonin and dopamine.

Evaluating

11 Using the stimulus–response model, **construct** a flow chart showing the steps involved in the scenario that follows below. Be sure to include these terms on your flow chart: stimulus, motor neuron, muscle, interneuron, sensory neuron, sensory receptor.
A person is standing in a crowd and hears someone call their name. They turn their head to see who had called them.
12 Caffeine is known to increase alertness levels. You usually feel tired when the neurotransmitter adenosine is released. **Discuss** how caffeine may affect adenosine receptors.
13 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.

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3.3 The spinal cord

Learning goals

1 To be able to label a reflex arc in the human body.
2 To be able to describe what happens when the spinal cord is injured.

WORKSHEET

Reflex actions

A **reflex action** or spinal reflex is a quick, automatic and 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. In these cases, the spinal cord is primarily responsible for responding to the stimulus and initiating a response. A message will be sent to the brain, but not until shortly afterwards – the brain actually registers the stimulus and the response *after* the response has occurred.

A reflex action therefore involves no more than three neurons. The signal travels to the spinal cord and back to the muscle, which contracts quickly. This can also be called a reflex arc. Figure 3.15 shows an example of a reflex arc.

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

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

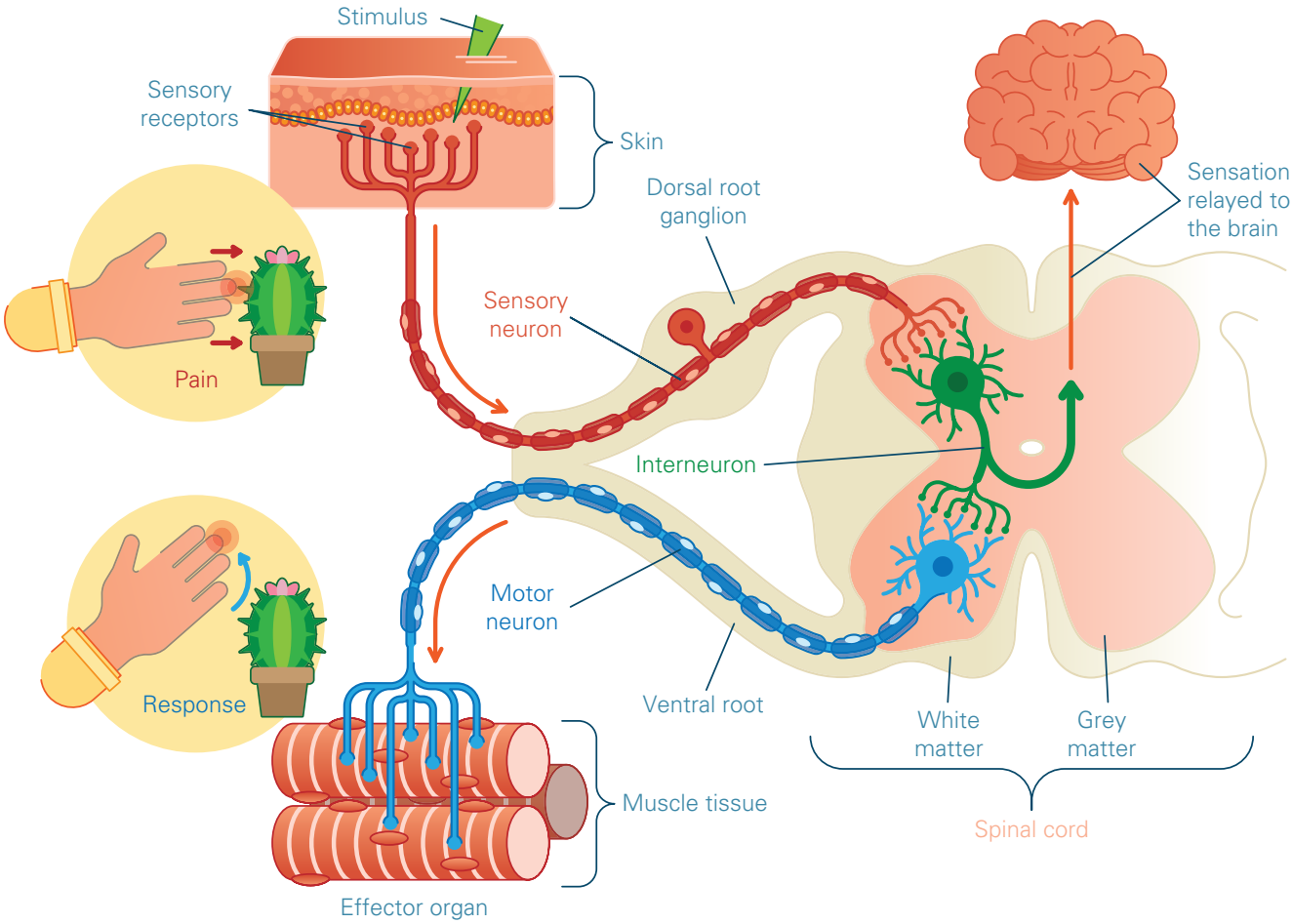


Figure 3.15 An example of a reflex arc. You touch a pointy cactus with your finger, and a receptor in a sensory neuron detects the pain and initiates an action potential. The impulse is carried to the spinal cord where the sensory neuron connects to an interneuron. The interneuron then connects to a motor neuron that sends an action potential through to the muscle tissue. Your muscles contract and you move your hand away from the sharp cactus.

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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.

Referring to the components defined in the table below, describe how the person's actions fit the stimulus–response model.

Part of the stimulus–response model	Definition of this part
Stimulus	Change in the environment
Receptors	Detect the stimulus and stimulate the sensory neuron
Sensory neurons	Transmit an action potential (nerve impulse) to the central nervous system
CNS	Brain coordinates an appropriate response by sending nerve impulses along interneurons which connect to motor neurons
Motor neurons	Transmit 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. This tendon connects to the quadriceps muscle on top of your thigh. The tap of the hammer causes a slight stretch within the quadriceps muscle. This stretch is detected by receptors in the muscle, which send a message to the muscle. Interestingly, the knee-jerk reflex is monosynaptic, meaning no interneurons are involved. Instead, the sensory neuron communicates directly across a synapse to a motor neuron in the spinal cord. The motor neurons conduct the impulse right back to the quadriceps, triggering a muscle contraction that makes you kick. The kick tells the medical professional that a particular section of the spinal cord and the associated nerves are working properly. A series of different reflex tests are required for a more precise health indicator of the whole nervous system.

The knee-jerk reflex is in use every time you stand up. Whenever you are upright, your muscles are continually contracting and stretching to keep you balanced. If you are standing up and start to lean back, your quadriceps are stretched and the reflex is triggered. Because you are standing, the muscle contraction that would cause you to kick upwards instead brings you back to a balanced central position. This reflex, combined with the Achilles reflex, helps us keep upright when walking.

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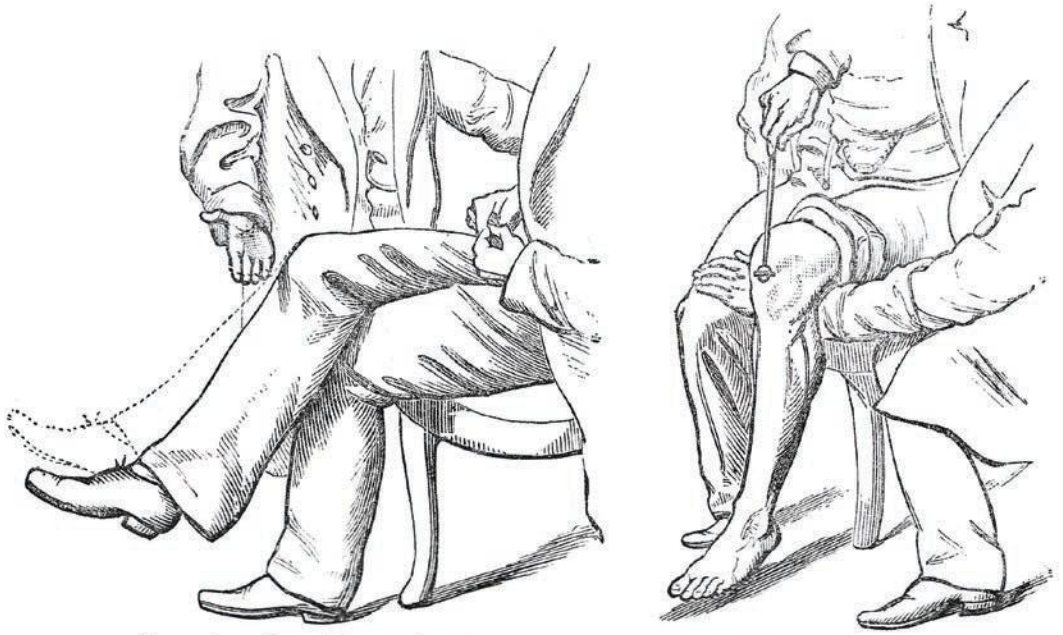


FIG. 1.—THE KNEE-JERK.
The dotted line indicates the movement which follows the blow on the patellar tendon.

FIG. 2.—THE KNEE-JERK.
Method of obtaining it when it is not readily produced in the ordinary way.

Figure 3.16 This illustration of the 'The Knee-Jerk' was drawn by William Richard Gowers, a pre-eminent clinical neurologist, for his *Manual of Diseases of the Nervous System* published in 1886.

Practical 3.1: Investigation

Testing your reflexes and response times

Background information

Reaction time is a measure of how quickly a person responds to a stimulus. Many factors can affect reaction time, including age, gender, practice, blood sugar, alcohol, caffeine and general fitness. You will design your own investigation to explore the effect of how long you practise on reaction time.

Aim

To plan and investigate the effect of practice time on automatic reflexes and response times.

Planning

1 Write a rationale on reaction times and the factors that affect this.
2 Create a relevant and specific research question for this investigation.
3 Write a risk assessment for this investigation.

Materials

- stopwatch
- ruler
- well-lit room

Method

Do not practise the experiment before starting to collect the results. You should start measuring immediately to ensure that the effect of practice time can be determined.

1 Have your partner lean their forearm on a bench with their weakest hand extending over the edge. If they are left-handed, they should use their right hand and vice versa. Ask them to make a pincer grip with their thumb and index finger with a gap of 2 cm between them.

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2 Dangle the ruler above their hand so that the end marked 0 cm is hanging between their thumb and index finger.
3 Instruct them to catch the ruler with their thumb and index finger when they notice you have released it.
4 Release the ruler without warning.
5 Take note of the measurement on the ruler where they have caught it. This is the number of centimetres that the ruler fell before the person responded. Use the conversion table to determine the reaction time.

Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)	Reading from ruler (cm)	Reaction time (s)
1	0.05	21	0.21	41	0.29	61	0.35	81	0.41
2	0.06	22	0.22	42	0.29	62	0.36	82	0.41
3	0.08	23	0.22	43	0.30	63	0.36	83	0.41
4	0.09	24	0.22	44	0.30	64	0.36	84	0.41
5	0.10	25	0.23	45	0.30	65	0.36	85	0.42
6	0.11	26	0.23	46	0.31	66	0.37	86	0.42
7	0.12	27	0.23	47	0.31	67	0.37	87	0.42
8	0.13	28	0.24	48	0.31	68	0.37	88	0.42
9	0.14	29	0.24	49	0.32	69	0.38	89	0.43
10	0.14	30	0.25	50	0.32	70	0.38	90	0.43
11	0.15	31	0.25	51	0.32	71	0.38	91	0.43
12	0.16	32	0.26	52	0.33	72	0.38	92	0.43
13	0.16	33	0.26	53	0.33	73	0.39	93	0.44
14	0.17	34	0.26	54	0.33	74	0.39	94	0.44
15	0.18	35	0.27	55	0.34	75	0.39	95	0.44
16	0.18	36	0.27	56	0.34	76	0.39	96	0.44
17	0.19	37	0.28	57	0.34	77	0.40	97	0.45
18	0.19	38	0.28	58	0.34	78	0.40	98	0.45
19	0.20	39	0.28	59	0.35	79	0.40	99	0.45
20	0.21	40	0.29	60	0.35	80	0.40	100	0.45

6 Each person should complete the drop test 15 times. Record the ruler reading and reaction time for each test.

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Results

1 Create a results table for this experiment.
2 Draw a graph of drop test number against reaction time.

Discussion

1 Identify any patterns, trends or relationships in your results.
2 The ruler drop experiment is not really testing a reflex. Draw a stimulus–response flow chart, highlighting the part that proves this is not a simple reflex. Explain why this is the case.
3 Compare your results with other people in your class. Do students who play particular sports or musical instruments have faster reaction times?
4 Identify any potential sources of error in this experiment.
5 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

Draw a conclusion from this experiment regarding practice time and reaction time. Justify your answer with data.

Did you know? 3.4



Voluntary and involuntary responses

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

Voluntary response to stimuli	Involuntary response to stimuli
Reaction involves the brain and a level of awareness	Reaction does not involve a level of awareness by the brain
Paid attention to stimulus	Do not have to pay attention for it to happen
Voluntary or intentional reaction	Involuntary or unintentional
Goal is often directed or purposeful	Reflexive or automatic, increasing chances of survival
Can be a more complex response	Most are simple responses
Tend to vary	Tend to occur in the same way each time
Can be learned	Do not require learning
Can control it	May not be able to control it

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Quick check 3.5

1 State if the following sentence is true or false: 'The brain is not immediately involved in a reflex arc.'
2 Illustrate a reflex arc for a person touching a flame.
3 Compare the reflex arc and stimulus–response models of the nervous system.

Causes and effects of spinal cord damage

The spinal cord is a bundle of nerves that carries messages between the brain and the rest of the body. It contains both white matter and grey matter, as shown in Figure 3.17.

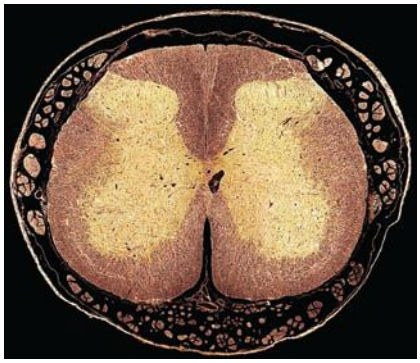


Figure 3.17 Light micrograph (LM) of a cross-section through the human spinal cord in the lumbar region. The spinal cord consists of a butterfly-shaped core (yellow) known as grey matter, which consists of soma, dendrites and axon terminals, so it's where the synapses are also found. Surrounding the grey matter is a larger region of white matter, coloured brown in this image, made up of myelinated axons that connect different parts of the grey matter.

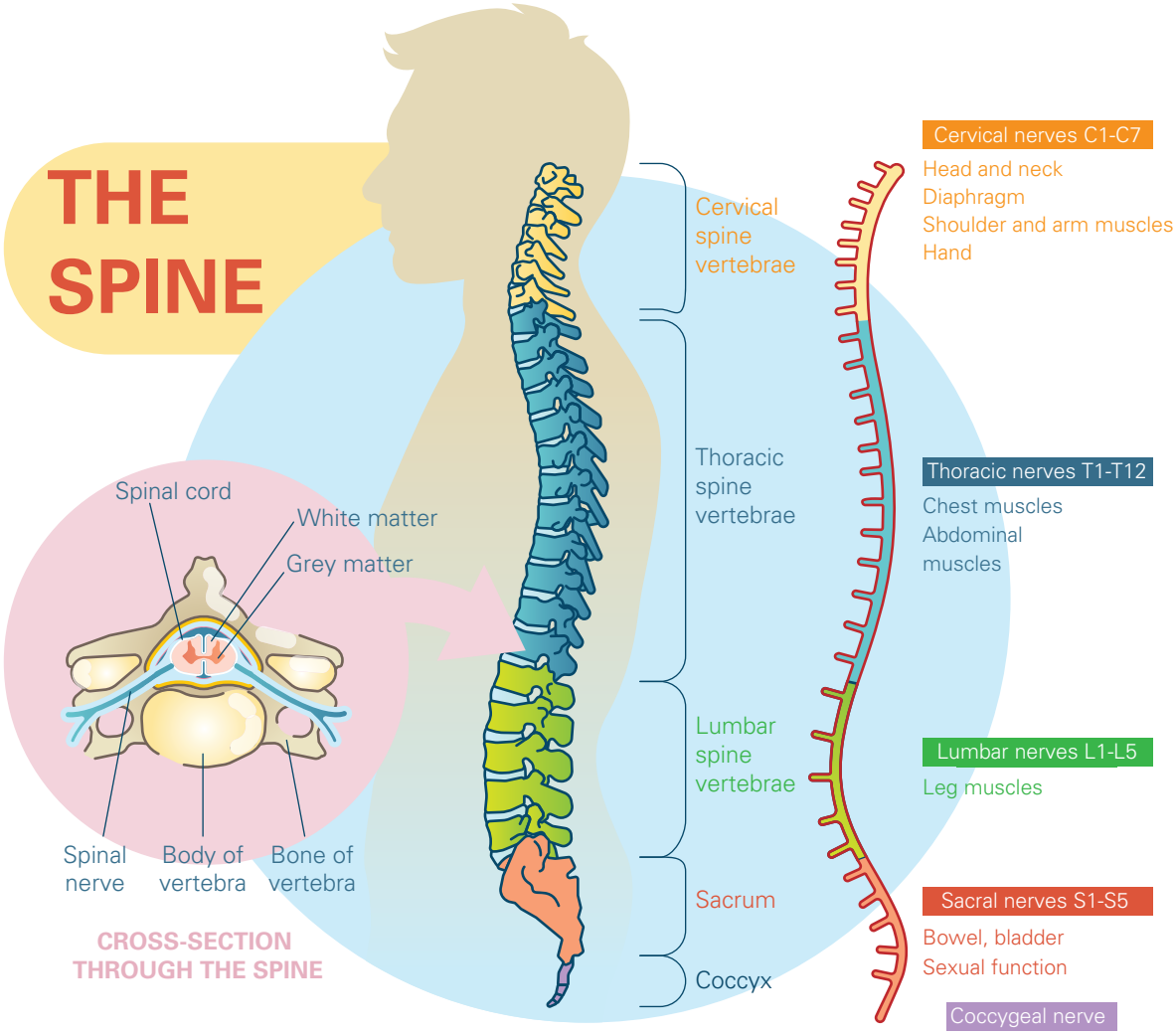


Figure 3.18 The spine showing the vertebrae, spinal cord and spinal nerves, divided into sections and their associated spinal nerves – cervical, thoracic, lumbar, sacrum and coccyx – along with a cross-section through a vertebra, the spinal cord and spinal nerves

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Classification	Description
Quadriplegia ('quad' means four)	Four limbs affected by impaired sensation and movement. If spinal injury is high up the spine, then chest muscles, such as the diaphragm, can also be affected
Paraplegia	Lower limbs affected by impaired sensation and movement
Triplegia ('tri' means three)	Rare incomplete spinal cord injury leads to three limbs affected by impaired sensation and movement

Table 3.5 Classification of spinal cord injuries

The spine consists of 33 vertebrae in five sections as shown in Figure 3.18. They are numbered in order going down, with a letter in front representing the section.

- 7 cervical (neck), C1 to C7
- 12 thoracic (upper back), T1 to T12
- 5 lumbar (lower back), L1 to L5
- 5 sacral (sacrum – located within the pelvis), S1 to S5
- 4 coccygeal (coccyx – located within the pelvis) Co1 to Co4, though this may vary.

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

Damage to the spine may result in spinal cord injuries. These may be caused by traumatic injuries including those from car crashes, sports or falls. Non-traumatic injuries, such as arthritis or degeneration of parts of the spine, may also cause spinal cord injuries.

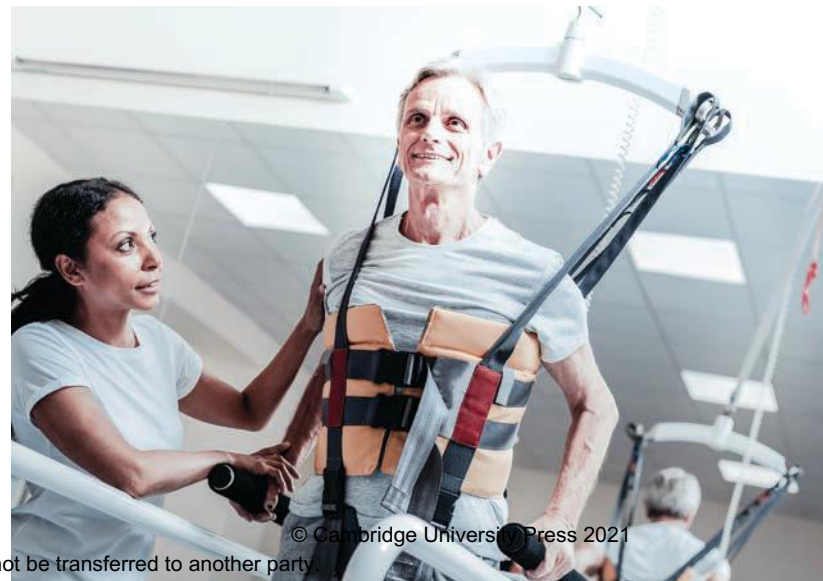
If the spine is injured, the location of the damage determines the effects that the person suffers. Spinal cord damage is classified according to the person's type of loss of motor and sensory function and the location is given by the spinal nerve numbering (see Figures 3.18 and 3.19). Table 3.5 describes the main categories of spinal cord injuries.

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

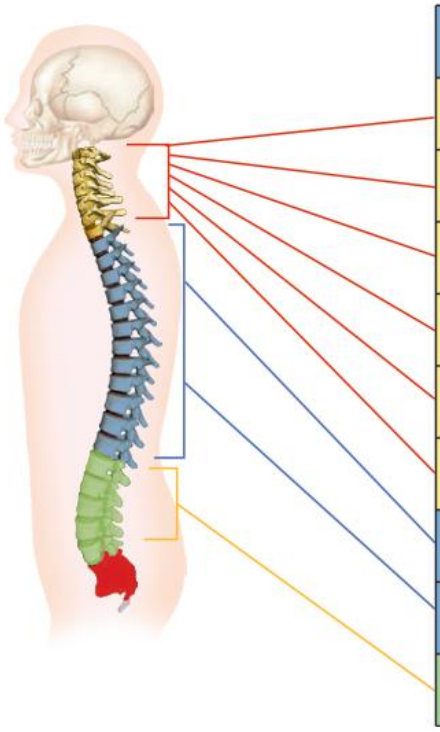
- muscle weakness or paralysis (including difficulty breathing if the diaphragm muscle is affected)
- sensory dysfunction such as loss of sensation or pins and needles
- sexual dysfunction
- digestive problems
- problems regulating their heart rate and blood pressure
- loss of control over bowel and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

Impairment and rehabilitation of spinal cord injuries

The position of the spinal cord injury will determine the extent of impairment and symptoms and the potential for rehabilitation. Figure 3.19 shows the levels of spinal cord injury down the spine and the associated rehabilitation potential.



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Level of injury	Possible impairment	Rehabilitation potential
C1 - C3	Unable to breathe, potentially fatal	Dependent on care
C4	Quadriplegia and breathing difficulty	Dependent on care, may need ventilator
C-5	Quadriplegia with little shoulder and elbow function	May need some respiratory support. May be able to self-feed with assistive devices or technology
C6	Quadriplegia with shoulder, elbow, and some wrist function	May be able to use wheelchair, feed and dress self. Usually needs help with bowel and bladder
C7	Quadriplegia with shoulder, elbow, wrist, and some hand function	May be able to assist with bowel and bladder management
C8	Quadriplegia with normal arm function; hand weakness	May be able to drive a car with modifications and assist with bowel and bladder management
T1 - T6	Paraplegia with loss of function below mid-chest; full control of arms	Quite independent with wheelchair
T6 - T12	Paraplegia with loss of function below the waist; good control of torso	May be able to participate in athletic activities with wheelchair
L1 - L5	Paraplegia with varying degrees of muscle involvement in the legs	May be able to walk short distances with braces or other assistive devices

Figure 3.19 Spinal cord injury levels, possible impairment and the potential for rehabilitation. The level of injury refers to the location using spinal nerve numbering.

Quick check 3.6

1 Name the different regions of the spine.
2 Define the terms 'quadriplegia' and 'paraplegia'.
3 State three ways a spinal cord injury might occur, including symptoms that might result from that injury.

Explore! 3.4

Spinal cord injury

Our bodies contain many specialised cell types, for example: blood cells, neurons and muscle cells. A muscle cell cannot become a neuron and vice versa. Stem cells are cells with the ability to become many different types of cells.

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 the treatment of spinal cord injuries?

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.



Figure 3.20 A catch of silver garfish

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Materials

- garfish
- Petri dish
- forceps
- scalpel
- probe
- newspaper
- dissection microscope
- dissection board
- disposable gloves

Be careful

Scalpels are extremely sharp. Proper cutting technique should be demonstrated before student use. Never use the scalpel to cut towards any part of your body. Extreme care is required when handling the scalpel. User discretion is advised.

Method

1 Working in pairs, place a garfish on a clean board.
2 Using forceps and scalpel, carefully make an incision down the underbelly from pectoral fins to anus.
3 Remove guts if necessary.
4 Remove as much flesh surrounding the backbone as possible so it is 'clean'.
5 Place spine (backbone) onto a Petri dish.
6 Discard flesh (wrap in newspaper before placing in bin).
7 View the spine using the microscope, and make a sketch showing the individual vertebrae. Include a title, labels and magnification.
8 Once this first sketch is completed, remove the dish from under the microscope for the next part of the activity.

Separating the spinal cord from the spine

9 Carefully try to separate the vertebrae from one another to try to locate and examine the spinal cord. If you are careful, you will be able to feel the resistance of the spinal cord. Do not rush this, as the spinal cord is very fine and will break easily.
10 Once you have a section of the spinal cord, place it (with the vertebrae, if still attached) under the microscope. Draw a sketch of the spinal cord. Include a title, labels and magnification.

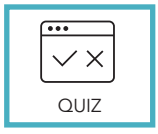
Results

Record your observations and include your two sketches.

Discussion

1 Comment on the appearance of the garfish's spine. Decide whether the spine provided sufficient protection for the spinal cord.
2 Differentiate between the appearance of the garfish's spinal cord and spine.
3 Discuss whether you expect fish to require a backbone as strong as a land creatures' backbone.

Section 3.3 questions



Remembering

1 A person suffers a spinal cord injury while surfing and loses motor control and sensation in their legs. **Name** this type of spinal cord injury.
2 **Define** what is meant by reflex action. Include its role in defending the body against damage.
3 **State** an example of a reflex action.

Understanding

4 **Identify** four different activities (perhaps activities you take part in!) that could pose a potential risk to a spinal cord.

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5 **Select** one word in each of the following sentences that makes the sentence incorrect. Change the words to make the sentences true.
   a A sensory neuron carries information from the central nervous system to the peripheral nervous system.
   b Involuntary responses to stimuli are often the most complex actions.
   c A spinal cord injury in the cervical region is likely to result in paraplegia.

Applying

6 A person picks up a very hot cup of coffee and immediately drops it, breaking the mug. **Illustrate** 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 coordinated by the brain.

Analysing

7 **Distinguish** between the stimulus and the response in the knee-jerk reflex.
8 **Contrast** at least three aspects of voluntary and involuntary responses.
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 Lucy has damage to her spinal cord at the L3 spinal nerve and her limbs are affected as a result. **Classify** her injury as paraplegia or quadriplegia.

Evaluating

11 Imagine this: You sneak up behind someone and make a sudden loud noise. They respond by blinking, twitching, moving their head suddenly, screaming or throwing their hands up. Using your knowledge of reflexes, **discuss** whether or not their response is voluntary, and give some reasons why this reflex might be a helpful mechanism to have.

3.4 The brain





Learning goal

1 To be able to label the main lobes and structures of the brain.

Cerebral cortex

The cerebrum is the largest part of the human brain. Its outer layer is called the **cerebral cortex**. It is only 2–3 millimetres (mm) thick, yet it contains three-quarters of the brain's neurons. The cerebrum is folded to increase the surface area of the cerebral cortex, and if you were able to unfold it, it would be the size of a pillow case! The cerebrum is divided into two hemispheres (left and right) which each contains four lobes. The left and right hemispheres are connected by a thick band of nerve fibres called the **corpus callosum**.

cerebral cortex
outer layer of the brain

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

contralateral organisation
each hemisphere of the brain is responsible for the motor function and sensation in the opposite side of the body

hemispheric specialisation
each hemisphere of the brain can exert greater control over specific functions

The hemispheres

Each of the left and right hemispheres is responsible for movement and sensation in the opposite side of the body. This is known as **contralateral organisation**.

Each hemisphere is also involved in specific functions; for example, the left side specialises in the ability to formulate and understand language. Each hemisphere can specialise or exert greater control 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.

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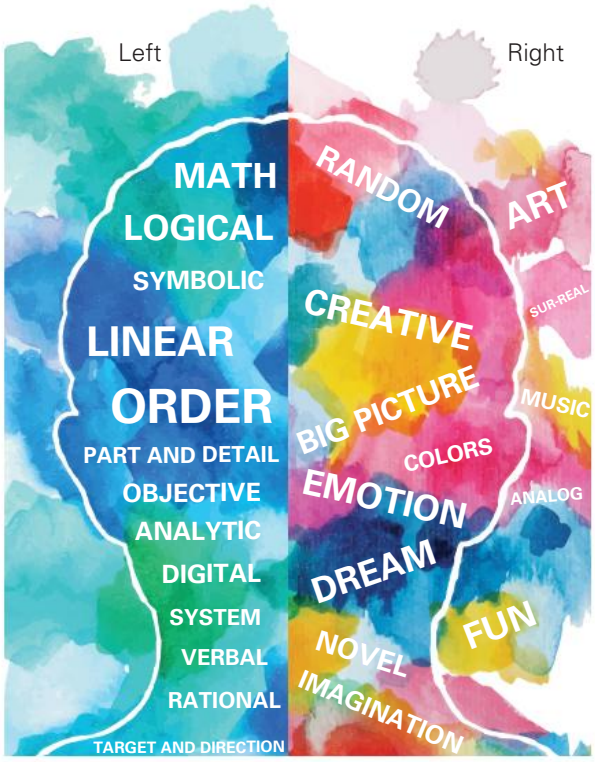


Figure 3.21 Both the left hemisphere and the right hemisphere of the brain are responsible for specialised functions.

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: the frontal lobe, the parietal lobe, the occipital lobe and the temporal lobe. They each have their own specialised functions as illustrated in Figure 3.22.

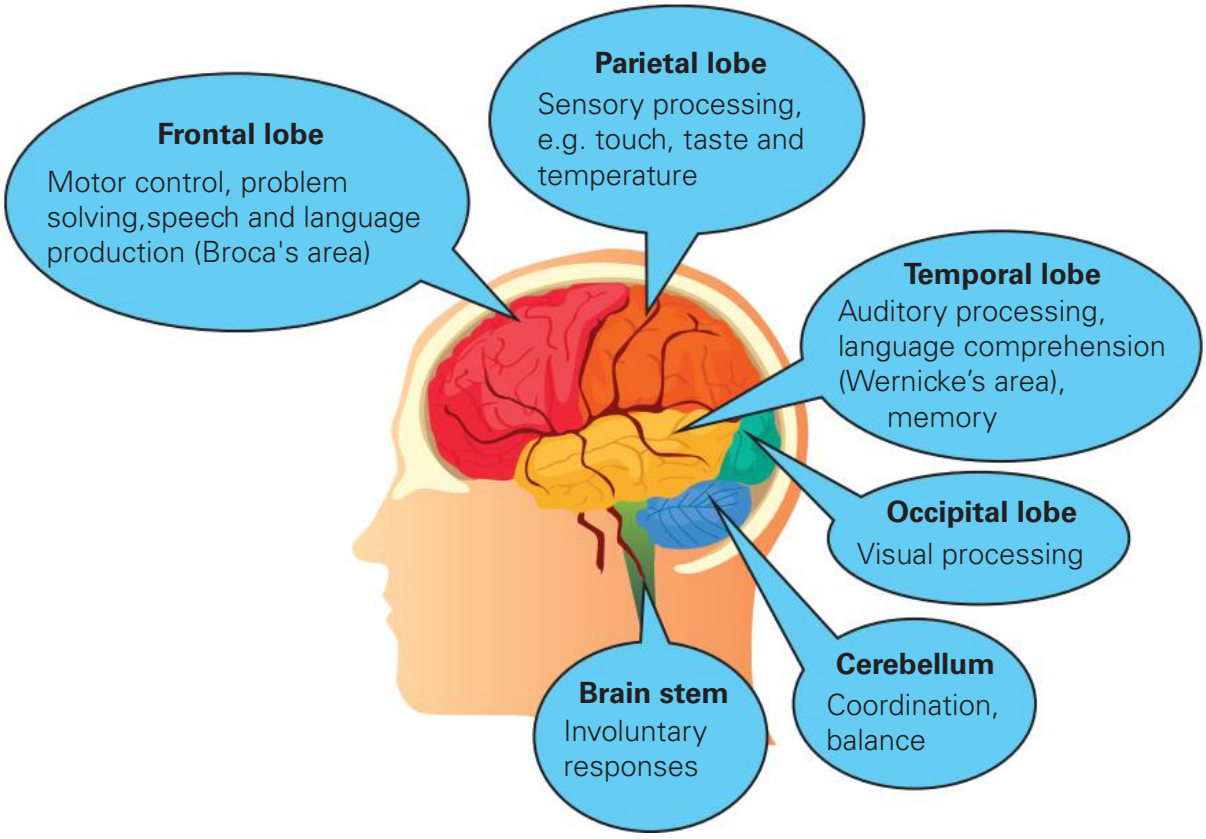


Figure 3.22 Specialised functions of the different lobes of the brain: frontal lobe (red), parietal lobe (orange), occipital lobe (green), and temporal lobe (yellow). Also shown are the cerebellum (blue) and brain stem (light green), which are located below the cerebral cortex.

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Structures within the brain

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

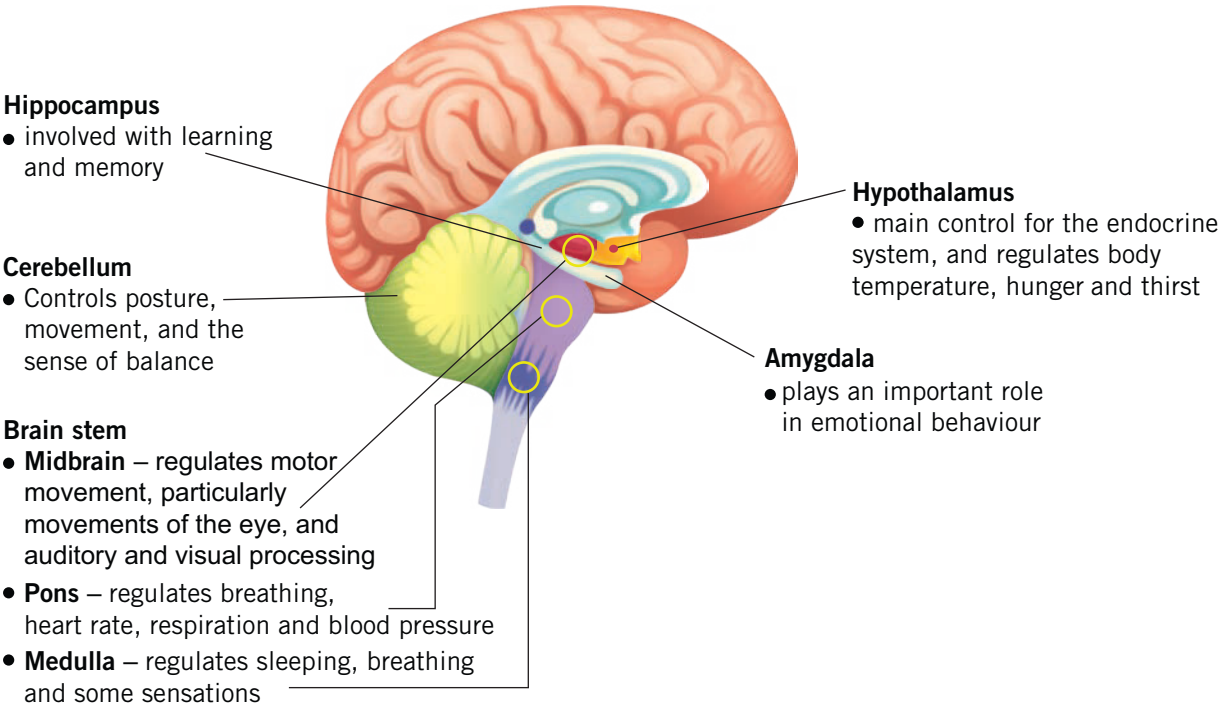


Figure 3.23 A cross-section of the brain

Try this 3.6

Brain poster

Make a poster or a slideshow about the brain. Use information from this chapter and 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 and temporal lobe and their functions
- Broca's area and Wernicke's area, describing their special roles
- a dorsal view of the brain (looking down from the top) showing the left and right hemisphere, and corpus callosum, and detailing their roles in processing sensory information and controlling activities on each side of the body.

Quick check 3.7

1 Recall the names of the four lobes of the cerebral cortex.
2 Name three structures found in the brain stem.
3 Recall the role of the occipital lobe.

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Did you know? 3.5

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.



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

Try this 3.7

Does talking interfere with right-hand motor tasks?

Humans are the only animals that are predominantly right-handed. Don't believe that right-handedness is more common? Do a quick survey in your class!

The part of the brain responsible for speech and language is in the left hemisphere of the cerebral cortex. It is also known that the left and right hemispheres control the movement in the opposite sides of the body.

Aim

To investigate whether talking will interfere with a balancing (motor) task.

Materials

- 30 cm wooden rod or similar
- stopwatch

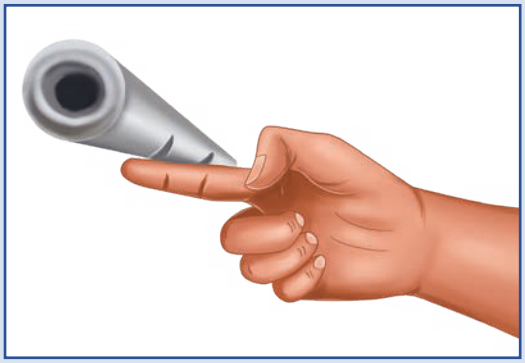
Method

1 Draw the results table below.

2 Construct a hypothesis about whether people will be better at balancing the rod when they are talking or silent, and whether there will be a difference between balancing on the side of their dominant or non-dominant hand.

3 Form groups of three and record whether each person is left- or right-handed – their favoured hand is their dominant hand.

4 Each person should practise balancing the rod on both their dominant and non-dominant index fingers. Ensure that the person balancing is standing, and that the rod is in the same position between the middle knuckles (as shown to the right).



5 Take it in turns. To begin with, the person being tested should place the rod on the index finger of their dominant hand while steadying it with the other. They should remove the steadying hand when the group member starts the stopwatch. Time how long they can balance it on that finger, up to a maximum of 30 seconds. Repeat with the rod on their the index finger of their non-dominant hand. Record these results in the table.

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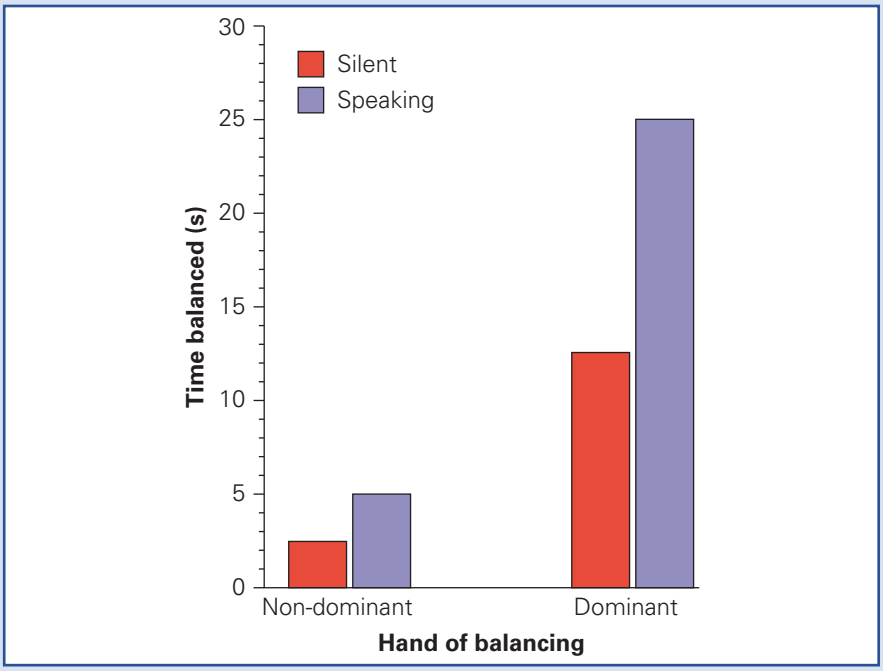
6 Now repeat this experiment, but as the person removes the steadying hand and the stopwatch starts, the third person should start saying words the person must spell out loud. Use the words suggested below. Record these results in the table.
Words to spell:
brain, conclusion, cerebral cortex, hemisphere, frontal, neuron, receptor, vision, sensory, spinal cord, vertebrae, parietal, occipital, experiment, reflex, hypothesis, cerebellum

7 Repeat the experiment with the other two group members.

Results

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

Create a graph of your results similar to that shown here, displaying the average for the group in each of the four time measurements.



Discussion

1 Identify any patterns, trends or relationships in your results.
2 Do the results support your hypothesis?
3 Explain the average results obtained using the facts stated prior to the Aim.

Sensitivity of body parts

Figure 3.25 shows a **homunculus**, which is Latin for 'little man'. It is based on a map of where sensory signals are processed in the cerebral. It also relates to 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 devised by brain surgeon Wilder Penfield and his colleagues. They produced the map, by electrically stimulating different areas on the cerebral cortex of patients whose skulls were opened for brain surgery under local anaesthetic. They asked the patients to identify where on their bodies they felt the stimulus.

homunculus (sensory and motor) a representation of body parts where size relates to the area of the cerebral cortex devoted to processing sensory or motor signals

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

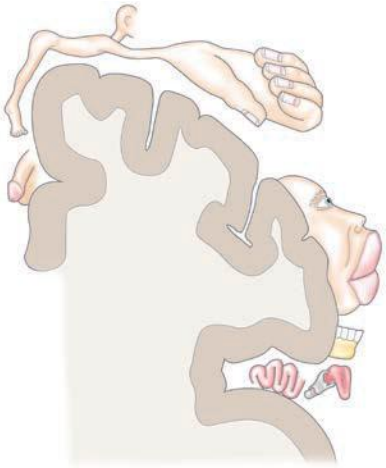


Figure 3.26 A pictorial representation of where the body parts are located on the cortex (seen here in cross-section). The larger the space along the cortex, the more sensitive the body part.

Try this 3.8

Sensory vs. motor cortex

Have a close look at the representations of the sensory and motor homunculi below. What are the differences between the two sculptures? Share your observations with the rest of the class. Discuss together what this means.

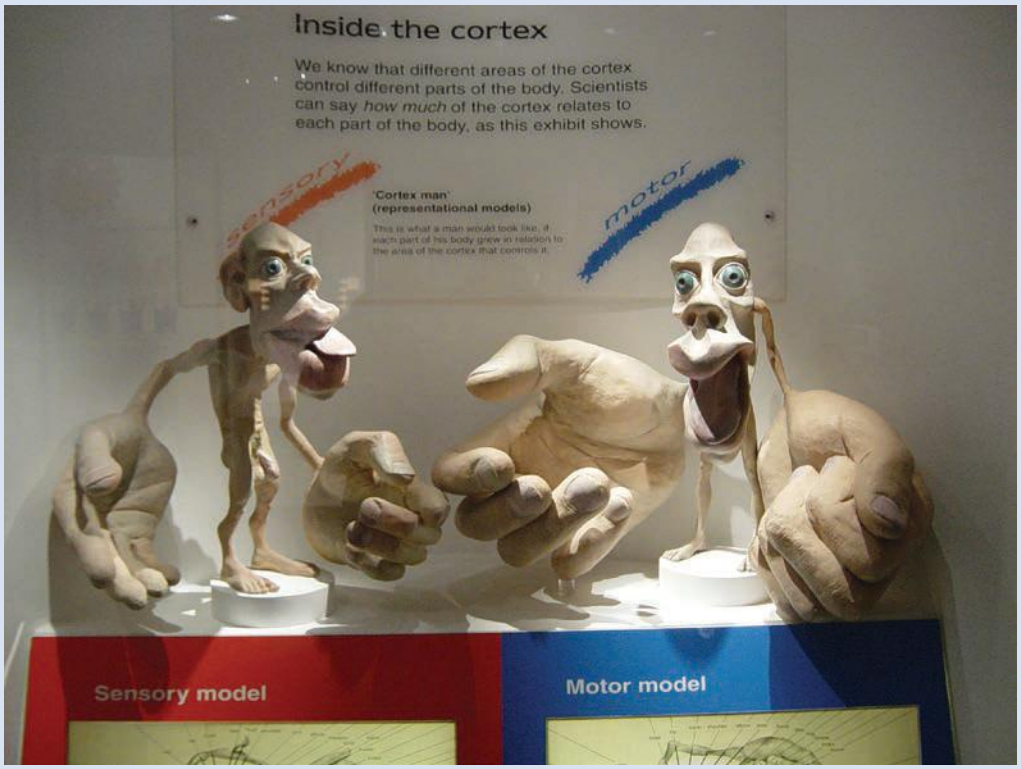


Figure 3.27 Sculptures of the sensory homunculus (left) and the motor homunculus (right), displayed at the Museum of Natural History, London

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Practical 3.3

Determining the sensitivity of body parts

Aim

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

Materials

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

Method

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



4 Open your paperclip.
5 Spread the ends and use the ruler to measure the distance between them.
6 Adjust them until they are exactly 4 cm apart.
7 The experimenter alternates touching the participant's fingertip with either both ends of the paperclip or one end of the paperclip. (A gentle touch is all that is required. Make sure the participant can't see the paperclip touching them.)
8 If the participant correctly feels whether one or both ends were used, tick the relevant column (✓); place a cross (×) if they do not feel the number of ends correctly.
9 Repeat steps **7–8** on the participant's upper arm and back and record your results in your table.
10 Repeat steps **5–9**, adjusting the paperclip ends closer each time until they are touching. Use the distances 3 cm, 2 cm, 1 cm, 0.5 cm and 0.0 cm (touching).
11 Complete the results table.

Results

Distance between paperclip ends (cm)	Fingertip one point (✓ or ×)	Fingertip two points (✓ or ×)	Upper arm one point (✓ or ×)	Upper arm two points (✓ or ×)	Back one point (✓ or ×)	Back two points (✓ or ×)
4.0						
3.0						
2.0						
1.0						
0.5						
0.0						

Discussion

1 Which body part proved to be the most sensitive? Did this support your hypothesis?
2 Why do you think different parts of the body have different levels of sensitivity? What function does this serve?
3 Looking back at the sensory homunculi, suggest one other body part that would have tested as highly sensitive and one other body part that would have shown low sensitivity.

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Quick check 3.8

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

Science as a human endeavour 3.2

Alzheimer's disease

Alzheimer's disease is an example of a neurodegenerative disease. It occurs when neurons in the brain shrink and eventually 'die' at a greater rate than normal. This causes the brain to shrink, which is especially seen in the ventricles of the brain. Over time, deposits of protein around neurons and twisted fibres inside neurons build up, preventing them from communicating properly.

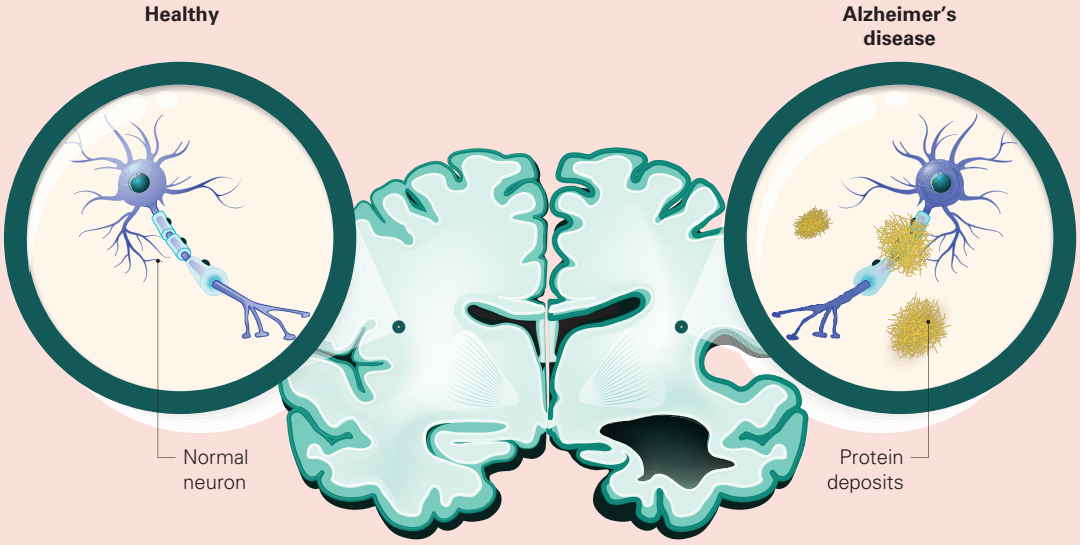


Figure 3.28 On the left is half of a healthy brain with normal neurons, while on the right the Alzheimer's brain shows protein deposits and brain shrinkage.

Early symptoms of Alzheimer's disease include the inability to form new memories, impaired recent personal memories, impaired memory for names, difficulty finding the right word when speaking, confusion, unusual irritation and impaired decision-making. Progressive symptoms include frequent repetition of stories or questions and the failure to recognise family members. There is no cure for Alzheimer's disease, but medications can slow the progression of symptoms.

In 2016, scientists found a new way to use brain-imaging technology called positron emission tomography (PET) scans. These scans were able to look at changes in the brain at a cellular level, while other scans only looked for a decrease in brain cells. PET scans involve the injection of a radioactive solution into the patient's brain. The amount of radiation measured in particular regions of the brain indicates how active those regions are at a particular time.

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…continued

This new way of using technology was tested on 86 adults without any neurodegeneration and 15 with suspected Alzheimer's disease. The scientists were able to prove definitively which people were clear of the disease, which were at risk and which people had the condition. The findings have also helped scientists understand more about how the twisted fibres and protein deposits build up as the brain ages.

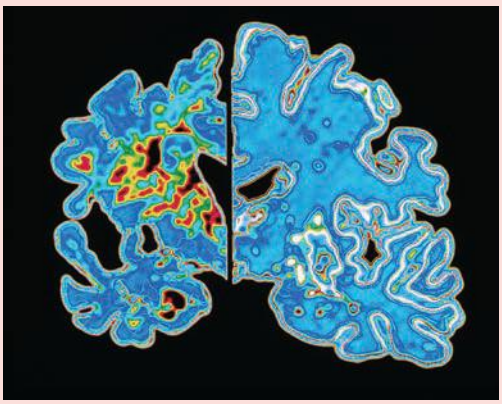


Figure 3.29 Computer graphic of a vertical slice through the brain of an Alzheimer's patient (left half) compared with a normal brain (right half).

The brain's plasticity

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

plasticity
the ability of the brain to change its neuron connections over time, in response to experiences

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 an electroencephalogram (EEG) to study their brain activity while the infants complete different tasks. The scientists use various experiments, often based on simple games, and test the babies' physical or cognitive (mental) responses with sensors including eye-tracking, brain activation and motion capture. Despite the lack of verbal communication, the EEG detects, amplifies and records the electrical activity of the brain, allowing scientists to make assumptions based on the readings.

A 4-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

Figure 3.30 This infant is undergoing an EEG during studies of cognitive development. A young child's brain develops about 1 million new neural connections per second.



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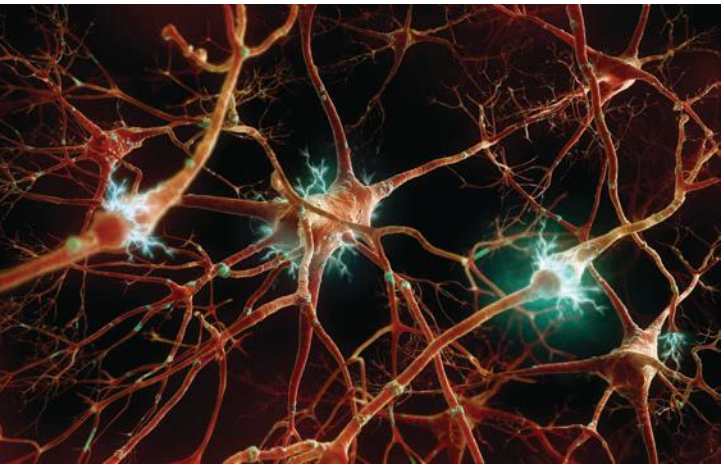


Figure 3.31 Each neuron can transmit 1000 nerve impulses per second and make tens of thousands of synaptic contacts with other neurons.

1000 trillion connections between neurons. It is no surprise 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 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, children can use other parts of the brain to form alternative neural connections to compensate for any missing or damaged part of the brain. This is also why it is easier to learn new skills and languages at a younger age.

One of the most famous examples of plasticity occurred when Jody Miller, aged $3\frac{1}{2}$, survived an 11-hour operation to remove the defective right hemisphere of her brain. The plasticity of Miller's child's brain is what allowed new neural connections to be made in her left brain that would perform functions once handled by her right brain. For example, when Jody Miller left the hospital 2 weeks after 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 the dangerous seizures she had experienced frequently before her surgery.

Quick check 3.9

1. Define the term 'brain plasticity'.
2. Explain why brain plasticity is useful.
3. Recall how much more energy a baby's brain uses compared to an adult's brain.
4. Explain what 'EEG' stands for and what it is used for.



Figure 3.32 Jody Miller takes physical therapy as she recovers from the operation to remove the right hemisphere of her brain.

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Did you know? 3.6

Bones in the human skull

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. Fontanelles provide a baby's skull with the flexibility needed to pass through the birth canal during childbirth. To avoid brain damage, you must be extremely careful to protect a baby's head. It is not until the age of one that the skull begins to fuse together and harden, forming visible lines called sutures.



Figure 3.33 A medical professional gently feels the fontanelle.

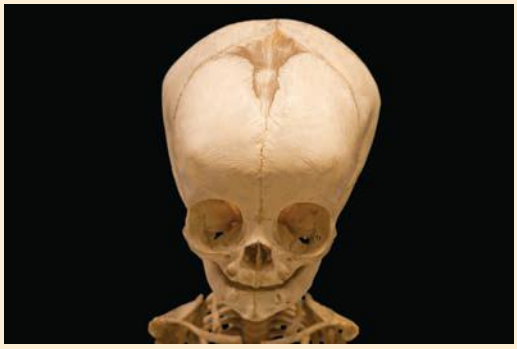


Figure 3.34 The skull of a 4-month-old baby is not yet fused together completely.

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 it continues to do so until around age 25. When you consider teenagers who have developed addictions to substances such as drugs and alcohol, keep in mind that teenagers are not just 'less-experienced adults' but are still a work in progress. They are prone to errors in judgement and tend to rely 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 of substance addiction than any other age group. Unfortunately, the use of addictive 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 occurs 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 forming habits. At the same time as your brain develops, unnecessary or underused neural connections are 'pruned' or disconnected.

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Figure 3.35 Combining imaging techniques can produce a great deal of information 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.

This process, known as 'synaptic pruning', 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, some sections of the brain are highly sensitive to alcohol. 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.

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Did you know? 3.7

Like, comment and subscribe

Using mobile phones and social media can also affect the brain. In most people, there is a release of dopamine during social interactions or when something pleasurable happens, such as receiving a like on a selfie, getting a text or being followed by someone new. Dopamine feels good, so we continually keep checking our phones, hoping to get another hit of it.



Figure 3.36 Are you addicted to your phone?

Explore! 3.5

Addiction

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

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.

Quick check 3.10

1. Define the term 'addiction'.
2. Recall why adolescent brains are particularly vulnerable to addiction.
3. Predict the symptoms you would expect to see in someone who has damaged their hippocampus and cerebellum through excessive alcohol consumption during adolescence.
4. State the neurotransmitter that is released when a pleasurable activity is done.

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Section 3.4 questions



Remembering

1 **Name** the outer layer of the brain and state how thick it is.
2 **Recall** where the word 'homunculus' comes from and what it means.
3 **State** why humans have a thick skull.

Understanding

4 **Define** the term 'brain plasticity'.
5 **Recall** reasons why adolescents are particularly vulnerable to addiction.

Applying

6 **Explain** what you might see underneath the cerebrum.
7 Apply your knowledge of the sensitivity of body parts to **explain** the unusual dimensions of the sensory homunculus.

Analysing

8 **Classify** the following as either left or right hemisphere characteristics.
   a Logical
   b Intuitive
   c Creative
   d Analytical
   e Objective
   f Subjective

Evaluating

9 **Decide** why it is incorrect to say that someone is 'right brained' or 'left brained'.
10 Mariam has suffered brain damage to her frontal lobe. **Predict** three symptoms she may display.
11 **Evaluate** whether you think it is easier for a child or an adult to learn a new language or skill, giving reasons for your decision.



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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

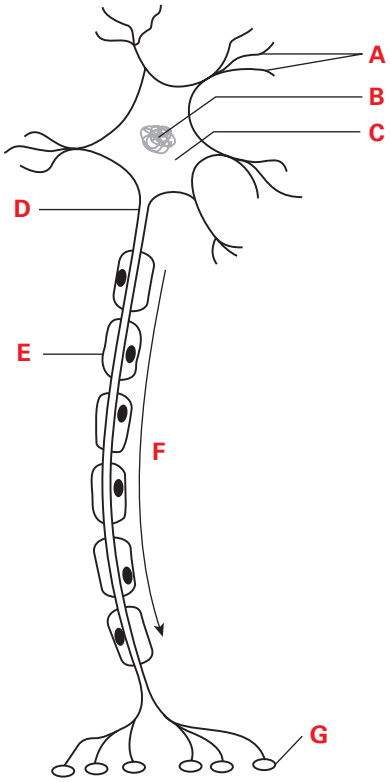
Success criteria	Linked question	Check
3.1 I can describe the structure of the nervous system.	8	
3.1 I can label the glands of the endocrine system and their hormones.	3	
3.2 I can compare the features of the nervous and endocrine systems.	10	
3.2 I can distinguish between a sensory neuron, interneuron and motor neuron.	9	
3.2 I can label the structure of a neuron.	1	
3.2 I can explain how nervous impulses pass between neurons.	5	
3.3 I can explain the importance of reflex actions.	7	
3.4 I can describe the structure and function of the brain.	2	

Review questions

SCORCHER

Remembering

1 **Name** the key structures (A-G) of the following neuron. Add labels for the direction and location of neurotransmitters coming in and out of the neuron.



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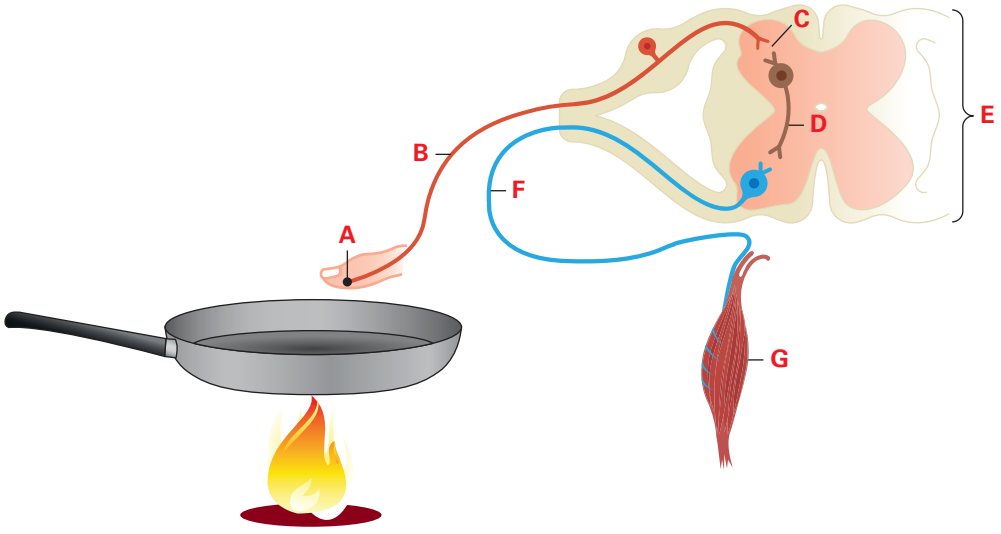
2 **State** the four lobes of the brain and, for each lobe, state one function for which they are responsible.
3 **Name** a hormone produced at the following endocrine glands.
   a Pituitary gland.
   b Pineal gland.
   c Adrenal gland.

Understanding

4 **Describe** the synapse.
5 **Describe** the steps involved in neurotransmission across a synapse.

Applying

6 **Explain** how the right side of the brain controls the movement of the left side of the body.
7 Ophia accidentally touches a hot pan and automatically snatches her hand away from it. The diagram shows the structures involved in this action.
   a **Identify** the structures (A-G) in the diagram below.



   b **Illustrate** a stimulus–response model referring to the diagram above.

Analysing

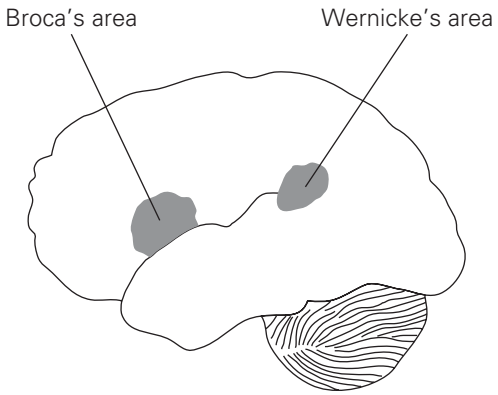
8 **Contrast** the sympathetic and parasympathetic nervous system.
9 **Contrast** the role of a sensory and motor neuron in the nervous system.
10 **Compare** the nervous and endocrine systems with respect to their: type of messenger, speed of signal and duration of control effect.

Evaluating

11 If a particular drug blocked the receptor sites on the dendrites of the post-synaptic neuron, **propose** how this may affect the neurotransmitters.
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'. In your response, **discuss** the effects that taking cocaine could have.

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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 that area may result in difficulties comprehending speech. Affected individuals may have trouble producing meaningful speech. Based on the information above, **discuss** appropriate methods that would aid talking to an individual suffering from damage to each area.



In your answer, refer to using:

- gestures
- questions that require yes/no answers.



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Data questions

Melatonin is secreted from the pineal gland in the hours of darkness and is a hormone that coordinates the body to go to sleep. The amount of melatonin produced in the average 14-year-old and 70-year-old across the hours of a day is presented in Figure 3.37. Note: this data assumes a bedtime (lights out) of 9 p.m.

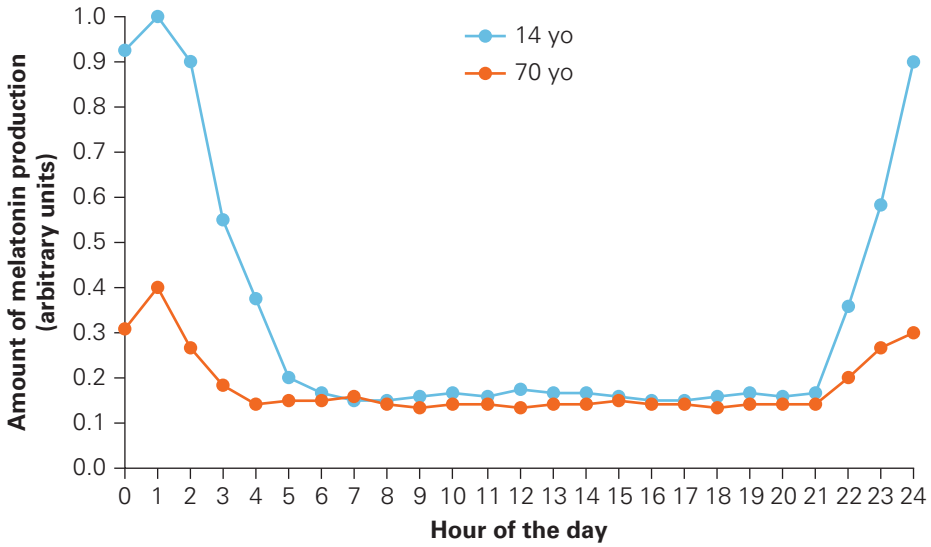
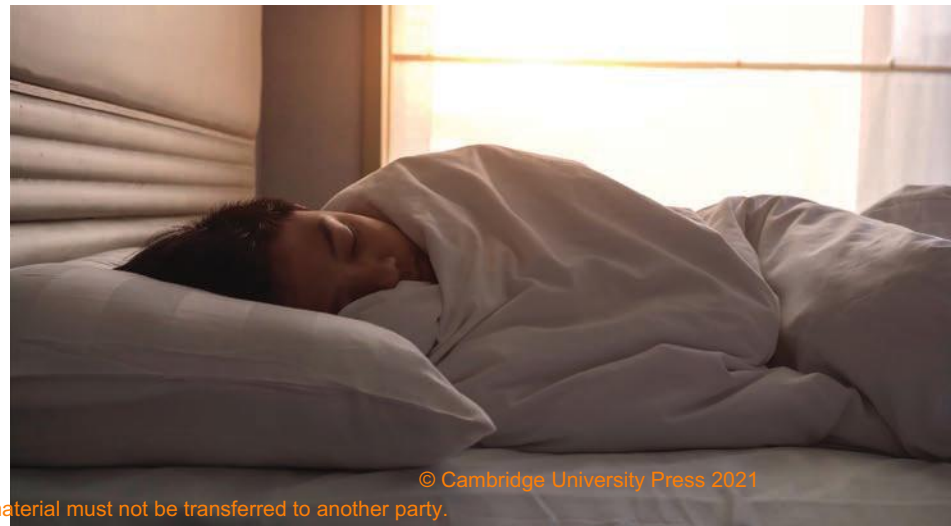


Figure 3.37 Amount of melatonin produced by the average 14-year-old and 70-year-old

1. **Identify** the time of day when most melatonin is produced for both the 14-year-old and 70-year-old.
2. If the 14-year-old produces 100 mg of melatonin at 1 a.m., **calculate** what mass of melatonin the 70-year-old produces at this time.
3. Over the course of 24 hours, **determine** who will produce more melatonin: the 14-year-old or the 70-year-old.
4. The melatonin production of a 30-year-old at 1 a.m. was determined to be 0.7. **Identify** a trend between the age of a person and their daily melatonin production.
5. **Identify** any patterns in the data presented.
6. **Contrast** their respective melatonin values and comment on whether the 14-year-old or the 70-year-old will feel sleepier at 10 p.m.
7. Use the data in Figure 3.37 to **justify** that melatonin production is triggered by darkness.
8. **Deduce** the melatonin production of a 30-year-old at midday.
9. **Predict** what would happen to the daily melatonin production of a 14-year-old or 70-year-old if at 9 p.m., instead of lights out, they watched videos on the internet for another 2 hours.



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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 (eyes) recognise the sudden change in light conditions on the road. That information is sent for processing, then the brain can decide what that information is and if any action is required. Your friend's brain compares the information coming from their 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 their 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, their 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 3.38 In Western Australia there are penalties for using a mobile device while driving or riding a bike. The fine is $1000 + 4 demerit points.

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

Activity instructions

Western Australia's Department of Transport is so worried about young people's attitudes towards texting while driving that it hired your young start-up company to conduct a sequence of experiments in the community to determine whether texting can slow down a person's reaction times.

In this activity, you will use materials and your imagination to create an experiment that produces:

- at least three sets of data
- at least three bar graphs
- a conclusion that clearly responds to the following scenario.

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Suggested materials

- 30 cm ruler
- scissors
- cardboard
- paper
- pen
- mobile phone to record amazing slow-motion videos
- Microsoft PowerPoint, Google Slides or Mac Keynote for presentations
- video-editing software for making short documentaries

Research and feasibility

1 Research and make a list of the factors that influence a person's reaction time.

2 Create a table and make predictions of how these factors will decrease or increase a person's reaction time.

Factor	Reaction time effect	Reason
e.g. Being tired	Decrease reaction time moderately	When a person is tired they have a decreased ability to process information, which decreases reaction time.

3 Discuss in your group, then list important information you will need to record about your participants whose reaction times will be tested. Hint: make sure you have thought about all the factors that might affect a person's reaction times, such as sleep, exercise or video game playing.

Design and sustainability

4 Using the materials on the material list, design a way to test the effect of mobile phone texting on a teenager's reaction time.

5 Design a table that includes information about each participant's recorded information.

Create

6 Perform your experiment, making sure you collect multiple sets of data for each participant and their important information.

Evaluate and modify

7 Discuss with your group the challenges you have encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.

8 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?

9 The results may change when a different type of ruler is used, such as metal, plastic or wood. Predict how the size or length of the ruler, and whether the dominant or non-dominant hand was used, might have affected the results.

10 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?

11 Create a graphical representation of your results and present your results to the class in the same way you would present to the Western Australia Department of Transport.

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Chapter 4
Ecosystems

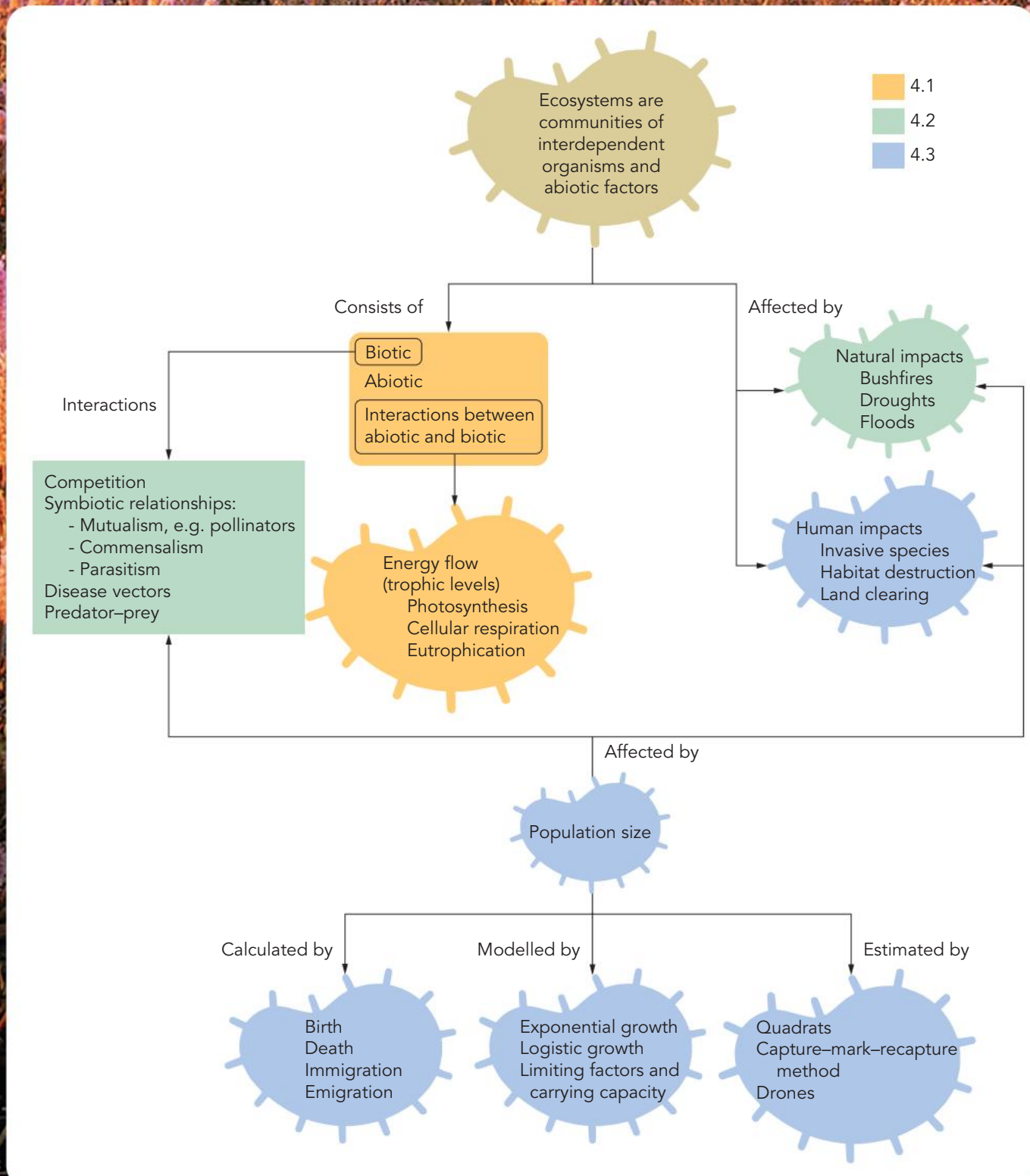


Chapter introduction

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.

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Chapter map



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4.1 Ecosystems and energy

WORKSHEET

VIDEO Australian ecosystems

Learning goals

1 To describe the six levels of organisation in an ecosystem.
2 To describe the 10% rule for energy flow through a food chain and web.
3 To be able to list the trophic levels in a food chain and web.
4 To explore the effect of fire, drought and flooding on Australian ecosystems.

Ecosystems consist of all the living things in an area, all of the non-living components (such as air, rocks, temperature, humidity, salinity) and all of the interactions taking place between the living things and their surroundings.



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 a few types of plant, such as mosses, lichens and algae, grow on the land surface, and Antarctic birds and mammals rely on food from the ocean.

Ecosystems consist of many different habitats and are often connected in a larger biome. A **biome** is a specific geographical area of the planet, classified according to the main climatic features, vegetation and specific adaptations of the organisms within that environment. A biome can be made up of many ecosystems. Australia contains many of the world's biomes, each of which have their own organisms and climate. Examples of types of global biomes include: aquatic, grassland, forest, desert and **tundra**.

ecosystem
an ecological unit made up of living components, non-living components and the interactions between them

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

tundra
plains of frozen soil and sparse tree growth in the Arctic region

biosphere
total region of Earth containing biomes

Biomes contain ecosystems of interacting living and non-living components, and the **biosphere** contains all of Earth's biomes.

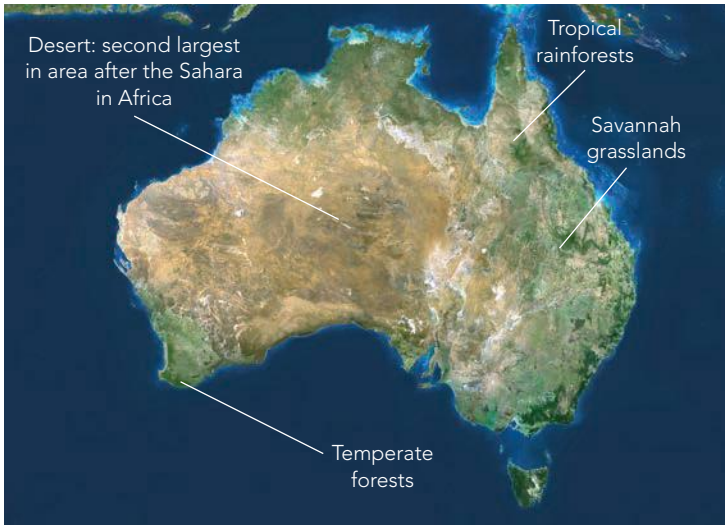


Figure 4.2 Location of some Australian biomes

Ecosystems vary greatly in size. The tidal pools in Figure 4.3 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 4.3 Tidal pools at Sugarloaf Rock near Margaret River, Western Australia



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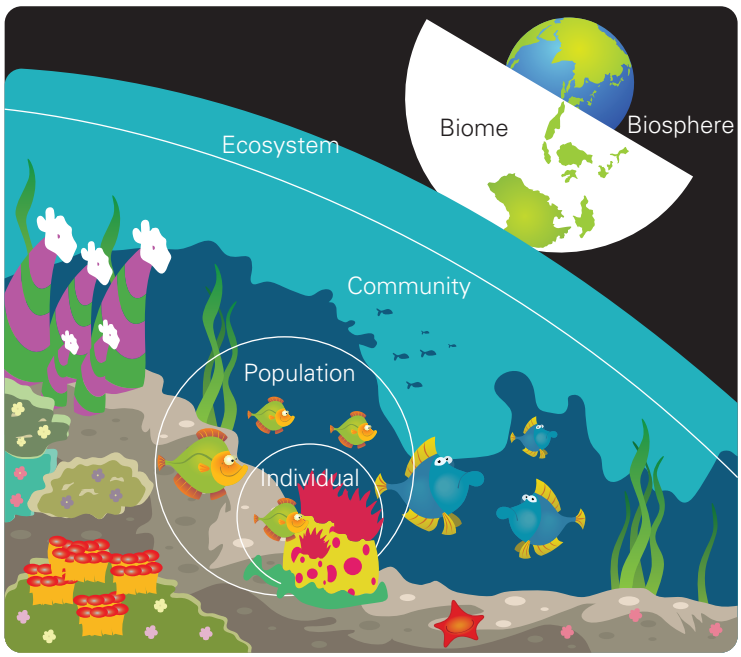


Figure 4.4 Levels of organisation in a reef ecosystem

VIDEO
Features of an ecosystem

- a non-living component (**abiotic** factors) that includes things such as rocks and sand, but also all the things that can be measured – such as temperature, light intensity, wind speed, rainfall, humidity, pH and salinity. Abiotic factors play an important role in the overall distribution and abundance of organisms within an ecosystem
- the interaction between the biotic factors and the abiotic surroundings.

An ecosystem can also be classified as a community and its **habitat**.

habitat + community = ecosystem

Components of an ecosystem

An ecosystem comprises three essential components:

- a living component (**biotic** factors) consisting of populations of different organisms (for example, humans, plants, animals, fungi, bacteria), some of which are microscopic, as well as the organic matter produced by these organisms, such as faeces or decaying organic matter

Within an ecosystem, the habitat is the place in which an organism lives. You can think of it as the organism's physical surroundings, which may be a pond, grassland or treetop canopy. It is usually considered abiotic, but the habitat could be considered biotic if the organism lives on or in another organism.

biotic
living factors, such as plants, animals and bacteria

abiotic
non-living factors, such as temperature, pH, salinity, rocks and water

habitat
the environment an organism lives in

Figure 4.5 An image of scenery in Tom Price, Western Australia, showing abiotic factors of water, rocks and light intensity along with biotic factors of plant life



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A **population** is a group of individuals of one species living in a certain habitat at a given time, for example, a mob of kangaroos who reside in a certain area of bushland.

population
members of one species living in a particular area at a given time

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

A **community** is a group of all the populations of different organisms that live within a habitat at a particular time, and is therefore always considered biotic. A river community might include kangaroos, birds, grasses, bacteria, fish and crocodiles. All species in the community interact with one another, and also with their habitat.

The productivity of an ecosystem depends on both biotic and abiotic factors. Living organisms interact with both the biotic and abiotic components of their ecosystem, forming different types of relationships that increase the complexity of the community.

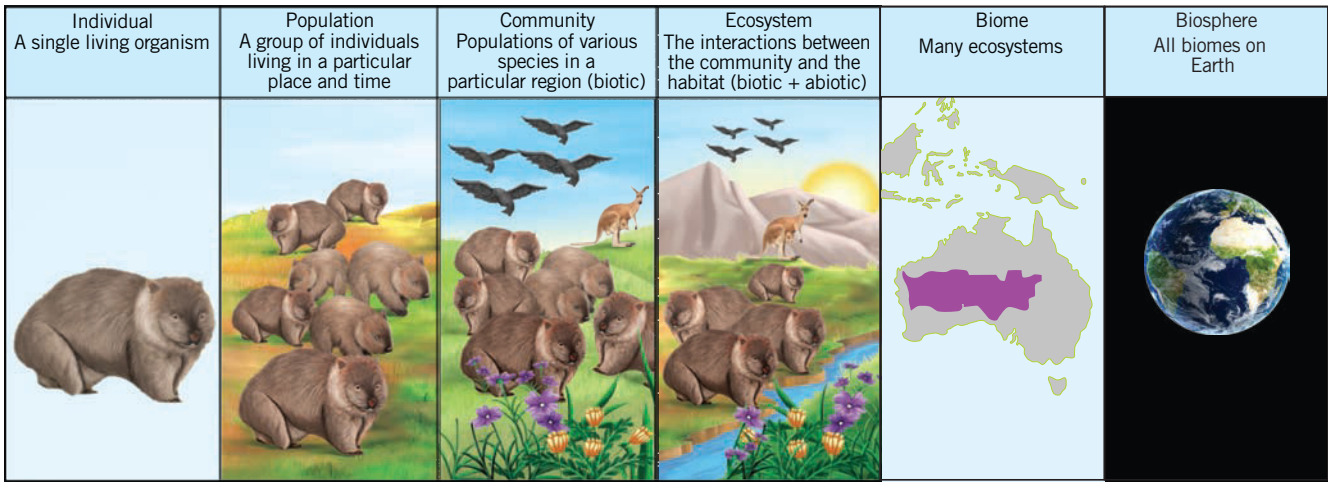
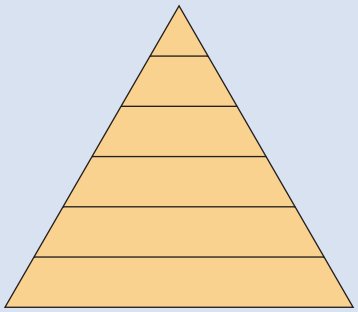


Figure 4.6 The various levels of organisation beginning from an individual organism right through to Earth's biosphere

Try this 4.1

Draw a diagram or a flow chart connecting these key concepts: individual, ecosystem, biosphere, biome, population, community. Annotate arrows in the flow chart to demonstrate 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.



Quick check 4.1

1 Define the terms 'population', 'community' and 'ecosystem'.
2 State the three essential components that are present within an ecosystem.
3 Distinguish between a biotic component and an abiotic component of an ecosystem, and include examples of each.

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Try this 4.2

Abiotic factors can be classified into chemical or physical components. For the factors below, select whether they belong to the chemical or physical domain. Copy the table and place a tick in the appropriate column.

Abiotic factor	Physical component	Chemical component
Humidity		
pH of soil		
Day length		
Temperature range		
Dissolved oxygen concentration of water		
Wind speed		
Rainfall		
Concentration of mineral ions in soil		

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. Within a food chain, organisms gain energy from other organisms, such as a kookaburra eating a snake as shown in Figure 4.7.

A **food chain** shows the flow of energy from organism to organism through an ecosystem, where the arrow points in the direction of energy transfer. The sun is the original source of the energy in most organisms but is rarely included in the food chain. A simple example of a food chain:

plant → mouse → snake → kookaburra

food chain
the flow of energy from organism to organism in an ecosystem

Figure 4.7 A Laughing Kookaburra, *Dacelo novaeguineae*, eating a yellow-naped snake, *Furina barnardi*



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As in this example, food chains typically start with a **producer**, in this case, the plant. The **consumer** that eats the producer is called a **primary consumer** (the mouse), and the consumer that eats the primary consumer is called a secondary consumer (the snake). Organisms that feed on **secondary consumers** are called tertiary consumers (the kookaburra) and organisms feeding on **tertiary consumers** within an ecosystem are called **quaternary consumers**. Numerous food chains exist within ecosystems, and these can all be interlinked in a complex pattern called a **food web**.

The term **trophic level** refers to the position an organism occupies in a food chain. Numerous organisms may occupy the same trophic level. Also, one particular organism may occupy different trophic levels within a single food web due to being a consumer in multiple food chains. Trophic levels are easily represented in a pyramid shape. Producers make up the first trophic level and herbivores, which are the first consumers in the food chain, are in the second trophic level.

producer
also known as an autotroph, an organism capable of making its own food

consumer
also known as a heterotroph, an organism that must eat or consume other plants or animals as a source of energy

primary consumer
the consumer who eats the producer in a food chain

secondary consumer
the consumer who eats the primary consumer

tertiary consumer
the consumer who eats the secondary consumer

quaternary consumer
the consumer who eats the tertiary consumer

food web
a series of interconnected food chains

trophic level
the position an organism occupies in a food chain

apex predator
the highest level consumer in a food chain

autotroph
also known as a producer, an organism capable of making its own food

heterotroph
also known as a consumer, an organism that must consume plants or animals as a source of energy

Food chains do not have an infinite number of trophic levels. Typically, land-based food chains have fewer than six levels. The highest-ranking consumer is sometimes referred to as the **apex predator**.

The Sun is the key abiotic factor that provides plants with the energy required to perform photosynthesis. Plants and algae can turn the radiant energy they absorb from the Sun into glucose, a form of sugar, which they then use to grow. Because plants produce their own food, they are called producers or **autotrophs** (meaning self-feeding).

Try this 4.3

Redraw the food chain you have been looking at and add the following labels: producer, primary consumer, secondary consumer, tertiary consumer. Also annotate it to show which of the consumers are herbivores and which are carnivores.

Reflect: Must a primary consumer always be a herbivore?

Consumers are organisms that must eat or consume other plants or animals (producers or other consumers) to obtain their energy, as they cannot produce their own food. They are known as **heterotrophs**. If an ecosystem had no producers, herbivorous consumers would not have a source of energy, and it would be impossible for all other organisms to exist. Producers capture the Sun's energy and bring it into the ecosystem in a useable form.

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?

Answers: autotrophs – trees and bushes; heterotrophs – mushrooms, all the animals; apex predator – crocodile.

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Energy transfer between trophic levels is not very efficient: only about 10% of the energy an organism consumes is passed on to the next organism in the food chain (that is, up to the next trophic level). The remaining 90% is lost as heat or in waste like faeces. Therefore, the amount of energy available to organisms decreases substantially at each subsequent trophic level. This produces a pattern called an 'energy pyramid'.

The energy pyramid in Figure 4.9 shows how much energy is present in each stage of an Australian woodland ecosystem.

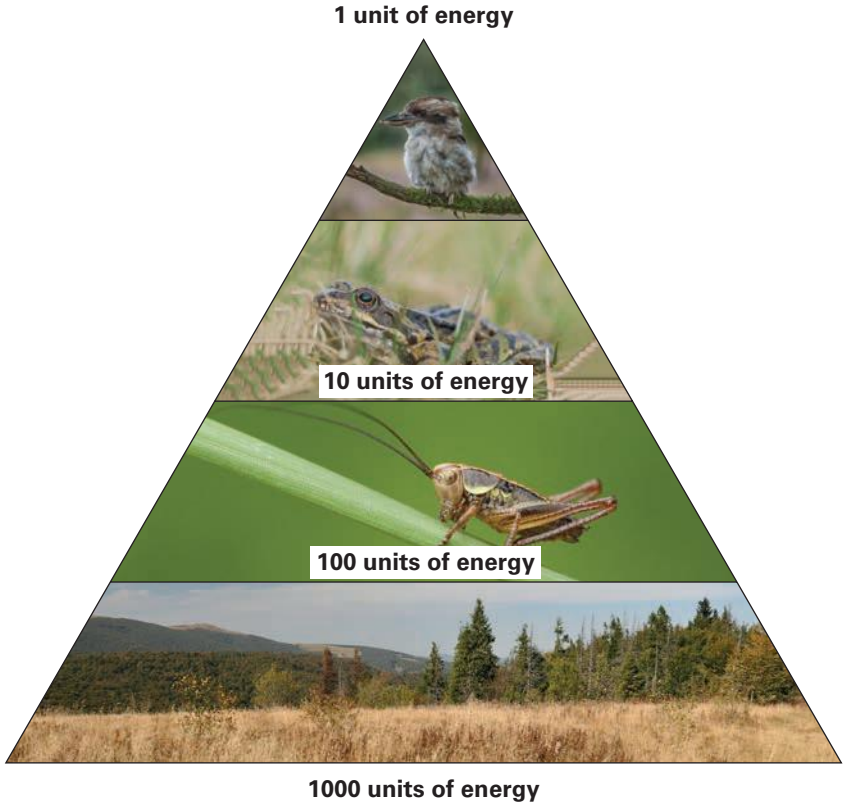


Figure 4.9 This trophic pyramid or 'energy pyramid' shows the energy flow from the grass through to the kookaburra.

Try this 4.4

1 Only 10% of the energy from one trophic level is transferred to the next level. What happens to the 90% energy that is lost?
2 Do you think a pyramid is a good shape to represent how matter and energy transfer in an ecosystem? Give a reason for your answer.

Quick check 4.2

1 State which organism in Figure 4.9 would fulfil each of the following roles: producer, primary consumer, apex predator.
2 Construct a food chain for Figure 4.9.
3 Distinguish between a producer and a consumer, and provide an example of each.
4 Explain why energy is an essential component within an ecosystem.

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Energy within ecosystems: photosynthesis, respiration and eutrophication

Photosynthesis

photosynthesis
the chemical reaction by which some organisms make their own food

An ecosystem derives its energy from the Sun, and this energy is cycled through the plants, animals and 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 you! Plants also use the glucose as their own energy source. Even the waste product of photosynthesis is incredibly useful for humans – plants release oxygen as a product of the chemical reaction.

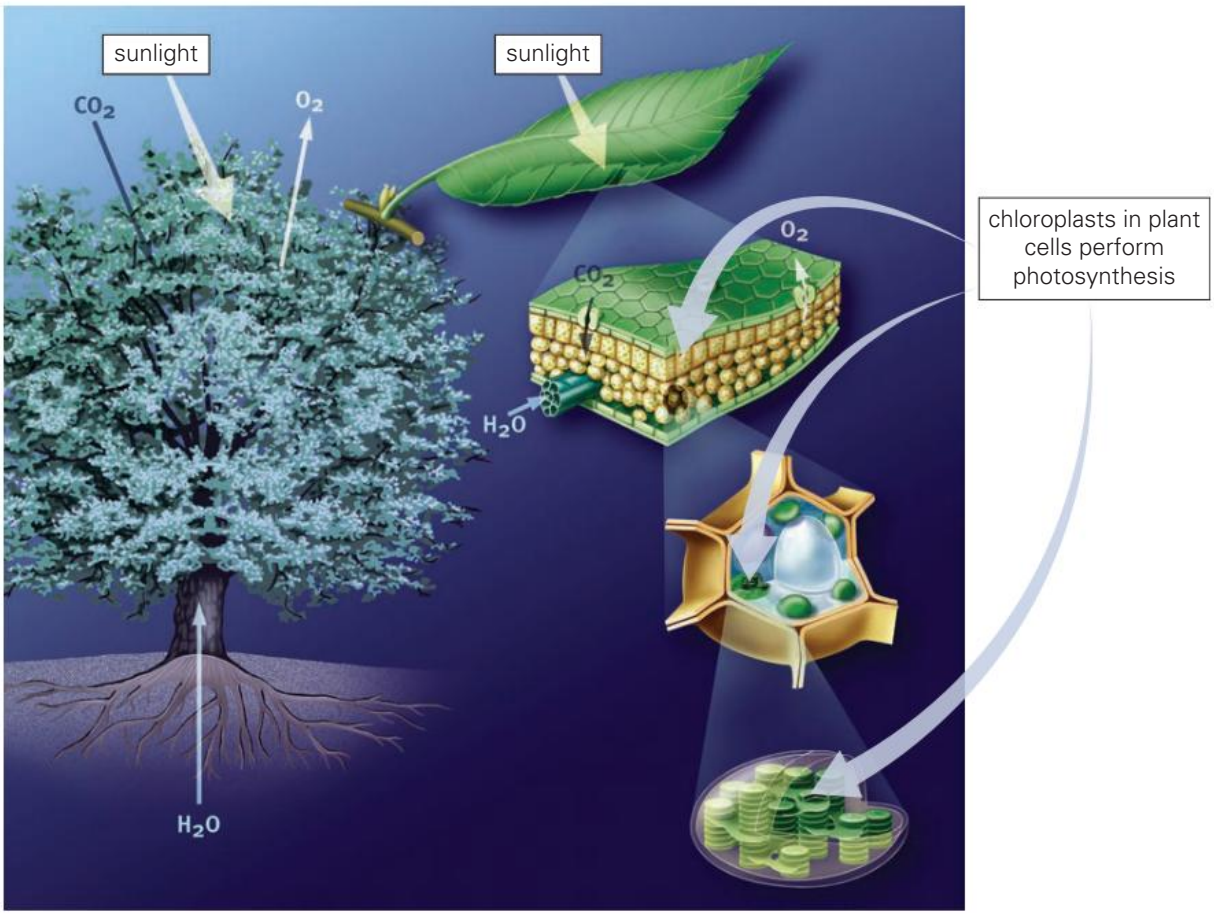


Figure 4.10 Plants trap sunlight in tiny organelles called chloroplasts and use it to produce glucose and oxygen from the reactants of carbon dioxide and water.

The chemical reaction named photosynthesis uses carbon dioxide and water, and in the presence of sunlight (energy) converts these into glucose and oxygen.

This reaction can be described with the simple equations shown below.

carbon dioxide + water + energy → (chlorophyll) → glucose + oxygen

$6CO_2 + 6H_2O + \text{energy} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$

Figure 4.11 Chemical and word equations of the photosynthesis reaction

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Photosynthesis occurs in chloroplasts, the organelles in plant cells that contain the substance chlorophyll, which is responsible for absorbing the Sun's energy.

Plants can either immediately use the glucose they produce, store it as starch, or build it into cellulose to make their cell walls or other cellular components. Photosynthesis can be affected by the plant's environment, with factors such as the availability and intensity of sunlight and the availability of water determining the effectiveness of the process.

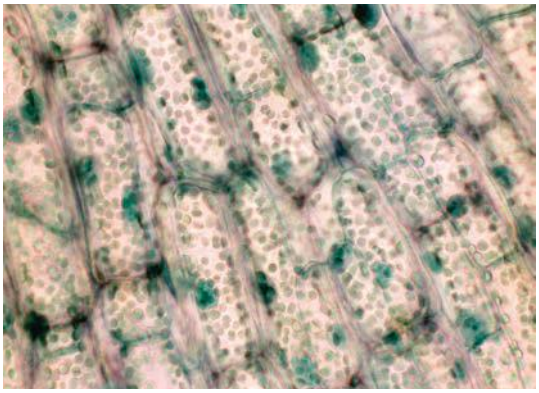


Figure 4.12 A leaf (from pondweed *Elodea canadensis*) as seen under a microscope at magnification of ×200. Note the green chloroplasts.

Try this 4.5

Looking at chloroplasts under a light microscope

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.

Practical 4.1: Investigation

The effect of light on plants

Aim

To investigate the effect of light on plant growth.

Planning

1. Write a rationale about the factors that affect plant growth.
2. Identify the independent, dependent and control variables for this experiment.

Materials

- 3 Petri dishes
- cotton wool
- fast-growing seeds such as mustard or cress

continued…

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…continued

Method

1 Draw a results table that will allow the collection of sufficient relevant data.
2 Cover the base of each Petri dish with cotton wool and dampen it by adding the same volume of water to each.
3 Add twenty seeds to each Petri dish and place them on a brightly lit, warm windowsill.
4 Wait a few days to allow the seeds to germinate, ensuring that the cotton wool does not dry out.
5 Once the seeds have been given enough time to germinate, ensure each Petri dish contains ten seeds, removing any extra seeds where necessary (not all of the seeds will have germinated, which is why twenty were added at the start).
6 Place one Petri dish in full light on a windowsill, the second in a dark room or dark cupboard, and the third in partially lit conditions.
7 For a week, measure the height of each seedling in each Petri dish and record the measurements in your results table. You must record the height of each individual seedling on each day. You may want to sketch a diagram that will remind you which seedling is which.
8 Calculate the mean growth (change in height) of the seedlings in each Petri dish each day.

Results

Record your data in your results table.

Discussion

1 Draw a graph that plots the day number against the mean growth. Plot all three sets of data on the one graph.
2 Identify any trends, patterns or relationships in your results.
3 Extrapolate your data to predict what the mean plant growth would be after 10 days.

Cellular respiration

Plants do not perform photosynthesis simply to produce glucose for consumers to eat! Producers, just like all living organisms, need to break down that glucose to release energy in a useable form. This process is called **cellular respiration**.

cellular respiration an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy in the form of ATP

ATP adenosine triphosphate: a molecule that provides useable energy in cells

During cellular respiration, glucose is broken down with oxygen, producing carbon dioxide and water as waste products. Small packets of energy are also released and stored in molecules of adenosine triphosphate (**ATP**). Bacteria, plants and animals (including humans) all need that energy to power the functions of their cells.

The word and chemical equations for cellular respiration are shown in Figure 4.13.

VIDEO Photosynthesis and cellular respiration

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy

Figure 4.13 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 4.14.

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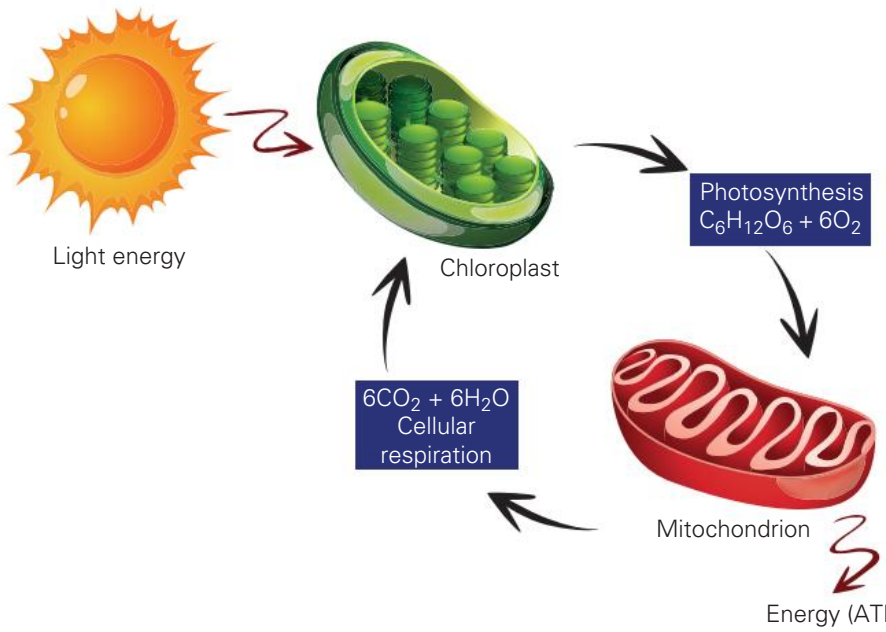


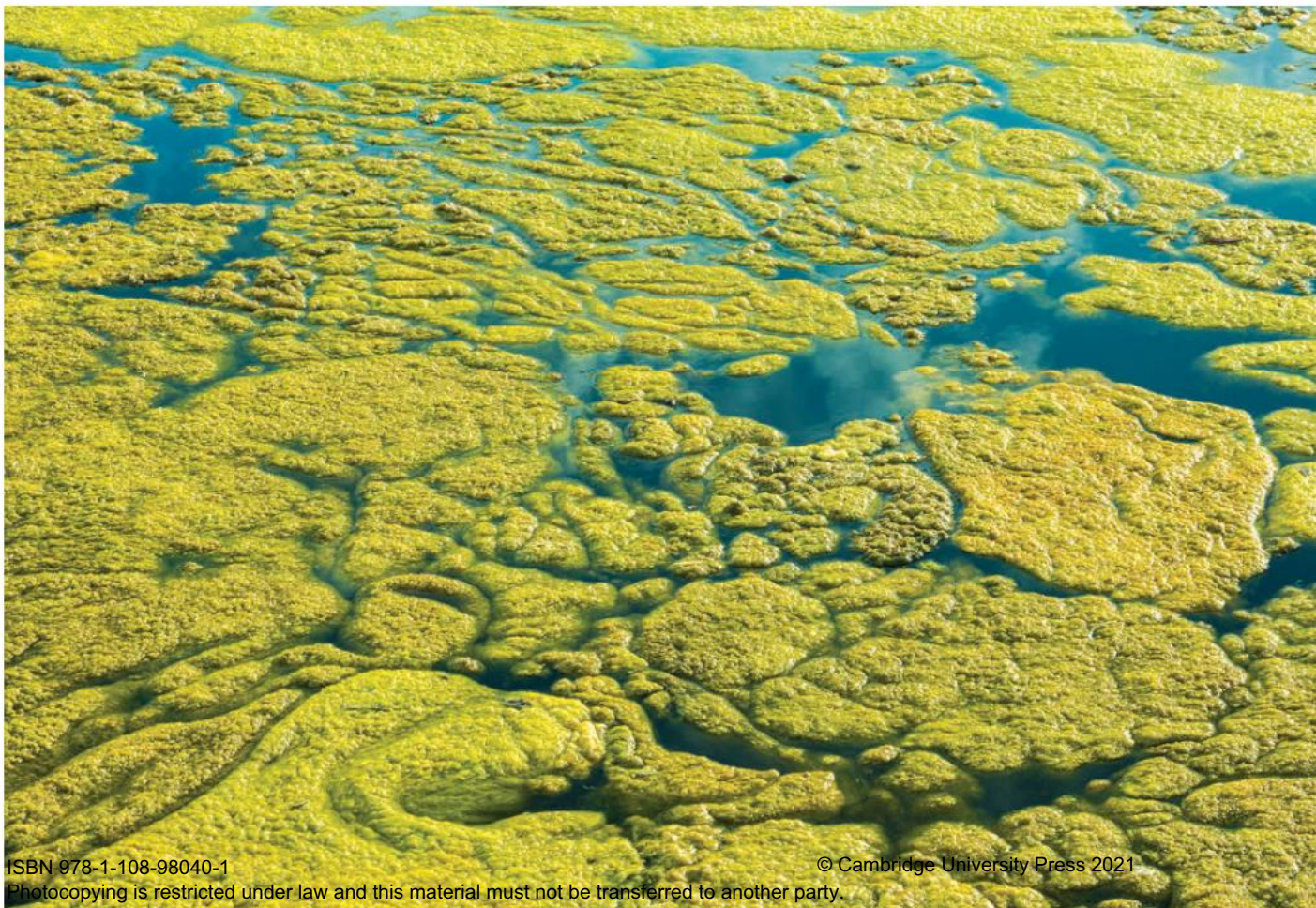
Figure 4.14 The relationship between photosynthesis and respiration. They are almost opposites of each other! However they are not exact opposites as there are different steps involved in each process. The form of energy absorbed and released is also different, i.e. sunlight is required for photosynthesis, yet it is not a product of cellular respiration, ATP is the product.

Eutrophication

Eutrophication is the term given when a body of water becomes too enriched with nutrients, causing an excessive growth of algae that may result in oxygen depletion of the water. This can kill other life within the water body.

eutrophication
high levels of nutrients in water bodies that result in excessive growth of algae and oxygen depletion of the water

Figure 4.15 An example of algae overgrowth in a lake



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Explore! 4.1

Eutrophication

1 Research how eutrophication occurs, then draw a flow chart summarising the key steps in the process of eutrophication.
2 Find some locations in Australia where eutrophication has occurred or is occurring. Make a list of five waterways affected and the state or territory they are in.
3 How can governments help prevent eutrophication and how can they fix the problem after it has already started? Summarise in dot points what you find out.

Practical 4.2: Investigation

Phosphates in fertilisers and detergents

Aim

To investigate the effect of detergent on the health of plants.

Planning

1 Complete some research about the ingredients of detergents and summarise your findings regarding the effect of detergents on plant growth.
2 Create a relevant and specific research question for this experiment.
3 Construct a hypothesis for this experiment relating to the effect that the detergent has on the overall health of the plant.

Materials

- water plant
- detergent (to make 1%, 5% and 10% dilutions as instructed below)
- tap water
- 4 × 250 mL beakers
- 10 mL measuring cylinder
- 100 mL measuring cylinder
- glass stirring rod
- weighing balance
- ruler

Method

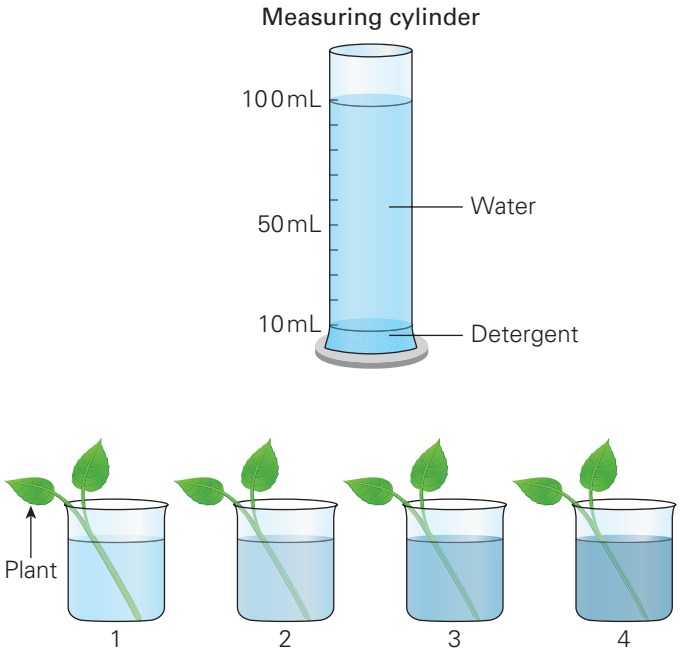


Figure 4.16 Experimental set-up

continued…

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…continued

1 Draw the following results table.
2 Cut four 20 cm lengths of a water plant, then weigh and record the mass of each piece.
3 Label the beakers 1–4, and place one length of the water plant in each beaker.
4 Fill the first beaker with 100 mL of tap water using a 100 mL measuring cylinder.
5 Measure 1 mL of detergent in the 10 mL measuring cylinder and then transfer to the 100 mL measuring cylinder.
6 Dilute with water by adding tap water up to the 100 mL mark. Use a glass stirring rod to ensure the solution is mixed consistently.
7 Transfer the 1% detergent solution to beaker 2.
8 Repeat steps **5–6** with 5 mL of detergent to create a 5% solution. Add to beaker 3.
9 Repeat steps **5–6** with 10 mL of detergent to create a 10% solution. Add to beaker 4.
10 Place the four beakers, uncovered, on a windowsill for 7 days.
11 After 7 days have passed, weigh and make observations of the plants. You can use the ruler for appropriate measurements.

Results

Complete the following results table below and graph these results.

Detergent solution (%)	Original plant mass (g)	Final plant mass (g)	Change in mass (g)	Observational change
0				
1				
5				
10				

Discussion

1 In a scientific experiment, it is often important to include a 'control' as it provides a benchmark to measure the other results against. No interventions are done to the control. State which beaker in this experiment represented the control and give a reason for your answer.
2 Explain whether the observational changes are related to the change in the plant's mass after 7 days.
3 Can you explain the effect detergent had, with reference to eutrophication?
4 Compare the results from the graph with your predictions about which percentage detergent solution would have the greatest effect on the plant.

Conclusion

1 Make a claim from this experiment regarding detergent and the health of plants.
2 Support the statement by using your observations (including potential sources of error).
3 Explain how your observations support your claim.

Quick check 4.3

1 Insert the correct words to complete these sentences:
   a Photosynthesis _____ glucose by capturing radiant _____ from the Sun.
   b Cellular respiration breaks down _____ to release useable energy.
   c Plants perform _____ and cellular respiration.
   d Humans can only perform _____ and must _____ other organisms for a source of glucose.
2 State the word equations for photosynthesis and cellular respiration.
3 Describe what happens when an excess supply of nutrients is introduced to a healthy body of water.

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VIDEO
Cause of bush fires

Environmental changes affecting ecosystems

Many biotic and abiotic factors affect population size. These factors are known as secondary ecological events as they affect one or more of the four primary ecological factors (birth, death, immigration and emigration rates). For example, seasonal changes, such as drought or flood, may increase the death rates within a population. Within Australia, fires, drought and flood all affect population sizes of organisms living within ecosystems.

Seasonal effects on ecosystems: fire

Bushfires have a major influence on Australian ecosystems. They have both positive effects, such as encouraging plant development, and negative effects, such as killing wildlife.

Bushfires can stem from natural causes such as lightning strikes, but can also be deliberately lit. Aboriginal and Torres Strait Islander peoples learned to harness bushfires as an important tool for purposes such as:

- creating easier access through thorny and thick vegetation
- attracting animals for hunting by encouraging new vegetation growth
- encouraging the growth of plants used for food and spiritual purposes.

The fires lit by Aboriginal and Torres Strait Islander peoples were regular in frequency and low in intensity, and contained within manageable areas. This regular use of fire resulted in vegetation of varying ages across the landscape. Such fire management practices continue to be conducted in some regions Western Australia under the guidance of First Nations peoples' knowledge of Country.

The primary fuel for bushfires is dead, fine vegetation. Bushfire risk has a lot to do with how moist the fuel is. If the vegetation is green and contains more than 30% moisture, it will

Figure 4.17 An uncontrolled bushfire in the Kimberley region of Western Australia



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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. The 'Black Saturday' fires caused the greatest loss of life of any Australian bushfire event, making it the country's worst peacetime 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; it also destroys the landscape. Many animals die in the fire; others escape to a safer area but are then unable to return to their natural habitat because there is no food available or their home is gone. In the Australian fires of 2019–20 (also referred to as 'black summer'), an estimated 1 billion animals were killed. It may take years for the food sources to recover, leading to the potential loss of more animals. This results in an increase in the death rate and a decrease in the birth rate.

However, fire has some positive outcomes:

- Burning releases nutrients locked in many Australian plant and rotting organic materials, enriching the soil for germinating seeds.
- The bushy undergrowth burns away, allowing more sunlight to reach seeds and young plants.
- Some seed pods are triggered to open, either by the heat of the fire or by a chemical in the smoke.



Figure 4.18 New tree growth sprouts on the 3-month anniversary of 'Black Saturday'.

Explore! 4.2

Bushfire policies and programs

In light of the bushfires in December 2019 and January 2020, where about 18 million hectares were burned, there is a heightened urgency to consider preventative measures. These were the largest bushfires since 1974 when 117 million hectares were burned.

continued…

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…continued

The Kimberley is a region in northern Western Australia. The Aboriginal peoples, and traditional owners of the land, conduct traditional burns in the area by lighting 'cool' fires during the early dry season (March–July).

1 Investigate the Kimberley Land Council's Indigenous fire management program on the KLC website. Explain how the program works.
2 What have been the findings of fire research on the effects of traditional Aboriginal and Torres Strait Islander peoples' fire regimes?
3 How have these findings influenced fire management policy throughout Australia?
4 What is the evidence regarding the effectiveness of traditional fire practices?



Figure 4.19 Rangers and traditional owners conduct burns in the Katiti-Petermann Indigenous Protected Area, in the remote desert country near the Western Australia and Northern Territory border.

Seasonal effects on ecosystems: droughts and floods

Droughts can significantly affect ecosystem processes. They can have major impacts on the rural economy and can lead to other environmental problems such as severe fires, dust storms and the degradation of land.

It is common in parts of Australia to experience droughts that are ended by floods. Flash floods tend to be localised, short-lived and generally the result of an extreme storm. Conversely, longer lasting flooding can result from heavy rain over the catchments of extensive river systems. Flooding can have negative impacts, including loss of human life, livestock and wildlife; damage to homes and infrastructure; land degradation (such as erosion and loss of mineral nutrients); and spread of disease. In Australia, flooding is estimated to cause in excess of $400 million in damage per year, more than any other natural disaster.

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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. Floods 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 breed or disperse to other areas. This can increase birth and emigration rates.

Explore! 4.3

Seasonal changes and population size

Populations can be affected by seasonal changes. Some animals will migrate, others may hibernate. In Australia, four species of pygmy possum, some bat species and the short-beaked echidna all hibernate at certain times in the year.

Complete some research about how seasonal changes may affect population sizes. Share your findings with the class.



Figure 4.21 The Western pygmy possum (*Cercartetus concinnus*) can be found in Western Australia's south-west as well as southern parts of South Australia.

Quick check 4.4

1. State two negative and two positive outcomes of bushfires.
2. Name the main fuel for bushfires.
3. Define a flash flood.
4. State two environmental benefits of flooding.

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Section 4.1 questions

QUIZ

Remembering

1 **State** the three components of an ecosystem.
2 **Recall** the word and chemical equations for cellular respiration.
3 **Recall** the word and chemical equations for photosynthesis.
4 When energy is transferred along a food chain from organism to organism (or up the trophic/energy pyramid), **state** the approximate percentage of energy that is efficiently transferred.

Understanding

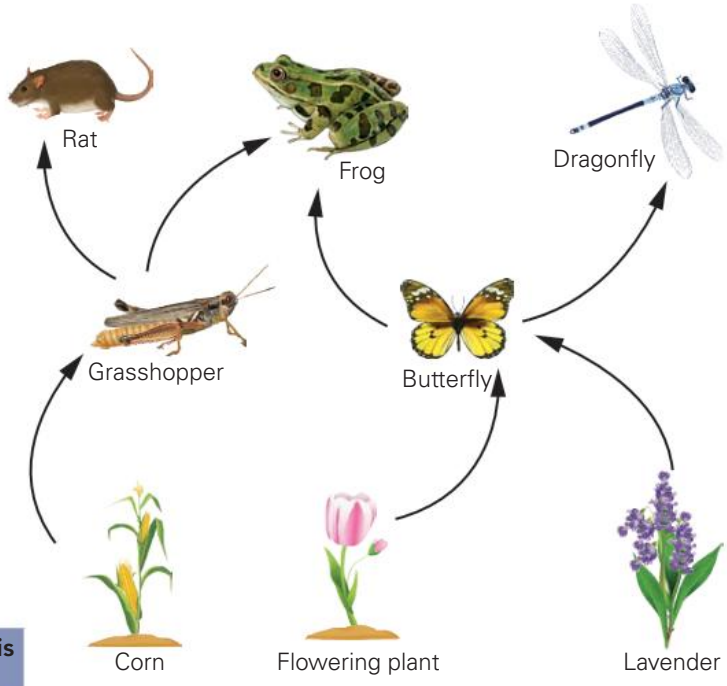
5 **Name** two specific examples of biotic factors found within the biome of an Australian desert.
6 **Explain** how burning helps to maintain biodiversity within an ecosystem. **List** two ways that fire can maintain diversity.
7 **Describe** two examples of how floods may negatively influence an ecosystem.

Applying

8 **Explain** why humans are not considered to be autotrophs.
9 A rabbit eats some grass to gain its energy. **Explain** where this energy originated and what processes it went through to be in a form the rabbit can use to carry out cellular functions.
10 **Discuss** the biological impacts that the use of detergents could have within ecosystems.

Analysing

11 **Classify** the organisms in the food web on the right as producers, primary consumers, secondary consumers and tertiary consumers.
12 **Compare** the role of a heterotroph with that of an autotroph within an ecosystem.
13 In your own words, **compare** photosynthesis and respiration.
14 **Contrast** a community and a habitat.



Evaluating

15 **Construct** a mind map showing the relationship between the different levels of consumer within an ecosystem.
16 The following table shows the rate of photosynthesis of plants at different light intensities.

Light intensity (%)	Rate of photosynthesis (bubbles/min)
9	4
15	9
28	17
48	29
55	34
90	55
100	60

a **Construct** a graph of the results.
b **Analyse** the findings.

17 **Evaluate** the following statement: 'Ecosystems would cease to exist, should producers be eliminated.'

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4.2 Interactions between organisms and their environment

Learning goals

1 To be able to describe the three symbiotic relationships in ecosystems.
2 To be able to describe the predator–prey relationship in ecosystems.



Abiotic factors play an important role in the overall distribution and abundance of organisms within an ecosystem. Some organisms have a narrow tolerance range for a certain abiotic factor, such as temperature, and this determines where they can live.

The role an organism fulfils within an ecosystem is known as its **ecological niche**. This includes its habitat, diet and relationships or interactions with other organisms within the ecosystem, for example, where it makes a home, what it eats, what time of the day it is active. Interactions occur between organisms of the same species or of different species within the niche. Interactions vary depending on how organisms behave at different times of the day and in different seasons. Many interactions take the form of competition or predator–prey. Other interactions represent a symbiotic relationship between species, such as mutualism, commensalism or parasitism.

Competition

Organisms in a similar niche within an ecosystem compete with one another for resources that are in short supply. This occurs when different organisms require the same resources, such as food, space, shelter and mates, to survive and thrive. Competition within and between species occurs in all communities. **Interspecific competition** is competition for resources, such as a specific food source, between members of different species. For example, kangaroos and sheep compete for grass as their major food source. In contrast, **intraspecific competition** is competition between the members of the same species, such as the male cuttlefish shown competing for a mate in Figure 4.22. Note that intraspecific competition is usually more intense than interspecific competition because organisms of the same species will have identical needs.



Figure 4.22 Male giant Australian cuttlefish competing for mates is an example of intraspecific competition.

ecological niche
the role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment

interspecific competition
competition for food or resources between members of different species

intraspecific competition
competition for food or resources between members of the same species



If two species are in competition with each other for the same limited resources, the better suited and more effective species will be able to use the resource more than the other species. This may lead the less efficient competitor to leave the ecosystem to find an environment with less competition.

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VIDEO
Relationships between organisms

Quick check 4.5

1 Define the term 'interspecific competition' and 'intraspecific competition'.
2 Describe what happens when two species are competing for food, and one species is better adapted or stronger.

Symbiotic relationships

When individuals from two different species share a close and long-term biological relationship, it is known as a **symbiotic relationship**. Examples include mutualism, commensalism and parasitism.

Mutualism

Mutualism is a symbiotic relationship in which both species benefit and neither is harmed. For example, plants have a mutualistic relationship with **pollinators**. Some plants, like grasses, are pollinated by wind, but many flowering plants rely on insects, birds, small mammals or reptiles to transfer pollen from one plant to another. Because the pollinator benefits from feeding on the nectar from the plant and the plant benefits by being pollinated, the relationship is mutualistic.

symbiotic relationship any type of close and long-term relationship between two types of living organism

mutualism a symbiotic relationship where both organisms benefit

pollinator an organism, such as an insect, that carries pollen from one plant, or part of a plant, to another

Another example is clownfish living with sea anemones in the Great Barrier Reef, as seen in the film, *Finding Nemo*. The clownfish hides from predators among the stinging tentacles of the anemone. In turn, the fish cleans the anemone, provides nutrients in the form of waste and scares away predatory fish such as the butterfly fish.

Figure 4.23 A bee pollinating a flower is an example of mutualism.





Figure 4.24 A clownfish living among a sea anemone's tentacles is protected from predators and provides nutrients to the anemone.

Science as a human endeavour 4.1

A strange relationship between salamanders and algae

In 2017, scientists discovered a new type of symbiotic relationship between salamanders and algae, and a very strange one at that! In a bizarre and intimate arrangement, these two very different species seem to share cells. The photosynthetic algae make their home inside the body cells of the salamander but it is not clear what benefit this has. The algae were already known to grow inside the egg capsule of the salamander, which was a mutualistic relationship. The algae releases oxygen into the egg capsule and feeds off the nitrogen-rich waste the embryo in the egg produces.

Scientists sequenced the DNA of both organisms, revealing that the salamander does still recognise the algae as 'foreign'. They hypothesise that it might potentially benefit the salamander by teaching its immune system to not let disease-causing agents migrate into their cells in the future.



Figure 4.25 The spotted salamander, *Ambystoma maculatum*, has an unusual symbiotic relationship with a green alga, *Oophila amblystomatis*.

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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 cattle egrets, which hang around grazing cattle (and other animals) to catch insects that are stirred up. The cattle receive no benefit or harm. Other examples include hermit crabs using the shells from dead snails (seashells) as their homes and mites getting a 'free ride' by attaching to other larger insects.



Figure 4.26 A cattle egret waiting to catch insects stirred up by a feeding cow



Figure 4.27 A hermit crab looking to upgrade his home to a larger shell

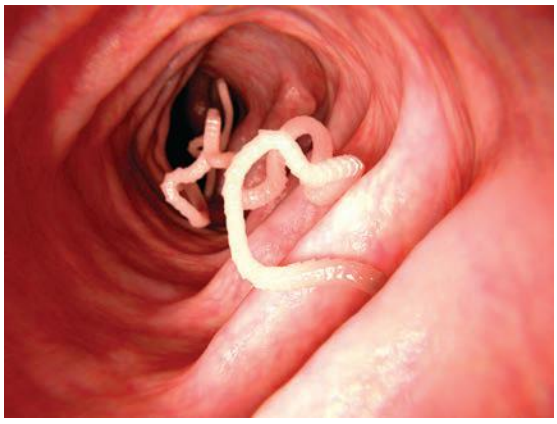
Parasitism

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 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.

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, fleas found on a dog. 'Endo' means inner or internal, so endoparasites are found living inside other organisms. An example of an endoparasite is a tapeworm living in a sheep's digestive system.

commensalism
a symbiotic relationship where one organism benefits and the other neither benefits nor is harmed

parasitism
a symbiotic relationship where a parasite benefits from living on or in a host (which is harmed)



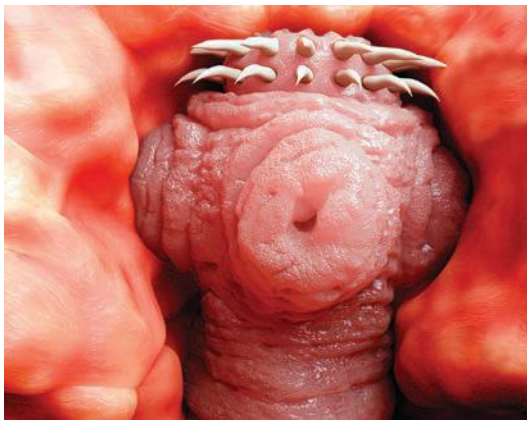


Figure 4.28 These tapeworms are endoparasites that inhabit the digestive tracts of animals (including humans). Tapeworms use their specialised hooks to anchor themselves in the intestine and absorb nutrients through their body wall. Disturbingly, they can grow to several metres in length, but they do not necessarily cause symptoms.

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Quick check 4.6

1 Describe the relationships between organisms, indicating whether the organism is affected positively, negatively or not affected. You may relay the information in a table as shown.

Relationship	Definition	Organism 1	Organism 2
Competition			
Mutualism			
Commensalism			
Parasitism			

2 Contrast an ectoparasite and an endoparasite.

Disease vectors

Within an ecosystem are organisms, called **vectors**, that spread 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 pathogen can be transmitted directly into the bloodstream from a bite. According to the World Health Organization, mosquitoes are the primary vector for transmitting both malaria and the Zika virus.



Figure 4.29 Mosquitos can transmit some diseases through a bite.

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

An 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 no large, stagnant pools of water.

Explore! 4.4

Zika virus

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 fever, 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 the mosquito's saliva will contain viral particles. When it bites another human, the viral particles can be transmitted, causing the 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.

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Did you know? 4.1

Mosquito factories

China is home to 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 4.30 A lab technician pours mosquito pupae into containers at the facility in Guangzhou, China.

Explore! 4.5

Northern Australia biosecurity

Northern Australia has 10 000 kilometres (km) of coastline, providing a large area from which exotic pests, weeds and diseases can reach the region. Travel mechanisms include wind, tide, animal migration, and ships and aircraft. Research and summarise how the Northern Australia Quarantine Strategy (NAQS) works with local Aboriginal and Torres Strait Islander communities to provide an early warning system for exotic pests and diseases.

WIDGET
Predator–prey interaction

Predator–prey

A predator–prey relationship occurs when one organism, known as the **predator**, kills and eats another organism, known as the **prey**. It is unusual for predators to depend upon one species of prey, so if one prey species reduces in supply, the predator can prey upon other species. For example, dingoes prey on various mammals, but are also capable of hunting and eating birds and reptiles.

predator
an animal that hunts other animals as its source of food

prey
a living animal that is captured and eaten by a predator

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The relationship between predator and prey is usually balanced, but occasionally there is a change in balance due to a change in conditions. For example, favourable conditions may lead to an increase in the prey population, which in turn can lead to an increase in the number of predators. If a period of adverse conditions occurs to reduce the prey population, predators will turn to another prey species and there may be an increase in intraspecific competition among the predators.

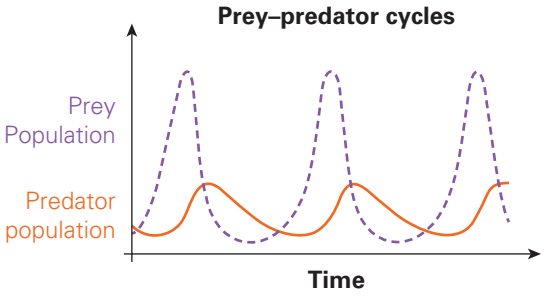


Figure 4.31 Predator and prey populations exhibit fluctuations in size. The prey cycle is mainly driven by an increase or decrease in predation, but other factors, such as a winter food shortage or drought, may also be important.

Modelling predator–prey cycle using the feral rabbit

In Australia, feral rabbits affect 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, rabbits eat whatever they can find, which amplifies their impact. Rabbits 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 4.32 Feral rabbits have caused damage in many different Australian habitats.

Explore! 4.6

Rabbit-proofing

Within Australia, three different methods are used for effective rabbit control: biological, chemical and mechanical. Combining two or more techniques has been 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 4.33 Despite the 1700 km long rabbit-proof fence that was built in 1901–07, rabbits have infiltrated Western Australia. The holes in the ground indicate their extensive warrens.

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Try this 4.6

Feral rabbits do have natural predators such as the red fox; however, their ability to reproduce quickly has seen rabbits continue to thrive within Australia. Generally, if there is a shortage of prey, then there will be fewer predators surviving in that environment. Another predator and prey relationship occurring in the deserts of Australia is that of the red kangaroo and the dingo. The dingo is the apex predator in this biome and although they do not usually prey on kangaroos, they will hunt and kill them when food is scarce.

Using the graph (Figure 4.34), answer the following questions.

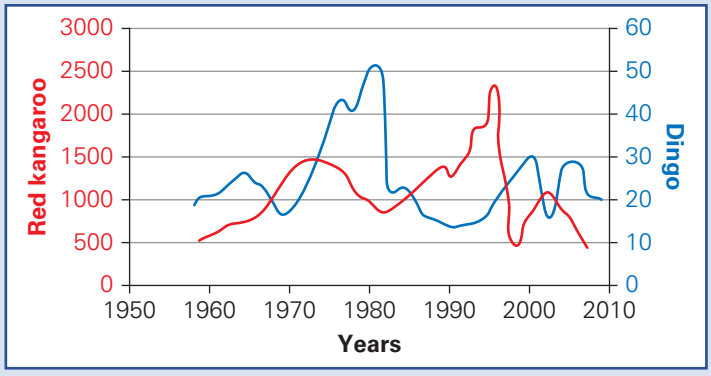
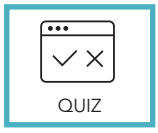


Figure 4.34 Population sizes over time for the dingo (in blue) and the red kangaroo (in red)

1. When was the greatest abundance of red kangaroos?
2. What happens to the dingo population as red kangaroo numbers increase?
3. Examine what happens to the dingo population size when the red kangaroo population size decreases.
4. Describe the pattern of the predator–prey relationship shown in the graph.
5. Identify and discuss a factor, other than the red kangaroo population, that may influence the size of the dingo population.
6. Identify and discuss a factor, other than the dingo population, that may influence the size of the red kangaroo population.

Section 4.2 questions



Remembering

1. **State** the type of symbiotic relationship that a pollinator and a plant have.
2. **Name** three insects that can act as vectors.
3. When there is a large increase in the population size of an animal that is prey, **recall** what tends to happen to the population size of the predators.

Understanding

4. Two male bull elephants fight for access to females. **Identify** what sort of competition is being demonstrated.
5. **Name** three predators and research what their preferred prey is.
6. Copy and complete the following table. **Define** each type of relationship, giving an example that has not appeared in this chapter.

Relationship	Definition	New example
Competition – interspecific		
Competition – intraspecific		
Mutualism		
Commensalism		
Parasitism		
Predator–prey		

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Applying

7 **Explain** what is meant by an organism's 'ecological niche'.

Analysing

8 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.

9 **Compare** an ectoparasite and an endoparasite, providing examples for each.

10 **Examine** the role of mutualistic relationships within ecosystems, using examples not already used in this chapter.

Evaluating

11 **Justify** the importance of both interspecific and intraspecific competition within an ecosystem.

12 **Decide** whether the following descriptions are examples of mutualism, commensalism or parasitism.

- a A man has tinea (a fungus) growing between his toes.
- b A woman notices her cat looks very bloated. She takes it to the vet and they suggest deworming the cat, as it probably has tapeworm.
- c Small fish swim around on the back of whale sharks for protection from predators.
- d Birds stand close to wild buffalo and eat the insects that are stirred up as the buffalo graze.

13 If all the predators from an area were removed, **discuss** the positive and negative effects on the overall sustainability of the ecosystem.

4.3 Population dynamics within ecosystems



Learning goals

1 To calculate the change in a population size using statistics for births, deaths, immigration and emigration.
2 To be able to describe exponential and logistic growth models of population.
3 To be able to describe methods of population sampling including using a quadrat and capture–mark–recapture methods.

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 relate to population size. Four primary ecological events determine population size:

- births
- deaths
- immigration
- emigration.

immigration
the movement of individuals into the population

emigration
the movement of individuals out of the population

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.

change in population size = (births + immigration) – (deaths + emigration)

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It makes sense that if the sum of the births and immigration is greater than the sum of the deaths and emigration of the population, then the population will increase in size. The many biotic and abiotic factors that affect population size are known as secondary ecological events because their influence occurs via their effect on one or more of the primary ecological factors.

Population growth models

Exponential growth

Within an ecosystem, population growth fluctuates. When **exponential growth** is observed, the population's growth rate rapidly accelerates or increases over time. You can see in Figure 4.35 that this creates a J-shaped curve.

Bacteria grown in a laboratory provide an excellent example of exponential growth. Bacteria reproduce by binary fission (splitting in half), and the time between divisions is about 20 minutes. So 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.

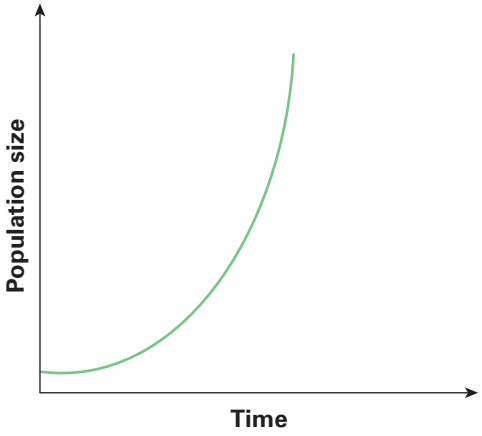


Figure 4.35 A graph showing an exponential increase in population size over time

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

exponential growth a rapidly accelerating increase in population size

logistic growth population growth that increases initially and then plateaus (flattens out) once it has reached a certain point

carrying capacity the maximum population size a particular environment can support

A better model that may more closely reflect the real world is known as **logistic growth**. The population increases rapidly at first, but then starts to plateau (flatten out) as resources are limited and competition increases. You can see in Figure 4.36 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).

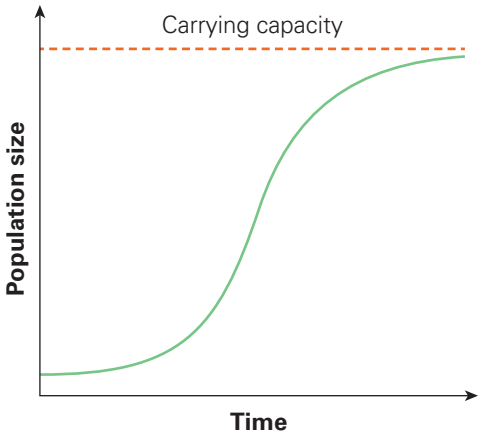


Figure 4.36 A graph showing logistic population growth over time (note the S-shaped curve)

As populations approach 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 of their environment, as shown in Figure 4.37. For example, when kangaroos move into a new area with abundant food, they may reproduce rapidly.

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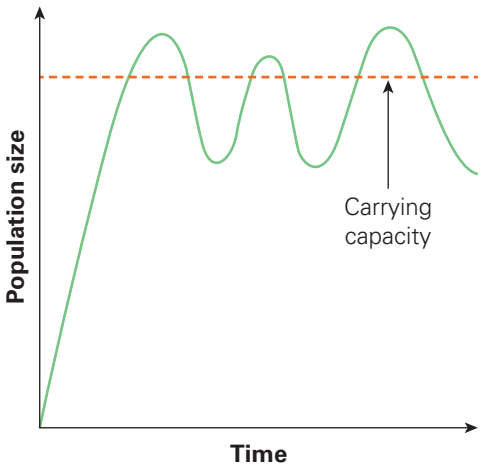


Figure 4.37 A graph showing population size versus time. Note how, despite the fluctuations, the population size tends to hover close to the carrying capacity.

However, there is only so much grass available, so as the number of kangaroos approaches the carrying capacity of that habitat, their rate of reproduction slows so the population size matches the carrying capacity.

Limiting factors versus carrying capacity

Any form of biotic or abiotic factor within an ecosystem that prevents the population from growing any larger is known as a **limiting factor**. For example, 100 western grey kangaroos may live in an ecosystem that has enough water, shelter and space to support 200 western grey kangaroos, but if there is only enough food for 100 western grey kangaroos, the population will not grow any larger. In this example, food is the limiting factor.

limiting factor
biotic or abiotic factor that prevents a population from growing

quadrat
a tool used to measure species abundance

VIDEO
Measuring populations

Figure 4.38 The carrying capacity of the environment for western grey kangaroos is 100 if there are only enough resources for 100 western grey kangaroos to feasibly survive.



Apart from food, other factors that can limit population growth include:

- shelter (for example, owls that rely on hollows in trees will search new locations for nesting spots)
- the number of predators
- availability of water
- the balance of male and female numbers
- the presence of diseases.

Limiting factors affect 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 treed area 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.

Quick check 4.7

1 Contrast exponential growth and logistic growth within a population.
2 Recall how limiting factors relate to the carrying capacity of a habitat for a particular species.

Methods used to determine the size of a population

Using a quadrat

In some cases, it may be possible to count the number of individuals of a particular species, for example, the number of echidnas in an area of state forest. However, in most cases counting all the individual organisms is impossible or impractical, so a sampling method may be necessary. A **quadrat** is a tool used to record the abundance or density of a particular species in a study area, so you don't need to record every organism. It is particularly useful for plants, slow-moving animals and marine algae. Using information from your quadrats, you can estimate the population number and density of each species over the whole study area.

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Figure 4.39 Using a 1-metre (m) square quadrat, like this one shown, would allow scientists to count the frequency of a particular species in that area.



Figure 4.40 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. To achieve truly **random sampling**, a grid of numbers and letters should be laid over the sampling area and specific sampling sites should be chosen on the basis of randomly generated combinations of numbers and letters. **Systematic sampling** may involve you placing a quadrat in an ordered way along a transect line, or on a grid arrangement through the area being sampled.

Once you have your sampling strategy, you can measure the species you are studying within the quadrat: either count the number of individuals or estimate the percentage cover. Direct counts are suitable when counting animals or larger plants. However, when a plant is abundant, percentage cover is more appropriate.

random sampling
a sampling technique where each sample has an equal chance of being selected

systematic sampling
a sampling technique where each sample is taken at fixed intervals that have been previously decided upon

When directly counting the number of plants or animals, you can calculate the average number of individuals (total number of individuals counted divided by number of quadrats), and then calculate the total population using the following equation:

$$\text{total population} = \frac{\text{average number per quadrat} \times \text{total area being studied}}{\text{area of quadrat}}$$

For example, four quadrats are randomly placed in a bushland area of 1200 square metres (m^2) and the number of native orchids is directly counted. The results are as follows:

Quadrat	Number of orchids
1	3
2	1
3	2
4	0

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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:

$$\text{total population} = \frac{\text{average number per quadrat} \times \text{total area being studied}}{\text{area of quadrat}} = \frac{1.5 \times 1200}{1} = 1800 \text{ orchids}$$

The native violet (*Viola banksii*) is a small, spreading ground cover that is found in shady areas. Due to its abundance, it is difficult to do a direct count, so percentage cover should be used instead.

Each quadrat can be split into smaller squares. When estimating, you should count the number of squares that the plant fills. For partly filled squares, you should ignore those that are less than half filled. In Figure 4.41a the quadrat has been divided into 25 squares. This means that each square is 4% of the total quadrat area. The native violet covers approximately five squares, so it covers 20% of the ground.



Figure 4.41 Setting up quadrats and counting plants. **(a)** A quadrat for measuring native violet. **(b)** In this example, the dark green plant in the bottom left corner covers 25% of the 1 m by 1 m quadrat that the two students are observing.

When sampling an area with four quadrats, you found the following results:

Quadrat	Percentage cover (%)
1	13
2	16
3	20
4	25

Therefore, the average percentage cover of native violet is $74/4 = 18.5\%$.

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Try this 4.7

Sampling an ecosystem

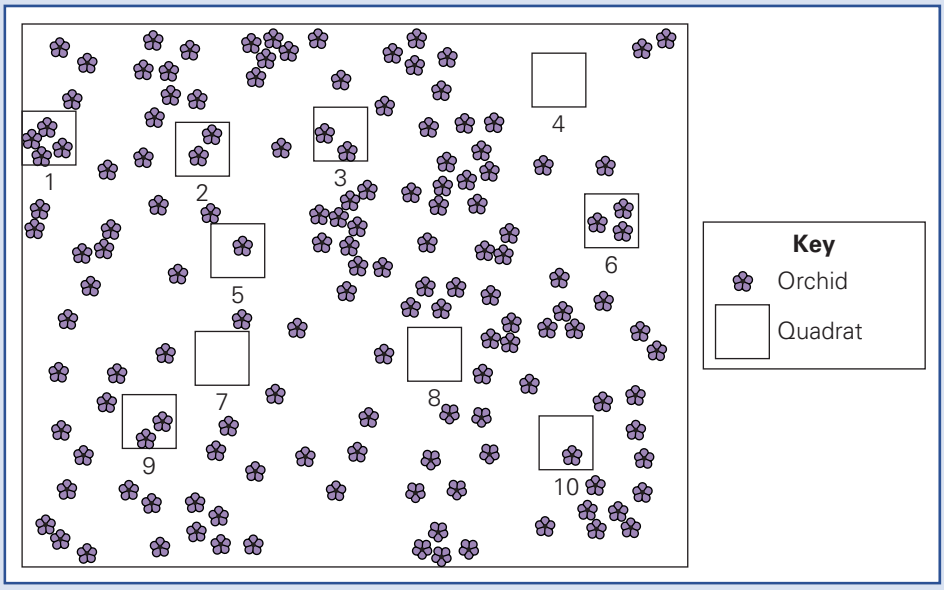
Aim

To estimate the species found in different ecosystems.

Some Year 9 students wanted to find the number of orchids growing in bushland.The students placed 10 quadrats at different positions on the lawn. Each quadrat measured 1 m × 1 m. The students counted the number of orchids in each quadrat.

1 Describe the method that the students should use to decide where to place the 10 quadrats.

2 The diagram shows the lawn with the positions of the orchids and the quadrats.



Complete the table to show:

- how many orchids were found in each of the quadrats
- the total number of orchids in the quadrats.

Quadrat number	Number of orchids
1	
2	
3	
4	
5	1
6	3
7	0
8	0
9	2
10	1
Total	

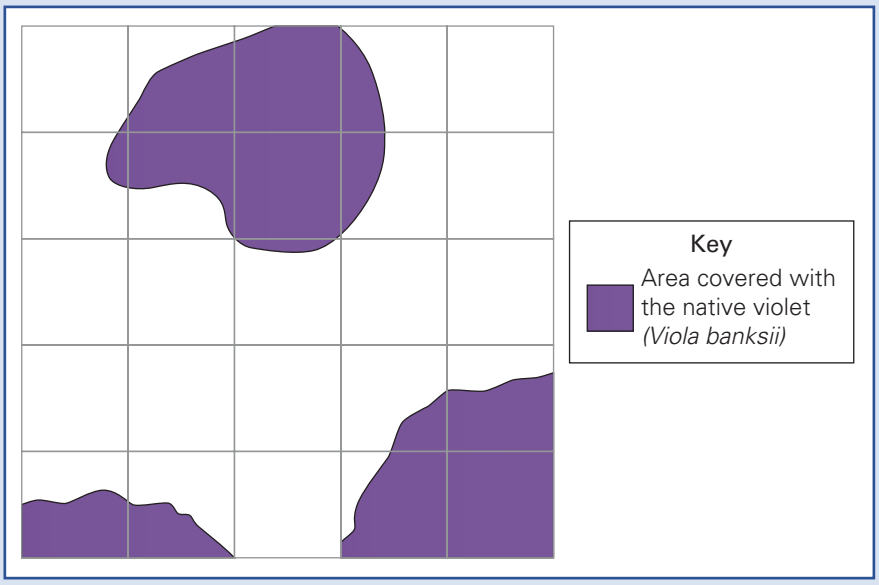
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3 Calculate the mean number of orchids per quadrat.
4 The bushland measured 120 m long and 100 m wide. Estimate the number of orchids in the bushland.

The students then decided to investigate the percentage cover of native violet.



5 Estimate the number of squares covered with native violet.
6 Describe how you worked out your answer to question **5**.
7 Use your answer from question **5** to calculate the percentage cover of native violet.
8 Suggest a strength and a limitation of using a quadrat to determine plant abundance in certain areas.

Investigating ecosystems in Australia

When planning field investigations, it is important to acknowledge Aboriginal and Torres Strait Islander peoples of Country. This may involve, but is not limited to, the following recommendations.

- Acknowledge cultural heritage sites, which might be protected under legislation. It is important to follow and honour legal obligations, particularly when planning field investigations.
- Collaborate with a local First Nations community. Field investigations might disturb the environment and affect the local community (see Explore! 4.2 Bushfire policies and programs and Explore! 4.8 Feral camels).
- Understand that Aboriginal and Torres Strait Islander peoples may have information that will help formulate hypotheses (see Explore! 4.7. Thylacine distributions).

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Explore! 4.7

Thylacine distributions

Have a look at the image of an Aboriginal cave painting at Faraway Bay in Western Australia. The thylacine survived in the island state of Tasmania until the 1930s. What can you hypothesise about the distribution of the thylacines in Australia at the time this cave painting was created?



Figure 4.42 A rock drawing, thought to have been created 20 000 years ago in a remote area of Faraway Bay in Western Australia, shows a Thylacine (*Thylacinus cynocephalus*).

Capture–mark–recapture

Measuring the population size of fast-moving animal species is sometimes difficult. A suitable way of measuring population size, rather than setting up quadrats or individually counting all the individuals within the species, is the **capture–mark–recapture method**.

1 Ecologists capture a sample of the species.
2 These individuals are tagged or marked in an inconspicuous way, ensuring any handling is humane and considerate of the animal's needs, and then released.
3 Sometime later, another sample is captured from the population.
4 Ecologists count how many marked individuals are in the second sample, and use this information to estimate the population size using the Lincoln Index:

capture–mark–recapture method
a method for estimating animal population sizes that involves capturing, tagging, releasing and recapturing a sample of the population

$$N = \frac{M \times n}{m}$$

where

N = Population estimate
M = Number of animals captured and marked in first sample
n = Number of animals captured in second sample
m = Number of n that were already marked

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Try this 4.8

Capture–mark–recapture modelling

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 estimate how many M&Ms there are. Record your estimate.
2 Using a spoon, dig out a sample of M&Ms. This is your first trapping sample, *M*. Record this.
3 To 'mark' these M&Ms, simply replace them with Smarties. Place these 'marked individuals' back into the population (container).
4 Shake the container and, without looking, remove another spoonful of chocolates. This is your second trapping sample, *n*. Record this.
5 How many of the chocolates in your second trapping sample were Smarties? This is *m*. Record it.
6 Now use the Lincoln Index equation to calculate your population estimate, *N*.
7 Count the actual total number of chocolates in the container. Record the number.
8 Was your estimate using the formula closer than your initial guess?
9 Suggest some ways how you 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.

Did you know? 4.2

The northern hairy-nosed wombat



Figure 4.43 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.

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, it is important to be able to accurately and regularly record the presence of individual wombats. The most accurate technique uses 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 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 owing to the implementation of the recovery program.

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Quick check 4.8

1 For each of the following organisms, state if a quadrat would be an appropriate tool for estimating the population.
   a Hawks
   b Cacti
   c Starfish
   d Beetles
2 Organise the following statements in the correct order to show how to estimate the number of organisms in an area.
   A Count the number of organisms present in the quadrat.
   B Randomly place the quadrats.
   C Multiply by the number of quadrats that would occupy the area you wish to estimate the population within.
   D Calculate the average number of organisms per quadrat.
3 A biologist captures a sample of wallabies and tags them for later identification. A year later, another sample is captured and the number of tagged wallabies is used to estimate the population size. Recall the name of this method.

Science as a human endeavour 4.2

Using drones for population sampling

Are ecologists working in the field a thing of the past? A 2018 study suggests that drones are more accurate at counting populations of wildlife than doing it the old-fashioned way! Whereas a ground-counting researcher needs to find a good location and rely on a set of binoculars, a drone can hover above the colony of animals and get a superior vantage point. The digital images taken by the drones can then be re-used later if researchers want to review the data manually.

More research is required into the impact of the drones on the wildlife so that drone protocols can be established to ensure the animals are not unduly stressed.



Figure 4.44 A drone collecting data on elephant numbers in Botswana, southern Africa

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Human impact on population dynamics

Aboriginal and Torres Strait Islander peoples have a 'Caring for Country' approach where they consider themselves an interdependent part of any environment, rather than above or separated from it. They have a deep appreciation of and respect for the natural environment and an ingrained responsibility to sustainably maintain the ecosystems they are living in.

An example of this is the hunting techniques used by Aboriginal and Torres Strait Islander peoples to catch marine animals. They are based on long-term sustainability, where animals are recognised as being both an important food source and essential to the marine environment. Totemic relationships also underpin what can and cannot be hunted by individuals, reinforcing sustainability. Archaeological evidence shows that Aboriginal and Torres Strait Islander peoples have been hunting and eating dugongs and turtles for thousands of years – their sustainable hunting approach has ensured the continuity of populations. For example, hunters select young, male dugongs rather than pregnant or nursing females.

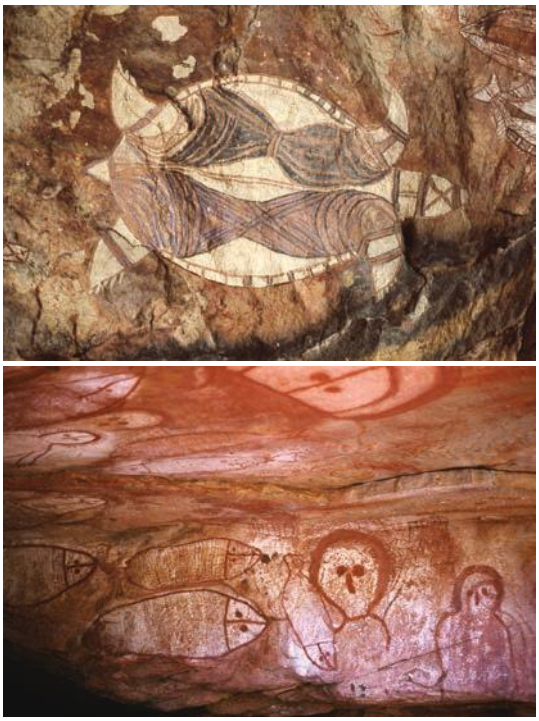


Figure 4.45 Rock art paintings of a turtle (top) from Arnhem Land, Northern Territory, and dugongs (bottom) in West Kimberley, Western Australia



Figure 4.46 Myrtle rust (*Austropuccinia psidii*) is a fungus which grows on plant hosts. As of the end of 2020, it has not yet been found in Western Australia.

Since European settlement in Australia, many different organisms have been moved from one part of the country to another or have been brought to Australia from overseas. This was done either deliberately or accidentally. Introduced species have caused many environmental problems including threatening native species.

A whole range of organisms have become invasive.

- The feral rabbit and feral camel are examples of introduced animals.
- The plant disease, myrtle rust, was first discovered in April 2010. It has now spread from New South Wales to Queensland, Victoria, Tasmania and the Northern Territory, threatening several plant species. As of the end of 2020, myrtle rust has not yet been found in Western Australia.
- The Athel pine is considered a weed in Australia and has economic and environmental impacts. It consumes water more quickly than native plants, reducing water holes. It also excretes concentrated salt through its leaves, making the ground underneath much saltier and preventing native pasture grasses from growing. This alters the flow pattern of rivers, causing flooding and bank erosions.

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Unfortunately, some native animals have disappeared or have suffered due to a loss of habitat or competition and predation by a variety of introduced animals, resulting in adverse effects on the ecosystems that exist within Australia. Of Australia's threatened and endangered species, 1257 are directly affected by invasive species comprising 207 plants, 57 animals and three pathogens.

Explore! 4.8

Feral camels

A lack of predators or an 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 a habitat's carrying capacity, which may result in overgrazing. Take, for example, the world's largest herd of feral camels. There are approximately 1–1.2 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 kilometres, across the states of Western Australia, South Australia, Queensland and the Northern Territory. They are mainly dromedaries, but some are Bactrian camels.



Figure 4.47 Feral 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 Aboriginal and Torres Strait Islander communities, 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.
4. Conduct some research on the feral camel situation in South Australia. Present arguments for *and* against feral camel culls that are sometimes implemented to reduce population sizes. Provide facts for the reasoning behind your arguments.

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Science as a human endeavour 4.3

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 approximately 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 many mammal species becoming smaller, with the overall size of many species much smaller today than in the past. Habitat destruction can also particularly disadvantage large species, who require larger areas to survive.



Figure 4.48 The case of shrinking mammals may continue to claim species, like polar bears, who are a valuable part of our ecosystem. A reasonable prediction is that worldwide, eventually there may not be anything larger than an average dairy cow.

Dr Martino Malerba, a postdoctoral researcher from Monash University, and his team conducted an experiment using a microscopic alga called *Dunaliella tertiolecta* that revealed the physiological reasons why many species are becoming smaller in response to climate change, overhunting and overfishing. As the algae reproduced, the research team purposely selected the small and large algae (but not the medium-sized), allowing them to reproduce within the two size groups. Over many generations, this produced a 'large' population and a 'small' population – the algae in the 'large' population were approximately ten times the size of those in the 'small' population. The researchers found that modifying the size of a species ultimately affects its ability to use energy. Larger organisms can convert energy they consume into biomass far more efficiently than the smaller organisms. But by evolving smaller body sizes, species can improve their survival rate if they live in an environment where resources are limited, but this means they are also disadvantaged by a decreased ability to convert food into biomass. Essentially, smaller and more adaptable animals have higher survival rates than larger animals.

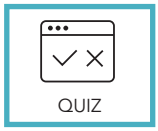


Figure 4.49 Thylacines (left) were hunted to extinction by humans, while the Bramble Cay melomys (right) became extinct due to habitat loss brought about by climate change.

Indirectly, global warming also may favour smaller sizes. Warming can increase the rate of enzyme reactions in organisms, leading to faster metabolisms and higher energy requirements, as is typical of smaller animals. Also, larger animals conserve their heat more efficiently, which is one reason why species that live closer to the equator are generally smaller than their polar equivalents. In a warming world, large animals will gain less advantage from their body size.

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Section 4.3 questions



Remembering

1 **State** two events that can increase a population's size and two events that can decrease a population's size.
2 **State** the Lincoln Index equation that is used to estimate the population size of a species using the capture–mark–recapture process. Define the variables (letters) in your answer.
3 **State** the word equation used to represent the change in population size.

Understanding

4 A population of animals immigrates to a new area where there is abundant food and space. They begin reproducing rapidly. **Identify** the model that best depicts their population growth.
5 An ecologist wants to estimate the number of birds living in a wetland. **Identify** a reason why a quadrat would not be an appropriate tool.
6 **Calculate** the estimated population size of the northern hairy-nosed wombat if 80 animals were captured and marked in the first sample and 60 were captured in the second sample, with 30 of this second sample already marked from the first sample.

Applying

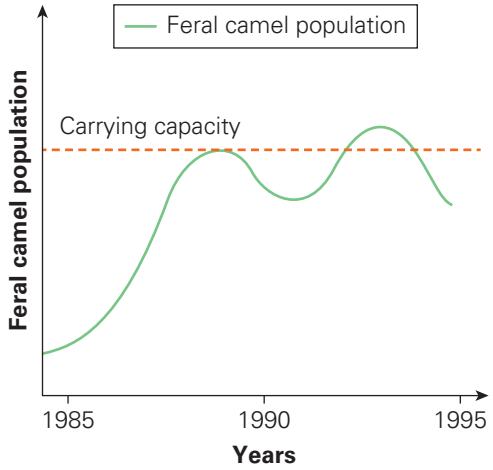
7 **Summarise** the key advantages of using quadrats to determine the population size of marine algae within a tidal coast ecosystem.

Analysing

8 **Analyse** the following statement: 'The population size is only as big as the environment's carrying capacity.' In your analysis, consider what factors come into play once the population size exceeds carrying capacity.

Evaluating

9 Use the following graph to answer the questions about feral camels.



a **Identify** one possible reason why the population decreased initially in 1990 after reaching the environment's carrying capacity.
b **Propose** why the population exceeded the environment's carrying capacity around 1992.

10 **Propose** three possible reasons why a species may immigrate to a new habitat.
11 **Discuss** how the capture–mark–recapture method is used to estimate population size within ecosystems.

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12 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 predator numbers increase and food supply decrease.

13 **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 endangered native species.	
Red fox		

14 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.

Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked question	Check
4.1 I can distinguish between the different components of an ecosystem.	4	
4.1 I can describe the efficiency of energy flow through an ecosystem.	8	
4.1 I can describe different trophic levels of an ecosystem.	14	
4.1 I can discuss the effect of fire, drought and flooding on an ecosystem.	9	
4.2 I can discuss the three types of symbiosis between organisms.	12	
4.2 I can describe the predator–prey relationship.	15	
4.3 I can calculate population size using Change in population size = (births + immigration) − (deaths + emigration).	7	
4.3 I can describe different population growth models.	8	
4.3 I can describe how to estimate population size of organisms in an area.	13	

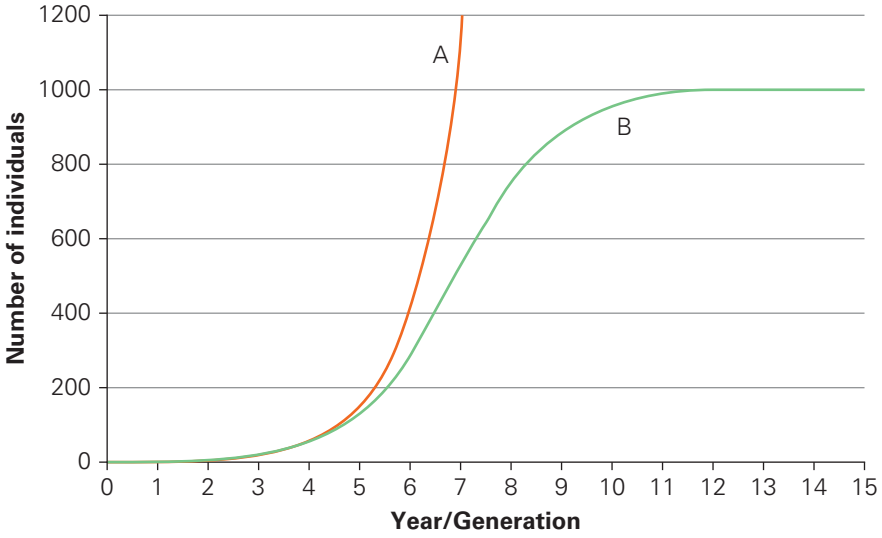
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Review questions

SCORCHER

Remembering

1 **State** the products from the process of photosynthesis.
2 **State** the products from the process of cellular respiration.
3 **Recall** the three components of an ecosystem.
4 **List** the six levels of organsiation in ecosystem.
5 Look at the following population growth versus time graph.

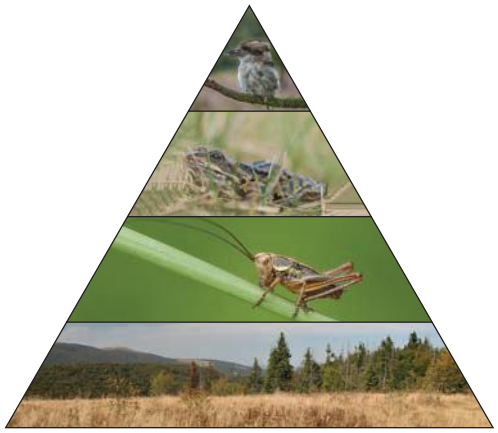


a **Identify** the exponential growth curve and the logistic growth curve.
b **Identify** the carrying capacity of the environment for the population shown in curve B.

Understanding

6 A population of 10 wallabies immigrates into a new area. Eight of the wallabies have a joey, one of which dies when only a few days old. One of the mothers is shot by a farmer, and two new wallabies immigrate into their mob. **Calculate** how many wallabies remain.
7 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 the eggs hatch, the larvae eat the host from the inside out. **Identify** which elements of this interaction are like a parasite and which are like a predator.
8 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 g. An average-sized grasshopper (like the one in the energy pyramid on the right) weighs 5 g and must consume half of its body mass in food per day. Use the energy pyramid to help you **calculate** how many blades of grass the grasshopper needs to eat per day.
b Assume a frog must eat five grasshoppers per day, while a kookaburra must eat two frogs per day. Use this information along with your answer from part a to **calculate** how many blades of grass are needed to keep a kookaburra alive for a day.



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Applying

9 **Describe** three positive outcomes of fire on Australian plants.

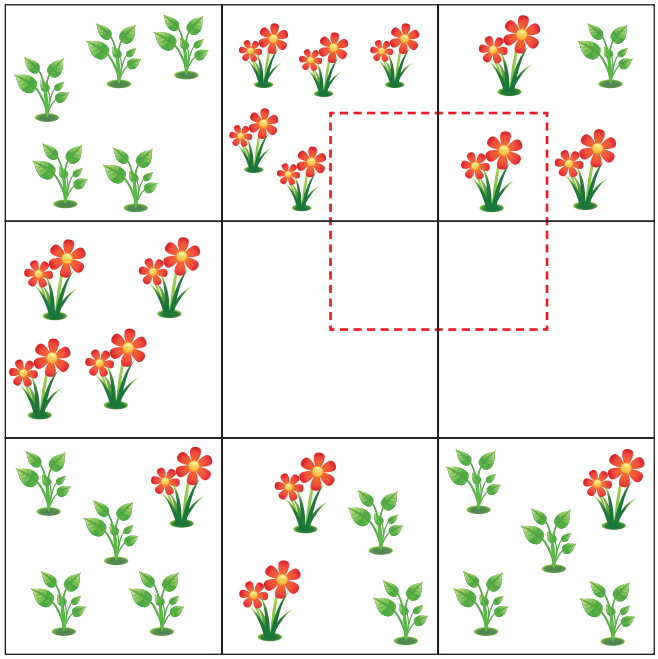
10 **Describe** the steps between the Sun (as a source of energy) and a secondary consumer.

Analysing

11 **Compare** which organisms perform photosynthesis and which organisms perform cellular respiration.

12 **Compare** the roles of a bee and a flower in their mutualistic relationship.

13 A plant biologist sampled using a quadrat to estimate the population size of the red-flowered plant, as shown in the diagram. The red dotted 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.



Evaluating

14 **Propose** which trophic level is the most important for an ecosystem and explain why.

15 The following table 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	6000
1910	65 000	18 000
1920	40 000	61 000
1930	28 000	28 000
1940	25 000	4000
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	4000	5000

a **Construct** a line graph that includes both the fox and rabbit data. Be sure to include all the appropriate labels including title, label of *x*-axis and label of *y*-axis as well as a legend.

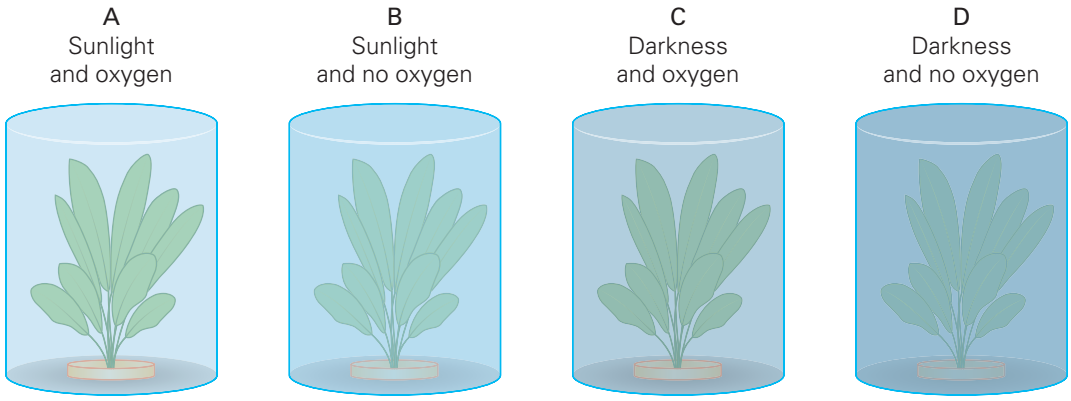
b These population growth curves are said to fluctuate. **Discuss** what this means, using data from the graph.

c **Propose** 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.

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16 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 three of the four jars are needed to answer the question: 'Do plants need sunlight and oxygen to grow?'

b **Propose** three variables that Elijah must control to get valid results.

Data questions

Figure 4.50 depicts the changing populations of dingo and red kangaroo in a desert region of Australia over a 50-year period.

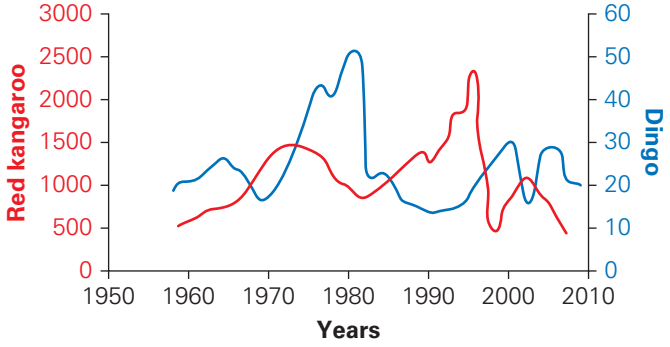


Figure 4.50 Red kangaroo and dingo populations from 1950 to 2010

1 **Identify** which line colour represents the population of dingoes over time.
2 **Determine** the population of dingoes in the year 2000.
3 **Identify** the year that had the largest dingo population.
4 **Identify** the pattern between the two populations with reference to the terms 'predator' and 'prey'.
5 **Deduce** the population of red kangaroos when the population of dingoes was at its peak.
6 **Infer** why the red kangaroo population was greatest in the mid-1990s.
7 In the year 2015 the red kangaroo population fell to a trough of approximately 300 in this region. **Predict** how the dingo population might have changed in this time.
8 **Predict**, if possible, the populations of red kangaroos and dingoes in 2030 given the data in Figure 4.50.

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STEM activity: Saving an endangered species!

Background information

According to scientists, the extinction of species is happening at a disturbingly fast rate. Exact reasons are rarely known, but we do know that most contributing factors are a consequence of human activities. These factors include 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 e.g. invasive 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

Design brief: Design a product that can help an endangered species survive.



Figure 4.51 A Margaret River burrowing crayfish (*Engaewa pseudoreducta*)



Figure 4.52 A western swamp turtle (*Pseudemydura umbrina*); turtles are known as *yarkan* in Noongar language

Activity instructions

Taking on the role of an engineer, you and your team are going to work through the design process. As you work through the design process, you will need to select an endangered species from Western Australia to investigate and research, including why it is now endangered. You will

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then design a product that will help prevent your endangered species from becoming extinct. You will not build your product, so this allows you to come up with a greater range of ideas. Your design will be pitched to your fellow engineers in class, so you can all give and receive feedback on your designs as critical friends.

Suggested materials

- web browser/internet access
- pencil
- paper

Research and feasibility

1 Define in your own words the problem you are being asked to solve, and decide which endangered species your group will focus on.

2 Research and list all the factors that are currently affecting that endangered species.

Factor	Issues	Impact
e.g. Location	Deforestation	Insufficient homes for animals.

3 Discuss in your group the main factor (or combination of factors) that is causing the greatest impact and threatening your species with extinction.

4 Include in your research a map of Western Australia showing your species' distribution, and tabulated data showing the population change of your species over time.

Design and sustainability

5 Considering all the factors you have researched, discuss in your group a possible solution to help rebuild the population of the endangered species.

6 Reflect on how to increase the sustainability of the area your group is focusing on and how the environmental conditions can be improved.

Create

7 Create a presentation (in any medium you wish) of your proposed solution. Draw a detailed design (including materials and annotations) for your solution, and describe how your design will work to solve the problem. Keep in mind what your prototype is made of and try to choose renewable resources.

Evaluate and modify

8 Discuss and evaluate with your class the positive, negative and interesting features of each team's design.



Figure 4.53 A white-bellied frog (*Geocrinia alba*)

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Chapter 5
Atoms

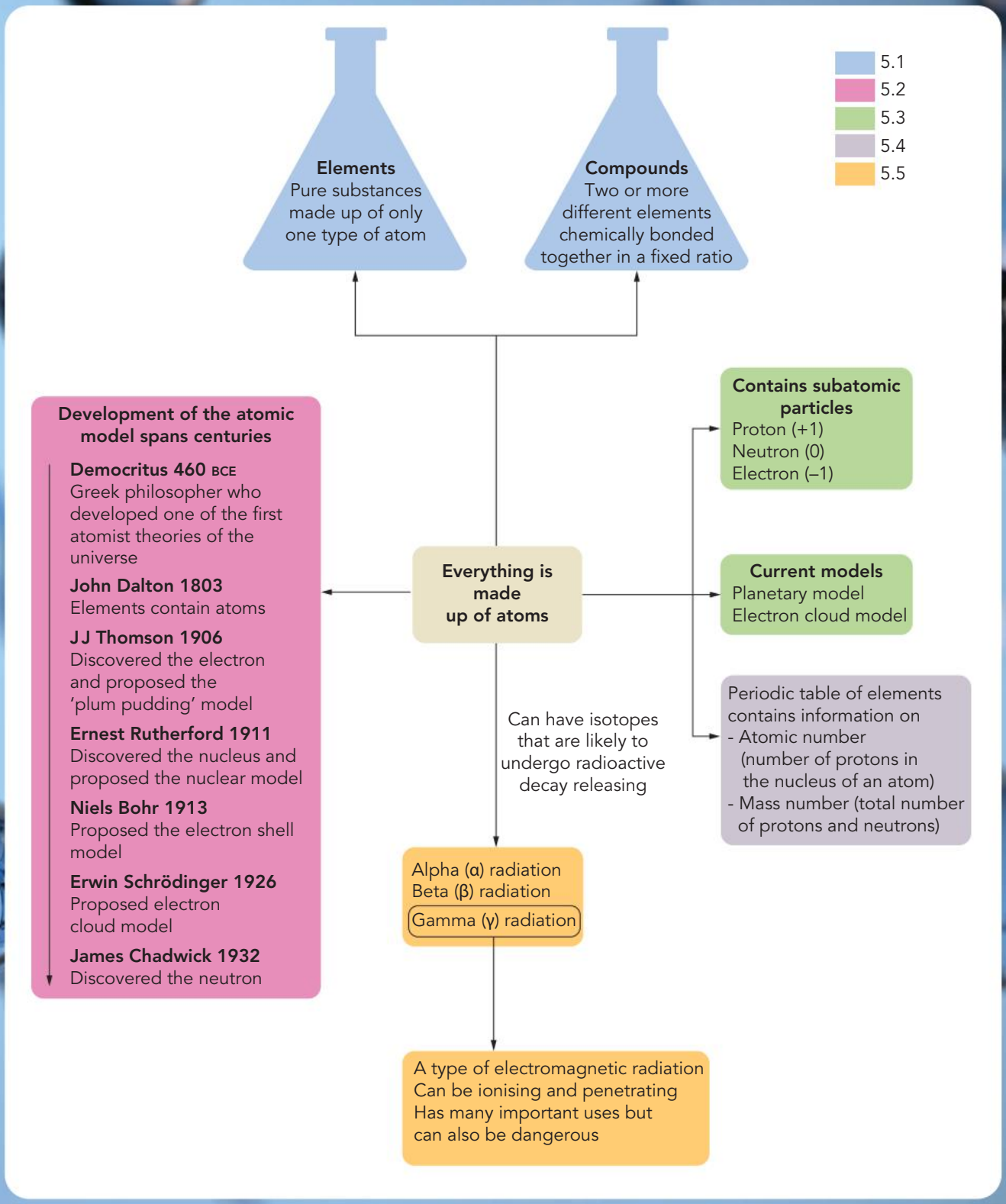


Chapter introduction

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 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.

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Chapter map



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5.1 Atoms, elements and compounds

WORKSHEET

Learning goal

1 To be able to define atoms, elements, compounds and molecules.

Atoms

Someone once told me not to trust **atoms** because they make up everything! To develop a language, you need an alphabet; similarly, to build complex chemical substances, you need atoms. The word 'atom' comes from the Greek word *atomos*, which means 'indivisible' or 'un-cuttable'. If you had a silver ring and cut that ring in half and then in half again and continued to do this, you would eventually be left with an atom of silver. It was thought that this silver atom could not be divided into smaller pieces. Modern physics now shows this is not true, which will be discussed later in the chapter.

atom
the building block of matter

An atom is the smallest possible form of an element on the periodic table, and there is a unique atom for every element. For example, if you cut an atom of silver in half, you would no longer be in possession of the element silver.



Figure 5.2 A ring made of silver atoms

Atoms are so small that they are not visible to the naked eye. 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. They were awarded a Nobel Prize for Physics in 1986 for their efforts. This discovery allowed scientists to view images of many different atoms that had previously been unseen.

Did you know? 5.1

You are a star!

More than 98% of all the atoms in the universe come from the two lightest elements: hydrogen and helium. The heavier elements are created at the end of a large star's lifecycle in a massive explosion called a supernova. So, next time your teacher calls you a star, they may be right! You can be safe in the knowledge that the elements that make up all humans have, at one point, come from a star.

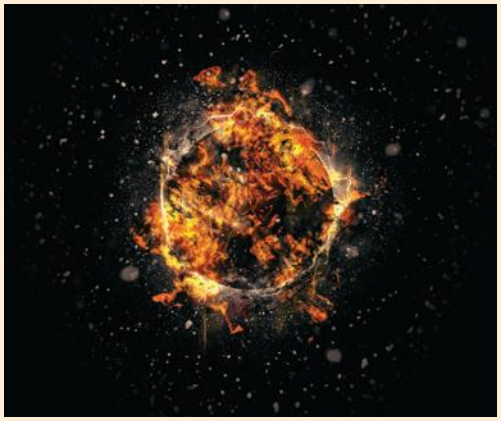


Figure 5.1 A digital impression of an exploding supernova

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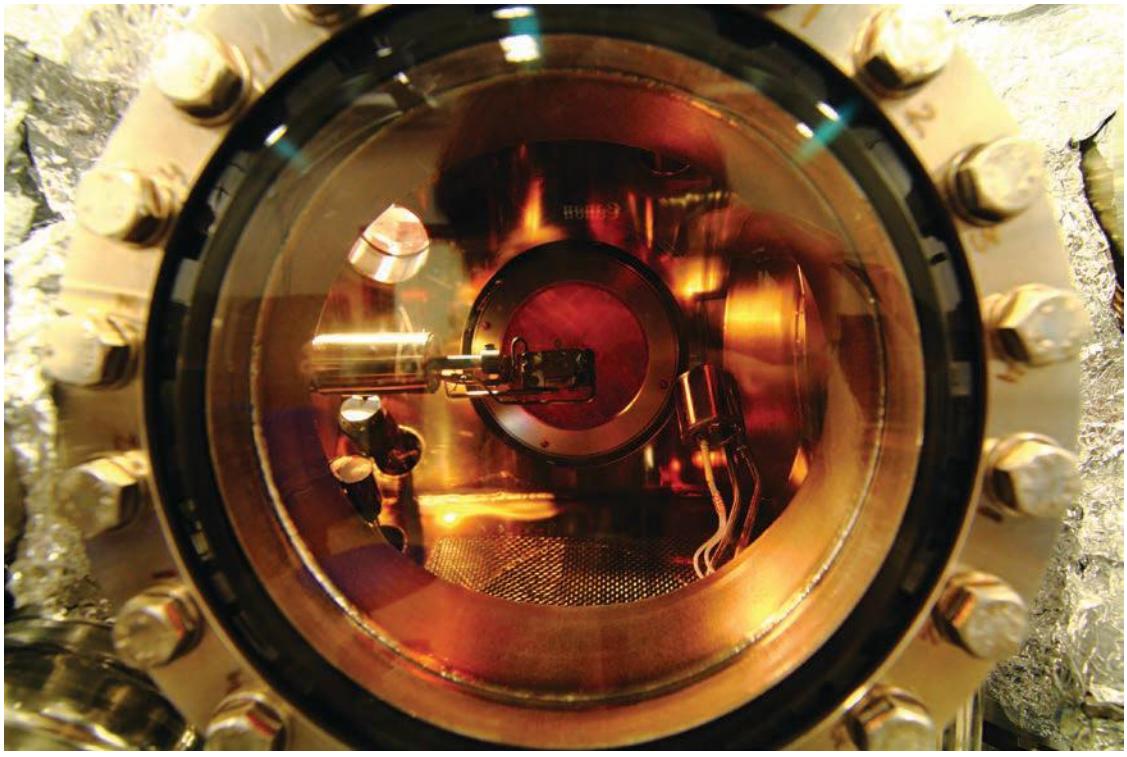


Figure 5.3 The interior of a scanning tunnelling microscope used to view the first image of an atom

Science as a human endeavour 5.1

The world's smallest movie

In 2013, researchers at IBM created the world's smallest movie. They used carbon monoxide molecules and moved them using the small tip of the scanning tunnelling microscope. The movie is called *A Boy and His Atom* – a boy meets an atom and they become friends. It was created using individual frames that were put together using stop-motion software. You can search for this film in your preferred web browser. Although it was constructed for fun, it shows just how far physics has come in the study of atomic and molecular systems.

Quick check 5.1

1 Define an atom.
2 Recall the name of the microscope which allowed scientists to view atoms.

Elements, compounds and molecules

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 according to their properties and are represented by a chemical symbol.



VIDEO
Uses of elements

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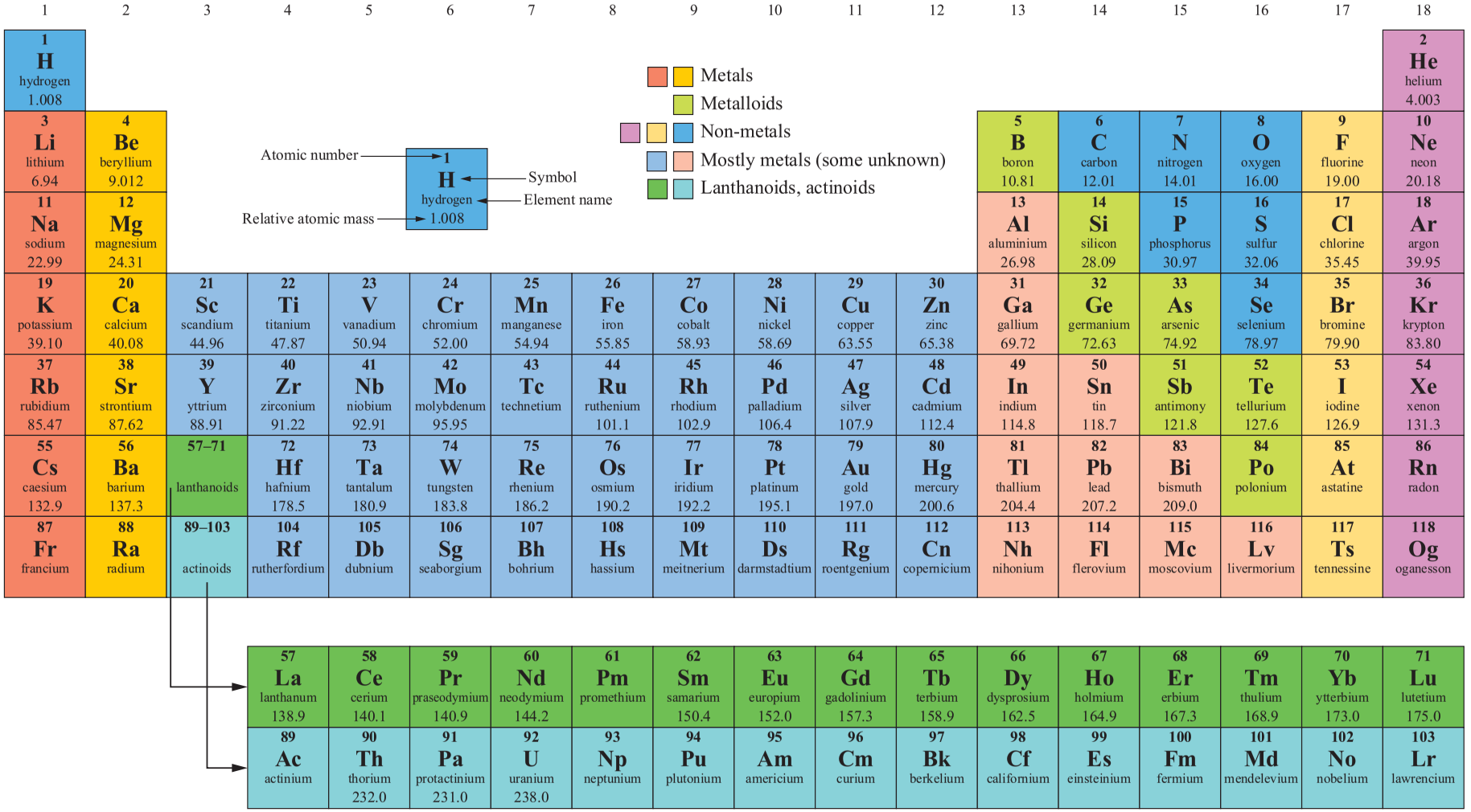


Figure 5.4 The periodic table

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Did you know? 5.2

Strange element symbols

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. Try to pick out the nine elements whose symbols come from their Latin names.

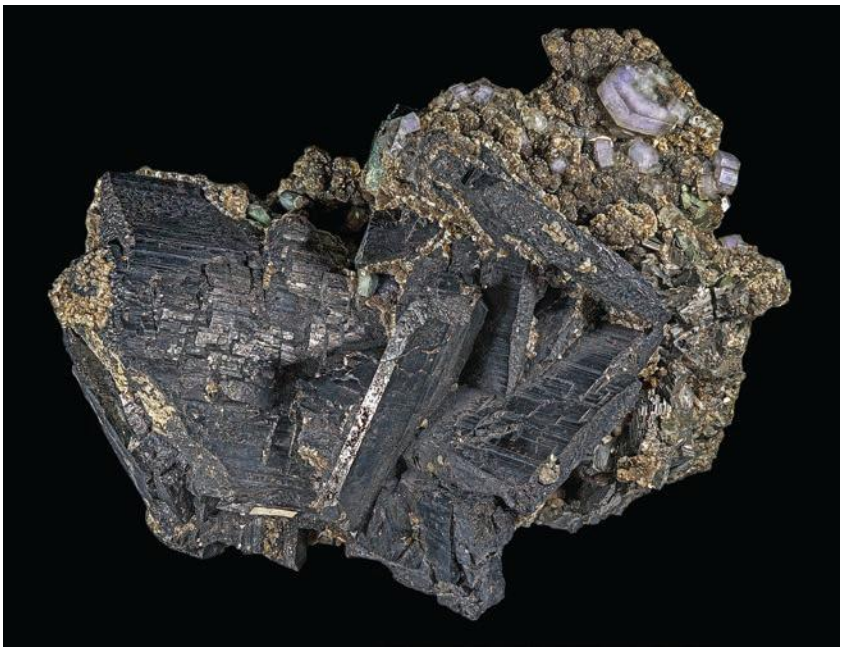


Figure 5.5 Tungsten was discovered in the mineral called wolframite, which are the grey areas shown here.

Compounds

Compounds are formed when two or more different elements combine with one another in a fixed ratio 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 coloured metal and oxygen is a colourless gas but their compound (aluminium oxide) is a white solid.

Molecules

The term **molecule** is often used to describe a chemical species generally made up of two or more non-metal atoms. For example, oxygen gas, O_2, is a molecular element while water, H_2O, is a molecular compound. Both are molecules, but one is made up of only one type of element and the other has different elements.

compound
chemical combination of two or more different elements combined in a fixed and definite proportion by weight

molecule
a chemical species generally made up of two or more non-metal atoms. A molecule can be elemental or a compound.

Aluminium oxide used in the previous example would not be classed as a molecule as it contains a metal element and therefore its chemical structure will be different. Compounds consisting of metals and non-metals are often classified as ionic compounds.

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Practical 5.1

Splitting molecules into atoms

Aim

To split molecules into atoms.

Be careful

Ensure connectors of the leads are separated and not in contact with each other when attached to the switched-on power pack.

Materials

- baking soda
- distilled water
- 250 millilitres (mL) beaker
- 250 mL measuring cylinder
- stirring rod
- safety glasses
- spatula
- 2 power leads
- 2 alligator clips
- power pack

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. Note: the baking soda will enhance the conductivity of the solution, but it is not involved in the chemical reaction.
3 Attach each lead to the DC terminals on the power pack, setting the voltage to 9 volts (V).
4 To the other end of each lead, attach an alligator clip, making sure the wires do not touch each 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 alligator clip.

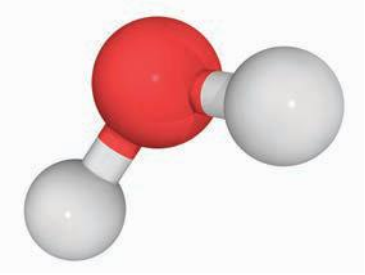


Figure 5.6 This molecular model of a water molecule shows two hydrogen atoms (white) and one oxygen atom (red).

Results

Compile a list of the observations that you made from this experiment. Remember, observations are things that you can see happening, not an explanation of what is happening.

Discussion

1 In this experiment, you split up water molecules into their atoms. Identify which atoms make up water molecules and how many of each single atom there are.
2 Distilled water is water that has undergone a process to remove impurities. Propose a reason why the use of distilled water was specified and suggest what, if any, effect this may have had on the outcome.

Quick check 5.2

1 For each of the following compounds, determine the elements (types of atoms) that form each compound.
   a Water – H_2O
   b Carbon dioxide – CO_2
   c Sodium chloride – NaCl (table salt)
2 Evaluate whether it is possible to predict if a substance is an element or a compound by its chemical formula or by its chemical name.

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Practical 5.2

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
- tongs
- crucible
- safety glasses
- matches
- Bunsen burner
- heatproof mat

Method

1 Draw the results table below.
2 Set up a Bunsen burner on a heatproof mat.
3 Hold the piece of magnesium ribbon in the tongs and put it into the hottest part of the flame until it catches alight.
4 Collect the compound formed in a crucible and observe the contents.

Results

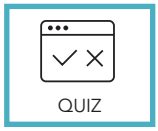
Complete the results table, listing the physical properties (appearance) of the substances in the reaction.

Substance	Physical properties (appearance)
Magnesium metal	
Oxygen gas	
Compound formed	

Discussion

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.

Section 5.1 questions



Remembering

1 **Name** the two most common elements in the universe.

Understanding

2 **Identify** the different elements present in ethanoic acid, the main ingredient in vinegar (CH_3COOH).

Applying

3 **Explain** why some elements in the periodic table have symbols that do not match their English name.
4 **Explain** why you do not find carbon dioxide (CO_2) on the periodic table.

Analysing

5 **Compare** an atom, an element and a compound.

Evaluating

6 **Decide** which of the following substances are compounds. Justify your choice.
oxygen potassium water sugar
candle wax hydrogen petrol

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5.2 Development of the atomic model

WORKSHEET

Learning goal

1 To be able to list the timeline of scientists who contributed to the development of the modern model of the atom.

Discussions about the atom and its structure have been going on within the scientific community for hundreds of years. In this section you will examine the major discoveries that have contributed to our understanding of the atom and highlight how new experimental evidence can lead to a scientific model being updated or replaced.

Democritus 460–370 BCE

Democritus was the first scientist to theorise about the atom. In the year 442 BCE, he said that if you take an object and cut it into smaller and smaller pieces, eventually you would reach a point where you could no longer cut it anymore. You would end up with a piece that was indivisible. It was Democritus that called this piece *atomos*, which means 'indivisible' in Greek. He thought, for example, that water was made of water 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.

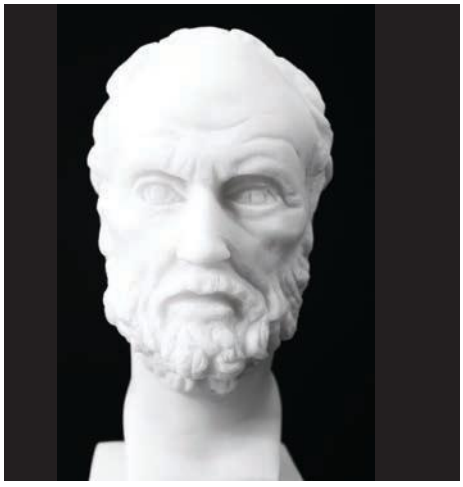


Figure 5.7 Sculpture of the Greek philosopher Democritus

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.

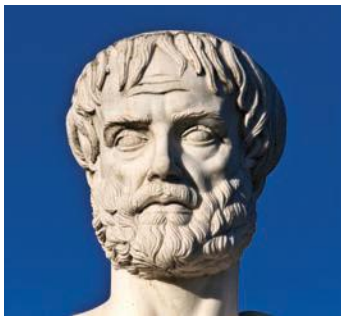


Figure 5.8 Sculpture of the Greek philosopher Aristotle

John Dalton 1766–1844

Dalton is credited for igniting research into modern atomic theory in 1803, more than 2000 years after Democritus first proposed his ideas on the atom. Dalton suggested that all elements, which are now arranged in the periodic table, contained atoms, and that atoms of the same element would be identical in size, shape and mass. He also stated that compounds were a combination of elements. The question he could not answer, though, was why atoms behaved the way they do.



Figure 5.9 John Dalton was an English chemist, physicist and meteorologist. He is best known for sparking research into modern atomic theory.

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Joseph John Thomson 1856–1940



Figure 5.10 J J Thomson proposed the 'plum pudding' model and is credited with discovering the electron.

Thomson was the first scientist to discover particles smaller than the atom, disproving Dalton's and Democritus' theories. Surprisingly, the first subatomic particle to be discovered was the lightest – the electron – and Thomson won a Nobel prize for his work in 1906. By studying 'rays' within a cathode ray tube, Thomson was able to determine that these 'rays' had a mass 1000 times smaller than a hydrogen atom, the lightest piece of matter known to science at the time. 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', but they are now called electrons.

The first model of the structure of the atom was proposed by Thomson and named the 'plum pudding model'. Thomson knew that electrons were negatively charged and that atoms were neutral, so he theorised that there must also be positive charge within the atom that equalled the negative charge of its electrons. He imagined the atom as negatively charged electrons (plums) embedded in a large 'sea' of positively charged 'pudding'.

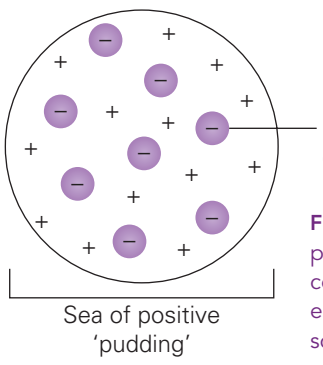


Figure 5.11 The plum pudding model, comprising negative electrons (the plums) scattered through a sea of positive charge (the pudding)

Ernest Rutherford 1871–1937

In 1911, Ernest Rutherford and colleagues Hans Geiger and Ernest Marsden fired **alpha particles** (helium nuclei) at a thin piece of gold foil, in the famous gold foil experiment.

alpha particle
a positively charged particle ejected spontaneously from the nuclei of some radioactive elements



Figure 5.12 Ernest Rutherford stated that there was a large concentration of charge and mass situated in the centre of the atom and that most of the atom was empty space.

Rutherford predicted that if the atom was like Thomson's plum pudding model, then all the alpha particles should pass straight through the atom undisturbed. This is not what happened! It was true that almost all (99.99%) of the alpha particles passed straight through the foil and were detected at the other side by the detector, indicating that the atom was mainly empty space. However, some of the alpha particles surprisingly bounced back or were deflected as if they had hit something (see Figure 5.13). Rutherford concluded that there must be an area of charge, concentrated in the middle of the atom, with enough mass to cause the alpha particles to deflect or bounce back, thus disproving the plum pudding model altogether. Rutherford's model is often referred to as the 'nuclear model' or 'planetary

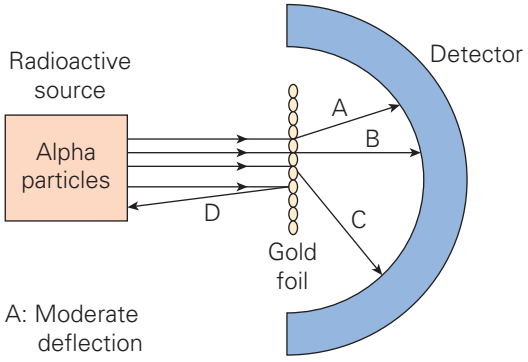


Figure 5.13 The gold foil experiment conducted by Ernest Rutherford and colleagues proved that most of the atom was empty space and that there was an area of charge and mass concentrated in the middle of the atom.

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model', but Niels Bohr's later work refined the planetary model.

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.

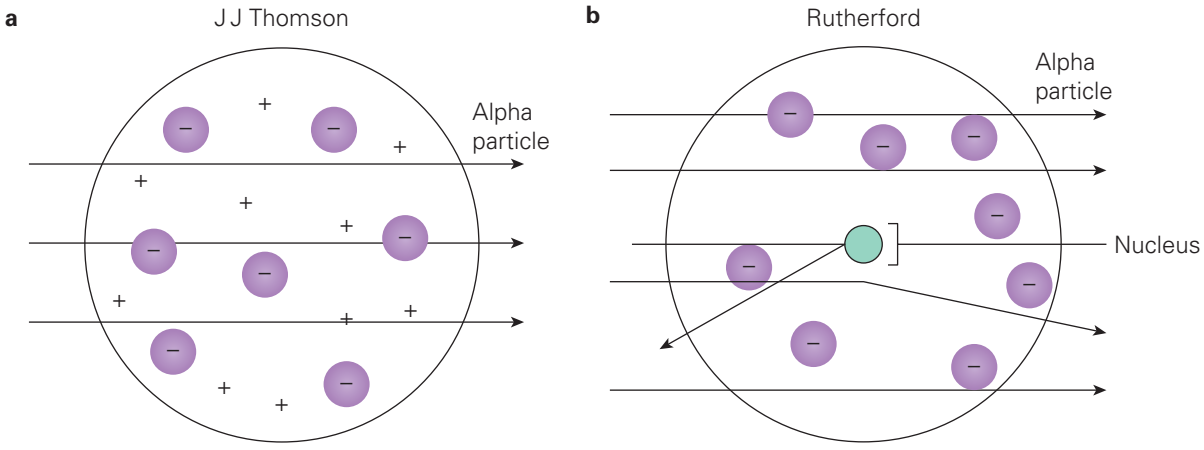


Figure 5.14 Comparison between atomic models: **(a)** Thomson's plum pudding and **(b)** Rutherford's central region of mass and charge

Quick check 5.3

1 Recall what Aristotle believed all matter on Earth was composed of.
2 State the name of the subatomic particle that Thomson discovered and the name of his atomic model.
3 Complete the sentences below using the word list.

alpha	empty space	plum pudding model
nucleus	passed through	

Rutherford conducted the gold foil experiment, firing _____ particles at a thin piece of gold foil. Most of the alpha particles _____; however, a small number were deflected back.
Rutherford hypothesised that the reason for this was that the alpha particles either passed through a region of _____ or hit a central region of concentrated mass and positive charge, which he called the _____, disproving the _____.

Practical 5.3: Teacher demonstration

Invisible spaces in water

Aim

To investigate the three-dimensional structure of molecules.

Materials

- 100 mL propan-2-ol
- 250 mL beaker
- 100 mL measuring cylinder

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…continued

Method

1 Draw the results table shown in the Results section.
2 Predict what will happen to the total volume when 100 mL of alcohol is added to 100 mL of water. Propose what the total volume of the solution will be.
3 Measure 100 mL of water using the 100 mL measuring cylinder and pour into the beaker.
4 Using the same measuring cylinder, measure 100 mL of propan-2-ol and pour into the beaker already containing water.
5 Note the actual total volume when the two solutions are mixed together.

Results

Prediction of volume with 100 mL of water and 100 mL of alcohol	
Actual volume with 100 mL of water and 100 mL of alcohol	

Discussion

Discuss whether the actual final volume differed from your prediction, and why this was the case.

Try this 5.1

Most of an atom is empty space

In this activity, you are going to make a scale model of a hydrogen atom. A hydrogen atom contains one proton and one electron; it is the simplest atom on Earth. You may need a larger space than the classroom to do this – a corridor or playing field may be more suitable. To complete the experiment correctly, you need to know these following important facts:

- The distance between an electron and a proton is 50 000 times the diameter of a proton.
- The mass of a proton is 1840 times greater than the mass of an electron.

Materials

- calculator
- metre ruler
- various spherical objects, such as marbles, table tennis balls, dried peas
- pencil
- 30 cm ruler
- scissors
- ball of string
- compass (for drawing a circle)
- A4 plain paper

Method

1 Draw the results table below.
2 Using the compass, draw a small circle on a piece of paper and record the exact diameter in the results table. This represents a proton.
3 Using the important facts at the start of the activity, calculate the relative distance of the electron from the proton.
4 Measure a piece of string to the distance calculated in step **3** and record the length in the results table. If you are outside on a field, you could stick the metre ruler into the grass, tie the string around it and draw out how big the atom would be for the proton drawn on your paper.
5 Repeat the calculation with one of the spherical objects to represent a different proton. Measure the diameter of your chosen spherical object with the 30 cm ruler and record it in the results table.

continued…

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…continued

6 This is the diameter of your new hydrogen proton. Now calculate the relative distance of the hydrogen electron from the proton.

7 Measure a piece of string to the distance calculated in step **6** and record the length in the results table. Again, if you are on a field, you could stick the metre ruler into the grass, tie the string around it and draw out how big the atom would be.

8 If you have time, repeat for the other spherical objects.

Results

Diameter of spherical object (cm)	Length of string/radius of the atom (cm)
Your circle	

Discussion

1 Propose how this experiment supports the work of Ernest Rutherford on the atom.

2 Design another way in which you can show the relative size of an atom.

Conclusion

State a conclusion about the size of the proton and the distance between it and the electron.

By the early twentieth century, scientists had a fairly good understanding about Rutherford's model of atomic structure; they just needed to identify where exactly the electrons were positioned in the atom.

Niels Bohr 1885–1962



Figure 5.15 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 investigating 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.

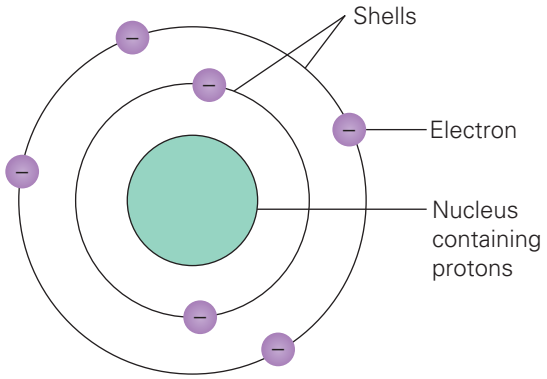


Figure 5.16 Bohr's model of the atom shows electrons orbiting the central nucleus in shells.

Scientists now know that Bohr's model has some flaws, but it provided some important theory about the behaviour of electrons. Perhaps more importantly, it is the foundation of the model that you will recognise and use the most in your studies.

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Erwin Schrödinger 1887–1961



Figure 5.17 Erwin Schrödinger proposed the electron cloud model, contradicting Bohr's model of fixed electron shells.

The position and behaviour of electrons in the atom was still an area that scientists knew very little about. Erwin Schrödinger stated that it is impossible to predict where a specific electron will be situated in the atom at any given time. The only thing you can predict is where in the atom you are most likely to find an electron. This contradicted Bohr's idea of electrons being in fixed shells around a central nucleus. Schrödinger proposed the electron cloud model, which shows the locations in the atom with the greatest probability of finding an electron. This is connected with the wave properties of the electron (quantum (or wave) mechanics).

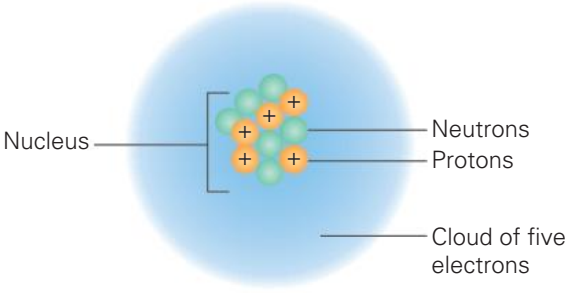


Figure 5.18 The modern electron cloud model of a boron atom

James Chadwick 1891–1974



Figure 5.19 James Chadwick discovered the neutron, completing the atomic model in use today.

There is one subatomic particle yet to be discussed. You may not be surprised that the neutron was the last of the three subatomic particles to be discovered. As it has no charge and does not repel the protons in the nucleus, it was relatively undetectable. This was the case until James Chadwick started working with beryllium atoms and alpha particles in 1932. When he collided these two particles together, an unknown radiation made up of neutrally charged particles was released. He named these particles neutrons. Often in high school, we use the Bohr model (protons in the nucleus) and shells of orbiting electrons; but we also include neutrons in the nucleus in our diagrams.

Quick check 5.4

1. Recall the name Bohr gave to the structures that contained electrons.
2. Describe how this explanation of these structures differed from Rutherford's model.
3. Identify the subatomic particle that James Chadwick discovered.

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Science as a human endeavour 5.2

The Higgs boson

In 1960, a British-born theoretical physicist named Peter Higgs proposed the existence of a particle that later was named after him: the Higgs boson. The detection of this particle became his goal as well as the goal of many other theoretical physicists.

In 2012, the European Organization for Nuclear Research (CERN) announced that they had conducted experiments on the Large Hadron Collider which showed promising results of a particle that could be a Higgs-like boson. You can imagine the excitement Higgs must have been feeling after all this time! In 2013, after almost 55 years of research, CERN finally had enough evidence to confirm that they had recorded the presence of a Higgs boson, and Higgs was awarded a Nobel Prize for Physics in the same year. This is a great example of how, with hard work and persistence, you can eventually achieve your goals!

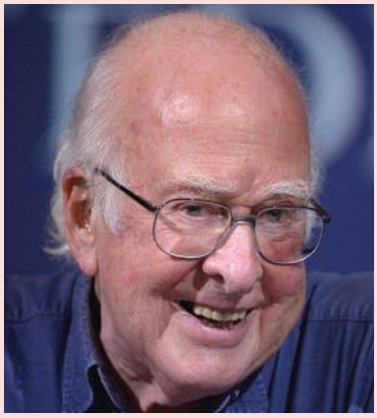


Figure 5.20 Peter Higgs (1929–present) discovered the presence of a new particle, which was named the Higgs boson.



Figure 5.21 Engineers attending to a part of the Large Hadron Collider at CERN where the Higgs boson was discovered

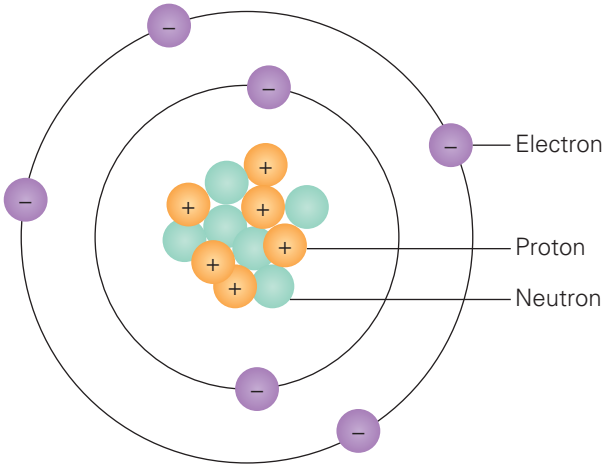


Figure 5.22 The modern Bohr model is used because it is a simplification of the electron cloud model.

The evolution of the atomic model is an excellent example of how different scientists individually contributed to our understanding of atomic structure. However, it is important to note that this is still a model and there may be new discoveries yet to come! After all, there was a time when it was thought that the plum pudding model was the correct model of atomic structure. 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 5.23 summarises the development of the modern atomic model.

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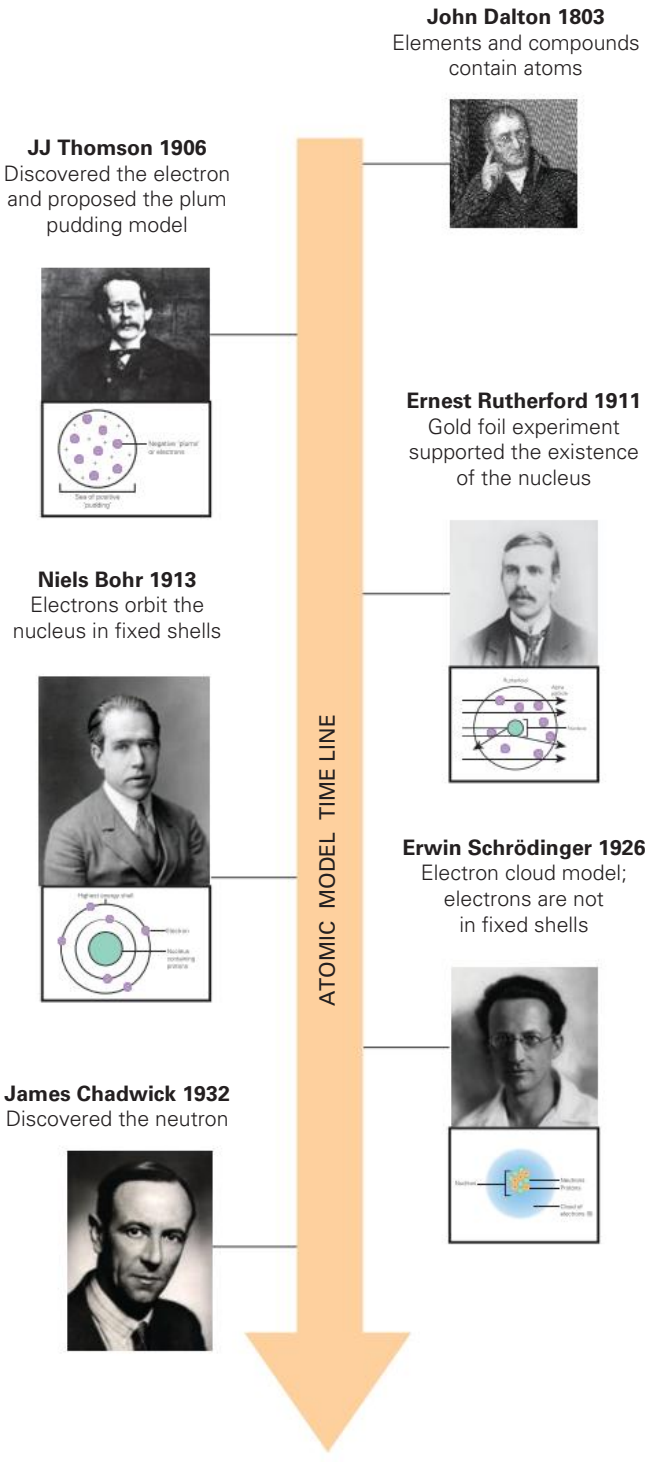


Figure 5.23 A summary of the development of the atomic model

Explore! 5.1

Other significant developments in the atomic model throughout history

A number of other scientists have been involved in developing our understanding of atomic structure.

Research the following scientists, noting their significant discoveries and how each discovery changed our understanding of the atom around at that time.

Maria Goeppert-Mayer, Lise Meitner, Robert Millikan, Werner Heisenberg



Figure 5.24 Nobel Laureate Maria Goeppert-Mayer



Figure 5.25 The element Meitnerium is named after Lise Meitner, who was the second woman ever in the world to earn a PhD in Physics

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Section 5.2 questions

QUIZ

Remembering

1 **Recall** what the Greek word *atomos* means in English. How does this relate to the word 'atom'?
2 **Recall** who discovered the neutron.

Understanding

3 **Summarise** what Rutherford predicted would happen, according to Thomson's plum pudding model, when he fired alpha particles at gold foil.

Applying

4 **Identify** the reason why some alpha particles bounced back towards the detector in Rutherford's gold foil experiment.

Analysing

5 **Compare** Rutherford's model of the atom with the plum pudding model.
6 **Analyse** the differences between Schrödinger's and Bohr's models of the atom.

Evaluating

7 **Discuss** 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.

5.3 The modern structure of the atom

WORKSHEET

Learning goal

1 To be able to compare the relative mass and charge of protons, neutrons and electrons.

Subatomic particles

You have already learned that the word 'atom' comes from the Greek word *atomos* meaning 'indivisible'. This idea, despite having a long history, only became widely accepted in the twentieth century. Even Dmitri Mendeleev, who many call the 'father of the modern periodic table', for a time 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.

subatomic particle one of the particles that make up an atom

proton a subatomic particle with a positive charge found in the nucleus of an atom

neutron a subatomic particle with a neutral charge found in the nucleus of an atom

electron a subatomic particle with a negative charge found orbiting the nucleus

As new technologies developed, physicists discovered that the atom is made up of three key **subatomic particles**: **protons**, **neutrons** and **electrons**. There are different numbers of these subatomic particles in each element, which will be discussed in more detail later in this chapter.

Since 2008, physicists have learned a lot more about particles within atoms from studies using the European Organization for Nuclear Research's (CERN's) Large Hadron Collider (LHC), a particle accelerator built in a



Figure 5.26 Dmitri Mendeleev, often called the 'father of the modern periodic table'

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Figure 5.27 The Large Hadron Collider

Did you know? 5.3

Ordinary hydrogen – an unusual element

Hydrogen is the only element that does not contain all three subatomic particles. A hydrogen atom only contains one proton and one electron. It is missing a neutron!

ring-shaped tunnel with a 27-kilometre (km) diameter underneath 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 it would create many miniature black holes that might even swallow the Earth. Fortunately, despite being the world's biggest machine, the LHC currently cannot produce nearly enough energy for this to occur.

Explore! 5.2

Particles smaller than the electron

There was once a time when scientists thought that the atom was the smallest particle that existed. You know that protons, neutrons and electrons make up the atom, but is there anything that makes up these subatomic particles? Because of its wavelike properties, it is extremely hard to define or measure the size of an electron. Some quantum physicists think that an electron could even be in two places at one time.

Research the particles that make up protons, neutrons and electrons. What are their names? What is known about them?



Figure 5.28 These Russian dolls fit inside each other, getting progressively smaller just like an atom and the subatomic particles within it.

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Modern atomic models

Even with the most powerful microscopes scientists cannot see inside the atom, so they create models of the atom to represent ideas that cannot be observed. To help visualise the structure of the atom, model it as a mini solar system. In the middle of our solar system is the Sun and orbiting the Sun are the planets, with most of the rest of the solar system being empty space.

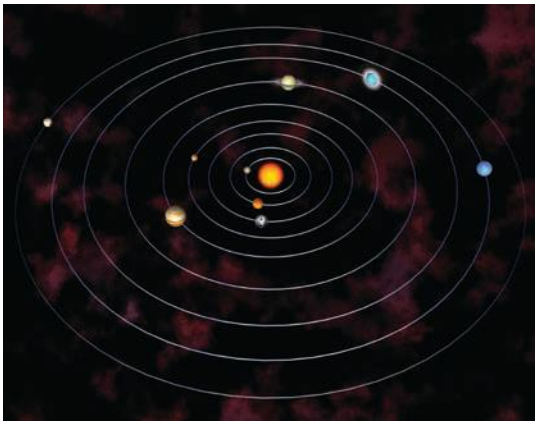


Figure 5.29 The solar system. The planetary model of the atom is based on the structure of our solar system.

nucleus
(plural: nuclei) the central part of the atom containing its protons and neutrons

The atom has a similar kind of structure. In the middle of the atom is a structure called the **nucleus**, which is where the protons and neutrons are situated. Orbiting the nucleus in shells or orbitals 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.

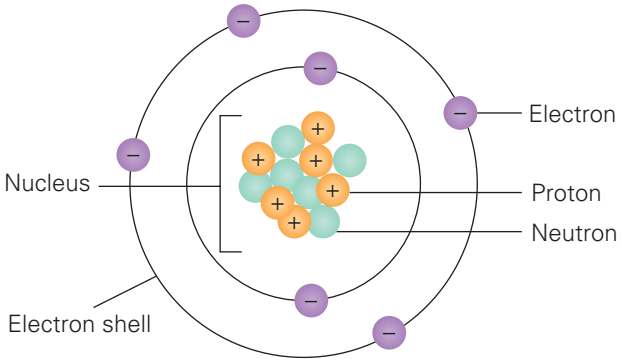


Figure 5.30 A Bohr diagram shows the positively charged nucleus (containing both protons and neutrons) and negatively charged electrons orbiting in shells of different energy levels.

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 in time. Therefore, the electron cloud model shows large areas in the atom where electrons are most likely to be situated (orbitals) at any point in time.

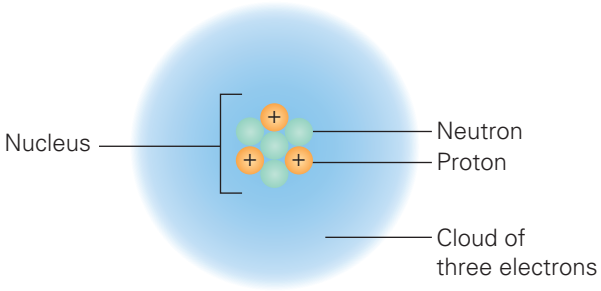


Figure 5.31 The electron cloud model shows the nucleus in the middle of a lithium atom surrounded by a cloud of electrons.

Try this 5.2

Build your own model of the atom using everyday household objects. Make sure you include labels.

Quick check 5.5

1 What is the name of the structure at the centre of the atom and what does it contain?
2 Where are the electrons located?

Properties of subatomic particles

To understand more about atoms and how they behave, you need to know more about the three subatomic particles within them.

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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 relative positive charge (+1). Electrons orbiting the nucleus have a relative negative charge (–1). Positive and negative charges follow two basic rules of electrostatics: opposite charges attract and like (the same) charges repel.

This means that the protons and electrons in an atom are attracted to each other, stopping the electrons from flying off into space. Neutrons are electrically neutral, which means they have relatively no charge at all (0). Table 5.1 summarises what you need to know about the relative charges of the subatomic particles.



VIDEO
What are subatomic particles?

Subatomic particle	Charge
Proton	+1 (positive)
Neutron	0 (neutral)
Electron	–1 (negative)

Table 5.1 The charges of the three subatomic particles

Try this 5.3

Demonstrating the attractions between charged objects

Investigate attractions between charged objects with the following two activities.

Activity 1

Follow the instructions using 2 balloons, 2 pieces of string about 1 metre (m) long, and a plastic tube.

1. Blow up both balloons and tie one piece of string to each balloon.
2. Hang both balloons from a common point on the ceiling.
3. Charge a plastic tube by rubbing it on some fabric.
4. Note the position of the two balloons.
5. Put the plastic tube between the two balloons and observe the effect.

Activity 2

Follow the instructions using a balloon.

1. Rub the balloon on the hair of a friend.
2. Bring the balloon away from their head and observe what happens.

Analysis

1. Determine which experiment showed repulsion. Suggest a reason for your answer.
2. Determine which experiment showed attraction. Suggest a reason for your answer.
3. Discuss what is happening in both experiments at an atomic level.

Mass

As well as knowing the charge of the subatomic particles, you also need to be able to recall their relative masses. Protons and neutrons have very similar masses: a proton has a mass of 1.673×10^{-24} grams (g) and a neutron has a mass of 1.675×10^{-24} g. These numbers are very small and almost the same, so for practical reasons, both protons and neutrons are assigned a mass of 1 atomic mass unit (amu). These values are much easier to remember and work with. Electrons have a mass $\frac{1}{1836}$ of a proton or a neutron. Table 5.2 summarises what you need to know about the relative masses of the three subatomic particles.

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Subatomic particle	Relative mass
Proton	1
Neutron	1
Electron	$^1/_{1836}$

Table 5.2 The relative mass of the three subatomic particles

Quick check 5.6

Summarise the differences in charge and relative mass of the three subatomic particles. You may choose to do so in a table as shown.

Subatomic particle	Symbol	Location	Charge	Relative mass
Proton	p^+			
Neutron	n^0			
Electron	e^-			

Section 5.3 questions

QUIZ

Remembering

1 **Name** the three subatomic particles that make up the atom.

Understanding

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.

Applying

4 **Illustrate** a labelled diagram that shows the Bohr (or planetary) model of the atom.

5 **Illustrate** a diagram of the electron cloud model of the atom.

Analysing

6 **Compare** the properties of protons, neutrons and electrons.

7 **Compare** the models you illustrated in questions **4** and **5**.

Evaluating

8 **Propose** several reasons why models are so useful in science. Explain the limitations of using models.

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5.4 Atomic number and mass number

Learning goals

1 To determine the number of protons and electrons in an element.

2 To be able to calculate the mass of an atom from the number of protons and neutrons.

WORKSHEET

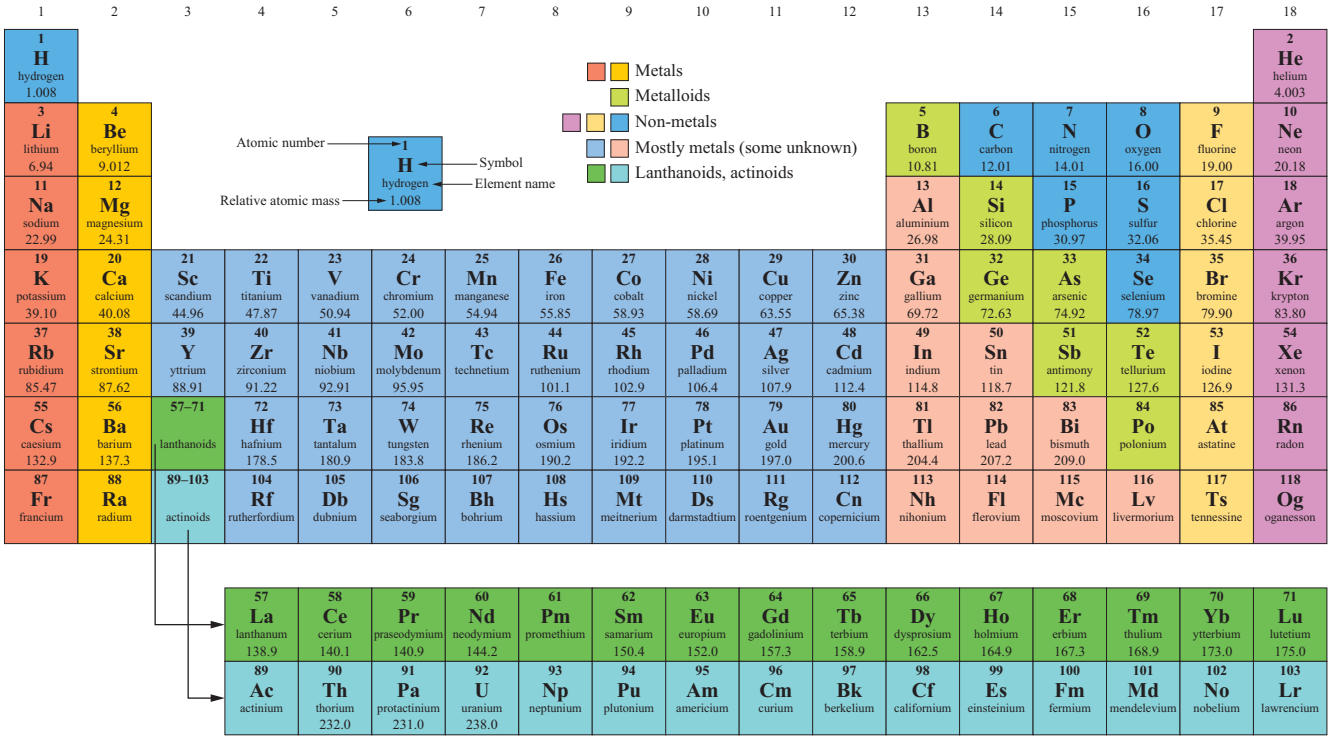


Figure 5.32 The periodic table gives you information about each element's atoms

The number of subatomic particles in an atom is unique to the type of element being considered. Look at the periodic table and you will notice that each element has a symbol and two numbers. These numbers provide information about the number of protons, neutrons and electrons in a neutral atom of that element.

Atomic number

The number directly above the symbol of the element is called the **atomic number**.

Number of protons

The atomic number is sometimes called the proton number as it presents the number of protons in an atom of that element. For example, the atomic number of carbon is 6, therefore carbon has six protons.

atomic number
the number of protons in an atom of an element

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 carbon, then an element with

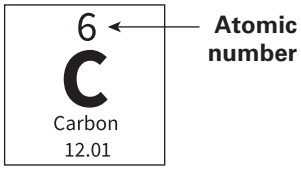


Figure 5.33 For the element carbon the atomic number is 6. You can therefore conclude that it has six protons.

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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.

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 5.34 Carbon, a black solid with an atomic number of 6



Figure 5.35 Liquid nitrogen, a colourless gas cooled down to –196°C to liquid state, with an atomic number of 7

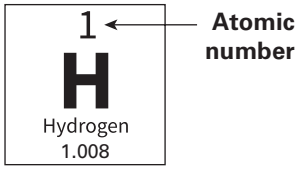


Figure 5.36 For the element hydrogen, the atomic number is 1, so you can conclude that it has one proton.

Quick check 5.7

Using an element of your choice as an example, explain what the atomic number tells you about the atom.

Number of electrons and formation of ions

The atomic number also gives you information on the number of electrons in an atom of an element. Recall that protons have a positive charge and electrons have a negative charge. An atom is neutral, meaning that it has an overall charge of zero. So, what does that mean about the numbers of protons and electrons? A neutral atom must have the same number of positive protons and negative electrons for the overall charge to equal zero (neutral). Carbon has an atomic number of 6, meaning it has six protons (six positively charged particles). Therefore, for the atom to have zero charge, it must have six electrons (six negatively charged particles). So, the atomic number also tells you how many electrons an atom contains.

Changing the number of electrons in an element will not change the type of element, unlike a change in proton number, but it will change the chemical properties of the element. If the number of electrons in the atom change, the atom is now referred to as an **ion** and is said to become charged. This is denoted by a superscripted plus (+) or minus (–) sign after the chemical symbol. A plus sign indicates the atom has become more positive (lost negatively charged electrons), whereas a minus sign indicates the atom has become more negative (gained negatively charged electrons). For example, Mg^{2+} denotes a magnesium atom that has lost two electrons and is now carrying an overall charge of +2. It has 12 protons in the nucleus, but as it has lost two electrons; it now only has 10 electrons.

ion
a charged version of an atom that has either gained or lost electrons

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Explore! 5.3

Charged particles

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.

1. When fluorine atoms become ions (negatively charged), they can combine with other elements, forming fluorides such as sodium fluoride. Research the properties of fluorine and compare them with the properties of sodium fluoride.
2. 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 column 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.
3. 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.
4. 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.
5. Predict what type of ion the following elements would form.
   a. Sulfur
   b. Barium
   c. Iodine

Practical 5.4: Investigation

Investigating which ions cause water hardness

Aim

To investigate the effect of different ions on water hardness.

Planning

1. Write a rationale about water hardness, what influences it and what problems hard water can cause.
2. Identify the independent and dependent variable for this experiment.
3. Identify as many controlled variables as possible and describe how these will be managed to prevent any from affecting the measurements.
4. Develop a hypothesis for this experiment.
5. Complete a risk assessment for this investigation, describing how any risks will be ontrolled.

Materials

- 8 test tubes
- 8 test-tube corks/bungs
- test-tube rack
- dropping pipettes
- 100 mL beaker
- marker pen

continued…

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…continued

- 50 mL soap solution in industrially denatured alcohol (IDA). This can be made by dissolving soap flakes (or shavings from a bar of soap) in IDA.
- 10 mL distilled or deionised water
- 10 mL sodium chloride, 0.1mol L^{-1}
- 10 mL calcium chloride, 0.1mol L^{-1}
- 10 mL magnesium chloride, 0.1mol L^{-1}
- 10 mL potassium nitrate, 0.1mol L^{-1}
- 10 mL sodium sulfate, 0.1mol L^{-1}
- 10 mL iron(II) sulfate, 0.1mol L^{-1}
- 10 mL magnesium sulfate, 0.1mol L^{-1}

Method

1. Set up eight labelled test tubes in a test-tube rack, each containing 1 centimetre (cm) depth of the distilled water or one of the seven different ion solutions.
2. Use a dropping pipette to transfer approximately 1 cm depth of soap solution to each test tube.
3. Seal the test tubes with a bung or cork and shake well.
4. Record which test tubes contain a lather (mass of bubbles) at the end of the shaking, and if a lather is present, the depth of it.

Results

Draw a results table that will allow the collection of sufficient and relevant raw data.

Discussion

1. Identify the ion/s that cause the most water hardness. Justify your answer with data.
2. Discuss the purpose of the distilled water test tube.
3. Identify any potential sources of error in this experiment.
4. Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

Draw a conclusion from this experiment regarding ions and water hardness. Justify your answer with data.

Quick check 5.8

1. Describe how an atom becomes positively or negatively charged.
2. Using your knowledge of the number of protons and electrons in an atom, explain why atoms become charged when the number of electrons is changed.

Mass number

The **mass number** of an atom is the sum of the protons and neutrons contained in the nucleus. The mass number is a whole number and is not found in the periodic table for any elements. It is not to be confused with the second number that is listed for every element in the periodic table, the relative atomic mass. Electrons are not considered when calculating the mass number because they have a much smaller mass than protons and neutrons, so small that it is considered negligible.

mass number
the sum of the protons and neutrons in the nucleus of an atom

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The second number listed for each element in the periodic table is called the relative atomic mass and it is seldom a whole number (see Figure 5.32). This is because every element consists of a mixture of atoms that have the same number of protons but different numbers of neutrons. Such atoms are called **isotopes** and will be discussed later in the chapter. The relative atomic mass shows the average mass of an element's atom when considering all natural isotope masses and their abundances.

Thus, for a single atom the mass number can be calculated by the following equation:

mass number = number of protons + number of neutrons.

For example, an atom of oxygen has an atomic number of 8 (8 protons) and a mass number of 16. Can we calculate the number of neutrons in this nucleus?

mass number (16) = number of protons (8) + number of neutrons (?)

This equation can be rearranged to solve for number of neutrons:

number of neutrons = mass number (16) – number of protons (8) = 8 neutrons

isotopes
atoms of the same element with the same number of protons but a different number of neutrons

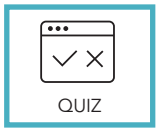
Unlike for protons, changing the number of neutrons in an element will not change the type of element, but it will change how it behaves.

Quick check 5.9

Locate the following elements on the periodic table. Using their atomic numbers and and number of neutrons provided, state the number of protons and electrons each atom contains.

	Atomic number	Atomic mass	Number of protons	Number of neutrons	Number of electrons
Nitrogen				7	
Sodium				12	
Sulfur				16	
Gold				118	

Section 5.4 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 named in question **1** is always the largest.
3 **State** the name of the element that has an atomic number of 20.

Understanding

4 An atom has a mass number of 45 and an atomic number of 16. **Calculate** how many neutrons it has. Show your working.
5 **Identify** the subatomic particles that have nearly the same mass.

Applying

6 **Explain** why the mass of the electron is not considered in the mass number.
7 **Summarise** the structure of the different atoms. You may do so in a table as shown.

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Name	Atomic number	Atomic mass	Number of protons	Number of neutrons	Number of electrons
Hydrogen-3 (tritium)	1	3			
Oxygen	8	16			
Potassium	19	39			
Aluminium	13	27			

Analysing

8 **Compare** the mass number and the atomic number of an element.

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 no two elements on the periodic table have the same atomic number.

11 **Evaluate** the statement: 'Atoms are always neutral.'

5.5 Isotopes

VIDEO
Too many neutrons!

Learning goals

1 To be able to define the term 'isotope'.
2 To be able to describe three types of nuclear radiation.
3 To be able to compare the ionising and penetrating power of alpha, beta and gamma radiation.

WORKSHEET

Earlier in this chapter, you learned how changing the number of protons in an atom results in a different element identity. 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 Frederick Soddy in 1913. In his early career, Soddy worked closely with Ernest Rutherford in Canada, but it was his 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 in the same way. He named these elements isotopes, which means 'same place', as they were in the same place on the periodic table. Scientists could not explain why this occurred until James Chadwick discovered the neutron.



Figure 5.37 Frederick Soddy discovered isotopes in 1913 in his work on uranium.

Let's take a look at an example. Carbon exists naturally in three forms (see Figure 5.38). All three of these forms are the element carbon as they all have an atomic number of 6 (6 protons).

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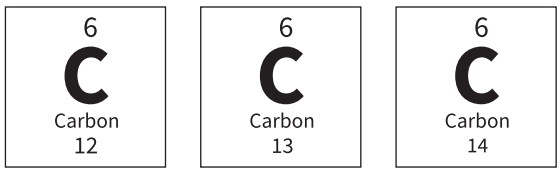


Figure 5.38 The three naturally occurring isotopes of carbon

Notice that the three forms of carbon have different mass numbers. This difference in mass number is because they have different numbers of neutrons. Remember that the number of neutrons in an atom is calculated by taking away the atomic number from the mass number. Therefore, the first form of carbon has six neutrons, the second has seven and the third has eight. As they have different numbers of neutrons but the same atomic number, they are called isotopes of carbon.

Naming isotopes

Isotopes 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, often a nuclide notation is used, wherby the mass number is written on the top left-hand side of the element symbol and the atomic number on the bottom left-hand side of the element symbol (see Figure 5.39). Another way of representing an isotope is to write the name of the element followed by the mass number. For example, the three isotopes of hydrogen are hydrogen-1 (H-1), also known as protium, hydrogen-2 (H-2), known as deuterium, and hydrogen-3 (H-3), known as tritium.

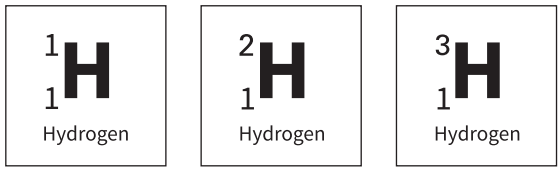


Figure 5.39 The three naturally occurring isotopes of hydrogen in nuclide notation

Explore! 5.4

Unusual mass numbers

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. Conduct some research as to why this is the case.

1. Why is the mass number of chlorine recorded as 35.5 on the periodic table?
2. Chlorine has two naturally occuring stable isotopes, Cl-35 and Cl-37. What is the difference between Cl-35 and Cl-37?
3. Which isotope of chlorine do you think is the most abundant form in nature?

Quick check 5.10

1. Define the term 'isotope'.
2. How would you name an isotope of magnesium that has a mass number of 25?

Stable and unstable isotopes

The stability of an isotope is based on whether it is likely to break down or decay into other elements. Often, heavy isotopes (that is, which have many more neutrons than protons) are unstable compared to lighter isotopes (which have similar numbers of neutrons and protons), which are stable. Unstable isotopes, such as the isotopes of the element uranium, are often called radioisotopes. In these types of isotopes **radioactive decay** occurs to achieve a stable nucleus (as discussed later in this section). On the other hand, stable isotopes are not radioactive, or radioactive to a much lesser extent, as their nucleus is stable and therefore not prone to radioactive decay. Elements can have more than one stable isotope, such as carbon-12 and carbon-13. Table 5.3 summarises the differences between stable and unstable isotopes.

radioactive decay when an unstable nucleus emits radiation (alpha and beta particles or gamma rays) 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

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Did you know? 5.4

Mass numbers in brackets

Look at francium (Fr) on the bottom left of the periodic table. On some periodic tables a relative atomic mass is not provided, while on others it has parentheses around its relative atomic mass (223). Elements written like this are radioactive, so they are very unstable. Most of their isotopes decay into other elements relatively quickly. If the relative atomic mass is not provided, it is because a stable isotope does not exist for an appreciable amount of time, or if the relative atomic mass is in parentheses, it represents the most stable isotope of that element – the one that exists the longest.

Can you find other radioactive elements on the periodic table?

Quick check 5.11

Recall the characteristics of unstable isotopes.

Radioactive decay



WIDGET
Nuclear equations

Emissions from radioactive decay are commonly 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. When the atomic number changes, a new element is formed. In this case, the new element has two fewer protons. The nuclear equation in Figure 5.40 shows what happens when an atom of uranium undergoes alpha decay.

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + \underbrace{{}^{4}_{2}\mathrm{He}}_{\text{alpha particle}}$$

Figure 5.40 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. The emitted He-4 is often described as an alpha particle.

beta particle
a charged particle (electron) that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom

Beta decay

Beta particles are simply fast-moving electrons emitted from the nucleus. During beta decay, a neutron is transmuted into a proton and an electron. Consequently, the atomic number will increase by one, which changes the identity of the element altogether. The mass number of the remaining atom will not be affected as it has lost a neutron but gained a proton. The equation in Figure 5.41 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.

$$^{42}_{19}\mathrm{K} \rightarrow {}^{42}_{20}\mathrm{Ca} + \underbrace{{}^{0}_{-1}\mathrm{e}}_{\text{beta particle}}$$

Figure 5.41 When a potassium-42 nucleus undergoes beta decay, it becomes a calcium-42 atom and emits a beta particle.

Gamma decay

Gamma decay is different from alpha and beta decay in that the atom undergoing gamma decay is not changed; that is, the mass and atomic numbers are not altered. This is because gamma decay involves the emission of a high-energy wave (gamma ray) from the atom's nucleus rather than a particle. The equation in Figure 5.42 shows gamma decay of radioactive barium.

$$^{137}_{56}\mathrm{Ba}^{*} \rightarrow {}^{137}_{56}\mathrm{Ba} + \underbrace{{}^{0}_{0}\gamma}_{\text{gamma ray}}$$

Figure 5.42 When radioactive barium decays, a gamma ray is emitted. The asterisk indicates that barium is initially in an excited and therefore unstable state.

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Electromagnetic radiation

As previously discussed, a **gamma ray** (sometimes called a photon) is a high-energy wave and unlike the emissions from alpha and beta decay. You might be surprised to learn that this emission is a form of electromagnetic radiation with properties similar to light!

The full range of the different forms of electromagnetic radiation is called the **electromagnetic spectrum**. The light you see in your daily life is called visible light and is only a small part of the whole spectrum. All the other types of radiation, such as gamma radiation, you cannot see.

The discovery and manipulation of electromagnetic radiation has led to enormous benefits throughout society. The transmission of microwaves is essential for 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 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 not visible to the human eye. Electromagnetic radiation is also incredibly important in 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.

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

electromagnetic spectrum
the range of all possible forms that electromagnetic radiation can take, plotted out in terms of lowest to highest frequency

Explore! 5.5

Marie Curie

Marie Curie was an exceptional scientist, and is the only person to date to have been awarded two Nobel Prizes in different scientific fields: Physics in 1903 (with her husband, Pierre Curie, and Henri Becquerel) and Chemistry in 1911. Research the work of Marie and Pierre Curie that led to their scientific discoveries in radiation.



Figure 5.43 Marie Curie

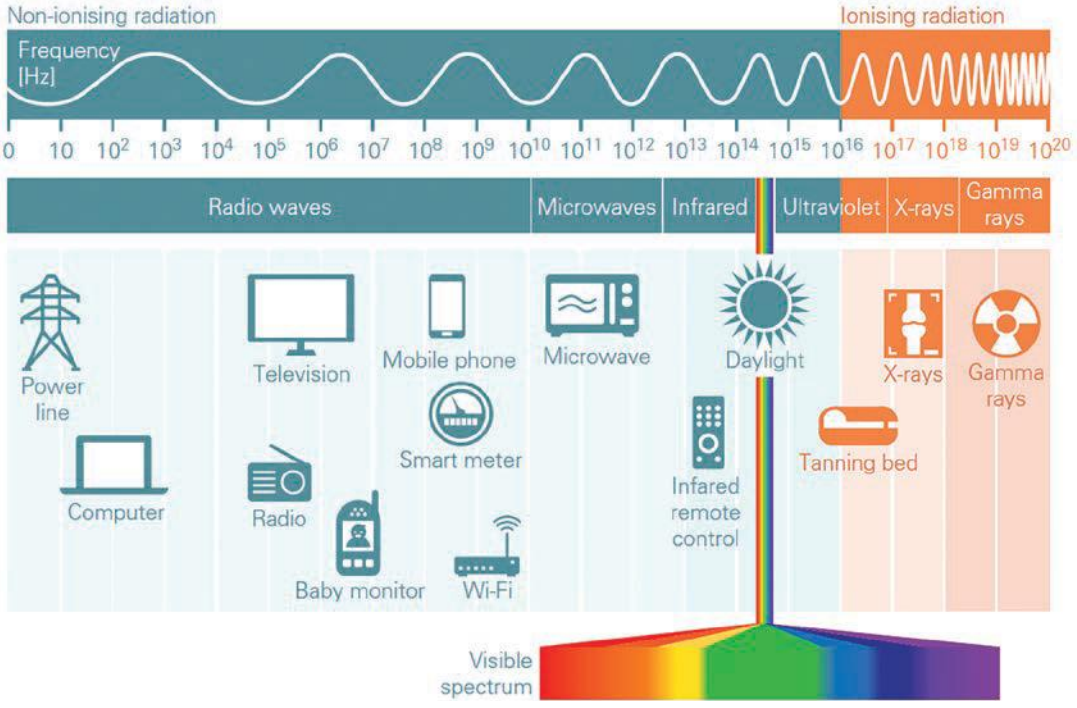


Figure 5.44 The electromagnetic spectrum and its application

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Ionising and penetrating powers

How dangerous a type of radiation is depends on its ability to penetrate materials and how much damage it can do (how ionising it is). Table 5.4 and Figure 5.45 summarise the properties of the three types of radiation.

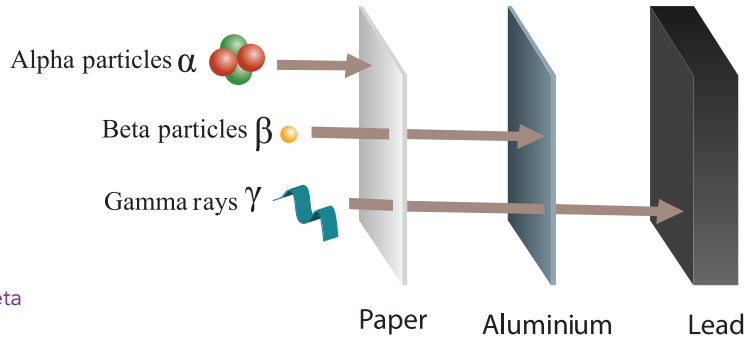


Figure 5.45 The penetrating powers of alpha, beta and gamma radiation

Type of radiation	Penetrating power	Ionisation power
Alpha	Least penetrating. It can be stopped by a sheet of paper.	Very strongly ionising; can cause the most damage, especially if they are inside the body
Beta	It can penetrate paper but is stopped by a thin aluminium sheet.	Not as ionising as alpha particles but more than gamma rays
Gamma	The most penetrating. It can only be stopped by thick pieces of lead or concrete.	Not very ionising so causes the least damage; can penetrate the body, and high-energy gamma rays are used to kill cancer cells

Table 5.4 Properties of the three different types of radiation

Quick check 5.12

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 radiation in the electromagnetic spectrum.

VIDEO
Uses of isotopes

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.

A 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 archeological artefacts; and nitrogen-14 (N-14), which is used in detecting explosives.

Figure 5.46 A patient undergoing radiotherapy for cancer



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Science as a human endeavour 5.3

Radiocarbon dating rock art

Carbon-14 is an isotope of carbon that primarily decays via beta radiation to nitrogen-14 on a consistent time scale. Scientists are able to predict the age of a fossil by examining the relative amounts of carbon-14 and carbon-12 (which does not decay) in an organic fossil, in a technique known as radiocarbon dating. Carbon dating techniques are continuously improving, allowing for more accurate dating.



Figure 5.47 An example of rock art from Quinkan country

In early 2020, a team of researchers from across Australia collaborated on dating Indigenous Australian rock art in the Kimberley region of Western Australia. Often, dating Indigenous rock art can be challenging as much of the carbon in the organic ochre has degraded. However, the team of researchers instead radiocarbon-dated overlying and underlying wasp nests to provide an age range for the paintings. It was estimated that this rock art could be as much as 12 000 years old!

Practical 5.5: Self-design and teacher demonstration

Investigating the penetration of alpha, beta and gamma radiation

You have been provided with the following materials. Suggest an experiment that could be done using this equipment to show the penetrating properties of alpha, beta and gamma radiation. You may wish to draw a diagram or write a method to demonstrate that you have done this task.

Aim

To investigate the penetrative strengths of ionising radiation.

Materials

- alpha radiation source
- beta radiation source
- gamma radiation source
- Geiger–Müller tube (detects radiation)
- absorbing materials: sheet of paper, aluminium sheet, lead sheet

Method

Your teacher will demonstrate the experiment. Due to the dangerous radiation that is emitted, this experiment can only be performed by a teacher and under strictly controlled conditions.

continued…

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…continued

Results

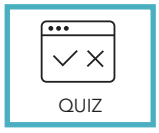
Copy and complete the table below.

Radiation	Material that stops most of the radiation from passing through	Penetrating power
Alpha		
Beta		
Gamma		

Discussion

1 Identify the most penetrating radiation and justify your choice.
2 Propose which type of radiation you think could cause the most damage if it gets into our bodies.
3 Research the effects that radiation can have on the body to explain why it is so damaging.
4 Discuss how the experiment could be modified to show the effectiveness of the radiation over different ranges and thickness of absorbing materials.

Section 5.5 questions



Remembering

1 **Determine** the name of an isotope of barium with a mass number of 130.
2 **Determine** the name of an isotope of potassium with 22 neutrons.

Understanding

3 **Name** three important uses of radioisotopes.
4 **Define** the electromagnetic spectrum.

Applying

5 **Describe** the relationship between the mass of an isotope and its stability.
6 **Summarise** what happens to the nucleus of an element during alpha decay.

Analysing

7 **Contrast** stable isotopes and radioisotopes.
8 **Compare** these isotopes of sodium: Na-23 and Na-24.

Evaluating

9 **Construct** an equation to show the alpha decay of uranium-235 to thorium-231.
10 An element undergoes radioactive decay, but its atomic number and mass number are not affected. **Deduce** the type of decay.
11 During the radioactive decay of an isotope a high-energy electron is released. **Deduce** the type of decay.

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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria		Linked question	Check
5.1	I can distinguish between atoms, elements, compounds and molecules.	14	
5.2	I can discuss how the model of the atomic structure was developed.	7	
5.3	I can distinguish between protons, neutrons and electrons.	15	
5.4	I can determine the subatomic particles found in an atom using information from the periodic table.	10	
5.5	I can describe how isotopes of an element differ from each other.	13	
5.5	I can discuss the different forms of radioactive decay.	17	

Review questions

SCORCHER

Remembering

1 **State** the names of the three subatomic particles within the atom.
2 **Recall** the charge of each subatomic particle.
   a Proton
   b Neutron
   c Electron
3 **Define** the term 'isotope'.
4 **State** where the protons and neutrons are located within the atom.
5 If a neutral atom has 18 protons, **state** how many electrons it has.
6 **Recall** the type of particle that is released during beta decay.

Understanding

7 **Describe** the planetary model of the atom.
8 **Explain** why atoms of elements have a neutral overall charge.
9 **Explain** how Rutherford's gold foil experiment led to the discovery of the nucleus.

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Applying

10 **Summarise** the three main isotopes of neon. You may do so in a table as shown.

Isotope	Mass number	Number of protons	Number of neutrons	Number of electrons
$^{20}_{10}Ne$				
$^{21}_{10}Ne$				
$^{22}_{10}Ne$				

11 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).

12 **Explain** why the neutron was difficult to discover.

13 **Describe** the differences between isotopes of the same element.

Analysing

14 **Contrast** an element and a compound.

15 **Compare** the properties of the subatomic particles in terms of their mass and charge.

Evaluating

16 **Deduce** the relationship between the mass of an element and how stable it is.

17 Ionising radiation is used in smoke detectors. **Decide** which type of radiation you would choose for this use and why.

18 **Propose** why radioactive sources in schools must be stored in lead-lined boxes.

19 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.

20 **Determine** the correct numbers in the equation below to show the particle released during alpha decay.

$$^{226}_{88}Ra \rightarrow {}^{222}_{\square}Rn + {}^{\square}_{2}\square$$

21 **Propose** why the atomic model has changed and why it may continue to do so.

22 'The current atomic model is perfect and accurate.' **Evaluate** the accuracy of this statement.

23 **Discuss** whether 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.

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Data questions

The isotope carbon-14 decays via beta radiation to form nitrogen-14 atoms, following the decay curve presented in Figure 5.48. Scientists are able to predict the age of a fossil using analytical techniques that measure the relative abundances of carbon-14 and nitrogen-14 in the fossil using the decay curves.

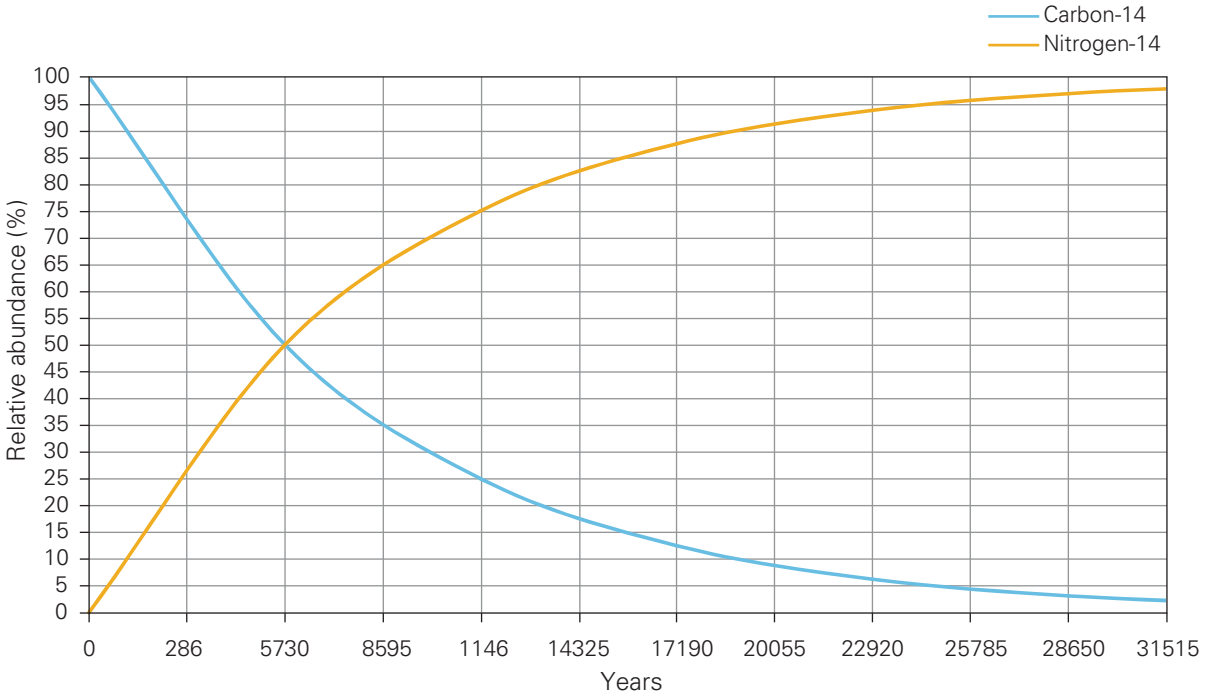


Figure 5.48 Relative abundance of carbon-14 (blue line) and nitrogen-14 (orange line) in an initial sample of carbon-14 over 31 515 years.

1. A scientist has measured the relative abundance of carbon-14 in a sample of ancient kangaroo fossil at 25% compared to nitrogen-14. **Determine** the age of the fossil.
2. The relative abundance of nitrogen-14 in a kangaroo fossil sample is 40%. **Calculate** the relative abundance of carbon-14.
3. **Identify** the relative abundance of nitrogen-14 in a fossil dated at 8595 years old.
4. **Contrast** the two curves and comment on the relative rate of decay of carbon-14 and growth of nitrogen-14.
5. **Deduce** the half-life (time taken for half of the carbon-14 to decay to nitrogen-14) of carbon-14.
6. After 28 650 years, the relative abundance of carbon-14 is 3.125%. **Predict** the relative abundance of nitrogen-14 after another 5730 years (34 380 years total).
7. **Predict** and explain whether it would be possible to find a fossil with a relative abundance of carbon-14 of 0%.
8. The use of radiocarbon dating is most efficient with fossils less than 20 000 years old. **Compare** the carbon-14 decay curve before and after 20 000 years and elaborate on this comment.

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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.

H H H H H H H H

C C C C C C C C

H H H H H H H H

Figure 5.49 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. First, most plastic is made from crude oil, a limited resource that is harmful to the environment to extract. Second, because of its 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.

bioplastic
a type of plastic made from renewable resources like plants



Figure 5.50 Plastic litter builds up on our beaches.



Figure 5.51 An oil refinery

Bioplastics are a type of plastic made from renewable resources like plants. They can easily be made at home with readily available ingredients. While they cannot solve the plastic problem alone, they can reduce carbon dioxide emissions, and some have the potential to biodegrade more easily than traditional plastics.

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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.

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.

Suggested materials

- corn starch
- vinegar
- glycerine
- water
- food dye (optional)
- saucepan
- wooden spoon
- hotplate
- non-stick/baking paper/aluminium foil and tray
- cookie cutters or moulds to shape the plastic
- safety glasses

Research and feasibility

1 Discuss in your group different plastic products you use in your everyday life, and list all the benefits to manufacturing these products as a bioplastic.

2 List all the restrictions you have to consider in your design based on the materials and space you have available.

3 Research how you would use the suggested materials, or other materials safe for use in a school science laboratory, to manufacture the bioplastic.

Design and sustainability

4 Decide on a plastic product that you could make using a bioplastic, justify your choice as a group by considering your constraints.

5 Design the method for manufacturing the bioplastic.

6 Design the mould you will use for making your product.

Create

7 Create the mould you will use for your bioplastic product.

8 Follow your design method and construct your bioplastic product solution. Remember it may take a week for your bioplastic to be set.

Evaluate and modify

9 Describe any difficulties you encounter when creating your product out of the bioplastic.

10 Suggest ways that the design of your product could be improved.

11 List the physical properties of your bioplastic and comment on how appropriate these properties were for your product.

12 Test your product by using it for its intended purpose under different conditions.

13 Evaluate the effectiveness of your product.

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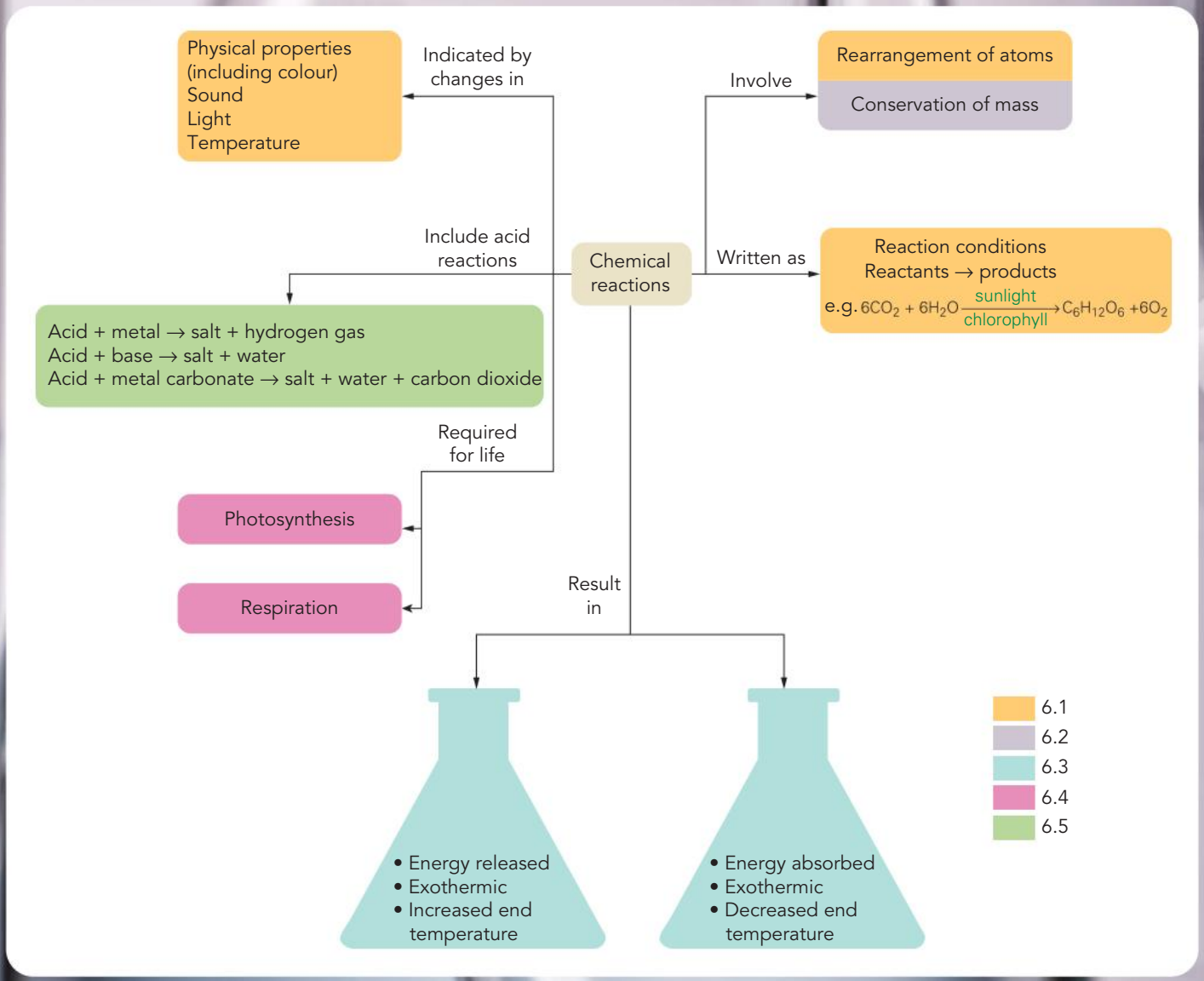
Chapter 6
Chemical reactions

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 explore what forms when acids react with bases, metals and carbonates.

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Chapter map



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6.1 Introduction to chemical reactions

WORKSHEET

Learning goals

1 To be able to recall the evidence of chemical change.
2 To be able to label reactants and products in a chemical equation.

By now in your science lessons you will have carried out a number of **chemical reactions** 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, are all 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?

chemical reaction
a process in which the structure of atoms or compounds that make up a substance are changed

rearrange
move things into a different order

The simplest way to describe a chemical reaction is that starting substances are converted into new substances, although there is more to it than just that. During chemical reactions, the atoms in the starting substances are **rearranged** to make new substances. For this to happen, bonds holding the atoms together in the starting substances must be broken and new bonds must form in different arrangements to make the new substances.

Figure 6.2 shows a chemical reaction in which compound AB is reacting with element C to make a new compound, BC, and element A.

In this reaction, the bond between A and B in the compound AB is broken and a new bond is formed between B and C to form compound BC – the atoms have been rearranged. The new substances are different from the starting substances; therefore, a chemical reaction has taken place. The arrow in a chemical reaction separates the starting substances that react together from the new substances produced by the reaction. The arrow indicates that a chemical reaction is occurring and is normally said aloud as 'yields'. A chemical equation does not have an equals sign.



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.

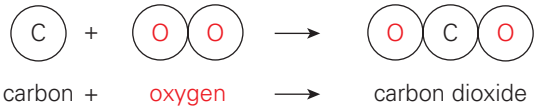


Figure 6.3 Formation of carbon dioxide is a chemical reaction.

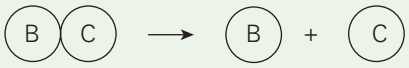
The rearrangement of the atoms has a notable effect on the properties of the substances in this chemical reaction. Carbon is a solid at room temperature and oxygen is a gas. The compound formed in this reaction, carbon dioxide, is a

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gas at room temperature. The arrangement of the atoms within a compound may influence properties of a substance, which is evidenced by the different properties of the compound formed in Figure 6.3 from the starting substances.

Quick check 6.1

1 Explain how new substances are formed during a chemical reaction.
2 Describe what is happening to the substances in the equation below.



Science as a human endeavour 6.1

Living concrete that can repair itself

Concrete was first used in ancient times and is the one of the world's most popular building materials. However, the problem with concrete is that over time it weakens, causing cracks to form. Water can enter these cracks, leading to the collapse of buildings or walls.

Henk Jonkers, of Delft University in the Netherlands, discovered a solution to this problem: concrete that contains bacteria and can repair itself. The bacteria selected for this process must be able to survive dormant for long periods of time without food or oxygen and to withstand the alkaline conditions within the concrete.

Bacillus pseudofirmus and Sporosarcina pasteurii bacteria were chosen for the job, but these bacteria do not naturally produce the limestone needed to repair the concrete. Jonkers first used sugar to help the bacteria create limestone, but this made the concrete too weak. The solution was to use calcium lactate.



Figure 6.4 The ageing and cracked concrete walls of Naples Island, California, are in danger of collapse, which could flood the homes located along the canals.

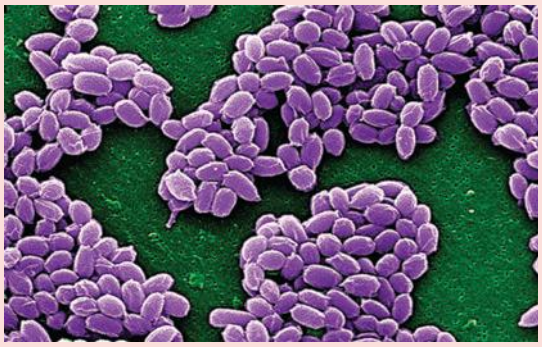


Figure 6.5 *Bacillus* bacteria under a microscope

In 2009, Jonkers manufactured capsules made of biodegradable plastic containing calcium lactate and the bacteria. The capsules open when in contact with water; that is, when there is a crack in the concrete. The bacteria feed on the lactate which causes a chemical reaction converting the lactate into limestone, and the crack closes. Jonkers had made concrete that repairs itself!

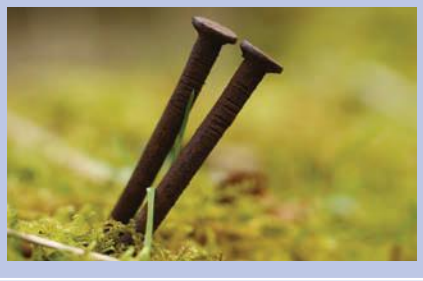
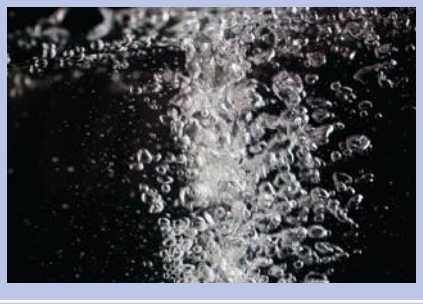
VIDEO
Indicators of a chemical reaction

Evidence of a chemical change

The difference in properties between the starting reactant chemical species and new product is one piece of evidence that a chemical reaction has occurred, but there are other distinctive ways in which this can be observed. In Year 8 you learned about the differences between a physical and a **chemical change**. Table 6.1 lists some observable evidence of a chemical reaction.

chemical change
a rearrangement of atoms

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Evidence	Example
Sound produced	Hydrogen and oxygen reacting together to make water creates a loud bang. 
Change in colour	A silver-coloured iron nail reacting with oxygen and water forms red rust (iron oxide). 
Bubbles observed (gas evolved)	Sodium (a soft metal) reacting with water (a colourless liquid) produces sodium hydroxide (a colourless solution) and hydrogen gas which is observed as rapid bubbling, also referred to as **effervescence**. 
Light produced	Snapping a glow stick starts a chemical reaction that produces light. 
Change in temperature	Magnesium metal reacting with an acid releases heat. 

effervescence bubbles or fizzing in a solution

Table 6.1 Common evidence of a chemical reaction

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A chemical change involves the reaction of chemical species to form new chemical species while a physical change has only a change of size, state or shape but no change in chemical composition. Both chemical and physical changes are reversible; however, some chemical changes are often referred to as 'irreversible' as they require large amounts of energy to convert new substances back to their original substances. Physical state changes such as the boiling and freezing of water are generally easily reversible.

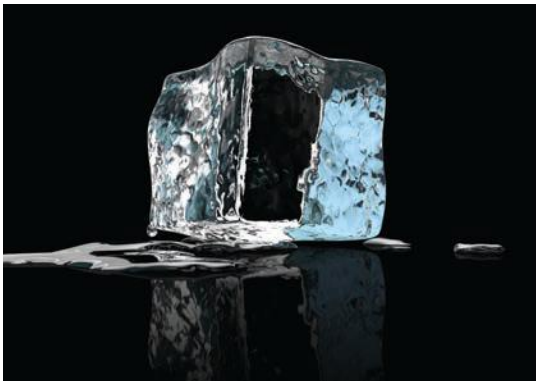


Figure 6.6 Ice melting and forming liquid water is an example of a physical change.

Quick check 6.2

1 Recall examples of a chemical change.
2 Identify if the following statement is true or false: 'All chemical changes are irreversible.'
3 When a pan of water is heated on a cooktop, 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?

How is a chemical equation written?

Reactants and products

In a chemical reaction, substances will react with each other to form new substances. As these are the substances doing the reacting, they are called **reactants**. Reactants are always written on the left-hand side of a chemical equation (written before the arrow). The new substances that are formed are called **products**. Products are always written on the right-hand side of an equation (written after the arrow). Figure 6.7 shows the reaction between magnesium and hydrochloric acid written in the form of a word equation.

Magnesium and hydrochloric acid are reactants and they are written 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.

reactant
substance that undergoes change in a chemical reaction

product
substance formed in a chemical reaction

magnesium + hydrochloric acid → magnesium chloride + hydrogen

reactants products

Figure 6.7 Chemical reaction between magnesium and hydrochloric acid

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Reaction conditions

reaction conditions
factors required for a chemical reaction to proceed

Not all chemical reactions happen immediately; that is, occur 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. These factors are called **reaction conditions**. When special reaction conditions are required, they are written above or below the arrow in a chemical equation. This shows that these conditions are required for the reaction but do not get directly involved in the reaction.



$$\text{nitrogen} + \text{hydrogen} \xrightarrow[\text{450–500°C, 150–200 atmospheres (pressure)}]{\text{iron catalyst}} \text{ammonia}$$

Figure 6.8 Nitrogen for fertilisers is produced using the Haber process, which converts atmospheric nitrogen and hydrogen to ammonia in the presence of a catalyst and high temperature and pressure.

Quick check 6.3

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?

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Explore! 6.1

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 your search engine of choice to research the following questions.

1 What is the Maillard reaction and how does it work?
2 What reaction conditions are required for the reaction?
3 Other than searing and browning meat, what is this reaction used for?

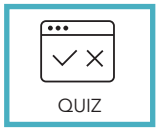


Figure 6.9 Searing or browning of steak is an example of the Maillard reaction.

Types of chemical equations

Chemical equations can be presented in different ways. Word equations show the reactants and products using their names, while symbol equations use symbols from the periodic table to represent atoms. Regardless of the type of chemical equation, they always have the same structure: an arrow separating the reactants on the left and the products on the right. They only differ in the way the reactants and products are represented. You will learn more about this next year.

Section 6.1 questions



Remembering

1 **State** what → means in a chemical reaction.
2 **Name** the reactants in the following reactions.
   a sodium hydroxide + iron carbonate → iron hydroxide + sodium carbonate
   b propane + oxygen → carbon dioxide + water
   c hydrogen + oxygen → water
   d calcium carbonate → calcium oxide + carbon dioxide
3 **Name** the products of each of the reactions in question **2**.
4 **Select** the correct definition for each keyword in the table below and rewrite them.

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.

Applying

6 **Compare** physical and chemical changes.
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.

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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 and rewrite the equation correctly.

carbon dioxide and water = glucose + oxygen

6.2 Conservation of mass

DOC WORKSHEET

conservation of mass a law that states that matter can neither be created nor destroyed in chemical reactions

VIDEO Law of conservation

Learning goal

1 To be able to define the law of conservation of mass.

One of the fundamental laws of chemistry is the law of **conservation of mass**. This law states that matter can neither be created nor destroyed in chemical reactions.

Historical understanding

In the eighteenth century, scientists thought that for something to burn it had to contain the element called phlogiston (from the Greek

Explore! 6.2

Mass and the universe

If the law of conservation of mass states that matter and energy can neither be created nor destroyed, how did the matter that is present now get here?

'We are made of star-stuff' is a famous statement by Carl Sagan, an American astronomer (although others had used the term 'star-stuff' before him). Use the internet to investigate how true the statement is and answer the following questions.

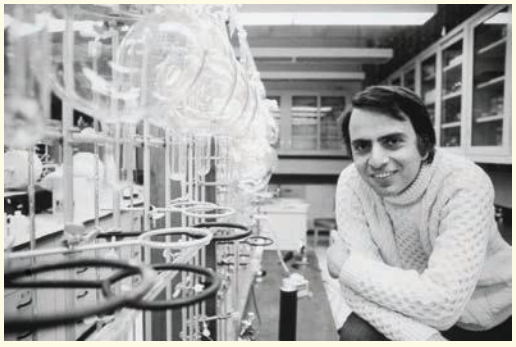


Figure 6.10 Carl Sagan said that 'we are made of star-stuff'.

1 What happened at the start of the universe and how did this cause matter to form?
2 How were elements heavier than hydrogen formed at the start of the universe?
3 When heavier elements are formed in this way, a large amount of energy is released. This does not seem to support the law of conservation of mass. How does Einstein's equation (Energy = mass × speed of light^2 or $E = mc^2$) explain this?
4 How were heavier elements in the universe (for example, iron) made?
5 Look up the composition of the human body on the internet. What are the six elements that make up nearly all of a human body? Among those, which one was not created by stars?

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Figure 6.11 Antoine Lavoisier proposed the law of conservation of mass.

phlox, which means flame). Scientists noticed that when something burns, the mass decreases, which led them to believe that burning releases phlogiston. 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 was the same as the mass of the substances at the start. In 1789 he called this Lavoisier's law – it was later renamed the law of conservation of mass.

Putting the law of conservation of mass into practice

The law of conservation of mass means that matter and energy can 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.



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.

However, as this is not a closed environment, there might be a difference between the two masses, 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 due to evaporation if it is left for long enough. The glass of water will now have a smaller mass. The water heats up, forming water vapour, which leaves the glass and goes into the air. The water vapour has left the glass, which is why the mass of the glass decreases, but it is still present in the air somewhere. This example demonstrates why it is important to observe the conservation of mass in a closed system (one in which matter cannot escape). In an open system, chemical reactions that produce gases will appear to lose mass.



Figure 6.13 Leave a glass of water outside on a hot day and it will appear to lose mass.

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Quick check 6.4

1 Who discovered the law of conservation of mass?
2 What is the definition of the law of conservation of mass?
3 If the mass of reactants is 30 g, what will the mass of products be?
4 Discuss why it is difficult to observe the law of conservation of mass in an open system.
5 Explain why the mass of a glass of water left out on a hot day decreases.

How does the law of conservation of mass relate to chemical equations?

As a scientist, you need to factor in the law of conservation of mass when you write chemical equations. Consider the reaction in Figure 6.14. Here copper chloride ($CuCl_2$) is being broken down into its elements: copper (Cu) and chlorine (Cl_2).

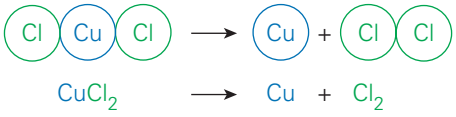


Figure 6.14 A structural representation and chemical equation showing the decomposition of copper chloride into its elements

For this reaction to obey the law of conservation of mass, there must be the same number of atoms of each element in the reactant and the products. In the reactant, there is one atom of copper and two atoms of chlorine. In the products, there is one atom of copper and two atoms of chlorine. Therefore, there is the same number of atoms on each side of the equation and therefore the same mass. The only difference is how the atoms are arranged.

Figure 6.15 shows depicts the chemical equation for the reaction between magnesium (Mg) and oxygen (O_2) to form magnesium oxide (MgO).

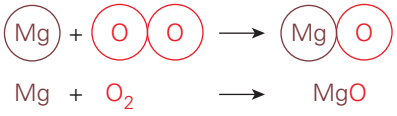


Figure 6.15 The reaction between magnesium and oxygen forms magnesium oxide.

What do you notice about the number of each type of atom in the reactants compared to the product? The number of each type of atom in the reactants and the product is different. This means that the equation in Figure 6.15 is not obeying the law of conservation of mass. There is one magnesium atom on each side of the arrow, but the left-hand side of the equation has two oxygen atoms while the right-hand side has only one. This shows the product as having less mass than the reactants, which simply does not happen. Therefore the chemical equation must be altered to show that the law of conservation of mass is observed.

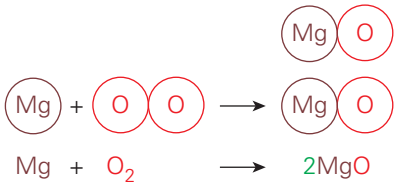


Figure 6.16 This equation now has the correct number of oxygen atoms, but it is still not observing the law of conservation of mass.

Figure 6.16 shows the equation adjusted so that it has two oxygen molecules on the right-hand side. This was done by adding another unit of magnesium oxide to the products. Notice that the chemical equation also now shows two magnesium oxide units in the products. However, adding the extra magnesium oxide unit to balance the oxygen atoms has also added another magnesium atom. The magnesium atoms are now unbalanced, with one on the left-hand side and two on the right-hand side of the equation. Adding one more magnesium atom to the left-hand side (reactants) will balance the equation

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(see Figure 6.17). Each side of the equation now has two magnesium atoms and two oxygen atoms. Again, notice that the chemical equation also reflects the addition of another magnesium atom. The addition of numbers to balance a chemical equation are called **coefficients**.

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.

coefficient
the number placed in front of a chemical symbol to balance a chemical equation

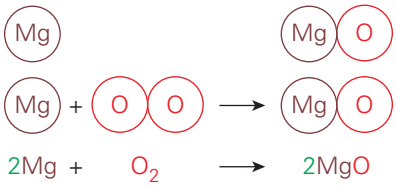


Figure 6.17 The correct balanced equation which has the same number of each atom in the reactants and products and therefore observes the law of conservation of mass

Quick check 6.5

1 Explain why it is necessary to balance equations.
2 Two students were doing an experiment in the laboratory. They measured the mass of reactants as 50 grams (g). After the reaction had completed, the mass of the products was 34 g. They noticed that a gas was given off during the reaction so they wanted to find out the mass of this gas. Determine the mass of the gas that escaped using the law of conservation of mass.

Practical 6.1

Observing the law of conservation of mass (1)

Be careful
Do not stare directly at combusting magnesium.

Aim
To observe the law of conservation of mass by reacting magnesium and oxygen.

Materials
- small piece of magnesium ribbon
- tongs
- crucible
- safety glasses
- matches
- Bunsen burner
- clay triangle
- tripod
- heatproof mat

Method
1 Copy the results table in the Results section.
2 Set up a Bunsen burner on a heatproof mat. Place the clay triangle on top of the tripod.
3 Weigh the crucible with its lid.
4 Place a piece of magnesium ribbon in the crucible and weigh it again with the lid on.
5 The mass of magnesium can be calculated by subtracting the mass of the empty crucible.
6 Heat the crucible using the Bunsen burner on the blue flame, carefully lifting the lid using the tongs to allow sufficient air into the crucible.
7 Continue heating until the magnesium has fully reacted.
8 When the crucible has cooled sufficiently, weigh it and its contents again. Calculate the mass of the new compound by subtracting the mass of the empty crucible.

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…continued

Results

Item	Mass (g)
Crucible + lid	
Crucible + lid + magnesium before heating	
Crucible + lid + compound after heating	
Magnesium	
Compound	

Discussion

1 Describe your observations when the magnesium reacted in the crucible. How did you know that a chemical change had occurred?
2 Oxygen is O_2. Write a balanced symbol equation for this reaction.
3 State if your results demonstrate the law of conservation of mass.
4 Explain why this reaction is a difficult example for showing the law of conservation of mass.
5 Propose how you could have made it easier to demonstrate the law of conservation of mass.
6 Identify any potential sources of error in this experiment.
7 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Practical 6.2

Observing the law of conservation of mass (2)

Aim

To observe the law of conservation of mass by reacting vinegar and baking soda.

Materials

- 10 millilitres (mL) of vinegar (acetic acid)
- 5 g of baking soda
- balance
- small measuring cylinder
- small conical flask
- resealable plastic bag (big enough to fit in the two cups, and with enough space for you to manipulate them)

Method

1 Copy the results table in the Results section.
2 Pour 10 mL of vinegar into the measuring cylinder.
3 Weigh out 5 g of baking soda into the conical flask.
4 Put the measuring cylinder and conical flask into the plastic bag. DO NOT spill any of the contents of the measuring cylinder or flask.
5 Measure the mass of the measuring cylinder, flask and plastic bag using the balance. Record this in your results table.
6 Seal the plastic bag again, being careful not to spill any of the contents.
7 Without opening the bag, pour the vinegar into the flask containing baking soda.
8 When you think the chemical reaction has finished, record the mass of the contents without opening the bag. Record this in your results table.

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9 Calculate the change in mass using the initial mass and final mass results. Record these in your results table.

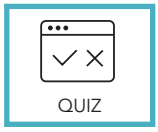
Results

Initial mass (g)	Final mass (g)	Change in mass (g)

Discussion

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 hydrogen carbonate), 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.

Section 6.2 questions



Remembering

1 **Recall** the law of conservation of mass.

Understanding

2 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. **Explain** to the students how they could calculate the mass of the second reactant.
3 **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

Applying

4 Emma carried out an experiment by reacting different amounts of magnesium with oxygen. Her measurements 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

Analysing

5 **Analyse** the following chemical equations and state which ones are properly balanced.
- A $C + O_2 \rightarrow CO_2$
- B $CaCO_3 \rightarrow CaO + CO_2$
- C $H_2 + O_2 \rightarrow H_2O$
- D $Na + Cl_2 \rightarrow NaCl$
- E $Ba + O_2 \rightarrow BaO$

6 **Distinguish** between an open and a closed system.

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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 permanently 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 **Develop** an experiment to prove who was correct.

6.3 Energy and chemical reactions

WORKSHEET

Learning goals

1 To be able to distinguish between exothermic and endothermic reactions.

2 To sketch an energy profile diagram for exothermic and endothermic reactions.

3 To recall the general chemical equation for combustion of hydrocarbons.

In many chemical reactions, the energy absorbed or released can affect whether the reaction is considered useful or efficient.

Exothermic and endothermic reactions

Because you cannot see atoms and molecules in a chemical reaction, it can be easy to think of them as stationary. However, molecules and atoms are constantly moving, which means they have **kinetic energy**. There is also chemical **potential energy** stored within the chemical bonds between atoms in molecules and compounds. Scientists refer to this internal energy as **enthalpy**. Enthalpy is also known as heat. When the atoms rearrange in a chemical reaction, the chemical potential energy stored in the bonds also changes. Sometimes energy from the reaction is lost into the surroundings, while sometimes the reaction requires energy from the surroundings. These changes in energy will be observed as a temperature change in the reaction surroundings, which can be measured during an experiment.

kinetic energy
the energy of moving matter

potential energy
(chemical) the energy stored in the chemical bonds of a substance

enthalpy
internal energy of a system

exothermic
heat is released from a reaction characterised by an increase in surrounding temperature

Reactions that release energy, like the burning of wood on a campfire, are described as **exothermic** reactions.

In science, it is useful to understand where words come from, so let us split up the word *exothermic*. The *exo* part of exothermic means external, while the *thermic* part means heat. If you put these two parts together, then exothermic just means external heat (heat leaving the reaction). Evidence of an exothermic reaction might be an increase in temperature of the surroundings. Heat has left the reaction and gone into the immediate surroundings; it is the temperature of the surroundings that you will measure in an experiment.



Figure 6.18 The word 'exothermic' means external heat.

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Figure 6.19 Burning wood is an example of an exothermic reaction because heat is released.

In exothermic reactions the products have less enthalpy than the reactants, and therefore extra energy is released into the surroundings. This change in enthalpy in an exothermic reaction can be illustrated in a simplified energy profile diagram, such as that shown in Figure 6.20.

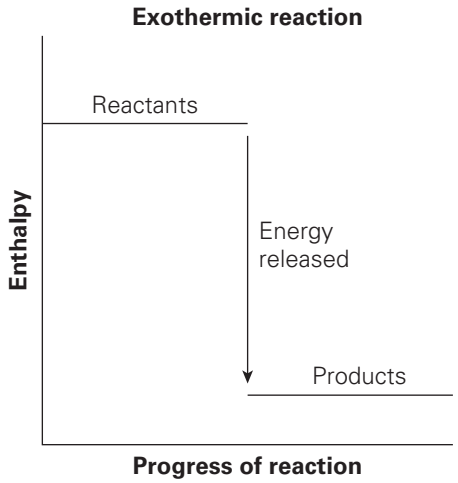


Figure 6.20 Simplified energy profile diagram for an exothermic reaction

In this reaction, the reactants have more enthalpy than the products, so surplus energy is released into the surroundings. This is indicative of an exothermic reaction.

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 in a chemical reaction characterised by a decrease in surrounding temperature

In this word, *endo* means internal and *thermic* means heat. An endothermic reaction might be observed with a decrease in temperature of the surroundings: heat has left the immediate surroundings and has gone into the reaction.



Figure 6.21 The word 'endothermic' means internal heat.



Figure 6.22 Photosynthesis, in which plants use the Sun's light energy to make their own food, is an example of an endothermic reaction.

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In endothermic reactions, the products have more enthalpy than the reactants, as extra energy is absorbed from the surroundings. The change in enthalpy in an endothermic reaction can be illustrated in simplified energy profile diagram, such as shown in Figure 6.23.

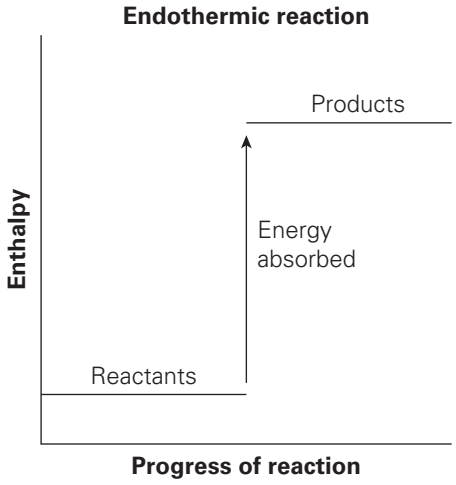


Figure 6.23 Simplified energy profile diagram for an endothermic reaction

In this reaction, the products have more enthalpy than the reactants, so energy is absorbed into the reaction from the surroundings. Therefore, in an endothermic reaction, an external source of energy is required to provide energy to the chemical reaction to proceed.

Quick check 6.6

1 During a chemical reaction, the temperature of the solution decreases. Infer whether this reaction is endothermic or exothermic.
2 'Respiration is an example of an endothermic reaction because it releases energy into the surroundings.' Is this statement true or false?
3 During a chemical reaction between hydrochloric acid and sodium hydroxide, the temperature went up by 5°C. Infer whether the reaction is endothermic or exothermic.
4 'Burning wood is an example of an exothermic reaction because the products have more potential energy than the reactants.' Propose whether this statement is true or false.

Practical 6.3: Teacher demonstration

Endothermic and exothermic reactions (1)

Be careful
Ensure that appropriate gloves are worn during this experiment.

Aim
To determine whether a reaction is endothermic or exothermic.

Materials

Experiment 1
- 1.4 g of potassium iodide
- 30% hydrogen peroxide
- food colouring
- dishwashing 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
Copy the results table.

Experiment 1
1 Place the 100 mL measuring cylinder in the middle of the plastic tray.
2 Add a squirt of dishwashing liquid and a few drops of food colouring to the measuring cylinder.

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3 Pour about 65 mL of 30% hydrogen peroxide into the measuring cylinder.
4 Add the potassium iodide to the flask, stand back and watch.

Experiment 2

1 Put a drop of water on the wooden block and place the 250 mL beaker on top of the water.
2 Mix the ammonium chloride and barium hydroxide together in the beaker, stirring with the thermometer, and observe the change in temperature.
3 Now try to remove the beaker from the block.
4 Pass the wooden block around the class and feel the change in temperature.

Results

Experiment	Observations	Exothermic or endothermic
1		
2		

Discussion

1 How did you know that a chemical reaction had taken place in both experiments?
2 Draw a potential energy level diagram for each experiment.
3 Determine why the reaction mixture shot out of the measuring cylinder in Experiment 1.

Conclusion

Draw a conclusion from this experiment regarding determining endothermic and exothermic reactions.

Practical 6.4

Endothermic and exothermic reactions (2)

Be careful
Ensure that appropriate gloves are worn during this experiment.

Aim

To determine whether reactions are endothermic or exothermic.

Materials

- 0.5 mol L^{-1} hydrochloric acid
- 0.5 mol L^{-1} sodium hydroxide
- 1 mol L^{-1} copper sulfate solution
- 1 mol L^{-1} sodium hydrogen carbonate
- 3 centimetre (cm) piece magnesium ribbon
- 1 spatula of zinc powder
- 1 spatula of citric acid
- 10 mL measuring cylinder
- thermometer
- polystyrene cup with lid

Method

1 Copy the results table, which gives the reactants to be used in four experiments.
2 Pour 10 mL of the first substance in Experiment 1 into the cup and measure the starting temperature. Record the temperature in your results table.
3 Add the required amount of the other substance listed in Experiment 1 to the cup, poke the thermometer through the lid and attach the lid to the cup.
4 When the temperature on the thermometer remains stable, record the final temperature in the results table.
5 Work out the temperature change and decide whether the reaction is endothermic or exothermic.
6 Repeat for the other experiments listed in the table.

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Results

	Experiment	Start temperature (°C)	Final temperature (°C)	Temperature change (°C)	Endothermic or exothermic
1	10 mL hydrochloric acid + 3 cm piece of magnesium ribbon				
2	10 mL hydrochloric acid + 10 mL sodium hydroxide				
3	10 mL copper sulfate solution + 1 spatula zinc powder				
4	10 mL sodium hydrogen carbonate + 1 spatula citric acid				

Discussion

1 Explain how you determined if each reaction was endothermic or exothermic.
2 Describe what happened to the energy in the reaction between sodium hydrogen carbonate and citric acid in Experiment 4.

Combustion reactions

combustion
the reaction of a fuel with oxygen, usually producing heat and light

Combustion reactions are specific examples of reactions that are exothermic in nature. Combustion is the scientific term for burning; when fuels burn they release heat. For a fuel to burn, oxygen is required. Combustion of fuels often take the general chemical equation shown in Figure 6.24.

fuel + oxygen → carbon dioxide + water

Figure 6.24 A typical combustion reaction

Fuels that contain hydrogen and carbon are called hydrocarbons. The equation in Figure 6.25 shows what happens when the simplest hydrocarbon, methane, is burned in oxygen.

methane + oxygen → carbon dioxide + water
CH_4 + $2O_2$ → CO_2 + $2H_2O$

Figure 6.25 Complete combustion of methane

This is an example of complete combustion because enough oxygen is present to combine with all the hydrogen and carbon in the fuel to form water and carbon dioxide. However, if only a limited supply of oxygen is available, methane will undergo incomplete combustion, which will lead to the formation of carbon monoxide and carbon (soot), as shown in Figure 6.26.

methane + oxygen → carbon monoxide + water
$2CH_4$ + $3O_2$ → $2CO$ + $4H_2O$

methane + oxygen → carbon + water
CH_4 + O_2 → C + $2H_2O$

Figure 6.26 Incomplete combustion of methane has two possible outcomes.

Carbon monoxide is produced instead of carbon dioxide when the oxygen supply is reduced slightly. However, if there is very little oxygen available, only the hydrogen will combine with the oxygen, making water, and leaving carbon on its own (sometimes referred to as 'soot'). Other outcomes are possible during an incomplete combustion of a hydrocarbon. For example, propane in the presence of limited oxygen produces both carbon monoxide and carbon dioxide in addition to water.

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Quick check 6.7

1 Explain why combustion reactions are described as exothermic reactions.
2 Identify the reactant gas required for all types of combustion reactions.
3 Carbon dioxide and water are released during the combustion of octane. Write a word equation to demonstrate this reaction.

Explore! 6.3

Controlled firestick farming

For thousands of years, Aboriginal and Torres Strait Islander peoples have used fire to sustain Australian bushland and plant growth in a practice known as firestick farming. Research the benefits of this practice and answer the following questions.

1 What is firestick farming?
2 At what time of year, in the north of Australia, is firestick farming most effective and why?
3 What are the products of combusting plant material in excess oxygen?
4 What are the effects of these products in the environment? Consider whether firestick farming enhances or reduces the magnitude of these effects.



Figure 6.27 A firestick is used to burn off dry grass in Arnhem Land, Northern Territory.

Section 6.3 questions

Remembering

1 **Identify** the gases that are a product of complete combustion reactions involving hydrocarbons.
2 **Recall** one example of an endothermic reaction and one example of an exothermic reaction.

QUIZ

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.

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Applying

5 **Compare** explosions with burning.
6 **Distinguish** between complete and incomplete combustion.

Analysing

7 **Contrast** exothermic and endothermic reactions with respect to the enthalpy of reactants and products.
8 **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

9 **Construct** a word equation for the complete combustion of butane (BBQ gas) to form carbon dioxide and water.
10 **Decide** if the following statement is true or false. 'Combustion is a chemical reaction.' Give reasons for your choice.

6.4 Reactions of life

WORKSHEET

Learning goal

1 To be able to recall the word equations for photosynthesis and respiration.

Life on Earth is dependent on two key chemical reactions: **photosynthesis** and **respiration**. Photosynthesis is carried out by plants and algae; respiration is carried out by all living organisms.

photosynthesis
the chemical reaction by which some organisms make their own food

respiration
a chemical reaction which converts glucose and oxygen into carbon dioxide and water as well as energy

Photosynthesis

Photosynthesis is the process by which plants, algae and some bacteria make their own food in the form of glucose. It takes place in any part of the plant that is green and exposed to sunlight. As leaves are exposed to the most sunlight, this is where most photosynthesis takes place. Leaves are green because they contain a green chemical called chlorophyll in tiny structures called chloroplasts. Photosynthesis can be summarised by the word equation and balanced chemical equation shown in Figure 6.28.

WIDGET
Photosynthesis

For photosynthesis to occur, plants and algae need to take carbon dioxide and water into chloroplasts. Carbon dioxide comes from the

$$\text{carbon dioxide} + \text{water} + \text{light energy} \xrightarrow{\text{chlorophyll}} \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O + \text{light energy} \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Figure 6.28 The word and balanced symbol equations for photosynthesis

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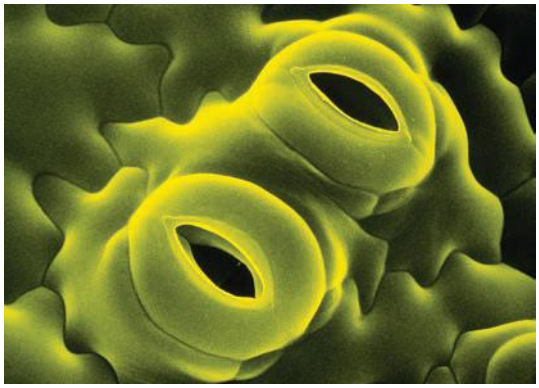


Figure 6.29 A scanning electron microscope image of leaf stomata (tiny holes found in the leaf). Carbon dioxide moves into the leaf through the stomata.

air and is absorbed into the leaf through tiny holes called stomata on the underside of the leaf (see Figure 6.29). Water in the soil is taken up into the plant by its roots.

Once carbon dioxide and water are inside the plant, they will not react on their own. For this reaction to take place, energy from sunlight is required. Chlorophyll, the green chemical within the chloroplasts in leaves, is also required to convert the light energy into chemical potential energy. When carbon dioxide and water react in the presence of sunlight and chlorophyll, glucose and oxygen are formed.

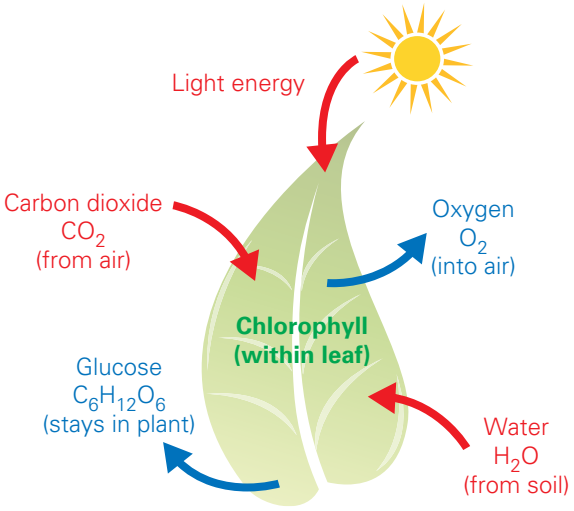


Figure 6.30 Photosynthesis: where the raw materials come from (in red) and what happens to the products (in blue)

Table 6.2 summarises the chemicals and energy involved in photosynthesis.

Reactants	Reaction conditions	Products
Carbon dioxide Water	Light energy Chlorophyll	Glucose Oxygen

Table 6.2 Chemicals and energy involved in photosynthesis

Practical 6.5: Investigation

Investigating factors that affect the rate of photosynthesis

Aim

To investigate how light intensity affects the rate of photosynthesis.

Planning

1. Write a rationale about the factors that affect the rate of photosynthesis.
2. Write a specific and relevant research question for your investigation.
3. Identify the independent, dependent and control variables.
4. Write a hypothesis for your investigation.

Materials

- water plant (e.g. *Elodea*)
- 250 mL conical flask
- 100 mL measuring cylinder
- electric lamp
- scissors
- metre ruler
- stop clock

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Method

1 Copy the results table.
2 Set up the lamp. Using the metre ruler, measure five distances (up to 1 metre [m]) away from the base of the lamp. These are the distances you will investigate. Record these distances in your results table.
3 Measure 100 mL of water using the 100 mL measuring cylinder and add it to the conical flask.
4 Place the conical flask the correct distance from the lamp.
5 Cut a 10 cm length strip of the water plant and add it to the conical flask, 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, repeat each distance and calculate the mean number of bubbles. Alternatively, you could share your results with the rest of your class so you have more data when calculating the mean.

Results

Distance from the lamp (m)	Number of bubbles produced in 1 minute

Discussion

Plot a scatter graph (with a trend line or a line of best fit) of your results.

1 Describe any patterns, trends or relationships in your results.
2 Explain any trends you have identified.
3 Identify any limitations in your investigation.
4 Propose how you could improve the investigation to make the results more:
   a accurate
   b reliable.
5 Design a similar experiment to investigate another factor that may affect the rate of photosynthesis.

Conclusion

Draw a conclusion from this experiment regarding light intensity and the rate of photosynthesis, using data to support your statement.

Quick check 6.8

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.

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Respiration

Respiration is the process by which living organisms produce energy from glucose. Both plants and animals carry out a process called aerobic respiration, which means respiration requiring oxygen. When you exercise, you need more energy from respiration and therefore more oxygen, which is why your breathing rate increases.



Figure 6.31 When you exercise, more energy is required, so you breathe faster.

You know already that the glucose plants use in respiration is formed during photosynthesis. In contrast, animals get their glucose from the food they eat. Aerobic respiration takes place in the mitochondria of a cell. Alongside the useful product of respiration (energy) other less useful products (carbon dioxide and water) are also produced.

Try this 6.1

Limewater becomes cloudy in the presence of carbon dioxide. Get a test tube, a straw and some limewater. Blow into the limewater. What do you think will happen? How does this give us evidence for one product of aerobic respiration?

Aerobic respiration can be summarised by the word equation and balanced symbol equation below.

glucose + oxygen → carbon dioxide + water + energy (ATP)

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy (ATP)

Figure 6.32 The word and symbol equations for aerobic respiration

Explore! 6.4

Aerobic and anaerobic respiration

Haile Gebrselassie and Usain Bolt are perhaps the most famous names in their sports. Usain Bolt ran the 100 m and 200 m, whereas Haile Gebrselassie ran long-distance races, including marathons. The energy requirements for these races differ dramatically and therefore so do the rate and type of respiration.



Figure 6.33 Haile Gebrselassie won the Berlin marathon in 2009.



Figure 6.34 Usain Bolt crossing the finish line. He is perhaps the greatest sprinter of all time.

1. During a race, how would the breathing rates of the two runners differ?
2. During a 100 m race, Usain Bolt only carried out a type of respiration known as anaerobic respiration. Research the differences between aerobic and anaerobic respiration to explain why marathon runners and sprinters use different types of respiration.
3. In a marathon, runners pick up glucose drinks at various points during a race. Propose a reason for this.

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Quick check 6.9

1 Name the two reactants required for aerobic respiration.
2 Name the three products produced during aerobic respiration.
3 Identify where aerobic respiration takes place.

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

QUIZ

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.

Understanding

3 **Recall** the word equation for aerobic respiration.
4 **Select** the correct words to complete the word equation for photosynthesis.
carbon dioxide + _____ → glucose + _____

Applying

5 **Explain** why light energy is written above the arrow and chlorophyll is written below in the word equation for photosynthesis.
6 List some factors that can affect the rate of photosynthesis and **explain** why they affect the rate of the reaction.

Analysing

7 **Compare** photosynthesis and respiration.
8 **Contrast** the ways that plants and animals get the raw materials required for aerobic respiration.
9 **Classify** respiration and photosynthesis as endothermic or exothermic reactions, giving reasons for your decisions.

Evaluating

10 During anaerobic respiration involving yeast, glucose is broken down into carbon dioxide and ethanol. **Construct** a word equation for this reaction.
11 **Deduce** why leaves are often flattened and do not overlap.
12 **Discuss** the reasons why plants can respire at any time of the day, but only photosynthesise during daylight hours.

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6.5 Acid reactions

Learning goals

1 To be able to predict the products of acid + metal reactions.
2 To be able to predict the products of acid + base reactions.
3 To be able to predict the products of acid + carbonate reactions.

WORKSHEET

In this section, you will learn about three types of reactions involving **acids**: acid–metal, acid–**base** and acid–carbonate reactions. A substance is classified as an acid when it has a pH of less than 7 (at 25°C). pH stands for 'potential of hydrogen' and is a measure of the concentration of hydrogen ions in a solution. The more hydrogen ions, the lower the pH.

pH is calculated using a scale from 0 to 14, where a value of 7 at 25°C indicates a neutral substance such as pure water. This means that an acid has a pH range from 0 up to (but not reaching) 7. The lower the pH value of an acid, the more acidic it is. Some acids are so strong, they go beyond the pH scale and have a value of –1 or –2.

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 hydrochloric, sulfuric and nitric acids.

In all the reactions that will be discussed, a **salt** will be one of the products formed. The table salt, that you put on chips, is sodium chloride. However, there are other types of salt.

In chemistry, a salt is a substance that is formed when acids react with bases, metals or metal carbonates. Salts are generally made up of a metal and a non-metal. You need to be able to predict the name of the salt formed when acids react with metals, metal carbonates and bases. The type of acid used produces different products and affects the name of the salt. If hydrochloric acid is reacted, the salt will be a chloride; if nitric acid is



Figure 6.35 Lemon juice is a common household acid.

acid
a substance that, when dissolved in water, has a pH of less than 7

base
a substance that has a pH greater than 7 and that can react with an acid to form a salt and water; known as an alkali if it can dissolve in water

salt
a product formed when an acid reacts with a metal, base or carbonate; generally made up of a metal and a non-metal

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used, the salt will be a nitrate; and if sulfuric acid is 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 generally 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 produced in reactions that involve acids.

Reactant 1	Metal present	Reactant 2: type of acid	Type of salt	Name of salt
Magnesium (metal)	Magnesium	Hydrochloric acid	Chloride	Magnesium chloride
Calcium hydroxide (base)	Calcium	Nitric acid	Nitrate	Calcium nitrate
Sodium carbonate (carbonate)	Sodium	Sulfuric acid	Sulfate	Sodium sulfate

Table 6.5 Examples of how to name the salt produced in the three types of acid reactions

Quick check 6.10

1. Describe the pH range 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 for naming a salt.

Acid–metal reactions

Acid–metal reactions occur when an acid reacts with a metal to produce a salt and hydrogen gas (H_2). The hydrogen produced in the reaction can be identified using a simple pop test: you can test for the presence of hydrogen gas produced in an acid–metal reaction by capturing any gas produced and holding a lit match to it. If hydrogen is present, you will hear a 'squeaky pop'. One general word equation for an acid reacting with a metal is shown below.

$$\text{acid} + \text{metal} \rightarrow \text{salt} + \text{hydrogen gas}$$

Figure 6.36 The word equation for any acid reacting with any metal

When hydrochloric acid reacts with magnesium, the salt magnesium chloride is formed, and the other product in the reaction is hydrogen gas. Remember that the first part of the salt name comes from the metal and the second part comes from the type of acid used. Hydrogen gas is produced no matter the identity of the acid or metal.

$$\text{hydrochloric acid} + \text{magnesium} \rightarrow \text{magnesium chloride} + \text{hydrogen gas}$$

Figure 6.37 The word equation for a specific acid–metal reaction

Some metals do not react with dilute acids to form a salt and hydrogen gas. Such metals include gold, silver, copper and platinum.

The reaction between acids and metals is a problem in everyday life. There is sometimes acid in rain (called acid rain) and this can cause a large amount of damage to the many buildings made of metals.

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Figure 6.38 The orange toxic water produced here is due to the reaction of acid rain with the metal in this abandoned mine.

Quick check 6.11

1 State the general word equation for when any metal reacts with any acid.
2 List four metals that do not react with dilute acids.
3 Complete the word equation below.

nitric acid + _____ → zinc _____ + hydrogen gas

Practical 6.6

Reaction of acids with metals

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To observe what happens when metals react with acids.

Materials
- 1 mol L^{-1} dilute hydrochloric acid
- 0.5 mol L^{-1} 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 Copy the results table.
2 Place the 8 test tubes in the test-tube rack.
3 In 4 of the test tubes, add 2–3 cm depth of hydrochloric acid.
4 In the other 4 test tubes, add 2–3 cm depth of sulfuric acid.
5 To each of the hydrochloric acid test tubes, add a different type of metal. Place a rubber stopper loosely in the top of the test tube and note your observations. Note: ensure all metal samples have been cleaned before adding them to the acid. Also note that the reaction between the acid and metals may be rather slow and not produce enough hydrogen gas to cause a pop.

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…continued

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?

Discussion

1 Discuss which of the metals reacted with the hydrochloric and sulfuric acids. How did you know?
2 Write word equations for each of the reactions you carried out in this practical.
3 State what happened to some of the reactions when the lit splint was put at the mouth of the test tube.
4 Explain what this experiment tells you about the reactivity of metals.
5 During this reaction, you may have felt the temperature of the reaction increase. Recall the name of this type of reaction.

Acid–base reactions

Acid–base reactions occur when a acid reacts with a base to produce a salt and water. Notice that a salt is produced, just like in acid–metal reactions, but instead of hydrogen gas being the other product, water is produced. A base is a substance that has a pH greater than 7 and that can react with an acid to form a salt and water. This means that the pH range of a base is from above 7 up to 14, and as with acids the higher the pH, the more basic the substance is considered. Also like acids, there exist some very strong bases which exceed a pH of 14.

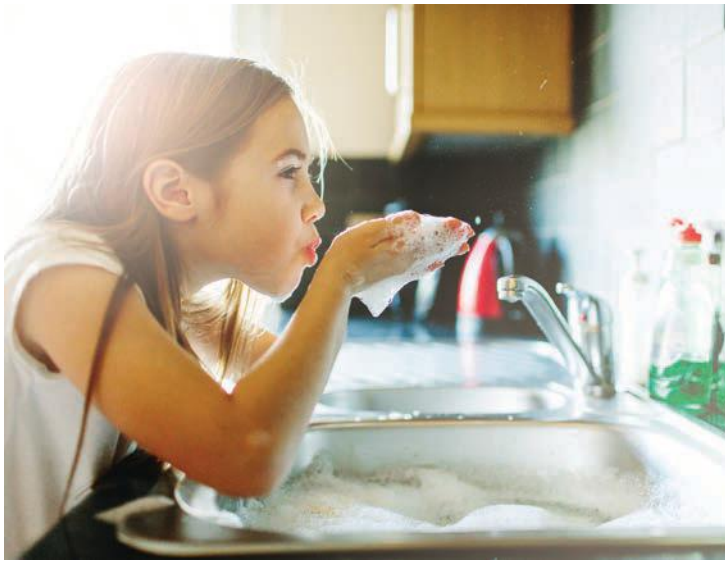


Figure 6.39 Dishwashing liquid is an example of a household base.

Bases that can dissolve in water (alkalis) tend to feel soapy on the skin. Common bases that you may have in your house are hand soap and oven

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cleaner. Bases that you will come across in your science laboratory include many metal hydroxides and metal oxides including sodium hydroxide, calcium hydroxide, sodium oxide and calcium oxide. Moreover, a common base that does not include a metal is ammonia (NH_3).

The general word equation for any acid reacting with any base is shown in Figure 6.40.

acid + base → salt + water

Figure 6.40 The word equation for any acid reacting with any base

When nitric acid reacts with sodium hydroxide, the salt sodium nitrate is formed.

nitric acid + sodium hydroxide → sodium nitrate + water

Figure 6.41 The word equation for a specific acid–base reaction

Acid–base reactions are also known as **neutralisation** reactions. This is because when acids and bases with the same volume and concentration react, they may result in a neutral solution (pH = 7). Treating indigestion with an antacid and soothing a wasp sting with vinegar are examples of acids being neutralised with a base.

neutralisation
a reaction between an acid and a base, forming a solution that has a pH of 7



Figure 6.42 The pain from a wasp sting can be soothed by vinegar because of a neutralisation reaction.

Quick check 6.12

1. State the general word equation for when any base reacts with an acid.
2. Identify the name for a reaction between an acid and a base.
3. Complete a word equation below.
   sulfuric acid + _____ → iron _____ + water

Practical 6.7

Reaction of acids with bases

Be careful
Ensure appropriate personal protective equipment is worn.

Aim
To observe what happens when acids react with bases.

Materials
- 0.5 mol L^{-1} hydrochloric acid
- 0.5 mol L^{-1} sodium hydroxide
- 250 mL beaker
- 25 mL measuring cylinder
- dropping pipette
- stirring rod
- universal indicator paper for checking pH and colour chart (full range)
- spotting tile
- pH meter

Method
1. Copy the results table.
2. Using a 25 mL measuring cylinder, measure 25 mL of hydrochloric acid and add to the 250 mL beaker.
3. Add a small piece of universal indicator paper to each of the six hollows on the spotting tile.
4. Using the 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.

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6 Using the 25 mL measuring cylinder, measure 5 mL of sodium hydroxide and add this to the beaker containing the acid.
7 Repeat steps **4–5**, recording your results in the results table.
8 Now add 5 mL of sodium hydroxide, and repeat steps **4–5**. Record the result against the total volume of sodium hydroxide added. Continue these steps until the table is complete.

Results

Volume of sodium hydroxide (mL)	pH using universal indicator paper	pH using digital meter
0		
5		
10		
15		
20		
25		

Discussion

1 Describe what happened to the pH as you gradually added more and more base.
2 Identify the type of reaction that you carried out in this experiment.
3 Write a word equation for the reaction that you investigated.
4 Compare the differences in the readings from the universal indicator and the pH meter. Which one is more accurate and why?
5 To demonstrate this type of reaction, explain why it is important to use the same concentration and volume of the acid and base.

Acid–carbonate reactions

Acid–carbonate reactions occur when any acid reacts with any carbonate or hydrogen carbonate to produce a salt, water and carbon dioxide. As with acid–metal and acid–base reactions, a salt is produced, but the other products are different. You can test for the presence of carbon dioxide produced in an acid–carbonate reaction by bubbling the gas through limewater. Limewater goes from colourless to milky in the presence of carbon dioxide (Try this 6.1).

The general word equation for any acid reacting with any carbonate is shown below.

acid + metal carbonate → salt + water + carbon dioxide

Figure 6.43 The word equation for any acid reacting with any carbonate

The general word equation for any acid reacting with any metal hydrogen carbonate:

acid + metal hydrogen carbonate → salt + water + carbon dioxide

Figure 6.44 The word equation for any acid reacting with any metal hydrogen carbonate

When sulfuric acid reacts with calcium carbonate, the salt calcium sulfate is formed. Similarly if sulfuric acid reacts with calcium hydrogen carbonate, the salt calcium sulfate will also form.

sulfuric acid + calcium carbonate → calcium sulfate + water + carbon dioxide
sulfuric acid + calcium hydrogen carbonate → calcium sulfate + water + carbon dioxide

Figure 6.45 The word equation for a specific acid–carbonate and acid-hydrogen carbonate

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Did you know? 6.1

Baking powder

A common type of carbonate that you may find in your home is baking powder. Baking powder is a mixture of an acid and a hydrogen carbonate. In the presence of water or another liquid, the acid and hydrogen carbonate react slowly in a cooking mixture, producing carbon dioxide and making your cakes light and fluffy.



Figure 6.46 An acid–hydrogen carbonate reaction causes cakes to rise in the oven.

Quick check 6.13

1. State 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 a correct word equation below for a carbonate or hydrogen carbonate.

   hydrochloric acid + _____ → potassium _____ + water + carbon dioxide

Practical 6.8

Reactions of acids with metal carbonates

Be careful

Ensure appropriate personal protective equipment is worn.

Aim

To observe what happens when acids react with metal carbonates.

Materials

- 1 mol L^{-1} nitric acid
- calcium carbonate powder
- limewater
- 2 test tubes
- delivery tube
- test-tube rack
- spatula
- rubber stopper with hole

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.

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3 Add a heaped spatula of calcium carbonate into the test tube containing the nitric acid, and at the same time place the rubber stopper on top of this test tube and the delivery tube into the limewater (see Figure 6.47).

Results

Record your observations.

Discussion

1 Write a word equation for the reaction you investigated.
2 Describe how your observations prove that carbon dioxide was present.
3 Research the reaction between carbon dioxide and limewater to explain your observations.

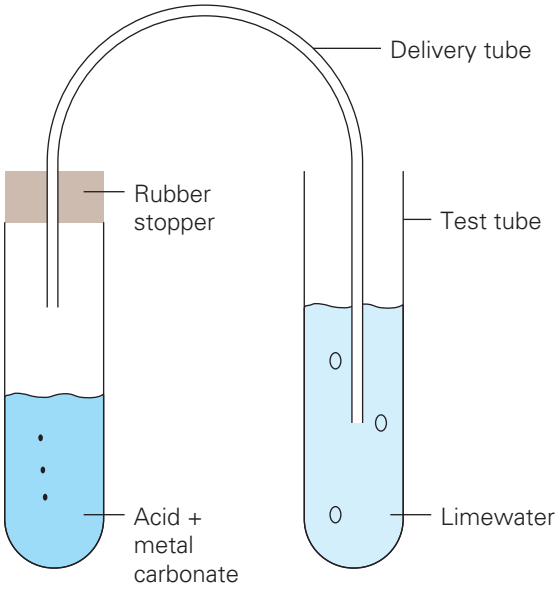


Figure 6.47 Testing for the presence of carbon dioxide using a delivery tube

Explore! 6.5

Weathering

Headstones are an important insight into what life used to be like and often hold huge sentimental value. The two pictures on the right show headstones of a similar age. The headstone in Figure 6.48 is made of limestone (calcium carbonate) and the one in Figure 6.49 is made of granite.

1 Describe the observations you can make about the condition of the headstones in each picture.
2 Explain why it is more difficult to read the inscriptions on the limestone (calcium carbonate) headstone than on the granite headstone.



Figure 6.48 Limestone headstone

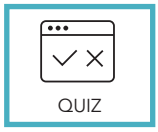


Figure 6.49 Granite headstone

3 Write a word equation to explain your ideas in question **2**.
4 Despite the obvious difference in durability between granite and limestone, 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?

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Section 6.5 questions



Remembering

1 **Recall** the products of the following reactions.
   - a acid + metal →
   - b acid + base →
   - c acid + carbonate →
   - d acid + hydrogen carbonate →

Understanding

2 **State** the pH range of an acid and a base.
3 **Recall** the two rules when naming a salt.
4 **State** the pH of a neutral solution.

Applying

5 During an experiment to show that a neutral solution is formed when acids and bases react, Martin used equal volumes of sodium hydroxide (base) and hydrochloric acid. However, the solution after mixing was not neutral. **Explain** how this could have happened.

Analysing

6 **Compare** acid–base reactions with acid–metal reactions.
7 **Categorise** the following equations as acid–base, acid–carbonate or acid–metal reactions.
   - a Produces a salt and water as products without production of carbon dioxide gas
   - b Produces a gas that can be identified by the squeaky pop test
   - c Nitric acid + sodium → sodium nitrate + hydrogen
   - d Produces a gas that turns limewater milky
   - e Is an example of a neutralisation reaction
   - f Forms a salt

Evaluating

8 **Predict** which of the following reactions will not produce a salt.
   - A Potassium hydroxide + hydrochloric acid
   - B Iron + sulfuric acid
   - C Platinum + hydrochloric acid
   - D Sodium carbonate + nitric acid
   - E Methane + oxygen

9 **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 A reaction forms the products barium chloride and hydrogen gas.

10 Heartburn is caused by acid from the stomach entering the oesophagus. **Justify** the use of antacids to alleviate the pain caused by heartburn.

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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked question	Check
6.1 I can identify indicators of chemical changes.	2	
6.2 I can recall the concept of the conservation of mass.	7	
6.3 I can distinguish between endothermic and exothermic reactions.	17	
6.4 I can describe photosynthesis and respiration.	4	
6.5 I can determine the products of different acid reactions.	14	

Review questions



Remembering

1 **Name** the gases produced in the following situations.
   a A hydrocarbon is completely combusted.
   b Carbon dioxide and water react during photosynthesis.
   c Nitric acid reacts with nickel carbonate.
2 **List** four pieces of evidence for chemical change.
3 Complete the table to **identify** the correct acid and salt.

Acid	Type of salt
Hydrochloric acid	
	Sulfate
	Nitrate

Understanding

4 With reference to the equation for aerobic respiration, **explain** why you breathe out carbon dioxide.
5 **Describe** factors that could increase the rate of photosynthesis of a pot plant.

Applying

6 **Explain** why condensation forms when you breathe out onto a cold window.
7 **Explain** how the law of conservation of mass is shown in chemical equations.
8 **Explain** why plants compete with each other to be the tallest.

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Analysing

9 **Compare** aerobic respiration to a combustion reaction.

10 **Analyse** the following word equation and formula equation to identify the following.

hydrochloric acid + magnesium → magnesium chloride + hydrogen

$$HCl + Mg \rightarrow MgCl_2 + H_2$$

- a The reactants
- b The products
- c Whether it observes the law of conservation of mass
- d 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

11 **Infer** why autumn leaves are orange or brown. Research via the internet to assess if you were on the right track.

Evaluating

12 **Sketch** the shape of an energy profile diagram for the reaction between copper sulfate and zinc in which the temperature of the reaction rose by 40°C.

13 **Discuss** what is happening in the following reaction. Use these keywords: reactants, products, reaction condition.

$$\text{hydrogen + oxygen} \xrightarrow{\text{heat}} \text{water + energy}$$

14 **Predict** the products of the following reactions.

- a Hydrochloric acid + copper carbonate
- b Nitric acid + potassium hydroxide
- c Sulfuric acid + iron

15 Reactants weighing a total of 20 g were reacted together. Only 18 g of product was made. **Propose** what may have happened to the remaining 2 g of mass.

16 In a darkened room with a plentiful supply of carbon dioxide and water, light is described as a limiting factor for photosynthesis. **Deduce** what is meant by the term 'limiting factor'.

17 The following reaction shows the thermal decomposition (breaking down in the presence of heat) of calcium carbonate. **Determine** whether you think this is an exothermic or an endothermic reaction. Justify your choice.

calcium carbonate → calcium oxide + carbon dioxide

18 'Photosynthesis and respiration are the reverse reactions of one another.' **Decide** whether you agree or disagree with the statement and justify your response.

19 Julia is observing a reaction and notices steam rising out of the test tube.

- a **Decide** whether the reaction is exothermic or endothermic.
- b **Justify** your choice.



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Data questions

A variety of fuel sources is shown in Table 6.6, with the number of carbon atoms per fuel molecule and the mass of CO_2 produced by burning 1 kilogram (kg) of each fuel.

	Number of reactant carbon atoms per molecule	Mass of CO_2 produced (kg)
Natural gas	1	2.74
LPG	3	2.99
Butane	4	3.03
Petrol 91	8	3.08
Petrol 98	8	3.08
Diesel	10	3.09
Coal	–	3.66

Table 6.6 Number of carbon atoms per fuel molecule and the mass produced by burning 1 kg of fuel.

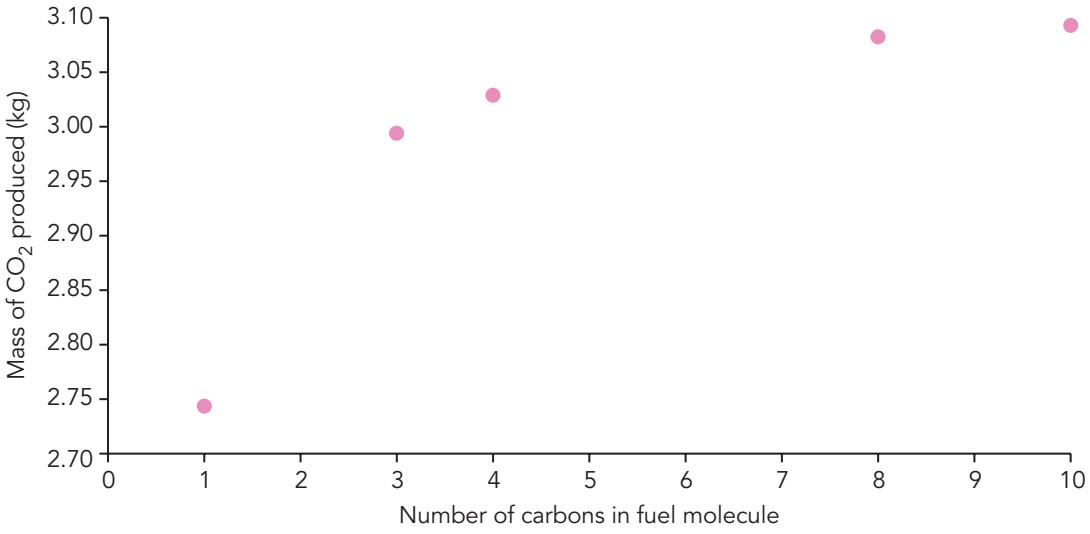


Figure 6.50 Number of carbon atoms per fuel molecule vs. the mass of CO_2 produced by burning 1 kg of fuel

1 **Identify** the fuel that produces the lowest mass of carbon dioxide per kilogram burned.
2 A premium unleaded (petrol 98) brand has stated that their fuel produces less carbon dioxide emissions than a petrol 91 brand. **Determine** whether this statement is correct.
3 A coal mining company has argued that the mass of carbon dioxide produced by burning 1 kg of their fuel is under 1 kg more than that produced from natural gas. **Determine** whether the evidence from Table 6.6 supports this claim.
4 **Identify** the trend between the number of carbon atoms per reactant molecule and the mass of carbon dioxide produced.
5 At atmospheric temperature, generally fuel molecules with four carbons or less are gaseous fuels, while those with five or more carbons are liquid fuels. Coal is a solid fuel. **Classify** the fuels in Table 6.6 as gas, liquid or solid.

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6 A fuel company is producing a new biofuel made primarily from ethanol, which is a molecule with two carbon atoms. **Predict** the mass of carbon dioxide that would be produced by burning 1 kg of this fuel.

7 Given the mass of carbon dioxide produced by burning coal, **deduce** the likely density of carbon atoms.

8 **Extrapolate** the data to predict the mass of carbon dioxide that would be produced by burning a fuel with a number of carbon atoms per molecule of 11.



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STEM activity: Baristas and the curdling milk problem

Background information

Science has applications in all industries, including medicine, technology and 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 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. If you add lemon juice or vinegar to hot milk, the milk will curdle almost immediately due to the acidity (low pH), but adding it to cold milk will not produce a reaction for quite some time. Sometimes curdling is what you want, for example, when you make 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 with baristas to create a range of soy milk that would not curdle in acidic coffee blends. However, not all coffee shops can afford speciality products.



Figure 6.51 Australians drink nearly 4 billion cups of coffee each year, so it is important that baristas 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. Use images from your experimentation process.

Activity instructions

As the chemical engineer representing the Coffee Union of Australia, you are responsible for ensuring that baristas 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 ratio of coffee to milk volume 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.

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Note: an infographic is a visual representation of information, designed to make the data and information easy to understand at a glance. Infographics are different from graphs, which are meant to be analysed. An infographic is simple, understandable and meant to communicate messages quickly.

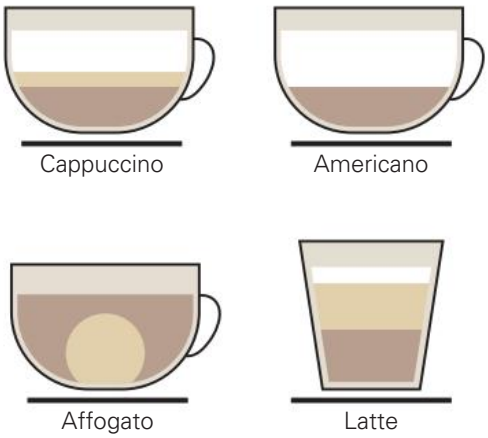


Figure 6.52 An infographic showing the various coffee, milk and froth ratios for different types of coffee drinks

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 cow's milk and soy milk
- water
- beakers
- 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
- digital balance
- permanent marker
- gloves

Research and feasibility

1 Research the process of how milk curdles and list all the factors.

2 Research and list the ingredients that are used in barista-made coffee, and the ratios involved. Take note of any temperatures and pH values of the ingredients. Make sure you include research on all the suggested materials.

Design and sustainability

3 Design an experiment that demonstrates the conditions under which combining coffee and milk results in either curdling the milk or achieving a smooth texture. Think about how milk curdles and see if you can replicate this situation.

Create

4 Perform your experiment, ensuring you take photos and notes of all observations of the experiment along the way.

5 Create an A5 'cheat sheet' for baristas using infographics so they can easily identify the ratios possible for cow's milk and soy milk with the most acidic coffee blends. You may do this by hand, or search for free infographic design tools on the internet.

Evaluate and modify

6 Discuss your findings with your colleagues and present your infographic.

7 Propose the best ratio of coffee to milk for preventing the curdling of milk for acidic coffee blends with different milk products.

8 Identify possible sources of error in your testing procedure and suggest some ways to improve and modify your experiments in the future.

9 Predict how the temperature of the milk may have affected your findings.

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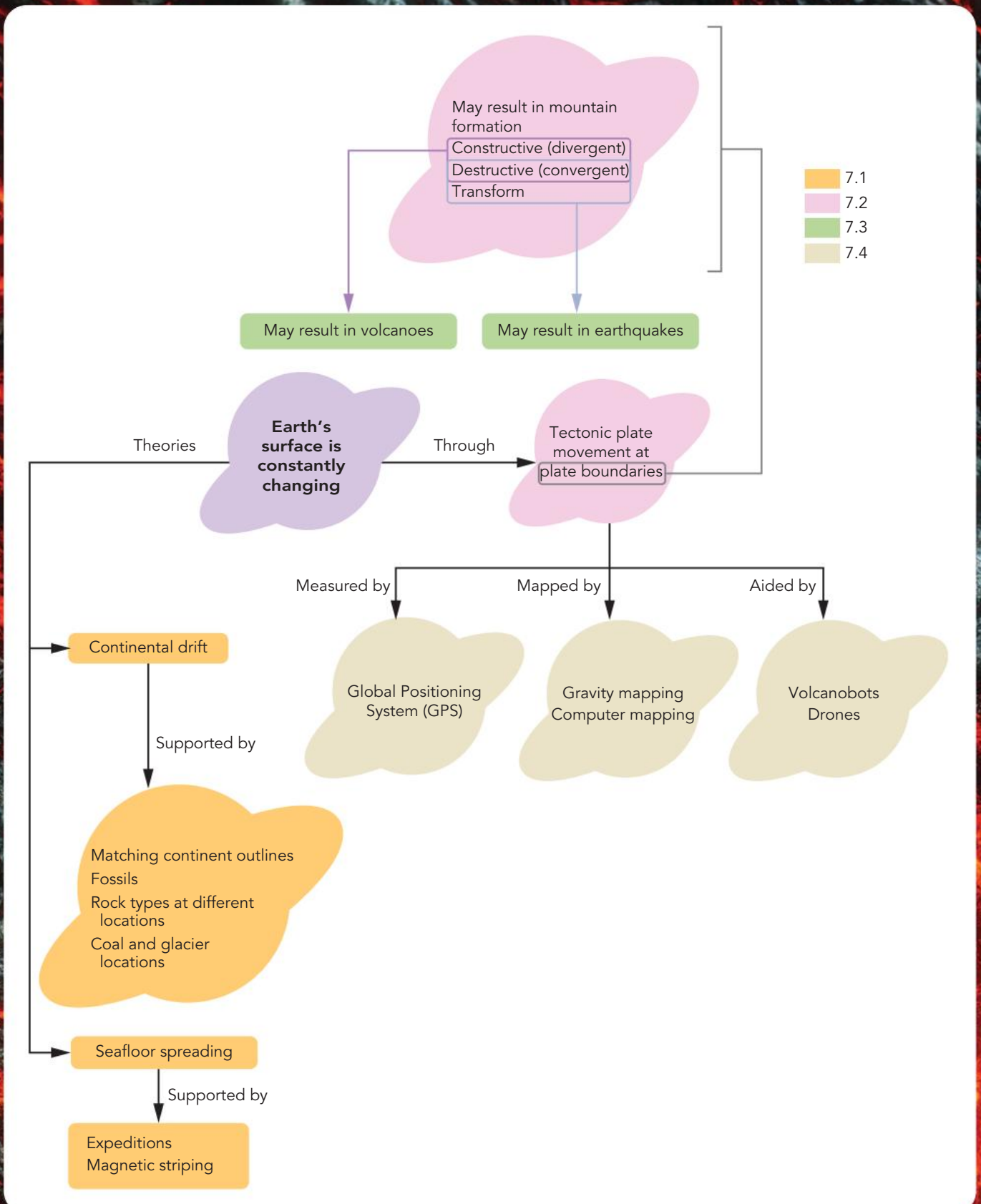
Chapter 7
Our changing Earth

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's surface was like the skin of an apple – unbroken. In this chapter, you will learn about the changing ideas about the structure of Earth and how they have led to a greater understanding of why geological natural disasters occur. You will look at the impact of these natural disasters and how early detection methods using modern technology have reduced these impacts.

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Chapter map



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7.1 Continent movement theories

WORKSHEET

VIDEO Alfred Wegener

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

Pangaea the original supercontinent which has since broken into pieces and drifted apart

Learning goal

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

Since the late sixteenth century, scientists have speculated that continents may have drifted on the Earth's surface. In this section, you will learn about the contribution that various scientists have made to the understanding of the theory of continental drift.

Alfred Wegener: continental drift

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



Figure 7.1 Alfred Wegener

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

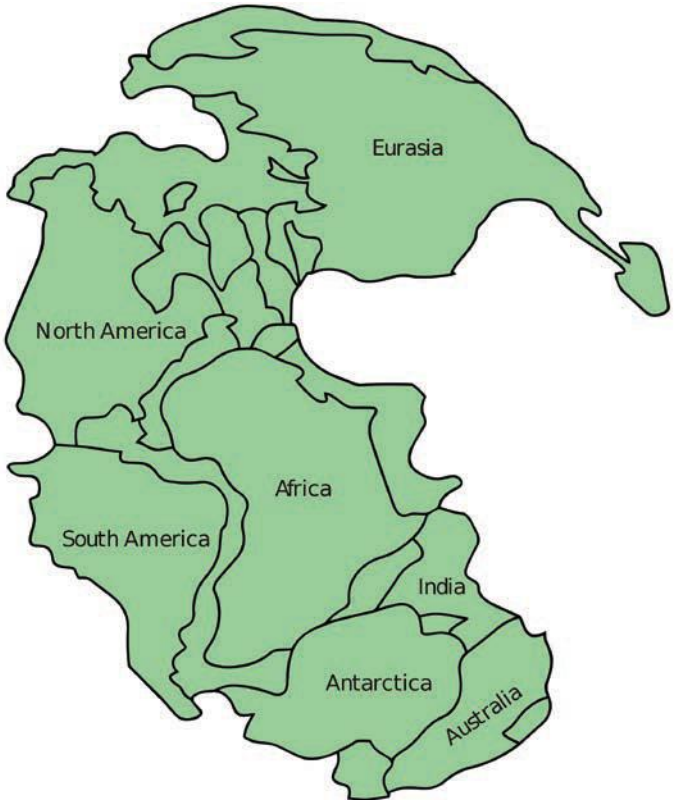


Figure 7.2 Wegener proposed that all the continents were once together in a giant landmass called Pangaea.

Over time, this giant landmass broke up and drifted apart to form the continents that you know today. Figure 7.3 shows how the continents have moved over millions of years. Follow the movement of Australia to see how far we have moved in that time.

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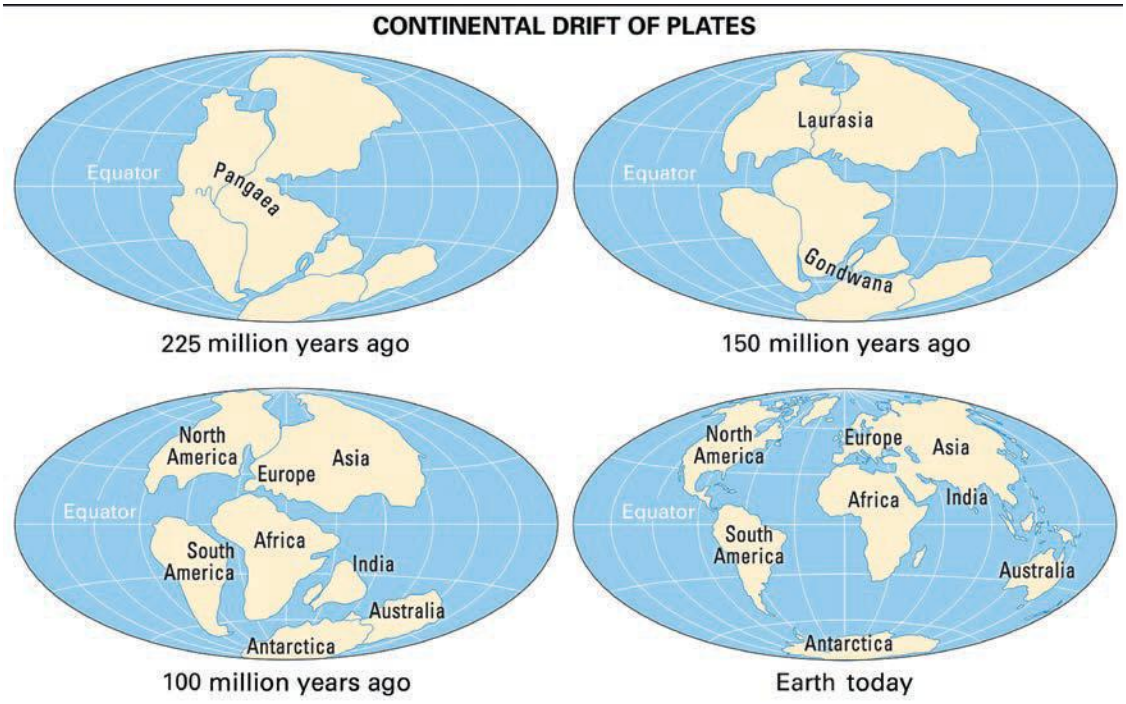


Figure 7.3 The movement of the continents from a single landmass (Pangaea) to their current locations.

A scientific theory cannot arise without evidence. So how did Wegener justify his theory to the scientific community? Wegener put forward four different pieces of evidence to support his theory.

1 Continental outlines matched

You can see from Figure 7.4 that, when put together, some of the existing continents look like they fit into each other – just like pieces of a broken jigsaw puzzle. One could argue that this is just a coincidence, so Wegener needed more evidence to back up his theory.



Figure 7.4 The outlines of Africa and South America fit together like pieces in a jigsaw puzzle.

2 Similar fossils were found on different continents

When observing the types of fossils on different continents, Wegener found examples of the same prehistoric land-based creatures on continents that are now separated by oceans. He stated that the landmasses must have been together at some stage (as shown in Figure 7.5) because these animals could not swim from one continent to another. Opposing geologists argued that land bridges could have existed in the past when ocean levels were lower. These land bridges would have allowed the fauna and flora to cross between continents.

3 Rock types on different continents matched each other

When Wegener put the continents together, he also found that bands of different rock types matched up, giving further weight to his theory.

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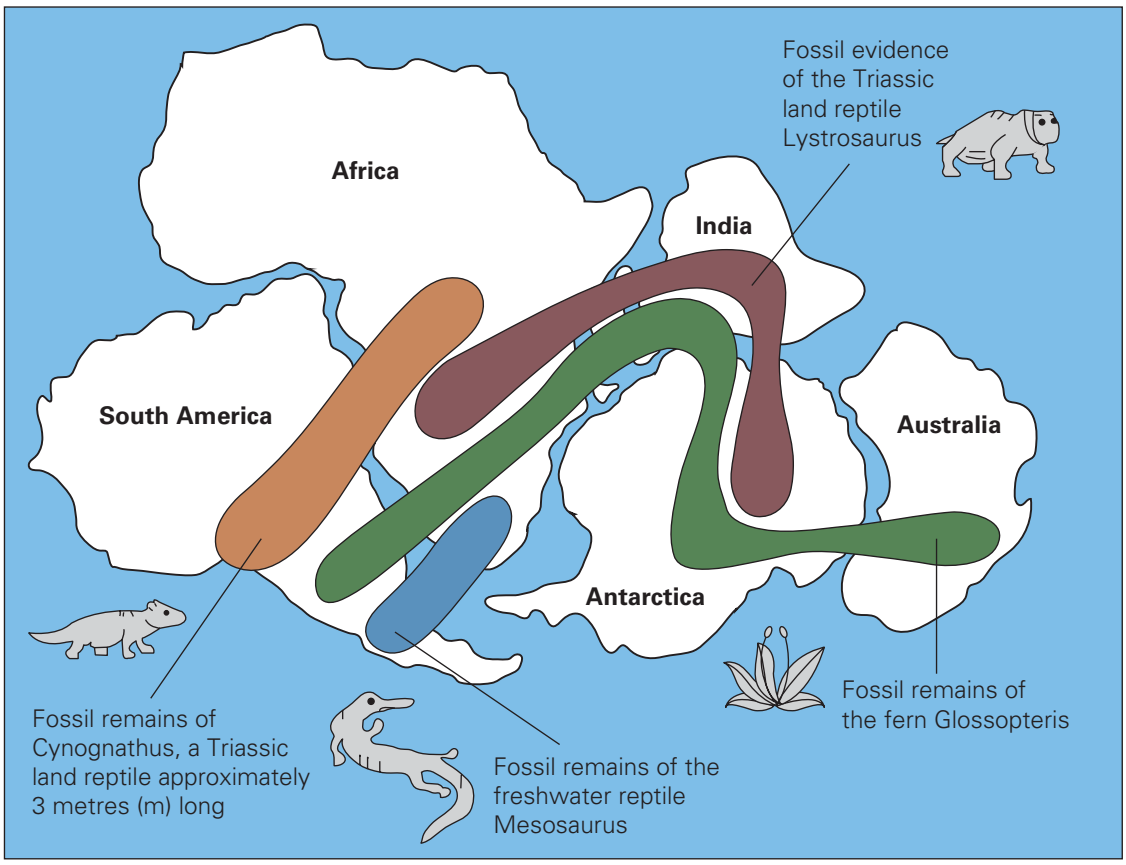


Figure 7.5 Wegener found that fossils on different continents matched up, supporting his theory of continental drift.

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

Coal only forms in hot and humid areas, and glaciers only form in cold areas, so how could there be coal in cold areas and evidence of past glaciers in regions that are now hot? Wegener concluded that this land could have once been part of the same landmass and in a different location.

Despite all the evidence compiled by Wegener, he was unable to convince the scientific community at the time of the validity of his hypothesis. Alternative theories (like the land bridges) were proposed, and geologists questioned his credibility because he was a meteorologist and geophysicist known for polar climate research, and not geology. However, the main flaw of Wegener's hypothesis was that he had no explanation



Figure 7.6 Coal only forms in hot, swampy areas; glaciers only form in cold areas.

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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 1930, he and another team member were caught in a blizzard on an expedition in Greenland and did not survive. He was initially buried there with a pair of skis marking the grave but his brother built a pyramid-shaped mausoleum for him later on. At the time, his hypothesis was still yet to be accepted by the scientific community.

Harry Hess: seafloor spreading

Around 30 years after the death of Alfred Wegener, new evidence came to light that appeared to support the theory of continental drift. Harry Hess, a professor of geology at Princeton University in the United States, first became interested in the ocean floor while serving in the US navy during World War II. During this time, he had access to sonar which allowed him to create a map of the ocean floor. Sonar works by sending sound waves into the ocean; when they bounce back they are picked up as an echo. The time they take to bounce back indicates the depth of that part of the ocean.

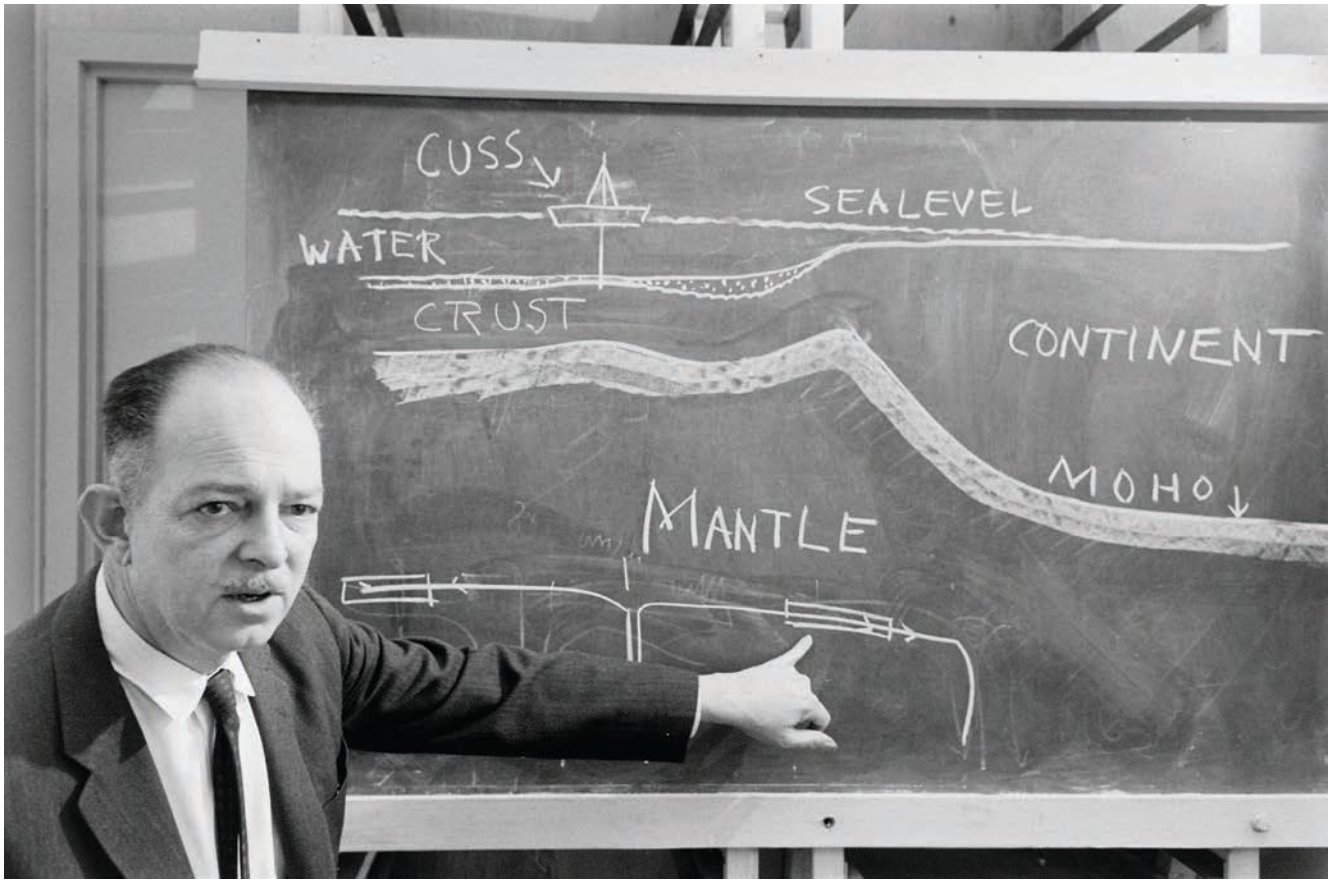


Figure 7.7 Harry Hess, a professor of geology who mapped the ocean floor

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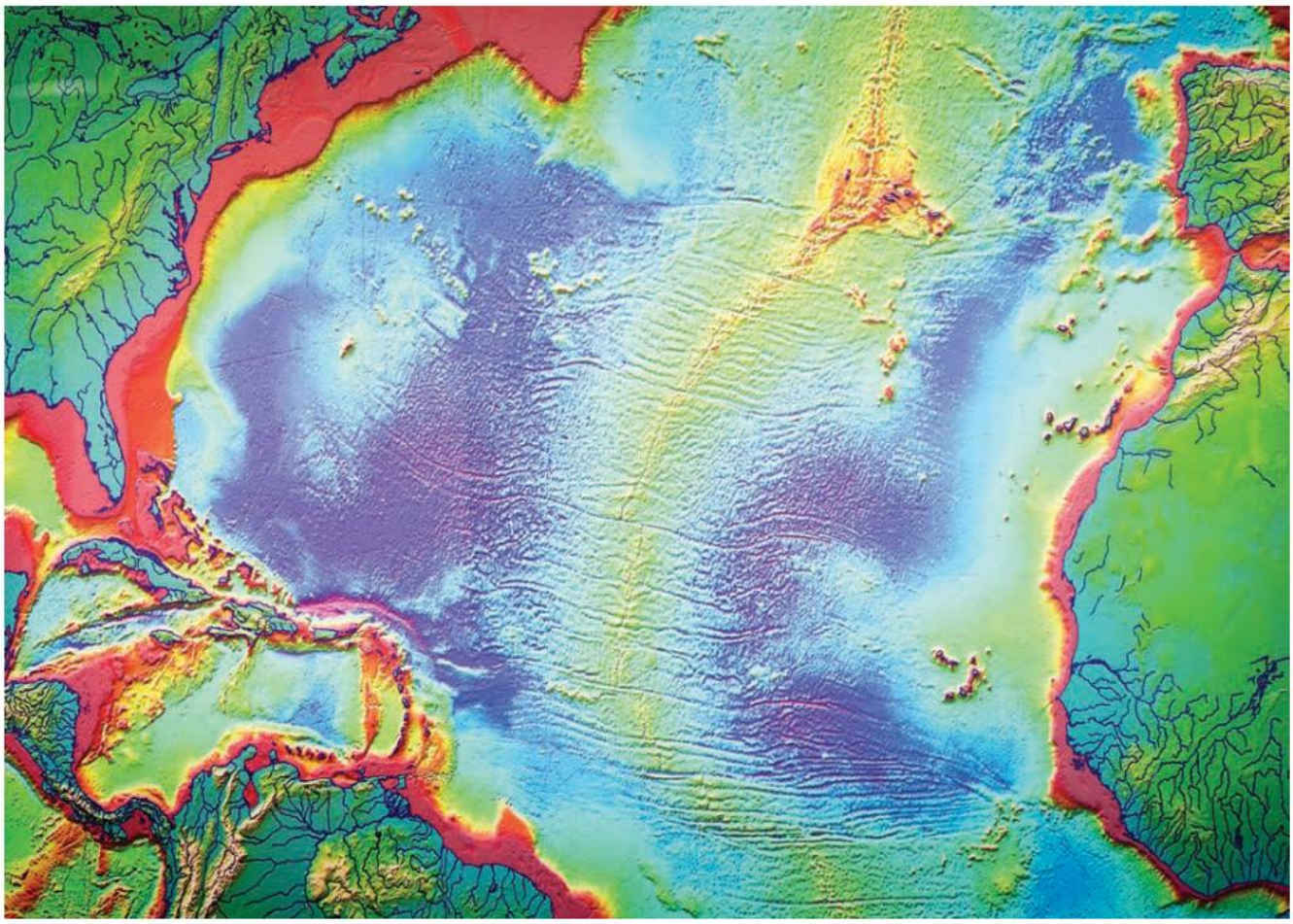


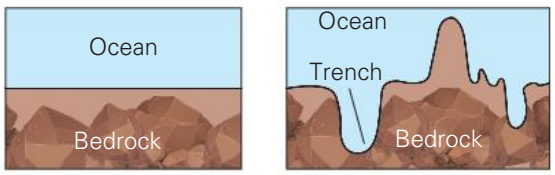
Figure 7.8 A map of the Mid-Atlantic Ridge and its volcanoes running down the middle of the Atlantic Ocean

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, underwater mountain ranges and volcanoes. What surprised Hess the most was that his findings appeared to show that the ocean floor was changing. He discovered mid-ocean ridges that were raised about 1.5 kilometres (km) above the flat sea floor.

In his book *The History of Ocean Basins*, Hess wrote that volcanoes lining up along these ocean ridges bring up molten rock from under Earth's crust. This molten rock cools and forms new oceanic rock. As more and more 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 on either side of the ocean must be doing the same. Hess also proposed that the old ocean floor was sinking in a process called subduction, forming ocean trenches, (as shown in Figure 7.9). You will look at subduction in more detail in the next section.



What people expected the ocean floor to look like

Harry Hess's map of the ocean floor

Figure 7.9 The sea floor is more interesting than was previously thought.

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Science as a human endeavour 7.1

Journey to the bottom of the sea

The Challenger Deep, located in the Mariana Trench in the western Pacific Ocean, is the deepest known point in the Earth's ocean, measuring a depth of 10994 metres. It is named after the Challenger expedition that made discoveries important to the foundation of oceanography during 1872–1876.



Figure 7.10 Trieste II was a deep-diving manned submarine built in 1964.

The first people to reach the bottom of the Challenger Deep were 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 that was very cramped for two adults and descended. About 9400 m down, they heard a loud bang, but as there appeared to be nothing wrong they carried on. Later they found out that a window had cracked.

Walsh and Piccard descended for nearly 5 hours, passing glowing creatures as they went. Finally, the cabin touched the ground, stirring the ocean floor beneath it. They waited for 20 minutes and then started the long ascent, which took 3 hours and 15 minutes, back to the surface.



Figure 7.11 Don Walsh (second from right) reached the bottom of the Mariana Trench in 1960.

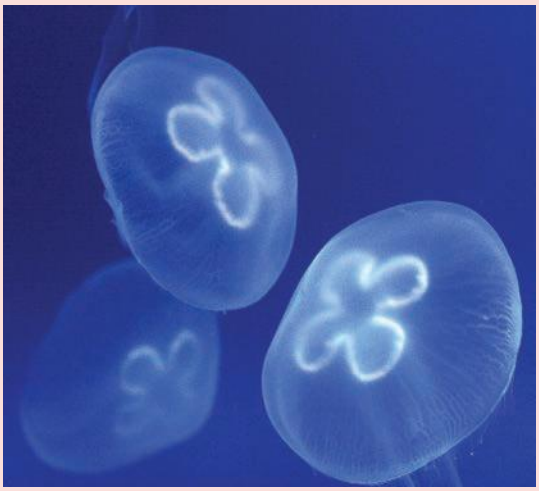


Figure 7.12 The only light that can be observed in the ocean depths is created by the animals that live there. This is called bioluminescence.

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Did you know? 7.1

Extreme exploration

In 2020, former NASA astronaut Kathryn Sullivan became the first person to both walk in space and descend to the deepest known point on Earth, after making the 11-kilometre ocean dive to the Challenger Deep. Her 3.5-hour space walk was in 1984.



Figure 7.13 Kathryn Sullivan

Quick check 7.2

1 Name the ridge located in the Atlantic Ocean.
2 Recall the name of the technique Harry Hess used to map the ocean floor.
3 Describe the results and major discovery of Harry Hess's ocean floor mapping.

Fredrick Vine, Drummond Matthews and Lawrence Morley: reading the ocean floor

A few years after Hess proposed his theory of seafloor spreading, further evidence was discovered to support his theory. Earlier work using magnetometers (which measure the direction of magnetic fields) showed that the sea floor has bands of alternating normal and reverse magnetism, running parallel to the mid-ocean ridges.

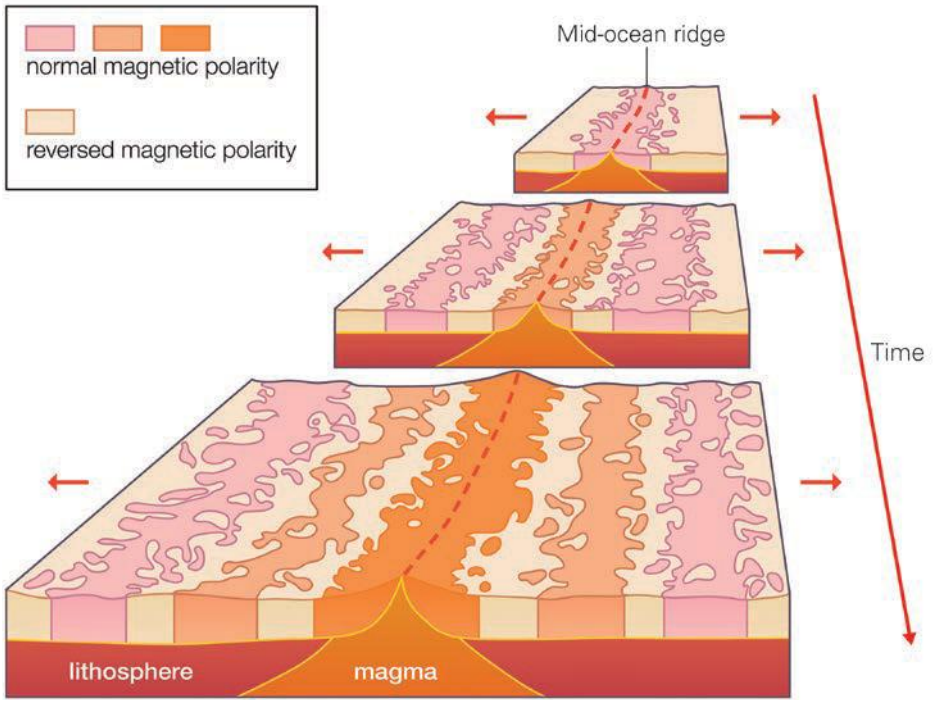


Figure 7.14 The pattern of magnetic stripes on the ocean floor

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Frederick Vine and Drummond Matthews, two British geologists, knew that the new molten rock produced by the ocean ridges contained magnetite, a magnetic mineral. While the molten rock cooled and solidified, the magnetite aligned with Earth's own magnetic field with its magnetic poles aligned with the Earth's magnetic poles. On average, Earth's magnetic field reverses direction every 450 000 years, and the cooling rock preserves the record of Earth's polarity at that time. For rocks to have their magnetic minerals aligned in different directions, they must have formed at different times. As the pattern of magnetic stripes leading away from the mid-ocean ridges is symmetrical, this led to Vine and Matthews to conclude that new sea floor was being added equally to each side of the ridge. At around the same time, but quite independently, Canadian geologist Lawrence Morley also saw the significance of the changes in the Earth's magnetic field, magnetism of new new oceanic crust and seafloor spreading as a mechanism for continental drift. That is why it is often called the Vine–Matthews–Morley hypothesis.

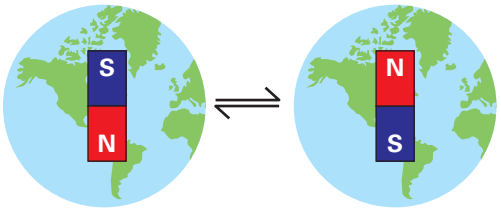


Figure 7.15 Earth's internal magnetic field has switched direction 183 times in the past 83 million years.

Explore! 7.1

Earth's magnetic field

On average, Earth's polarity switches in a full reversal every 450 000 years, though the actual time between reversals varies. The last time Earth's poles switched was 780 000 years ago. Use your preferred search engine to explore the following:

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 living organisms use Earth's magnetic field.
4. Discuss the consequences of Earth's magnetic field weakening for a significant period.



Figure 7.16 The next switching of Earth's magnetic field is overdue.

Further evidence to support the notion of seafloor spreading comes from the age of the rocks on the sea floor. If new rock is forming at the ridge and spreading out equally in opposite directions, you would expect that as you move further away from the ridge, the rock would increase in age. This is exactly what Vine, Matthews and Morley found.

Quick check 7.3

1. Identify the name of the mineral in molten rock that is magnetic.
2. Discuss what happens to this magnetic mineral when the molten rock cools.
3. Describe how the presence of magnetic stripes in rocks parallel to ocean ridges prove that the sea floor was spreading.
4. Identify another piece of evidence that supports Hess's theory of seafloor spreading.

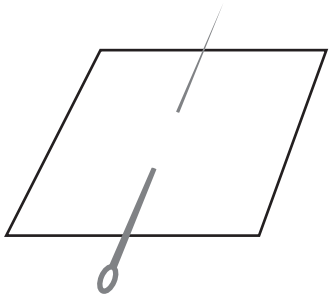
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Practical 7.1

Making a compass

Aim

To make a simple compass.



Materials

- 250 millilitres (mL) beaker half full of water
- steel or nickel sewing needle
- small square of paper
- bar magnet

Method

1. Draw the results table below.
2. Stroke the needle 20 times with the bar magnet. You must stroke in one direction only and with one end of the magnet only.
3. Thread the needle through the small square piece of paper as shown above.
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°

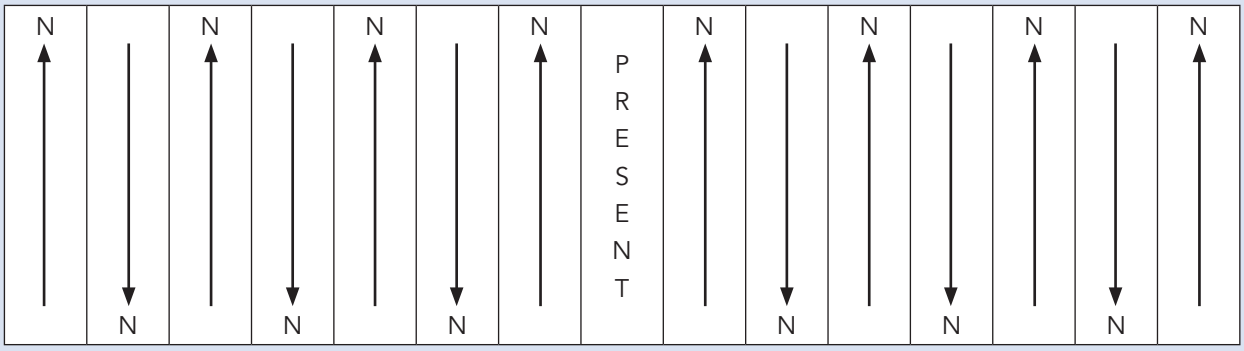
Discussion

1. Describe what happened to the magnetised needle when the beaker of water was rotated.
2. Explain the role of the paper in this experiment.
3. The needle in this experiment is acting as a temporary magnet. What is a temporary magnet and how does it differ from a permanent magnet?
4. Discuss the importance of having the needle magnetised only in one direction.

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Try this 7.1

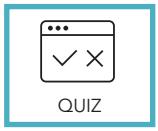
1 Get a piece of paper and re-create the diagram below, which shows the Earth's magnetic field changing over time from the present (centre) to the distant past (left and right edges).



2 Fold the paper in half in the middle of the section labelled 'Present'.
3 Put the paper into a gap between two tables with the two short ends of the paper on the tables' edges, and the reminder of the paper dropping down into the gap. Push the tables together so that the gap is closed and most of the paper cannot be seen.
4 Pull apart the ends of paper to show the movement of the sea floor away from an ocean ridge.

You have just modelled seafloor spreading!

Section 7.1 questions



Remembering

1 **Name** the theory proposed by each of the following scientists.
   a Alfred Wegener b Harry Hess
2 **Recall** the piece of evidence that supported Harry Hess's theory.

Understanding

3 **Describe** one piece of evidence that Wegener used to back up his theory.
4 **Explain** why Wegener's theory was not accepted during his lifetime.
5 **Communicate** using labelled diagrams the results of Harry Hess's mapping of the ocean floor.
6 **Describe** how sonar works.
7 **Summarise** 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 volcanoes.
9 **Distinguish** between magnetic striping and magnetic field reversal.

Analysing

10 **Compare** the properties of oceanic rock as you move away from a mid-ocean ridge.
11 **Classify** the following as theory or evidence.
   a The sea floor spreads away from a mid-ocean ridge.
   b The rock is older the further away from a ridge.
   c The continents drifted away from one another.
   d Rock types on different continents match up with one another.

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Evaluating

12 **Deduce** what would happen to a compass if Earth's magnetic field was to change direction now.

13 With the examples of Alfred Wegener and Harry Hess, **evaluate** the impact of scientific ideas accepted at a time on the willingness of the scientific community to adopt new theories.

7.2 Plate tectonics and plate movement

WORKSHEET

Learning goals

1 To be able to list the four layers of the Earth.
2 To be able to explain how tectonic plates move.
3 To be able to describe the consequence of three types of plate boundaries.

crust
the top layer of the Earth, which supports all life on Earth

mantle
the layer of the Earth underneath the crust, which is made up of mostly solid rock and is where convection currents take place

core
the inner part of Earth's structure

lithosphere
the solid outer layer of Earth consisting of the crust and top layer of the upper mantle. It is split into giant slabs called tectonic plates.

asthenosphere
the softer layer of rock under the lithosphere

With the help of Harry Hess, Fredrick Vine, Drummond Matthews and Lawrence Morley, evidence for Wegener's theory of continental drift was mounting. But in order to explain how the continents moved, scientists needed to understand more about the structure of Earth.

Earth is made up of four layers: the **crust**, **mantle**, outer **core** and inner core. The mantle is divided into a lower and upper mantle. The **lithosphere** consists of the topmost layer of the upper mantle, which is solid, and the crust. The **asthenosphere** is the softer layer of rock in the upper mantle, under the lithosphere.

The 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

VIDEO
Plate tectonics

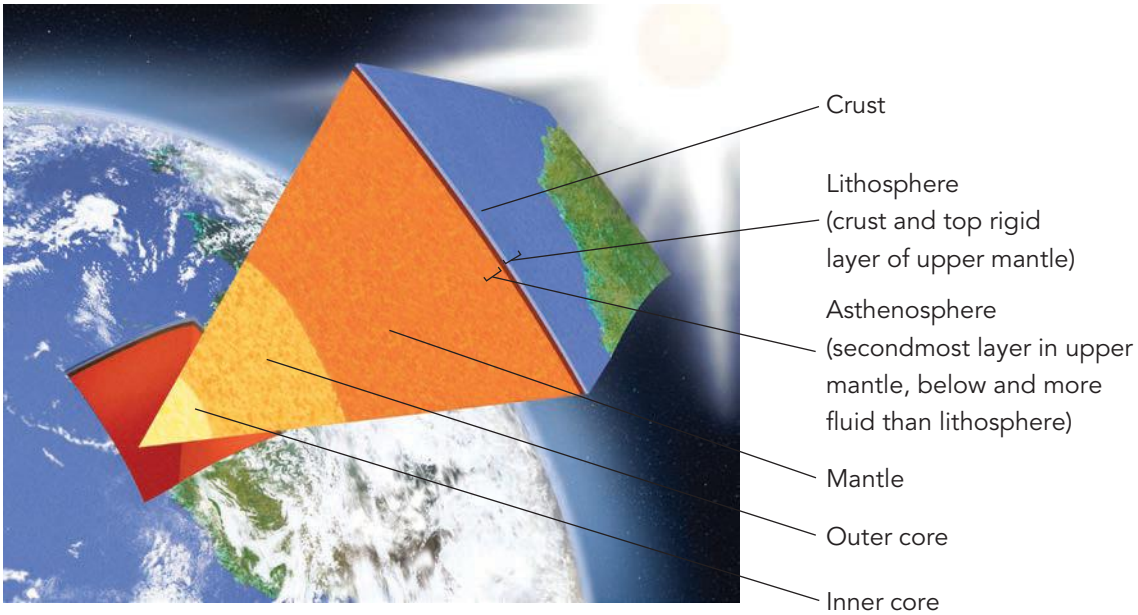


Figure 7.17 Earth's layers

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the Sun, these metals are in solid form due to the intense pressure from all the layers above. The outer core is completely liquid and, like the inner core, contains heavy metals. The mantle is mostly made of semi-molten rock 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 continents and continental shelves make up the continental crust.

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 proposed that Earth's surface is split into **tectonic plates**, gigantic slabs of rigid rock, which float on the Earth's asthenosphere.

plate tectonics
the theory that the Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

tectonic plates
gigantic slabs of rigid rock which float on the Earth's asthenosphere

Quick check 7.4

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.

Tectonic plates

Figure 7.18 depicts the major tectonic plates, which are named after the continents that lie on them. Australia is situated in the middle of the Australian Plate, which is largely the reason why Australia does not experience significant geological activity. You will find out more about this in the next section. There are a few major plates and dozens of smaller or minor plates. No matter how small, every tectonic plate plays a role in shaping the Earth. One of the smallest plates, the Juan de Fuca Plate, located off the eastern coast of North America, is largely responsible for the volcanic activity there.

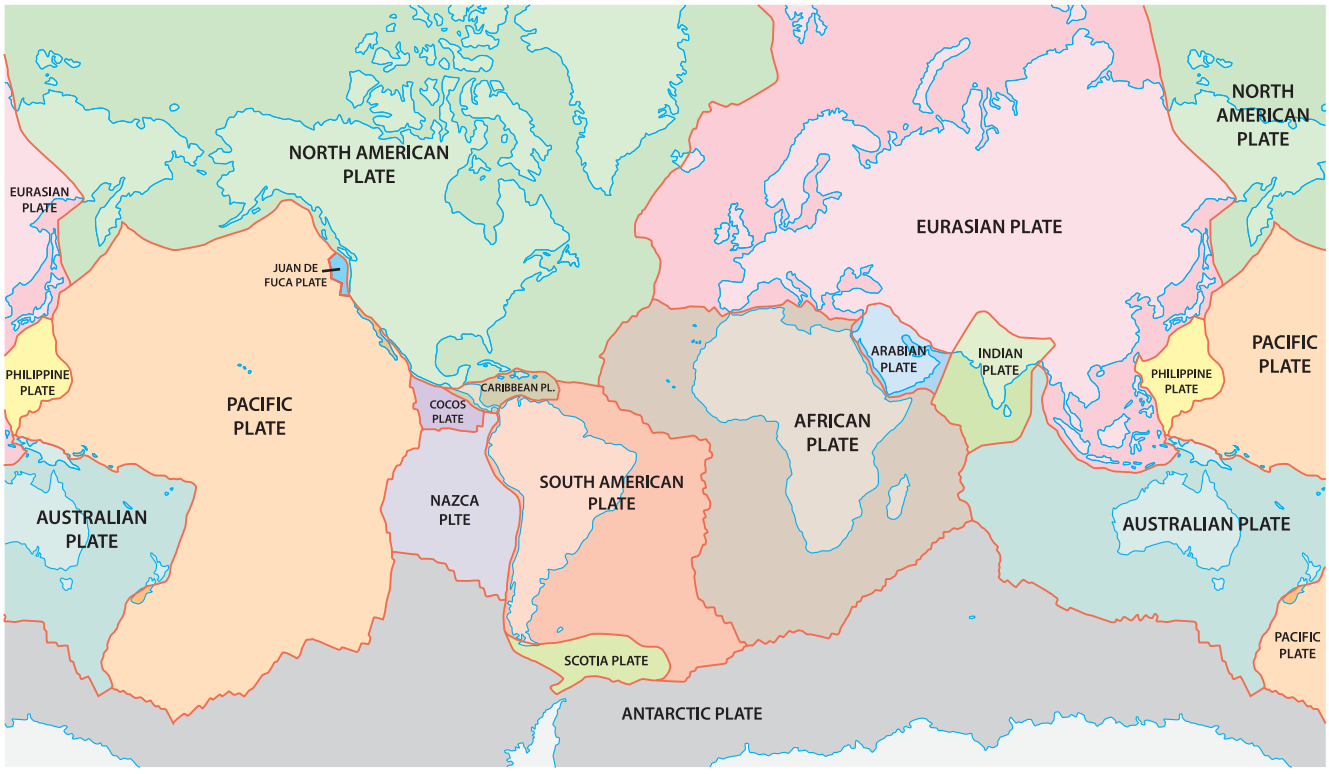


Figure 7.18 The major and some minor tectonic plates on Earth's surface

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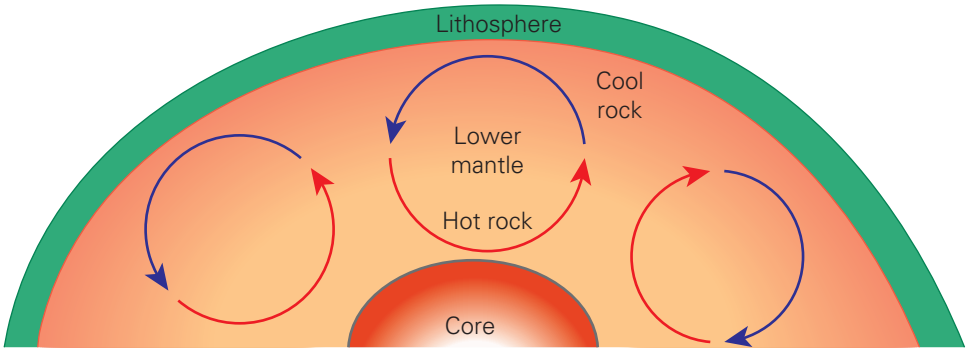


Figure 7.19 Convection currents in Earth's mantle drive the movement of the tectonic plates.

How do the plates move?

Tectonic plates, which are made from pieces of the crust and the topmost rigid layer of the upper mantle (referred to as the lithosphere), float on top of the asthenosphere, the next layer down in the upper mantle. In the top layer of the upper mantle (the lithosphere) the rock is hard, but lower down in the asthenosphere, the rock is softer and beginning to melt in places, a little bit like toffee when it is heated. In the lower mantle, the rock becomes more solid due to the weight of the rock above it.

convection currents movement of rock within Earth's mantle due to temperature differences between the upper and lower layers

The temperature increases at lower depths of the mantle and 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 rock in the lower mantle, causing it to become less dense and rise towards the crust. As it rises towards the cooler surface, it begins to cool down and become denser. It is pushed aside by the hot rock that is still rising and falls back towards the core, as shown in Figure 7.19. This cycle of hot rock rising and cooler rock sinking is called a convection cycle and is caused by **convection currents** in Earth's lower mantle.

At the top of each cycle, the sideways movement of the cooling rock in the mantle causes the movement of the tectonic plates above it. Figure 7.20 shows what can happen when the sideways movements of rocks in the mantle are in opposite directions.

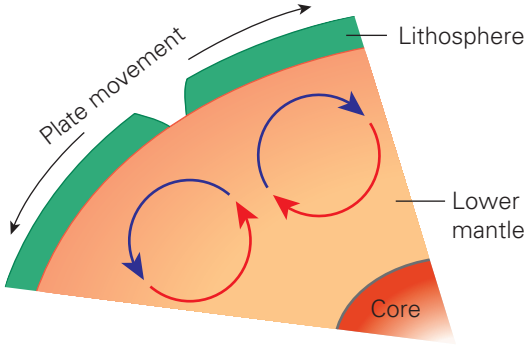


Figure 7.20 The sideways movement of rock in this example causes the tectonic plates to move in opposite directions, away from each other.

Quick check 7.5

1. Recall how the major tectonic plates are named.
2. Describe the differences in structure between the rocks in the upper and lower mantle.
3. Explain why hot rock rises.
4. Describe how this movement of rocks in the mantle drives the movement of tectonic plates.

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Practical 7.2

Observing convection currents

Aim

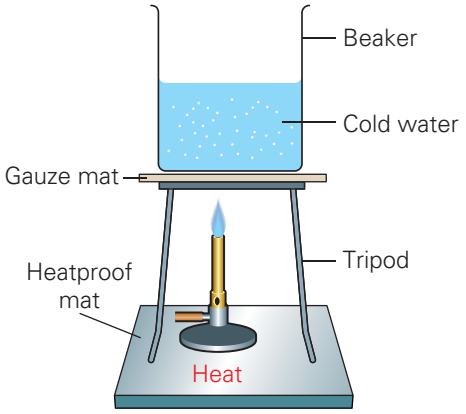
To observe convection currents.

Materials

- dark food colouring
- cold water
- 250 mL beaker
- ice cube tray
- Bunsen burner
- gauze mat
- tripod
- heatproof mat

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 observe the water.

Results

Record your observations.

Discussion

1 Describe what happened to the ice cube when it hit the warm water.
2 Describe the distribution of the coloured water from the ice cube just after it had melted.
3 Explain what you observed.
4 Discuss what happened to the distribution of the coloured water from the ice cube as the Bunsen burner heated up the water.
5 Explain what you observed.
6 Describe and explain the appearance of the water at the end of the experiment.
7 Draw a labelled diagram to show what was happening to the water in the beaker.

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How fast is Australia moving?

Australia is situated in the middle of the Australian Plate. Since the last adjustment was made to Global Positioning System (**GPS**) coordinates in 1994, the continent has moved 1.5 m. That's about 7 centimetres (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 which uses an approximately 1:100 000 000 scale, meaning 1 cm on the map corresponds to 1000 km on the ground. You will see that to represent a shift of 1.5 m would make little observable difference to of the map. It is only important to the mapping systems, such as the GPS used worldwide for navigation, and other applications that rely on very accurate mapping, such as traffic signal timing and synchronisation of mobile phone base stations.

GPS
Global Positioning System, a radio navigation system that allows land, sea and airborne users to determine their exact location, velocity and time

plate boundaries
the edges where two tectonic plates meet

What happens at plate boundaries?

You have learned that convection currents in Earth's mantle cause the tectonic plates floating on top to move in different directions. The direction of plate movement causes different types of **plate boundaries** to form. Figure 7.22 shows the major tectonic plates and the direction they are travelling. There are three types of plate boundaries: destructive (convergent), constructive (divergent) and transform (conservative), relating to the movement of plates towards, away and alongside each other.

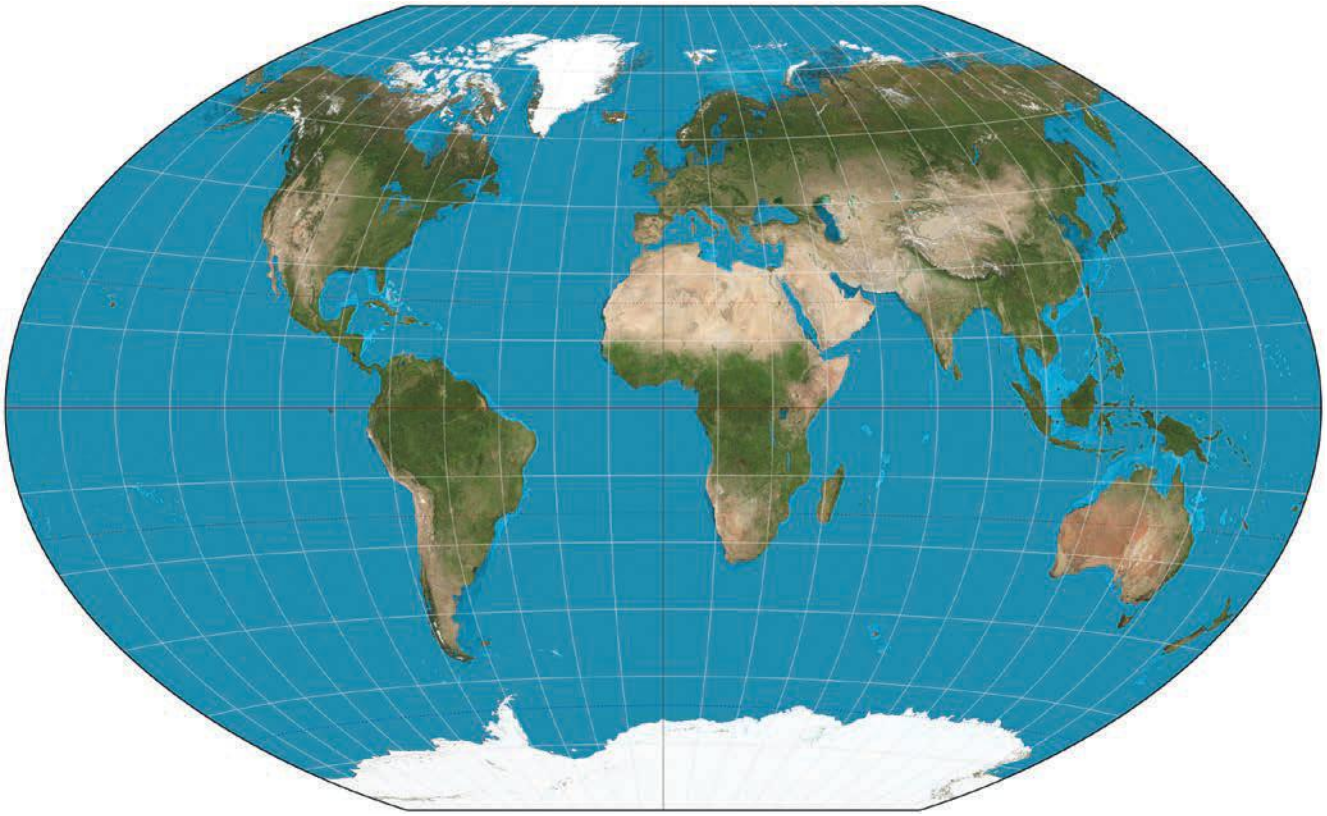


Figure 7.21 Maps drawn using 1994 (and older) GPS data do not show Australia in its correct geographical location due to the relatively fast movement of the Australian Plate.

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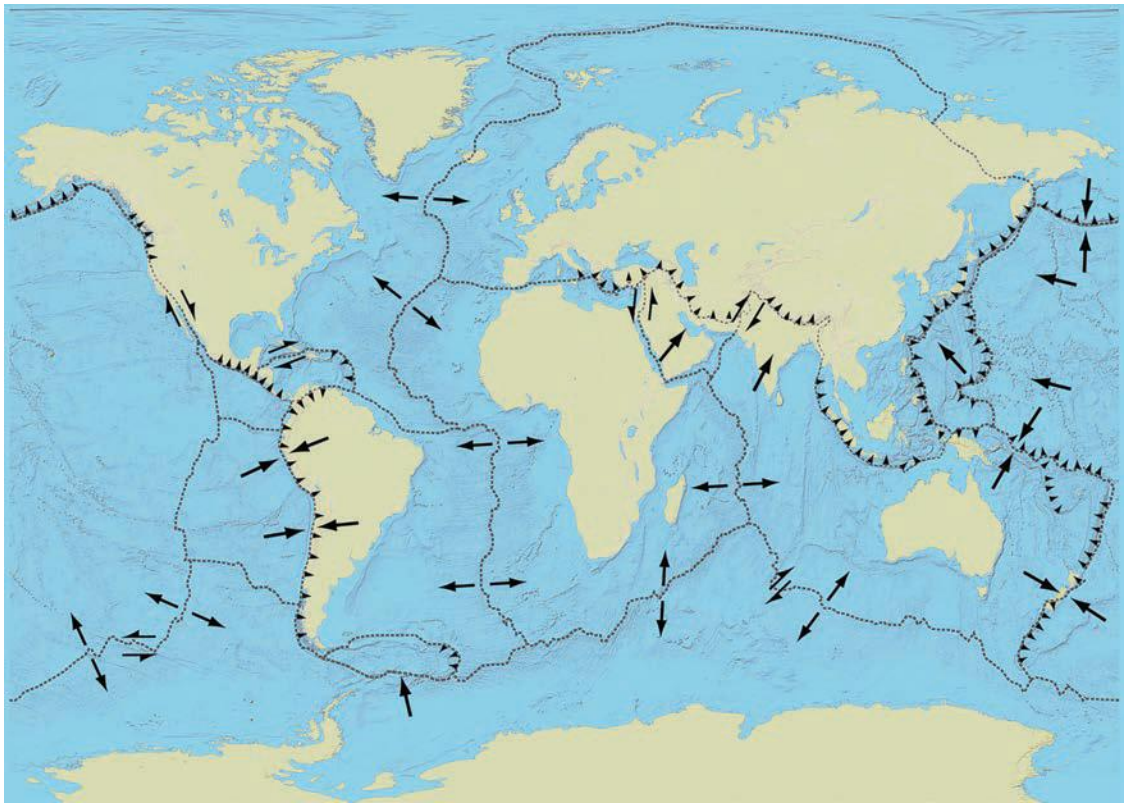


Figure 7.22 The major tectonic plates and their direction of travel. The small triangles on the lines indicate a convergent plate boundary.

Explore! 7.2

The Chile Triple Junction

The Chile Triple Junction is located on the sea floor of the Pacific Ocean off the southern coast of Chile. Use your preferred search engine to answer the following questions.

1. List which three tectonic plates meet at the Chile Triple Junction.
2. Discuss why the triple junction is unusual.

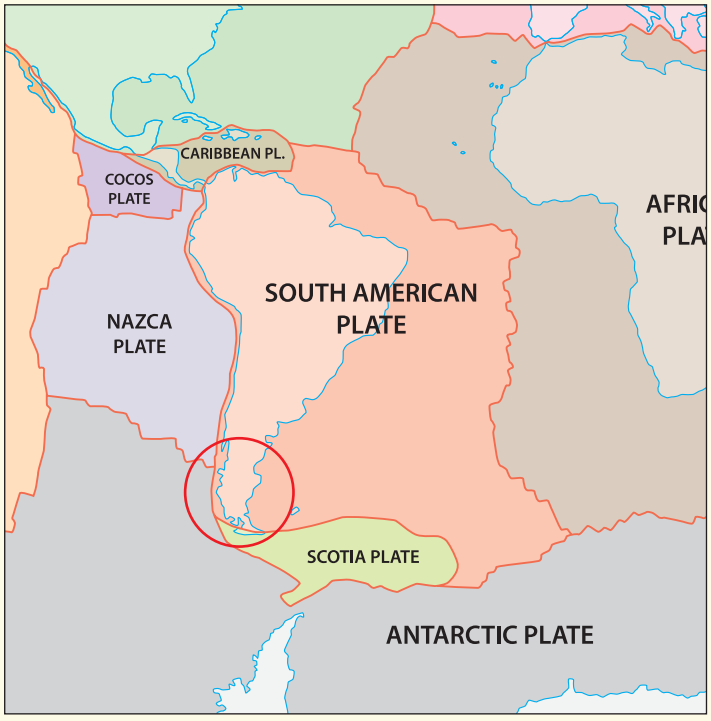


Figure 7.23 The Chile Triple Junction

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Destructive boundaries

When plates are moving towards one another, this is called a **destructive** plate boundary. These boundaries are destructive because as they collide, some of the Earth's crust melts and forms magma. The plates are colliding, so they are also called **convergent** plate boundaries. The effects and the features that form at these boundaries depend on what the two plates are made from. You have already learned that there are two types of crust: oceanic and continental. Oceanic crust is thin and dense; in comparison, continental crust is thicker and less dense. So, what happens when plates with two different types of crust on top of the upper mantle collide?

destructive (convergent) a type of plate boundary that occurs when plates move towards one another

subduction when the denser oceanic plate sinks underneath less dense continental plate

magma hot liquid rock found just below the surface of the Earth

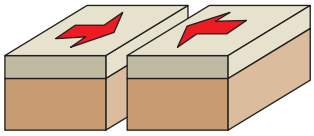


Figure 7.24 A destructive, or convergent, plate boundary

Quick check 7.6

1 Describe the movement of plates at a destructive plate boundary.
2 What affects the features that form at this type of plate boundary?

When an oceanic plate meets a continental plate

As the plate with the oceanic crust is denser than the plate with the continental crust, when they collide, the denser oceanic plate will sink underneath the continental plate in a process called **subduction**. As the oceanic plate sinks deeper and deeper into the mantle, it begins to melt, forming **magma**. This magma can rise up through the continental plate to form volcanoes.

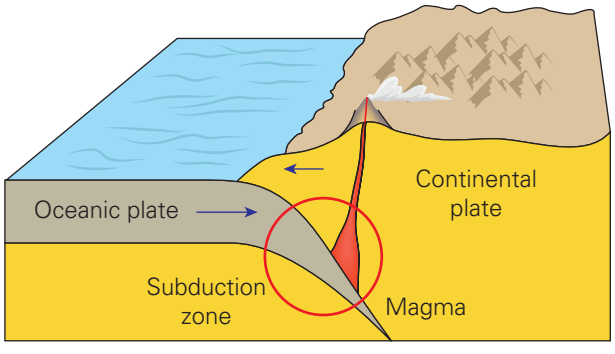


Figure 7.25 A subduction zone forms when the denser oceanic plate subducts underneath the less dense continental plate.

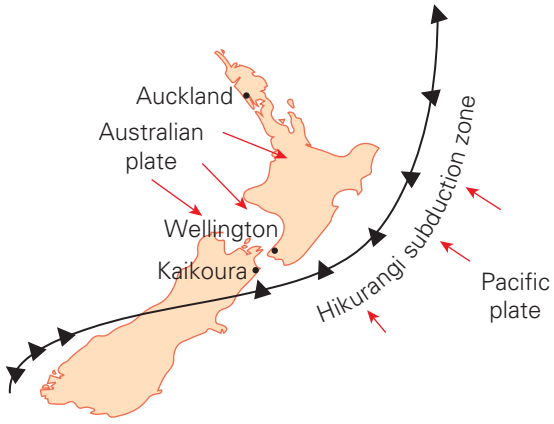


Figure 7.26 The Hikurangi subduction zone is located off the coast of New Zealand's North Island.

The Hikurangi subduction zone located off the east coast of the North Island of New Zealand has formed because of the subduction of the Pacific Plate underneath the Australian Plate. It poses the largest threat of earthquakes and tsunamis to the residents of New Zealand.

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.

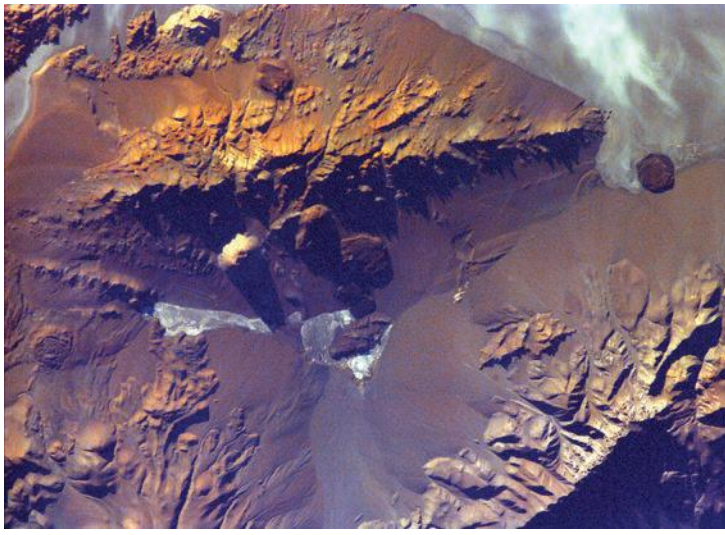


Figure 7.27 The Andes mountains in South America formed due to the subduction of the Nazca plate underneath the South American plate.

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When two continental plates meet

In this case, both plates have the same density, so when they collide, subduction does not take place. Instead, the crust buckles and breaks down. The pressure of the collision forces the damaged crust upwards, eventually forming mountains.

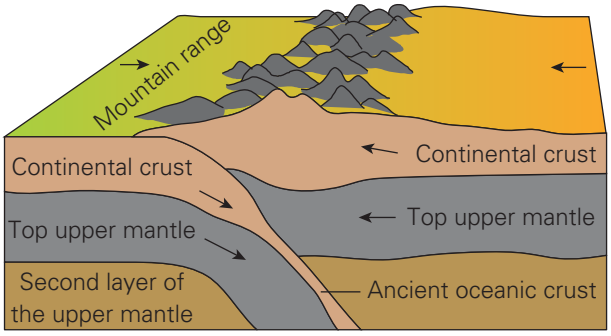


Figure 7.28 The formation of mountains when two continental plates collide

The Indian Plate and the Eurasian Plate are colliding in this type of boundary. These plates collided over 50 million years ago, causing a huge uplift of the land and forming 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, the collision may create a ridge instead, potentially forming islands.

Quick check 7.7

1 State the term which describes the action of one plate sinking underneath another.
2 List some of the features that can form at destructive plate boundaries.
3 Discuss why subduction does not take place when two continental plates collide.

Practical 7.3

How dense are different rocks?

Aim

To compare the densities of different rock types.

Materials

- 4 different types of rock (basalt, granite, sandstone and chalk)
- 10 mL measuring cylinder
- displacement can
- balance

Method

1 Draw the results table below.
2 Measure the mass of each rock type and record in your results table.

continued…

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…continued

3 Fill the displacement can with water.
4 Holding the 10 mL measuring cylinder at the spout of the displacement can, gently drop in one of the rocks.
5 Record the volume of water expelled in cubic centimetres (cm^3) in the results table. (Note: 1 mL = 1 cm^3)
6 Repeat twice more with the same piece of rock, refilling the can before each procedure.
7 Following the same procedure, repeat for the other rock types.
8 Calculate the average volume of water expelled from the displacement can.
9 Using the formula below, calculate the density of each rock type.

$$\text{density (g/cm}^3\text{)} = \frac{\text{mass (g)}}{\text{volume (cm}^3\text{)}}$$

Results

Type of rock	Mass (g)	Volume of water expelled (cm^3)			Mean volume (cm^3)	Density (g/cm^3)
		1	2	3		
Basalt						
Granite						
Sandstone						
Chalk						

Discussion

1 Organise the rocks from most dense to least dense.
2 Using your results, explain why oceanic crust made of basalt subducts underneath continental crust made predominantly of granite at **destructive** plate boundaries.
3 Explain why the experiment was conducted three times for each rock type.
4 Explain why you should always measure at the bottom of the meniscus when measuring water levels.
5 Compare the density of each rock that you calculated to densities obtained from secondary sources on the internet. How close were you to those values?

Did you know? 7.2

As the Eurasian and Indian plates are constantly moving towards each other, Mount Everest – the highest mountain in the world at 8850 m above sea level – is actually getting taller each year, by 4 millimetres (mm) in fact. If your ambition is to climb Mount Everest, then you had better do it sooner, rather than later, if you do not want to have to climb even further!

Constructive boundaries

Plates moving away from one another are called **constructive** plate boundaries. They are boundary more widely known as **divergent** plate boundaries and can occur beneath the ocean or on land.

constructive (divergent) a type of plate boundary that occurs when plates move away from one another

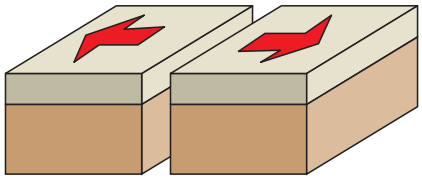


Figure 7.30 At constructive plate boundaries, plates move apart.

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In the ocean

When plates move apart in the ocean, magma (molten rock) rises to fill the gap. As it reaches the colder surface, the magma cools, forming igneous rock and gradually building more oceanic crust. The Mid-Atlantic Ridge, a series of underwater volcanoes running down the Atlantic Ocean between Africa and America, is an example of this type of plate boundary. Here, the North American and South American plates are moving away from the Eurasian and African plates.



Figure 7.31 Basalt rocks in a volcanic crater near Portugal.

On land

Constructive plate boundaries that occur on land form rift zones. An active rift zone is currently dividing Eastern Africa from the rest of Africa. This rift will eventually be filled with ocean, creating a new island version of East Africa. It is already having damaging effects with major roads in cities cracking and caving under the strain. Scientists think the rift zone is moving so fast due to a superplume. A superplume occurs when heat from Earth's core rises up through the mantle, intensifying the convection currents and causing the plates to separate much faster.



Figure 7.32 Thingvellir in Iceland is part of a fissure zone running through the country, which is situated on the tectonic plate boundaries of the Mid-Atlantic Ridge.

VIDEO
Describe what causes an earthquake

Quick check 7.8

1. Describe the movement of plates at a constructive plate boundary.
2. List some of the features which can form at this type of boundary.
3. Why are constructive plate boundaries also known as divergent boundaries?

Transform boundaries

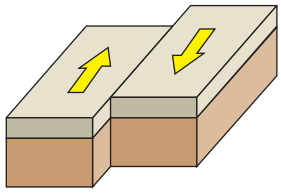


Figure 7.33 At transform plate boundaries, plates slide past one another.

transform
a type of plate boundary that occurs when plates move parallel to 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 that is 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, which runs down the east coast of North America through California. Here, the North American Plate and the Pacific Plate are sliding past each other.

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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

Quick check 7.9

1 Describe the movement of plates at a transform plate boundary.
2 List one of the characteristics of this type of boundary.
3 Explain why transform plate boundaries are also known as conservative boundaries.

Table 7.1 summarises each type of plate boundary.

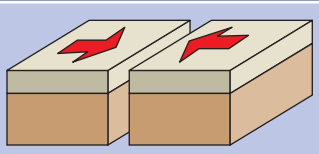
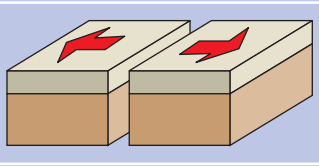
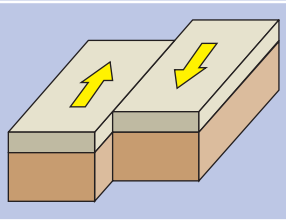
Type of boundary	Diagram	Type of movement	What happens to the crust?	Key features
Destructive (convergent)		Plates move towards each other.	Destroyed	Mountains Trenches Subduction zones Volcanoes Earthquakes
Constructive (divergent)		Plates move away from each other.	Created	Volcanoes Rifts Ocean ridges
Transform (conservative)		Plates move parallel to each other in opposite directions.	Conserved	Earthquakes

Table 7.1 A summary of each type of plate boundary

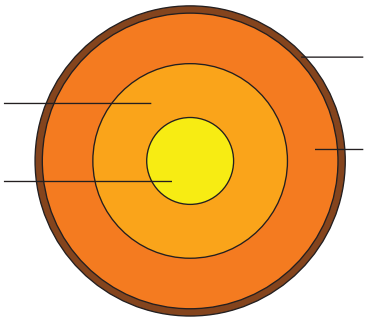
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Section 7.2 questions



Remembering

1 **Name** the three types of plate boundaries.
2 **State** the name of the mechanism which causes tectonic plates to move.
3 **Select** the correct words to label the following diagram of 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 **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
7 **Describe** how temperature affects the structure of rocks in the mantle.
8 **Explain** why the physical states of the inner and outer core differ.

Applying

9 At destructive plate boundaries, crust is destroyed. **Explain** why the overall amount of crust on the Earth has stayed the same despite this destruction.
10 **Summarise** how magma forms at a subduction zone.

Analysing

11 **Compare** oceanic and continental crusts.

Evaluating

12 **Propose** why mountains and trenches continue to increase in size.
13 **Construct** a labelled diagram to show an oceanic plate subducting underneath a continental plate.
14 **Propose** reasons why countries like Australia do not experience significant amounts of geological activity.
15 **Discuss** why tectonic plates move across the surface of the Earth.
16 **Propose** your own reasons why some tectonic plates move faster than others.

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7.3 The effects of plate movement

WORKSHEET

Learning goals

1 To be able to describe how volcanoes, earthquakes and tsunamis form.
2 To distinguish between S and P waves and the information they provide about earthquakes.

If you live near a plate boundary, you are at risk of experiencing some of the geological activity discussed. In this section, you will examine the reasons for, and effects of, three types of disasters that can occur at plate boundaries.

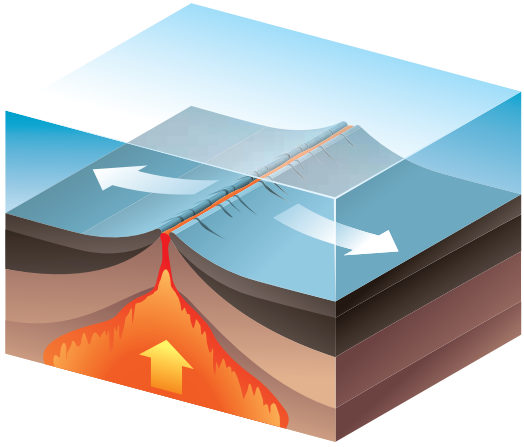


Figure 7.36 A constructive plate boundary forms where magma rises to fill the gap when the plates move apart.

Volcanoes

Where do volcanoes form?

Volcanoes can form at two types of plate boundaries. When two plates move apart at a constructive plate boundary, magma rises and seeps into the gap, as in Figure 7.36.

At a destructive boundary (particularly at subduction zones), friction caused by one plate subducting underneath another produces intense heat. This heat is enough to melt the rock of the subducting plate, forming magma. As the magma rises to the surface, it will form volcanoes.

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 in the northern Pacific Ocean. They are made up of a long chain of volcanoes associated with the Aleutian Trench.

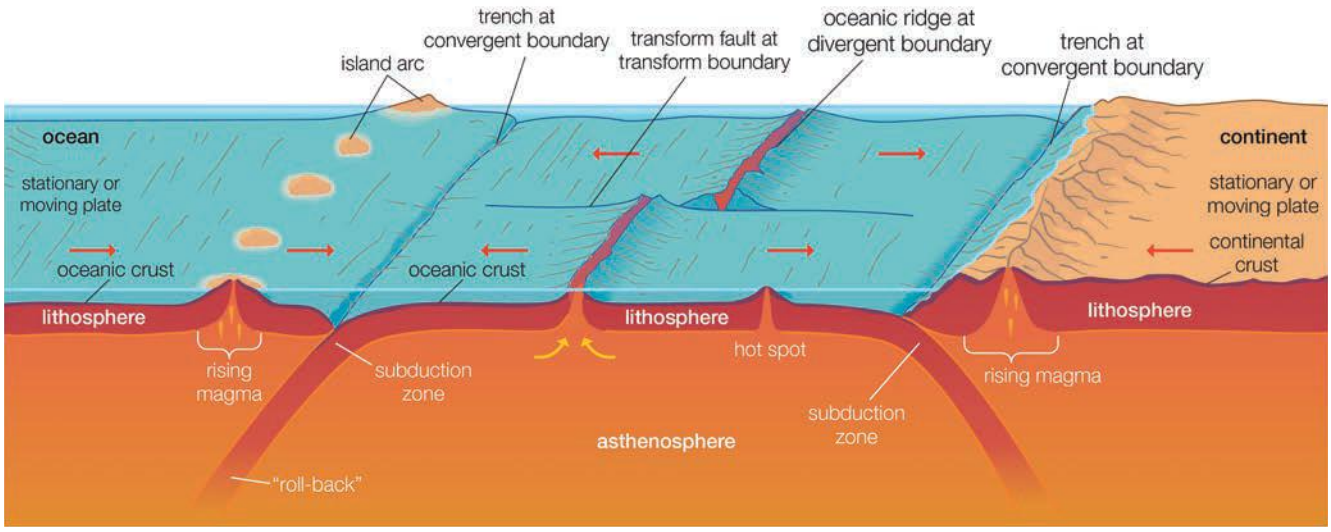


Figure 7.37 Volcanoes can form at destructive (convergent) and constructive (divergent) plate boundaries.

Over three-quarters of the world's active volcanoes can be found in an area called the Pacific Ring of Fire, the shape of which can be seen in Figure 7.38.

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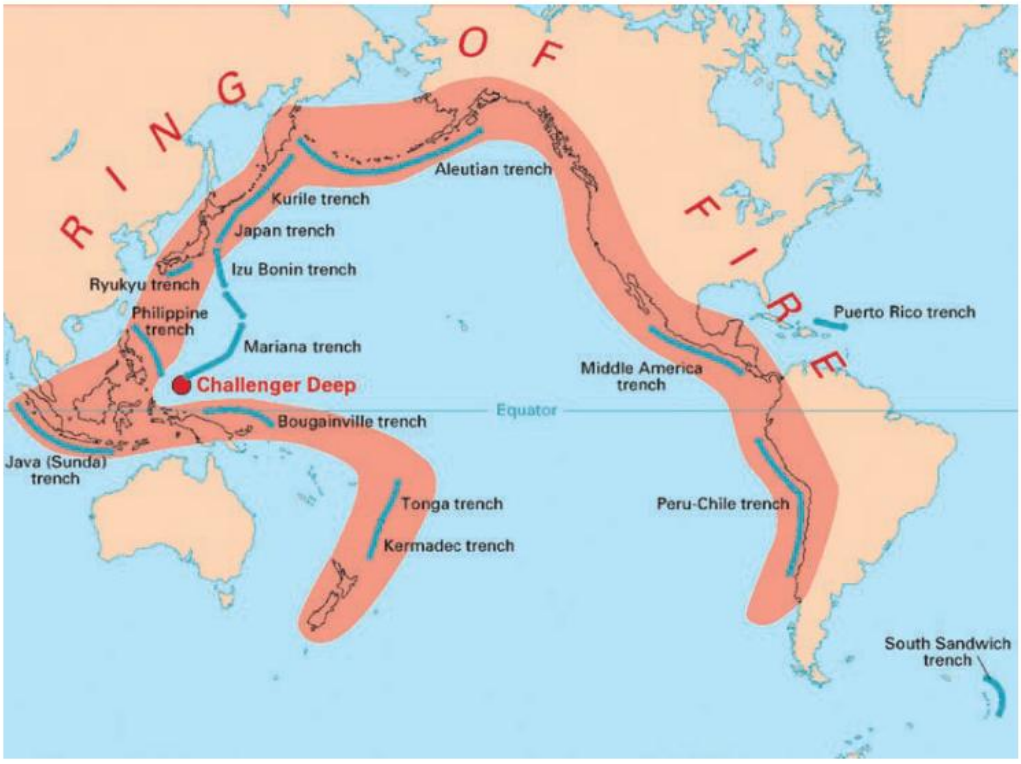


Figure 7.38 The Ring of Fire is an active area of many subduction zones around the Pacific Ocean.

VIDEO
Island hotspots

Volcanoes are unique geological features in that they do not always occur where two plates meet. They can form anywhere that a **hotspot** exists. A hotspot is a pocket of magma that sits just underneath the crust. It has the potential to erupt at any time, forming volcanoes. As the tectonic plate above the hotspot moves, the volcano created by the hotspot also moves, allowing for another hotspot volcano to form. Chains of volcanic islands like the Hawaiian Islands have been made in this way.

hotspot
a pocket of magma that sits just underneath the crust

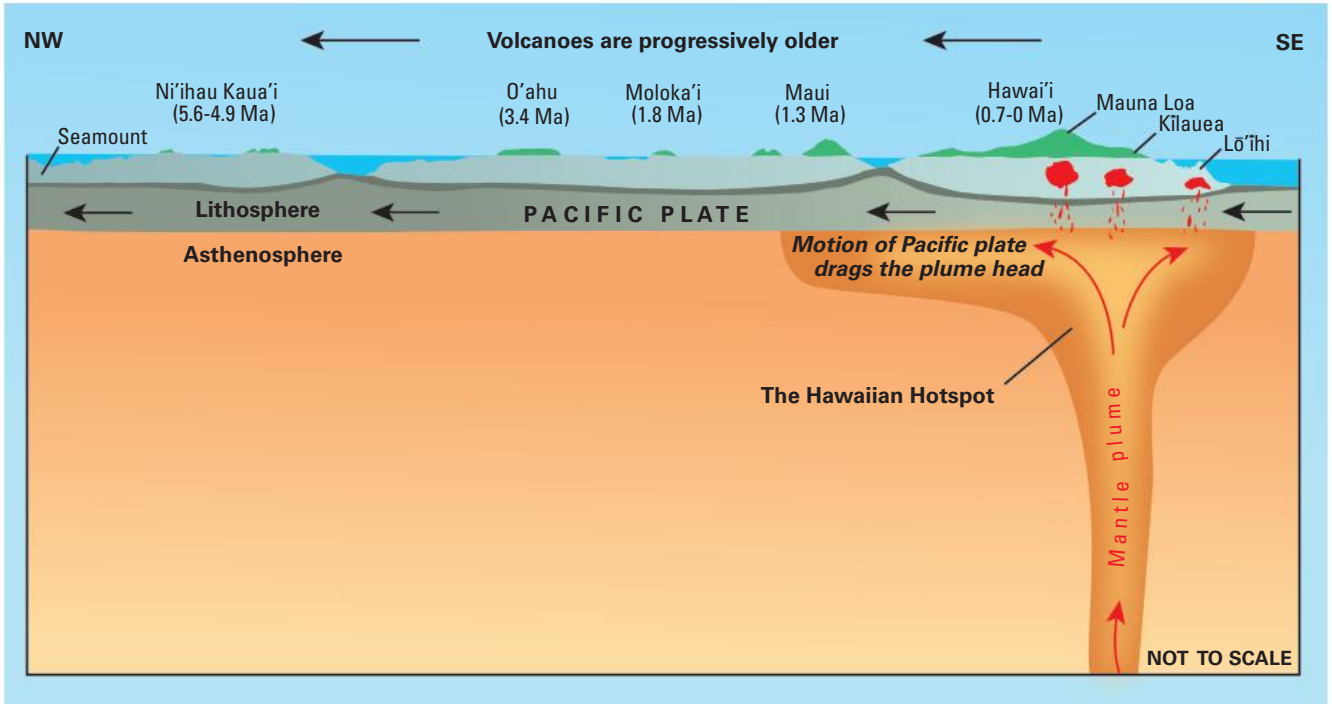


Figure 7.39 The Hawaiian island chain formed as the Pacific plate moves across a hotspot. The oldest island, Ni'ihau, formed around 5.6 million years ago (Ma) and the top of the newest volcano, Lo'ihi, is less than 1000 m below the sea surface.

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Quick check 7.10

1 Recall at what type of plate boundaries volcanoes occur.
2 Name the area of the world that contains the greatest number of active volcanoes.
3 Discuss what hotspot volcanoes are and how they differ from volcanoes formed in other ways.

What happens during a volcanic eruption?

When the pressure of the magma rising to the surface increases quickly, a volcano can erupt. When magma reaches the surface, it is called **lava**. The type of lava produced by a volcano makes a huge difference to the effects of a volcanic eruption. Lava with large amounts of silica is viscous (thick and sticky) like golden syrup. Air pockets can build up in viscous lava leading to a very explosive eruption. Lava 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

pyroclastic
consisting of or relating to small pieces of rock from a volcano

Lava is not the only hazard of a volcanic eruption. Gas and ash clouds, acidic gas causing acid rain and **pyroclastic** flows made up of hot gas and rock can also cause major damage, not only to the surrounding areas but across the world, as shown in Figure 7.41.



Figure 7.40 The viscosity of the lava has a huge effect on the damage caused by a volcanic eruption.



Figure 7.41 Pyroclastic flows from the eruption of the Sinabung volcano in Indonesia in October 2017

Quick check 7.11

1 Distinguish between magma and lava.
2 Explain how the viscosity of lava affects a volcanic eruption.

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Explore! 7.3

Iceland's Eyjafjallajökull volcanic eruption in 2010

In 2010, the Eyjafjallajökull volcano in Iceland erupted, throwing volcanic ash several kilometres into the air. Conduct was research to answer the following questions.

1. 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, or if their effects can reach around the world. Use this case study as an example in your answer.

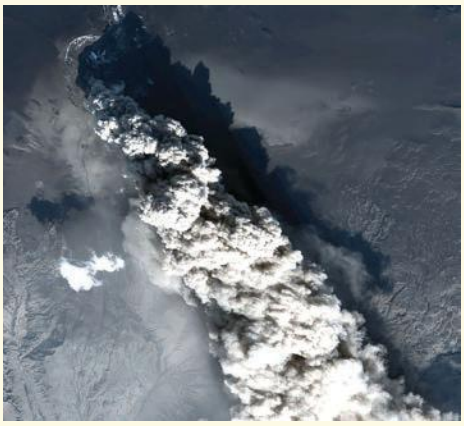


Figure 7.42 This satellite image shows the volcanic ash thrown out of Iceland's Eyjafjallajökull volcano in 2010 from the force of the eruption.

Earthquakes and tsunamis

Where do earthquakes occur?

Earthquakes occur when there is a sudden movement of land. This can happen at a transform or destructive (convergent) plate boundary. Friction between two plates must be overcome before the plates can slide past each other. When the driving force is strong enough to overcome this friction, the two plates will suddenly move, sending out waves of energy called **seismic waves**. The exact point under the Earth where the earthquake occurs is called the **focus**. The point directly above the focus, on the surface of the Earth is called the **epicentre**.

How are earthquakes detected?

Earthquakes are detected by using an instrument 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.

When the land moves from side to side, the base remains fixed to the ground and moves with it, but the mass on the end of the spring stays in its original position. It is not affected by the movement of the ground.

seismic wave
wave that moves through Earth during an earthquake

focus
the exact point under the surface of the Earth where the earthquake occurs

epicentre
the location on Earth's surface directly above the focus of an earthquake

seismometer
an instrument that measures the intensity and duration of seismic waves during an earthquake

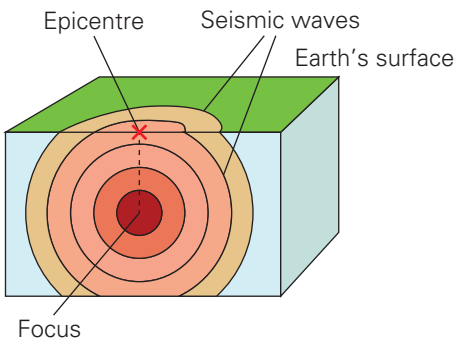


Figure 7.43 A diagram showing the location of an earthquake's focus and epicentre

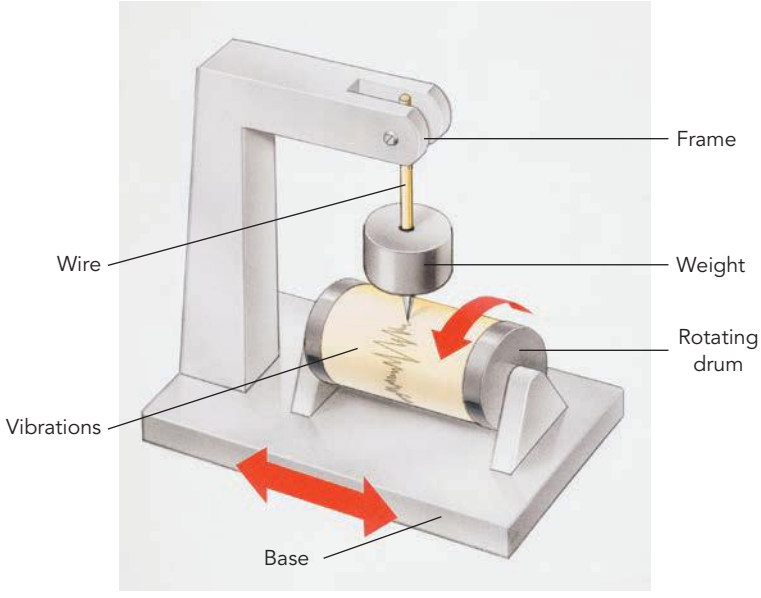


Figure 7.44 A simple seismometer

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	P waves	S waves
Name	Primary	Secondary
Speed	Fast	Slow
Movement	Longitudinal (back and forth)	Transverse (side to side or up and down)
Materials they can travel through	Liquids and solids	Solids only
Level of damage caused	Minimal damage to buildings from up and down movements	Very destructive due to side to side movements

Table 7.2 The properties of P and S waves

seismogram
the pattern produced when seismic activity is recorded by a seismometer

lag time
the time between the arrival of the P and S waves of an earthquake

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 digital seismometers are also available for many smartphones.

The two main types of seismic waves produced by an earthquake are primary (P) waves and secondary (S) waves (see Figure 7.45).

The properties of these waves are summarised in Table 7.2.

As P waves are the faster of the two waves, they are detected by the seismometer first. You can see the first seismic activity detected by the seismometer on the seismogram in Figure 7.46 is the P wave. The S waves are slower and so arrive second. They are also the most intense and so register larger movements on the seismogram.

Quick check 7.12

1. Identify the two plate boundaries at which earthquakes occur.
2. Why do they occur at these boundaries?
3. Recall the name given to the part of Earth where the earthquake is generated.
4. Name the equipment used to detect seismic activity.
5. Identify the type of seismic wave that is faster and therefore first to arrive following an earthquake.

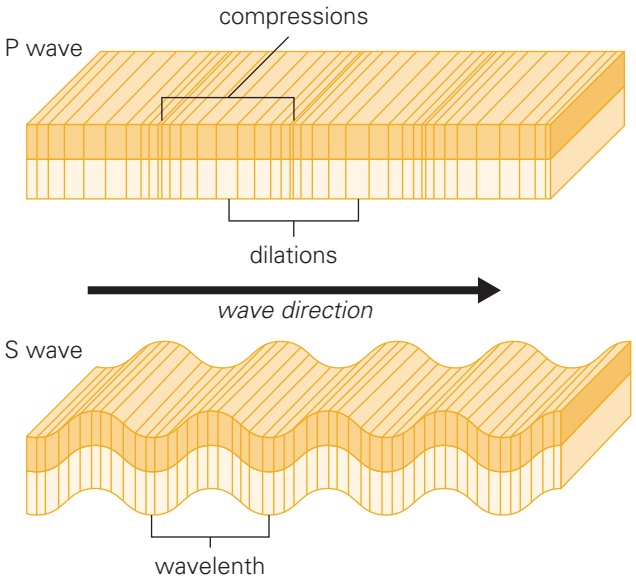


Figure 7.45 P and S waves travelling through the Earth

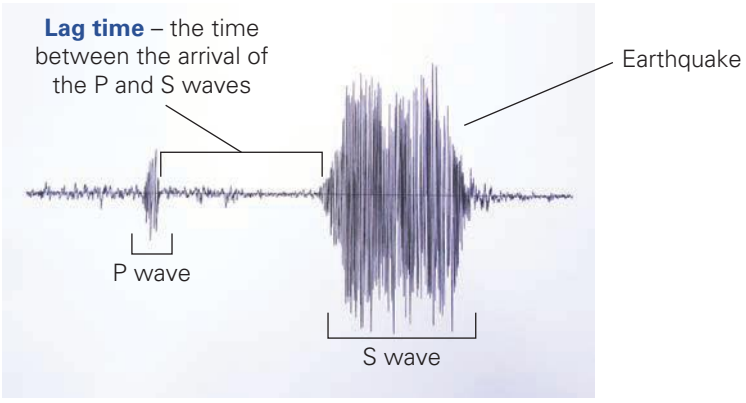


Figure 7.46 A seismogram of seismic activity within the Earth

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Explore! 7.4

How do P and S waves give us evidence for the structure of the Earth?

The properties of P waves and S waves generated by an earthquake can be used to determine the properties of the layers of the Earth. Danish scientist Inge Lehmann discovered that the Earth has a solid inner core inside a molten outer core in 1936 after she analysed data from seismic stations around the world. She noticed some irregularities in the data that disproved the accepted idea that the core was entirely molten. It wasn't until 1970 that her theory was confirmed!

1. What can you conclude about the movements of P and S waves through Earth using the diagram in Figure 7.48?
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 7.47 Inge Lehmann

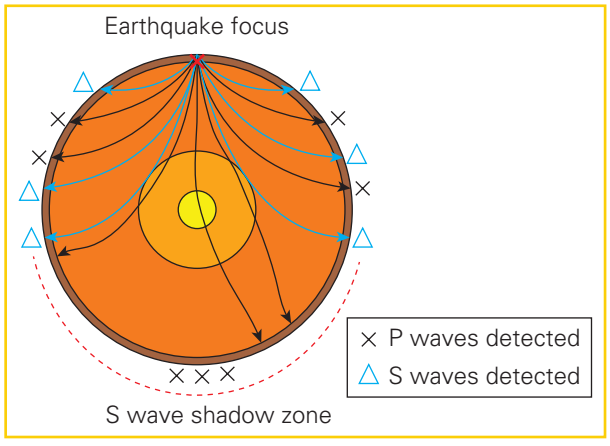


Figure 7.48 The pattern of seismic activity away from an earthquake's focus



Figure 7.49 A tsunami breaching the embankments after an earthquake measuring 9 on the Richter scale occured off the coast of northern Japan in 2011.

The effects of earthquakes

The severity of an earthquake is measured using the **Richter scale**: the more severe the earthquake, the higher the number on the Richter scale. The Richter scale is a logarithmic scale. This means that an earthquake measured as four on this scale is ten times more severe than an earthquake measured at three.

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.

Richter scale
a system used to measure the strength of an earthquake

tsunami
a great wave produced by an earthquake in the ocean

On Boxing Day 2004, an earthquake was measured in the Indian Ocean, off the coast of Indonesia, at 9.1 on the Richter scale. The tsunami waves produced following this earthquake reached up to 15 m high in some places near to land and affected more than 14 different countries. It is estimated that over 200 000 people may have died and almost 2 million people were displaced from their homes.

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Figure 7.50 An aerial view of the devastation caused in Indonesia by the Boxing Day tsunami in 2004

Quick check 7.13

1 Identify 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.

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.

For example, in 1989, an earthquake of magnitude 5.6 hit Newcastle in New South Wales, killing 13 people. Furthermore, situated on the Antarctic plate, approximately 4000 km south west of Fremantle is the Australian territory of Heard Island and McDonald Islands. These Australian islands are home to an active volcano, with a last recorded eruption in 2019. However, there is little risk to the Australian people as the population of the islands is currently zero!



Figure 7.51 Rescue workers searching for survivors under the rubble beneath the Kent Hotel in Hamilton, Newcastle, after the 1989 earthquake

Did you know? 7.3

The largest earthquake ever recorded occurred in Chile on 22 May 1960. It was recorded at 9.5 on the Richter scale. The earthquake killed 1655 people and displaced more than 2 million people from their homes.



Figure 7.52 An active volcano on Australia's Heard Island, known as Big Ben. Heard Island actually lies on the Antarctic plate rather than the Australian plate.

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Section 7.3 questions



Remembering

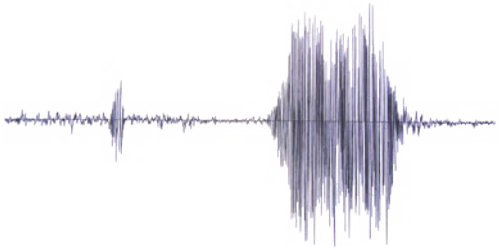
1 **Recall** the name for the volcanic hazard that produces hot, fast-moving gas and rocks.
2 **Name** the equipment used to measure the seismic activity of the Earth.
3 **Name** the scale used to measure the magnitude of an earthquake.
4 **Name** the point on Earth's surface directly above the focus of an earthquake.

Understanding

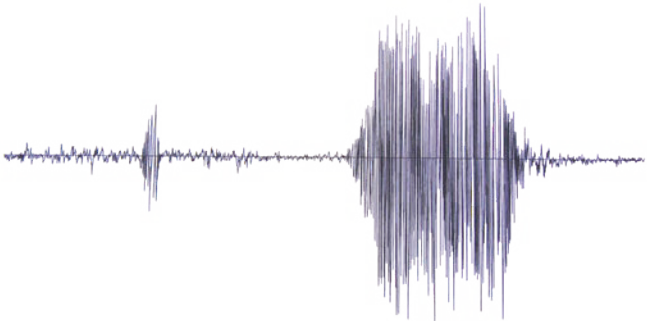
5 **Describe** how earthquakes can cause tsunamis.
6 **Explain** why plates at a transform or destructive plate boundary do not slide past each other all the time.
7 **Explain** how the silica content of lava can affect the outcome of a volcanic eruption.
8 **Summarise** the reasons why the Ring of Fire in the Pacific is so volcanically active.

Applying

9 On the seismogram below, **identify** which is the P wave and which is the S wave.



10 **Identify** the area on the seismograph below that shows the lag time.



Analysing

11 **Compare** the properties of P waves and S waves.
12 **Contrast** magma and lava.

Evaluating

13 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. **Decide** who is right and give reasons why.
14 There are many different types of volcanoes. **Deduce** definitions for the following types of volcanoes.
   a Dormant b Extinct c Active
15 **Decide** whether more geological activity is experienced by countries in the middle of a plate or by countries on a plate boundary. Outline your reasoning.
16 **Discuss** the intensity and frequency of geological activity in Australia.

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7.4 Technologies and natural disasters

WORKSHEET

Learning goal

1 To be able to list methods that can be used to map or predict plate movements.

As technology improves, so does our understanding of geological patterns and changes. This greater understanding has allowed scientists to predict the movement of tectonic plates. It also assists governments and aid organisations to respond quickly and more effectively when plate movements result in natural disasters.

geoid
a model of the Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

Measuring and mapping plate movement

Global positioning system (GPS)

Forecasting the movements of tectonic plates has become an important area of geology. To do this, geologists use GPS and small base stations on the surface of Earth. GPS relies on two dozen active satellites among a total of thirty two 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 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.

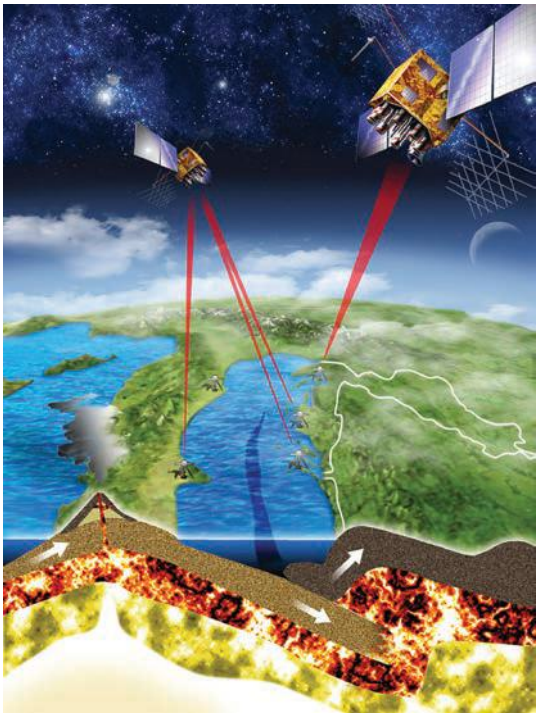


Figure 7.53 GPS is used to measure position and therefore the rate of movement of tectonic plates.

Gravity mapping

Gravity can be stronger and weaker at different points of Earth's surface. The Earth's surface is very uneven due to mountains and ocean trenches, both of which affect gravity. Where rocks are denser the gravity is stronger, and where they are less dense it is weaker. The internal structure of the Earth can also affect gravity as the materials within the interior do not have a uniform distribution. Scientists can create a gravitational map of Earth, called a **geoid**, using these gravitational measurements.

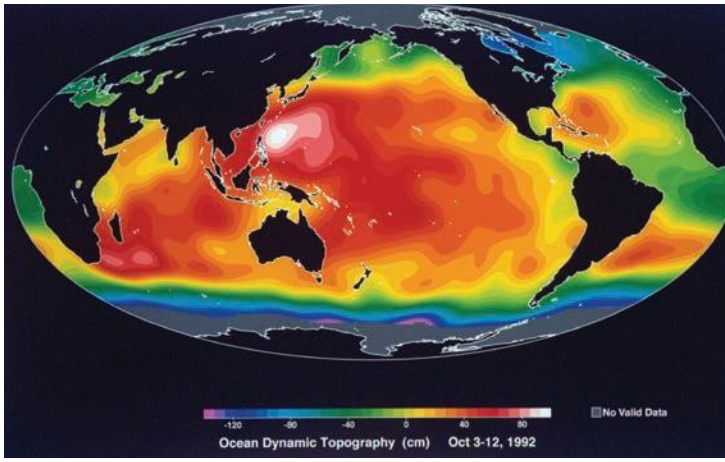


Figure 7.54 A geoid of the Earth.

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Computer modelling

Computer models that simulate the way tectonic plates move are becoming more and more accurate. New models are consistently being refined by scientists to be highly accurate in predicting plate motion and the way in which plate boundaries deform.



Figure 7.55 3D visualisation and geological modelling suite being used by geologists to interpret seismic data from an oilfield

Quick check 7.14

1 List two pieces of technology used in predicting plate movements.
2 Define the term 'geoid'.

Predicting and responding to natural disasters

NASA volcanobots

Studying active volcanoes is dangerous. Volcanologists (scientists who study volcanoes) working together with robotics engineers are 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.



Figure 7.56 Robots similar to the one used in the mission to Mars are being created to explore areas of volcanoes that humans could never access.

Drones

Drones can make finding survivors faster and easier than ever before. The sooner people can be found, the higher their chances of survival. Not only do drones help find survivors, they can also quickly map the areas in greatest need of aid, no matter how remote they might be. This allows rescue teams and aid to be deployed first to those who need it the most. Drones are also useful for getting medical aid into areas that have been blocked off by landslides or collapsed buildings.



Figure 7.57 Drones are being used to search for survivors following natural disasters.

Quick check 7.15

1 State the name given to scientists that study volcanoes.
2 Suggest one use of drones after an earthquake.

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Construction techniques

Most buildings are designed to support vertical forces; for example, the walls support the roof. However, earthquakes also produce sideways or horizontal forces, which is why many buildings struggle to withstand high-magnitude earthquakes. A building can be made 'earthquake proof' in three ways.

- Base isolation: buildings do not sit directly on the ground, but are supported by ball bearings and springs, which act like shock absorbers.
- Vibration control: mass dampers are built to sway in the opposite direction to the building's sway during an earthquake.
- Seismic resistance: the walls, roof and foundations are tied together into a rigid box that holds together when shaken by an earthquake.

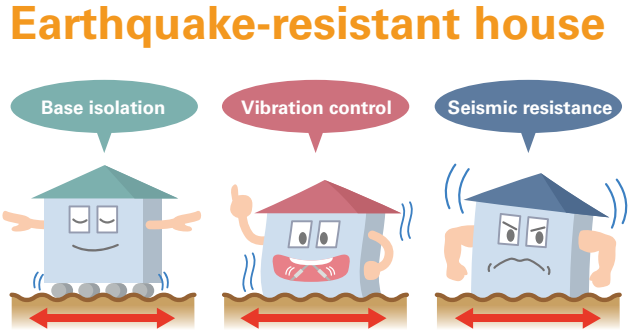


Figure 7.58 Buildings can be made earthquake proof by three different methods.

Quick check 7.16

1 Provide one technique in which a building can be made earthquake-proof.
2 Discuss why many existing buildings are not able to withstand high-magnitude earthquakes.

Science as a human endeavour 7.2

Levitating houses!

Air Danshin, a company in Japan, has invented levitating homes. Inventor Shoichi Sakamoto developed a remarkably simple technology to raise a whole house during an earthquake until the tremors stop. This has already been deployed in nearly 90 sites across Japan. The house is separated from its foundations by an air chamber. When an earthquake hits, air fills the chamber lifting the whole structure about 3 cm off the ground. A sensor detects when the shaking stops, and the house gently falls back into position. Although it seems like an excellent solution to protect against earthquakes, it offers no protection if a tsunami hits.



Figure 7.59 Would you want to live in a floating house?

Explore! 7.5

The Taipei 101

This building in Taiwan (previously called the Taipei World Financial Center) is designed to withstand earthquakes and typhoons. Answer the following questions by researching the structure of the building, using the search engine of your choice.

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?



Figure 7.60 The Taipei 101

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Practical 7.4: Investigation

Investigating how earthquakes affect buildings

Aim

To investigate how earthquakes affect buildings of different heights.

Planning

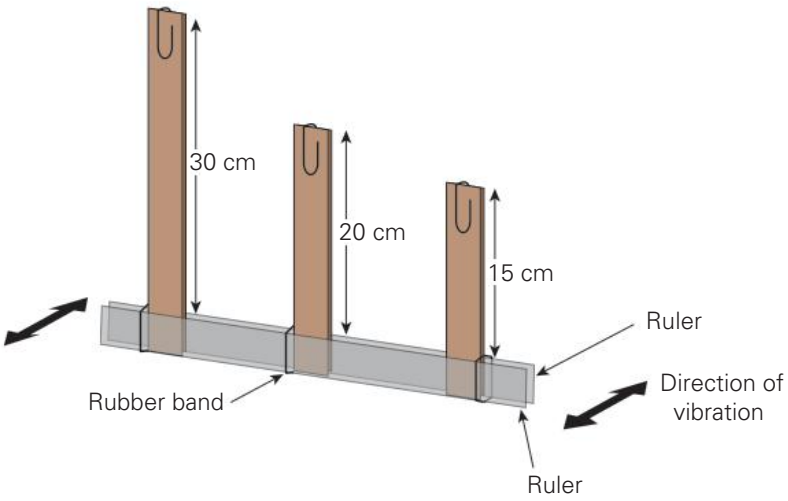
Complete some research and write a rationale about the effects of earthquakes on buildings of different heights.
Hint: research the 1985 Mexico City earthquake.

Materials

- 2 rulers
- elastic bands
- pieces of card
- paper clips

Method

1 Draw the results table below.
2 Set up the experiment as shown in the diagram. Each 'tower' is made of 4 card strips held together at the top by a paper clip and 2 rulers at the bottom. The rulers are held in place using rubber bands.
3 Vibrate the rulers in a slow and gentle way in the direction shown in the diagram.
4 Slowly increase the rate of vibration until the shortest card strip begins to resonate (start to regularly and strongly vibrate). Note: This simulates a high-frequency earthquake. The results would differ for low-frequency earthquakes.



5 Count the number of complete vibrations that occur in 10 seconds.
6 Continue to vibrate the rulers until you have recorded the three trials for each strip in your results table.

Results

Height of strip (cm)	Number of vibrations in 10 seconds			Mean number of vibrations	Frequency (vibrations per second)
	1	2	3		

Discussion

1 Calculate the frequency by dividing the mean number of vibrations by 10.
2 Plot a graph of height of strip against frequency of vibrations.
3 Identify any trends, patterns or relationships in your results.
4 Determine the height of buildings that would be damaged most by high-frequency earthquakes.
5 Identify any potential sources of error in this experiment.
6 Suggest any changes that could be made to the method to improve the quality of the data in future experiments. Justify your suggestions by explaining how each change will improve the data quality.

Conclusion

Draw a conclusion from this experiment regarding building height and high-frequency earthquake damage. Justify your answer with data.

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Practical 7.5: Self-design

Designing earthquake-proof building bases

Aim

To observe the effect of base isolation on damage to buildings during an earthquake.

Materials

- 100 gram (g) masses
- plastic or paper straws
- masking tape
- cardboard
- string
- wooden block
- wooden dowels or pens

Planning

Research base isolation. Propose if base isolation will create more or less damage to a building during an earthquake.

Method

1. Using the equipment provided, except for the wooden block, dowels and pens, design two identical earthquake-proof buildings. (You may want to refer to the STEM activity at the end of this chapter for the building creation.)
2. Draw the results table below.
3. Put your finished design on a table and shake the table for 20 seconds. Record what happened in your results table.
4. Now lay the pens or the wooden dowels on the table so they align.
5. Place the wooden block on top of the pens or dowels and put your second building on top.
6. Shake the table again for 20 seconds and record what happened in your results table.

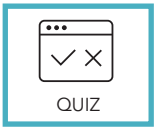
Results

	Observations
Without base isolation (just on the table)	
With base isolation (on the pens and wooden block)	

Discussion

1. Identify which structure was the most earthquake resistant and why.
2. Discuss how base isolation helps the building survive an earthquake.
3. Discuss how design and construction decisions make the building more earthquake resistant.
4. Recommend what you would do differently next time in the construction of your building. Explain why.

Section 7.4 questions



Remembering

1. **Recall** what GPS stands for.
2. **Name** the three methods of earthquake proofing buildings.
3. **Identify** the name of NASA's first robot used to explore volcanoes.

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Understanding

4 **Explain** why scientists need to study the inside of volcanoes.
5 **Explain** how GPS can map the position of tectonic plates.

Applying

6 **Summarise** the advantages of using drones after an earthquake.
7 Apply your knowledge of tsunamis to **explain** why levitating homes are not effective in preventing damage caused by tsunamis.

Analysing

8 **Compare** the three methods of protecting buildings from earthquakes.

Evaluating

9 **Propose** reasons why humans cannot enter some parts of volcanoes.
10 **Discuss** the 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.



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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

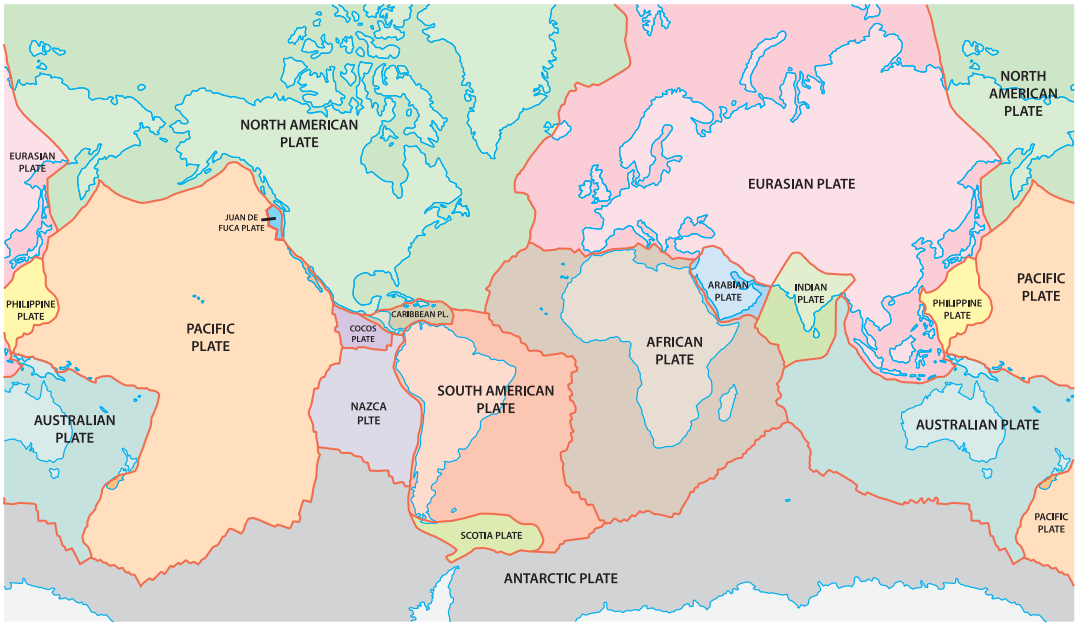
Success criteria	Linked question	Check
7.1 I can discuss the evidence surrounding continental drift.	11	
7.2 I can describe the layers of the Earth.	2	
7.2 I can explain the theory of plate tectonics and how the plates move.	14	
7.2 I can describe the effects of tectonic plates interacting with each other.	18	
7.3 I can explain how volcanoes form.	20	
7.3 I can distinguish between P and S waves.	8	
7.4 I can explain how GPS can be used to track place movements.	3	

Review questions

SCORCHER

Remembering

1 **Identify** five major tectonic plates using the image below.



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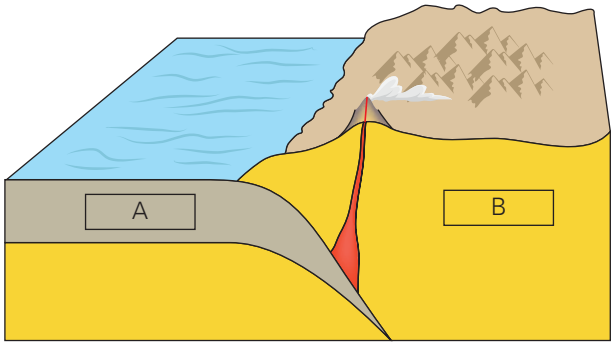
2 **Match** the layer of the Earth (A–D) to its physical properties (1–4).

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 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 **State** the name of one piece of technology used to measure plate movements.
4 **Name** the tectonic plate that contains Australia.
5 **Name** the mechanism in Earth's mantle that causes tectonic plates to move.

Understanding

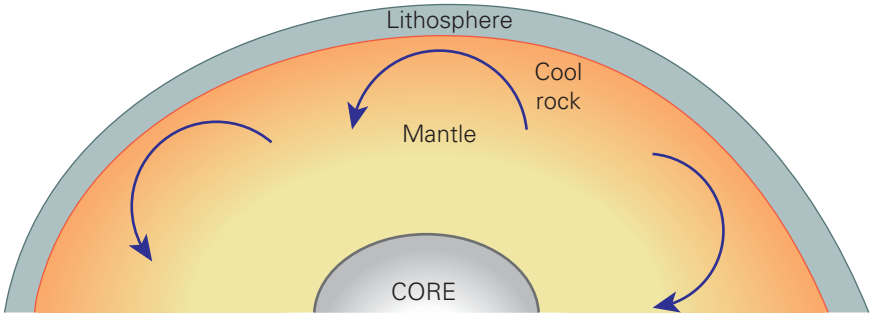
6 **Identify** the continental and oceanic plates at the subduction zone in the following diagram.



7 **Identify** the source of heat causing convection currents in Earth's mantle.
8 **Identify** the type of seismic wave from the description.
   a A transverse wave that cannot travel through liquids
   b A longitudinal wave that can be detected on the opposite side of Earth to the epicentre of an earthquake

Applying

9 **Describe** the three types of plate boundaries and how they affect the amount of crust present.
10 **Explain** how mid-ocean ridges form.
11 **Summarise** the evidence proposed by Alfred Wegener for his continental drift theory.
12 **Explain** why the rocks in the sea floor are magnetised and how this supports Hess's theory of seafloor spreading.
13 **Describe** how a seismometer works.
14 Using the diagram below, **model** how convection currents in the mantle move tectonic plates.



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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** the two types of destructive plate boundaries.

17 **Infer** whether the following effects indicate a constructive, destructive or transform plate boundary.

- a No mountains form
- b Island arcs
- c Crust is conserved

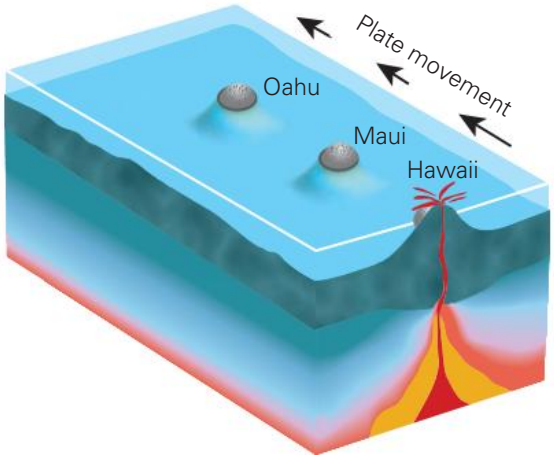
18 **Classify** the following as constructive, destructive or transform plate boundaries.

- a The Himalayas
- b Mid-Atlantic Ridge
- c 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.

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Data questions

New Zealand is a country that lies very close to a fault boundary and consequently experiences thousands of earthquakes each year. Earthquakes are categorised using the Richter scale, which measures earthquake magnitude on a scale of 0 to 10 (see Table 7.3). The magnitudes of ten New Zealand earthquakes from 2010 to 2019 are presented in Table 7.4.

Richter scale	Observation
0.0–2.9	Not felt by humans
3.0–4.9	Felt by humans and not damaging
5.0–5.9	Small risk of damage to buildings
6.0–6.9	Moderate risk of damage to buildings
7.0–7.9	High risk of damage to buildings
8.0+	High probability of severe destruction

Table 7.3 Severity of earthquake observed with Richter scale value

Earthquake reference	Magnitude (Richter scale)
1	4.1
2	7.8
3	4.3
4	2.9
5	5.1
6	6.6
7	2.3
8	6.1
9	1.1
10	7.6

Table 7.4 The magnitude on the Richter scale of ten earthquakes that occurred in New Zealand between 2010 and 2019

1 **Identify** the most severe earthquake recorded in Table 7.4.
2 **Determine** the earthquakes that had a high risk of damage to buildings.
3 The media are reporting a new earthquake in New Zealand that measures 6.5 on the Richter scale. **Identify** the likely observations relating to buildings in the area.
4 **Categorise** the earthquakes presented in Table 7.4 as 'not felt' or 'felt'.
5 **Identify** a trend in the Richter scale and severity of earthquakes.
6 Based only on the ten earthquakes presented, **infer** whether there is a higher chance that an earthquake in New Zealand would not be felt or would damage buildings.
7 There are over 10 000 earthquakes a year in New Zealand. **Justify** whether your answer to question **6** would be reliable.
8 The largest magnitude earthquake ever recorded in New Zealand was 8.2 on the Richter scale while the largest in Japan was 9.0. **Justify** whether it is possible to suggest that Japan is more at risk than New Zealand for severe earthquakes.
9 The media in New Zealand are reporting a mild earthquake that caused a tremor that did not damage buildings but moved furniture in buildings in the area. **Deduce** the magnitude of this earthquake on the Richter scale.

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STEM activity: Earthquake-proof structures

Background information

In this chapter, you have gained an insight on the inner workings of our planet. You learned that, contrary to appearances, our planet has been very active for over 4 billion years. Our planet is constantly changing via many important geological processes over eons, and some of the movements produce earthquakes.

Unfortunately, poorer countries have been greatly affected by earthquakes over the centuries, as whole populations live in earthquake-prone areas (for example, the Pacific Ring of Fire and the Andes). Experts have demonstrated that most deaths in earthquakes occur because buildings and dwellings collapse due to poor construction.

Papua New Guinea (PNG) is located in the Australasia 'ecozone', which includes Australia, New Zealand, eastern Indonesia, and several Pacific island groups, such as the Solomon Islands and Vanuatu. PNG is one of the poorest countries in the world and is severely affected by earthquakes. Earthquakes are particularly severe in PNG because of a combination of factors – steep terrain, poor infrastructure and housing, lack of roads and extensive seasonal rains – all of which create an environment that is prone to collapse after an earthquake.

Knowledge has the power to improve people's lives. How can you use technology and your knowledge of geology to improve the lives of people living in these high-risk areas?



Figure 7.61 (a–c) Damage caused by earthquakes in Papua New Guinea. Earthquakes occur all over the world, in developed and underdeveloped countries. They have the power to destroy whole cities, move entire mountains and lift or drop the ground by many metres. **(d)** Scientists analyse data collected during an earthquake.

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Design brief: Design and test building designs to improve durability in earthquake risk zones, and present this information in a format that would be useful to a small PNG community.

Activity instructions

In groups (maximum of four people), you will investigate how housing design can affect the stability of a building by building a series of small structures and testing their durability on a shaker table. It will be useful to allocate roles for this activity: project manager, engineer, builder and presenter.

Role	Responsibility
Project manager	Making sure the project is on time and within a budget. The project manager is responsible for all of the parts of the project
Engineer	Conducting research on the current models, finding new ways to improve and drawing a sketch of the proposed design
Builder	Creating the proposed design and checking that the design is functional
Presenter	Researching information on cultural awareness of the local community and how to present in the most effective way, and creating a presentation to match this

Together, the group members need to manage their time and help each other through each stage.

Suggested materials

- wooden sticks
- sticky tape
- glue
- mobile phone or video recording equipment for vlog (if chosen as mode to communicate ideas)
- software for creating a presentation
- software for video editing

Research and feasibility

1 Research current house design in villages and list the features, including types of materials used.
2 Discuss and research as a group how a structure's strength can be improved.
3 Research social and cultural information about PNG communities.

Design and sustainability

4 As a group, discuss some design features you could use in a model house structure and make multiple sketches with ideas.
5 Decide as a group which design will be the most sustainable and suitable to build with the PNG communities in mind.
6 Decide and design the format you will use for your presentation design for the PNG community.

Create

7 Construct your design using allowable materials.
8 Test your design by performing the following tests. Draw a results table.
   A **Shake test:** Place your design on a table and secure it using tape. Shake the table forwards and backwards four times. 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 kilogram (kg) masses are placed on top of it. Describe how your design behaves under the weights.
   C **Combination test:** Your design is still standing – that is great! Now, repeat tests **A** and **B** at the same time. Describe what happened.
9 Reflect and, if there is time, create and test another design. Reflect on how the second design performed.
10 Create the presentation while building and testing your design.

Evaluate and modify

11 Take time to think about the investment required to change the lives of villagers. Imagine that a 10 cm wooden stick used to build your model costs around $10 to purchase, and that the piece that joins them costs $2. Calculate the current cost of building a house.
12 Evaluate the effectiveness of your design. It is important to remember who your target audience is throughout this project.
13 Give your presentation to the class and reflect on how it demonstrates cultural awareness and how well it communicates effective building methods.

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Chapter 8
Transfer of energy

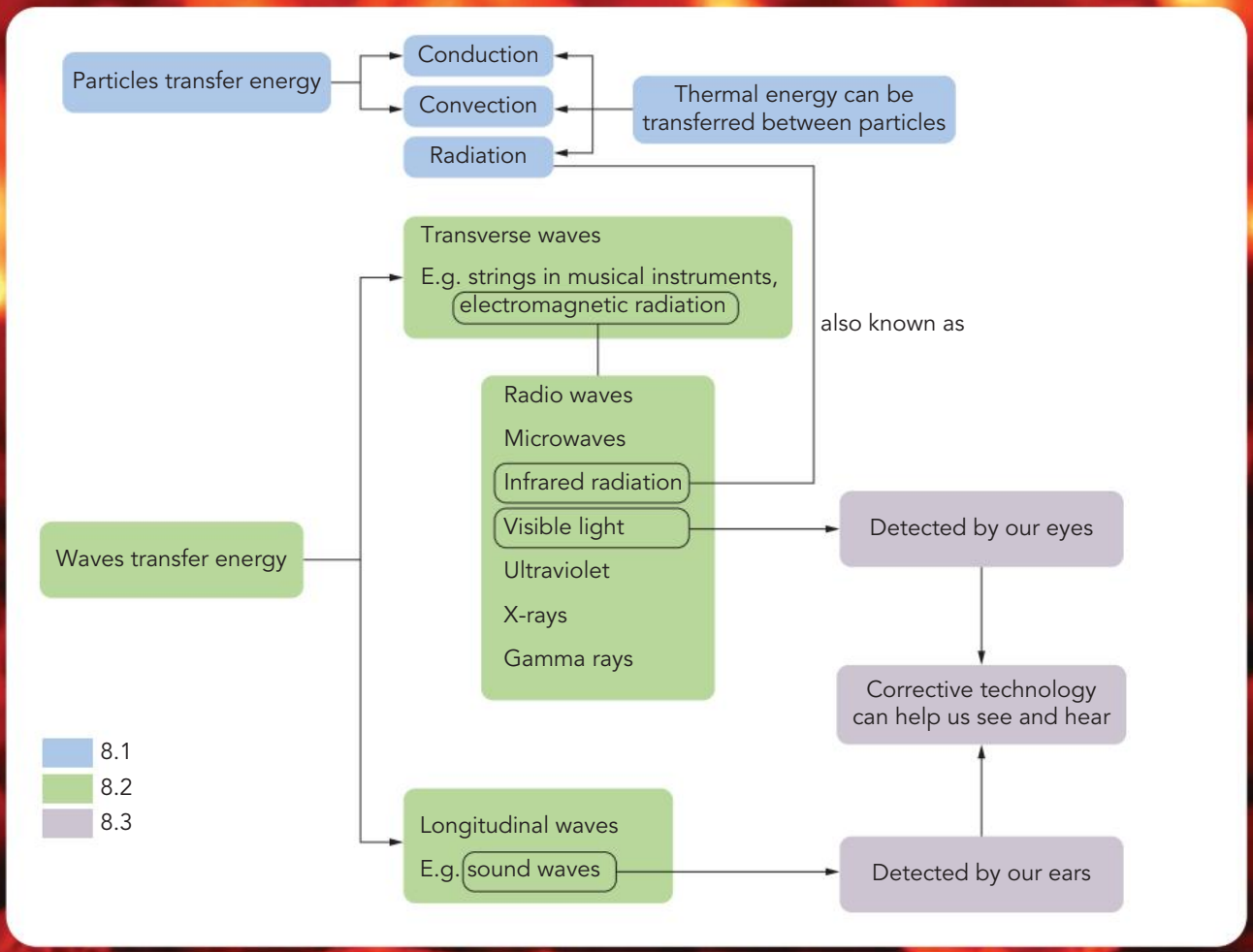
Chapter introduction

In this chapter, you will study the wave and particle models of energy transfer. You will consider the movement of energy through different mediums by investigating the transfer of thermal energy by conduction, convection and radiation.

You will explore light and sound, both situations where energy is transferred by waves. You will take a look at the human eye and learn how light interacts with the structures in the eye to produce signals that our brain interprets as images. This chapter also explores how fast sound travels, and how sound is produced by musical instruments.

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Chapter map



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8.1 Particles transfer energy

WORKSHEET

Learning goals

1 To describe the difference between thermal energy and temperature.
2 To be able to explain heat transfer by conduction, convection and radiation.

The particle model

In Year 8, you learned about the particle model and how it provides an explanation for the properties of solids, liquids and gases. According to the particle model:

- All matter is made up of particles.
- Particles are always moving.
- As the temperature increases, particles move faster.

You also learned that the energy of moving matter is called **kinetic energy**, and therefore all particles of matter have kinetic energy because they are in constant motion. Objects with a higher temperature have faster moving particles, and the particles have higher kinetic energy. **Thermal energy** of an object or a system relates to the total kinetic energy of its particles. Thermal energy is often called **heat**, but in science we use heat to mean specifically thermal energy that is transferred. Thermal energy on the other hand is something an object possesses whether there is transfer or not.

kinetic energy
the energy of moving matter

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

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

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

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

Therefore, thermal energy can be explained by the particle model as the movement of particles.

Note that it is the kinetic energy of an object's particles, not the motion of the object itself, that relates to thermal energy.

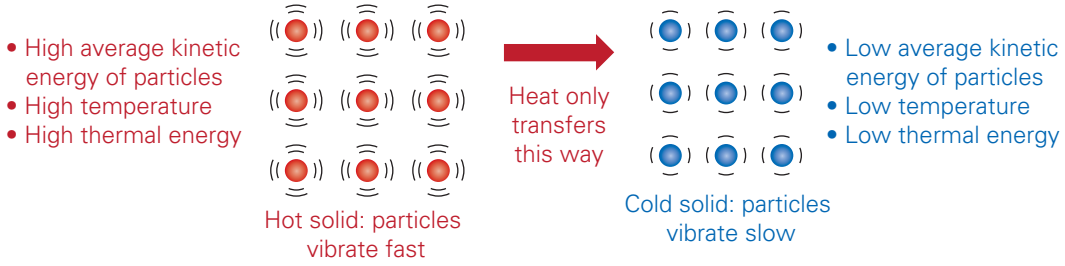


Figure 8.1 The particles in hot and cold solid objects of the same mass. The relationship between average kinetic energy of particles, thermal energy, heat and temperature is shown. This diagram also applies to liquids and gases, except there the particles aren't vibrating but instead are moving around.

Quick check 8.1

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

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Thermal energy

To change an object's temperature, thermal energy needs to be either added (to raise it by heating) or removed (to lower it by cooling). The amount of thermal energy in an object depends on three factors:

- temperature – objects at higher temperatures have more thermal energy than identical objects at lower temperatures
- mass – heavier objects have more thermal energy than lighter ones of the same material and temperature
- material – some materials are better at storing thermal energy than others.

The total thermal energy depends on all three factors. For example, a warm bath contains a lot more energy than a cup of hot coffee. The particles of coffee have greater average kinetic energy than the particles of water in the bath, and the higher temperature of the coffee is a measure of that average kinetic energy. However, the mass of the bath water is much greater than the mass of coffee in the cup. This means that there are many more particles of water in the bath than in the coffee. All those moving particles have greater total kinetic energy, even though their average kinetic energy is less. Therefore, the bath water has greater thermal energy than the coffee.



Figure 8.2 A warm bath of water contains more thermal energy than a burning match or a hot cup of coffee.

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Try this 8.1

Take three large containers and fill one with room-temperature water, one with warm water (be careful that it is not too hot) and the last one with cold fridge water. Place one hand in the cold water and the other in the warm water for 2 minutes. Take your hands out of the warm and cold containers of water and place both hands in the room-temperature water. How does the water feel?

Think about these questions. Discuss your answers.

1 Why did you leave your hands in the warm and cold water for 2 minutes?
2 Why do your hands detect different temperatures when you put your hands into the room temperature water?

Practical 8.1

Investigating thermal energy

Aim

To investigate the heating of different volumes of water when provided with the same amount of energy.

The specific heat capacity of a substance is the amount of energy that is required to raise the temperature of 1 kilogram (kg) of that particular substance by 1°C. For example, water has a specific heat capacity of 4200 J/kg°C, meaning it takes 4200 J to raise the temperature of 1 kg of water by 1°C. The amount of thermal energy stored or released in a system as the temperature is changed can be calculated using the following equation.

change in thermal energy = mass × specific heat capacity × temperature change

$$Q = mc\Delta T$$

Where:

Q = change in thermal energy (J)

m = mass (kg)

c = specific heat capacity (J/kg°C)

ΔT = temperature change (°C)

NOTE: Δ means 'change in'

Materials

- Bunsen burner
- heatproof mat
- tripod
- gauze
- matches
- 600 millilitres (mL) glass beaker
- thermometer
- stopwatch

Method

1 Draw the results table below.
2 Put 200 mL of water in a beaker and measure the temperature. Record this in your results table.

continued…

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…continued

3 Remove the thermometer and heat the water for 2 minutes.
4 Stir the water and measure the final temperature after it has been heated. Record in your results table.
5 Repeat steps **2–4** using 300 mL, 400 mL and 500 mL of water. Make sure the glass beaker is cooled between experiments, so that the initial temperature is the same. It might save time to start with four identical beakers with water at room temperature.

Results

Volume (mL)	Initial temperature (°C)	Final temperature (°C)	Change in temperature (°C)	Change in thermal energy (J)
200				
300				
400				
500				

Discussion

1 Calculate the change in thermal energy (Q) by using the equation given above. Remember, 1 litre of water weighs 1 kg, so 200 mL of water is 0.2 kg.
2 Plot a graph of volume against change in temperature.
3 Identify any trends or patterns in your results.
4 Predict what you think would happen if the following different substances were used. You may need to complete some research on specific heats of different substances. Explain the reasoning behind your predictions.
   a Liquid mercury
   b Air
   c Ethanol

Conclusion

Draw a conclusion regarding volume and thermal energy from this experiment, supporting your statement with data.

Quick check 8.2

1 Define the term 'thermal energy' of an object.
2 State three factors that the total thermal energy of any object depends on.
3 Explain why a warm bath contains more thermal energy than a burning match.

Heat transfer

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

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Figure 8.3 Keeping warm around a campfire and roasting marshmallows require the transfer of heat.

radiation
transfer of energy without the presence of particles

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

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

In Figure 8.3, three types of heat transfer are occurring simultaneously. As you sit around the campfire, you feel an intense warmth on your skin – **radiation**. You also notice that the air above the fire is hotter than beside the fire and will burn the marshmallows – **convection**. Finally, when roasting your marshmallow over the flames you notice that heat is travelling along the metal fork, which is starting to feel warm in your hands – **conduction**. What exactly are these types of heat transfer?

Conduction

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

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

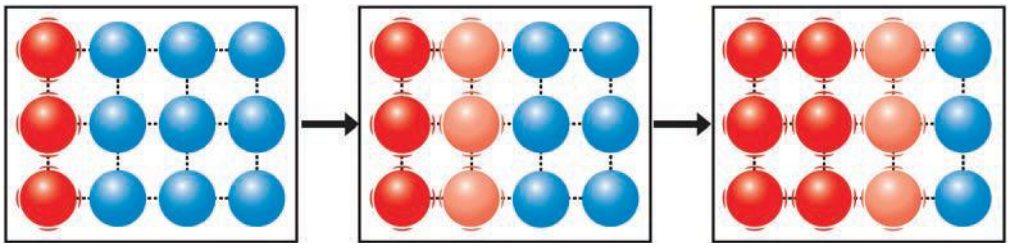


Figure 8.4 A time sequence showing heat flowing through the particles of a solid by conduction. The heat source (not shown) is on the left of the particles. At first only the particles next to the heat source become hot and vibrate. They bump into particles next to them, which warm up, and so on.

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Figure 8.5 Warming up your hands with a hot drink on a cold day is an example of conduction.

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

How would holding the hot drink feel different if it was a polystyrene cup? Or a metal cup? Some substances, such as metals, are good **conductors** of heat. This is because the electrons in metal can leave their atoms and move around as **free electrons**. These free electrons move fast and result in vibrations (and the associated kinetic energy) passing more quickly between particles in a metal. So thermal energy in metals spreads quickly from hot to cold. (see Figure 8.6).

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

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

free electron
an electron that is not attached to an atom

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

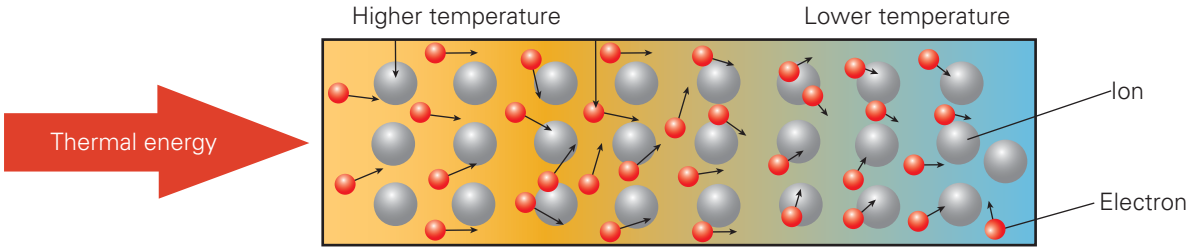


Figure 8.6 Free electrons can travel through metals and help thermal energy spread quickly from hot to cold areas.

Try this 8.2

Heat-sensitive slime

You will need:

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

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

Mix in the rest of the starch, bit by bit, until well combined. Your slime will no longer be sticky.

Observe what happens as the slime cools. When it is hot, it will be the colour of the food colouring. When it is cold, it will be the colour of the thermochromatic pigment.

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Convection

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

Have you ever heard the saying, 'Hot air rises'? In a building with two or more floors connected by an open stairwell, the top floor will be warmer if there are no doors to block the flow of air. When a liquid or a gas is heated, the particles vibrate faster and the space between them gets bigger, causing the liquid or gas to expand. This means that the warmer regions become less dense than the colder regions, and so begin to rise. Figure 8.7 shows water in a pot being heated from the bottom, causing the hot water to rise. Away from the heat source, at the top of the pan, the water cools again. The water becomes more dense and sinks back down to the bottom where it will be heated again. This cycle is called a 'convection current'.

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

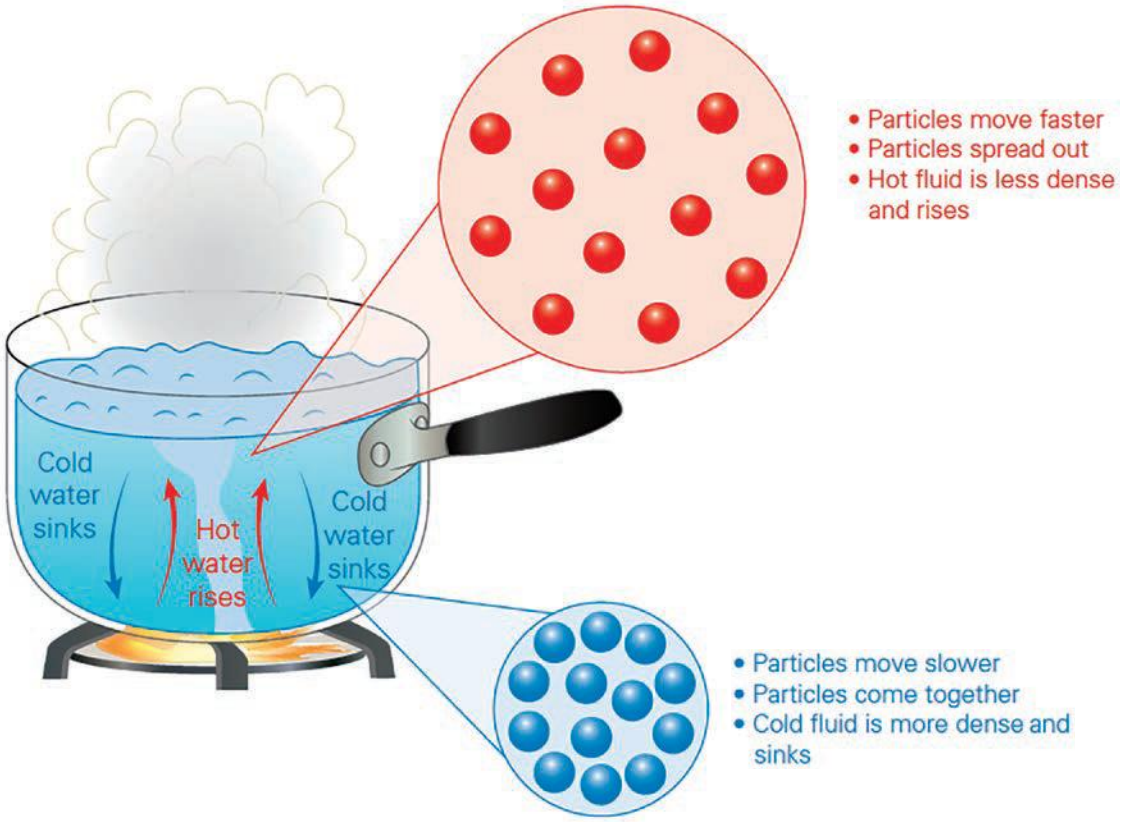


Figure 8.7 When water is heated, the hotter less dense water at the bottom rises and the colder more dense water sinks to take its place.

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Explore! 8.1

El Niño vs La Niña

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

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

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

Try this 8.3

Convection spiral

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

Radiation

Any object with thermal energy radiates heat, and you do not need to be in contact with the object to feel this thermal radiation. This is why you can feel the warmth of a fire when you stand in front of it, or feel the Sun's warmth when you are outside. Thermal radiation, or radiant heat or infrared radiation, is a form of electromagnetic radiation (like light and radio waves) and travels in waves (explored further in 8.2). This differs from convection and conduction, as it does not rely on particle movement.



Figure 8.8 Bread being toasted via radiant heat transfer

Explore! 8.2

How do animals stay warm?

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

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

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Quick check 8.3

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

Practical 8.2: Self-design

Modelling heat transfer

Aim

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

Materials

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

Method

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

Results

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

Discussion

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

Did you know? 8.1

Clothing technology

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

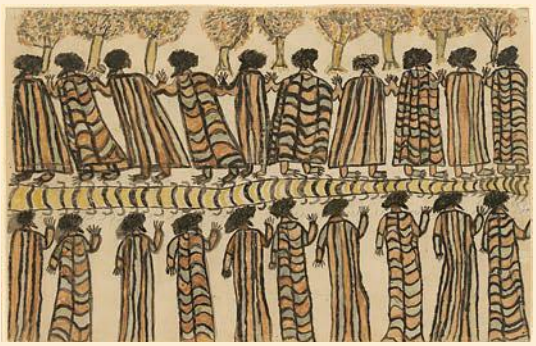


Figure 8.9 Artwork by William Barak, an influential Aboriginal Australian spokesperson, depicts the use of possum skin cloaks.

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Summary of heat transfer

The particle model can be used to explain conduction and convection, as they both involve the transfer of thermal energy through particles. Although radiation also involves the transfer of thermal energy, it does not require the presence of particles. Thermal radiation is an electromagnetic wave that can travel through empty space where there are relatively few particles. This is why we can feel the warmth of the Sun despite it being about 150 million km away. Therefore, such radiation is explained using the wave model.



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

Table 8.1 The three different processes of heat transfer

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Section 8.1 questions

QUIZ

Remembering

1 **Define** thermal energy.
2 **State** the conditions required for conduction to occur.
3 **Recall** the three factors that determine how much thermal energy is present in an object.

Understanding

4 **Explain** how an object with a higher temperature can have less thermal energy than an object that has a lower temperature.
5 An electric oven has a heating element on the top and bottom surface, and two wire racks (shelves), a top and a bottom. It does not have a fan to circulate the air inside. A recipe calls for the baking dish to be placed in the hottest part of the oven. **Explain** whether you should place it on the top rack or the bottom rack.



Applying

6 **Explain** why energy is received from the Sun by radiation and not by convection or conduction.
7 Convection occurs in liquids and gases. **Explain** why convection does not (as a general rule) occur in solids.

Analysing

8 **Classify** the following as heat transfer by either conduction, convection or radiation.
   a Heat escaping from the top of a cup of a hot coffee
   b Heat from a stove burner transferring to a frying pan placed above it
   c An ice cube melting in your hand
9 **Differentiate** between heat insulators and conductors in terms of their ability to transfer heat quickly.
10 Josh says insulation keeps out the cold. **Critique** this statement.

Evaluating

11 **Decide** at what point thermal energy transferring between two substances in contact will stop being transferred.
12 1 L of gas in a cylinder is rapidly compressed by a piston until it occupies 0.1 L. As a result the molecules of gas have less space to move, they undergo many more collisions which causes them to speed up. **Predict** what happens to the temperature of the gas.
13 Two cups of water have their temperature measured. One is 20°C and the other is 30°C. Using your understanding of temperature and particles, **discuss** how the movement of particles differ.

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8.2 Waves transfer energy

Learning goals

1. To be able to distinguish mechanical and electromagnetic waves.
2. To be able to label the amplitude and wavelength of a transverse and longitudinal wave.
3. To list the different types of electromagnetic radiation.
4. To be able to label the compressions and rarefactions in longitudinal waves.

WORKSHEET

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



Figure 8.10 Lightning and thunder are forms of light and sound energy that travel as waves.

The wave model

A **wave** is a carrier of energy that transfers it from one place to another without any matter accompanying it. Some waves, called **mechanical waves**, require matter, called the **medium**, to move through. Sound and water waves are examples of mechanical waves. They create a disturbance in the medium that transfers the energy. Another kind of wave, called **electromagnetic waves**, don't require a medium and can travel through a **vacuum**. Light and radiant heat are examples of electromagnetic waves.

Mechanical waves transfer energy from the source of a wave (a force that starts the disturbance in the medium). The matter through which the wave travels is called the medium and can be in any state. In mechanical waves, a disturbance in a medium results in the transfer of energy by the vibration or **periodic motion** of particles. Mechanical waves therefore require particles to allow the energy to travel through matter. These particles don't move along the wave, they only pass on the energy of the disturbance to the particles next to them. For example, a duck will bob up and down as a ripple passes, revealing the periodic motion of the water particles, but it returns to its original position – it does not travel with the wave.

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

mechanical wave
a disturbance in a medium that transfers energy through that medium

medium
the matter through which a mechanical wave travels

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

vacuum
a space totally devoid of matter

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

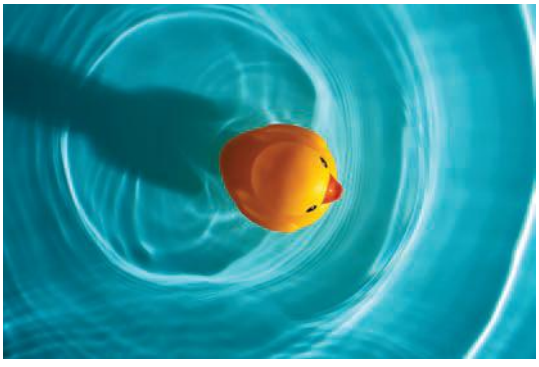


Figure 8.11 As a ripple passes through the medium (water), the duck is temporarily displaced as it bobs up and down, before returning to its original position.

Depending on how the particles of the medium move relative to the direction of energy transfer, a mechanical wave can be classified as a transverse, longitudinal or surface wave.

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

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

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

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

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

frequency
the number of cycles of a wave per second

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

wavelength
the distance from one wave crest to the next

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

Quick check 8.4

1 Define a mechanical wave.
2 What is the medium of a mechanical wave?
3 List three types of mechanical waves.

Transverse waves

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

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

Note that there are three measurements that tell you all about the dimensions of a wave: frequency, wavelength and amplitude.

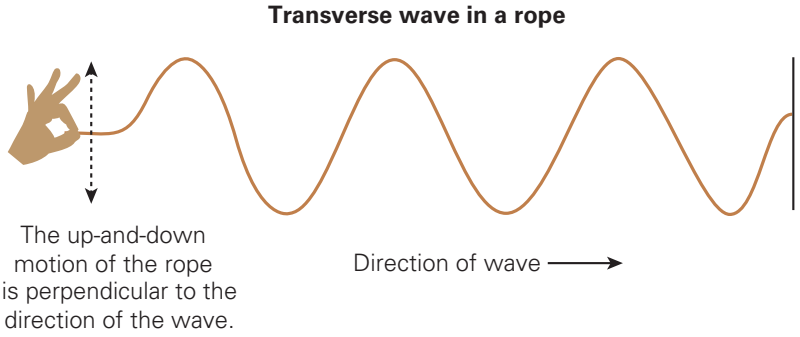


Figure 8.12 In a transverse wave the particles move perpendicular (at right angles) to the direction of the wave.

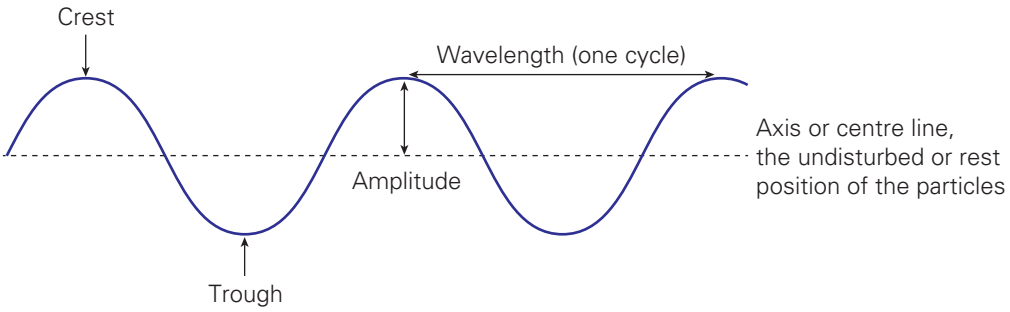


Figure 8.13 The parts of a transverse wave

Try this 8.4

Looking at wavelength and amplitude

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

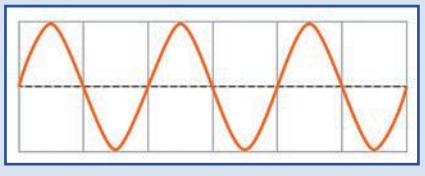


Figure 8.14 A wave

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Quick check 8.5

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

Examples of transverse waves

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



Figure 8.15 When the strings of a guitar are plucked, they vibrate up and down while waves travel along the string to its ends.

Electromagnetic waves

Electromagnetic waves are examples of transverse waves. They consist of **oscillating** electric and magnetic fields, not disturbances in matter as a medium. **Electromagnetic radiation** is the transfer of energy by electromagnetic waves. The waves transfer energy through empty space or matter, such as when light passes through glass. If these waves travel through matter, some energy is lost to the particles of matter. When they travel though a vacuum, no energy is lost.

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

seismic waves
waves that moves through Earth during an earthquake

oscillating
moving back and forth with periodic motion somewhat like vibration

electromagnetic radiation
transfer of energy by electromagnetic waves

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

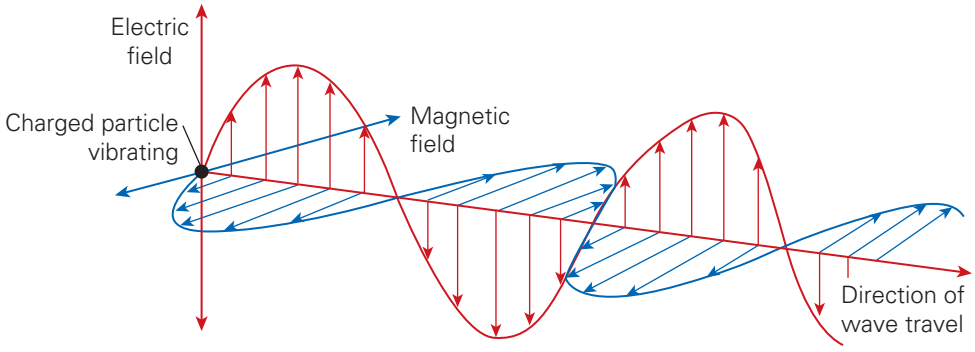


Figure 8.16 A vibrating charged particle generates vibrating electric and magnetic fields. These fields are perpendicular to each other and to the direction of the wave.

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

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

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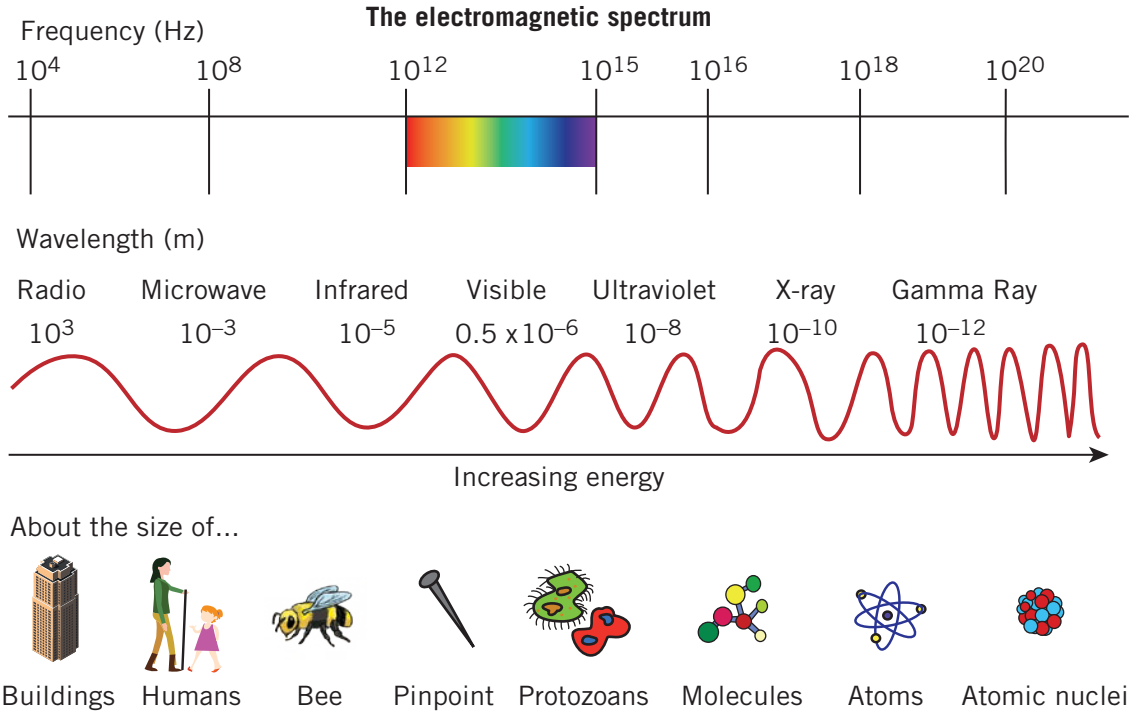


Figure 8.17 The electromagnetic spectrum extends beyond the visible spectrum (light).

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

- **Radio waves** are useful for communications and signals over long distances (including for radar). Radio waves were originally used for communication with ships at sea then broadcasts by radio and television stations, and are now also used to send communications around the world via satellites. Radio waves have very long wavelengths (some of them are several kilometres long) but energy and frequency are very low.
- **Microwaves** are used for cooking, Wi-Fi communications and mobile phone technology. In a microwave oven, any water molecules present in food will vibrate at the same frequency as the microwaves and convert this energy into heat, cooking the food quickly. Microwaves are also used in mobile phone networks. When a mobile phone is switched on, it produces microwave signals (that you might know as 3G, 4G or 5G) that are picked up by receivers in mobile phone towers. The towers then transmit signals back to the phone for incoming calls, to connect to the internet and to download files, images and video.
- **Infrared radiation** is the radiation you feel immediately when you stand near a fire or when you feel heated by the Sun. It is also used in home remote controls. Objects at a higher temperature release more infrared radiation than similar objects at a lower temperature (this was covered as a type of heat transfer in section 8.1). Infrared cameras can be used to detect infrared waves being emitted by an object. The signals are then processed to produce a false-colour image showing the relative temperatures of parts of the object. Similarly, higher-frequency infrared waves can be detected in night vision technologies to produce a false-green coloured image.
- **Visible light** is the section of the electromagnetic spectrum that is visible to the human eye.
- **Ultraviolet light** is invisible radiation that can cause sunburn and skin cancer. Not all ultraviolet is bad though: skin cells use low-frequency ultraviolet light to make vitamin D.

radio waves
electromagnetic radiation that has the longest wavelength

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

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

visible light
the part of the electromagnetic spectrum that we can see

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

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- **X-rays** are high-energy electromagnetic waves that are used to create images of bones. Bone absorbs most of the radiation whereas X-rays will pass through soft tissue such as fat and muscle. This results in bones appearing white, soft tissue appearing grey and air appearing black in X-ray images. The development of imaging technologies has contributed greatly to our understanding of the functions and interactions of body systems. X-rays can cause cancer, although the radiation dose from medical scans is small (see Explore! 8.3).
- **Gamma rays** are high-energy, high-frequency waves with a short wavelength. They are released when atomic nuclei decay, and although they can cause cancer, they can also be used in its treatment.

The higher the frequency (and the shorter the wavelength) of an electromagnetic wave, the more energy it carries. Higher frequency ultraviolet rays, X-rays and gamma rays have enough energy to knock electrons off atoms, so they become ions. This is referred to as **ionising radiation**, and it damages living cells.

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

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

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

Explore! 8.3

X-rays and tissues

Everyone is exposed to small amounts of ionising radiation in daily life, commonly referred to as background radiation. Its effect on the body is negligible because the exposure is so low. Under controlled conditions, the use of X-rays on living tissue is safe. In fact, the radiation dose from an X-ray is not much greater than that of background radiation. For example, a chest X-ray is equivalent to 2.4 days of exposure to natural background radiation, while a CT (computed tomography) scan, which also use X-rays, of the abdomen is equivalent to 2.7 years of natural background radiation. X-ray imaging has different effects on different tissues.

Conduct some research to find out the different X-ray procedures and their associated natural background radiation equivalents, and discuss why they have different values.

Did you know? 8.2

Did you know that, although light (an example of a transverse wave) travels incredibly fast at close to 300 000 kilometres per second in a vacuum, the time taken for it to travel starts to be noticeable at astronomical distances as the light takes longer to reach your eyes. You are seeing the moon as it was 2 seconds ago, the Sun as it was 8 minutes ago and Saturn as it was about 80 minutes ago. The light from distant galaxies varies from being 2.5 million years old in the case of the nearest galaxy, Andromeda, to over 10 billion years for the most distant galaxies.

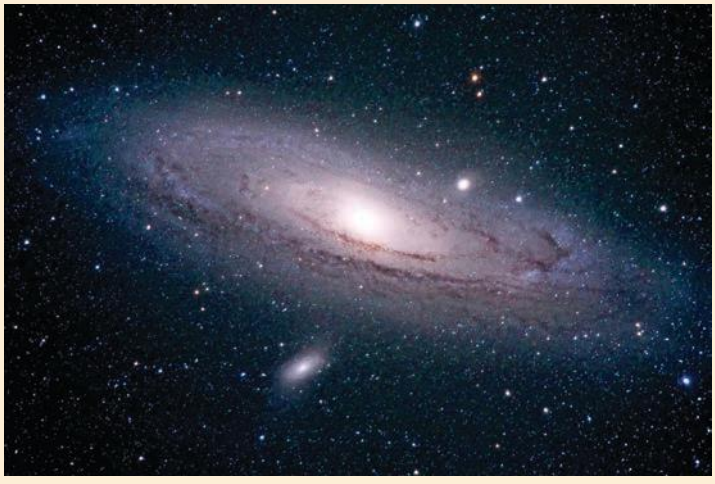


Figure 8.18 When looking at our closest galaxy, Andromeda, we are looking 2.5 million years into the past.

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Explore! 8.4

Wi-Fi

Did you know that an Australian invented Wi-Fi? This physicist and engineer was actually studying radio waves being emitted from black holes and built a machine to detect these weak signals. He used his machine to allow computers to communicate wirelessly. Conduct some research on Wi-Fi to answer the following questions.

1 Who is credited with inventing Wi-Fi?
2 When was Wi-Fi patented?
3 How does Wi-Fi work?

Science as a human endeavour 8.1

New uses for Wi-Fi

Wi-Fi can be used not only to connect computers wirelessly, but also to detect dangerous objects. Wi-Fi signals are able to penetrate bags, so they can be used to identify objects such as weapons or bombs being carried around public places.

Researchers have also created 3D-printed objects, known as 'smart objects', that can connect to other Wi-Fi devices without other electronics. The technology within each object allows it to sense certain aspects of its environment and send this information to your smart phone. So a smart object might, for instance, let you know when you are running low on detergent.



Figure 8.19 This attachment senses how much laundry liquid is being used and can automatically order more when it is running low.

Did you know? 8.3

The 5G network has major implications for communications

As wireless companies are beginning to roll out their next-generation 5G networks around the world, people are both excited for the faster download speed and reduced latency and, in some cases, worried about possible impacts.

In Western Australia, 4G networks work at frequencies between 700 megahertz and 1800 megahertz. In contrast, 5G uses two bands: one below 6 gigahertz and another above 24 gigahertz. This is considered a high frequency for radio waves.

Some people fear that 5G may behave like ionising radiation, which has been linked to cancer. Any wave that has a higher frequency than violet light is ionising radiation. So for 5G these fears are unfounded! The frequency of 5G is so low that it cannot ionise any atoms.

A more realistic concern, raised by meteorologists, is that 5G networks could disrupt weather satellite forecasts because the frequencies used for 5G are extremely close to the

continued…

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…continued

frequency at which water molecules vibrate (23.8 gigahertz). Weather satellites use this frequency to track the water vapour in the atmosphere to give accurate weather forecasts. As the frequencies are so close, 5G networks may interfere with weather satellites, reducing the reliability of the models that predict dangerous storms. This could affect, for example, warnings for early evacuation of areas in the path of a storm.



Figure 8.20 Meteorologists have raised concerns that the 5G network could interfere with the frequencies used by weather satellites to collect data used to predict and monitor dangerous storms.

Transverse wave summary

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

Table 8.2 The two types of transverse waves

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Quick check 8.6

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

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

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

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

Longitudinal waves

A **longitudinal wave** is a wave in which the particles of the medium oscillate (that is, vibrate) parallel to (in the same direction as) the energy transfer. The particles vibrate back and forth creating a series of **compressions** and **rarefactions**. As can be seen in Figure 8.21, longitudinal waves have areas where the particles (coils in this case) crowd close together and areas where they are spread apart. Places where the particles in a medium are closer together are called compressions, and places where the particles in the medium are further apart from each other are called rarefactions. If a wave has more energy, then the particles in compressions are closer together and the particles in rarefactions are farther from each other.

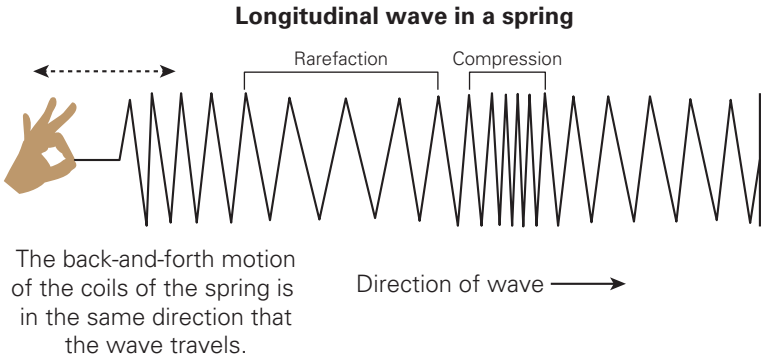


Figure 8.21 In a longitudinal wave, the particles move parallel to the direction of the wave.

Examples of longitudinal waves

Sound is a longitudinal wave because the air particles vibrate backwards and forwards in the same direction as the travelling sound wave. The motion of sound through the air is similar to when you move the end of a slinky forwards and backwards quickly to send a series of pulses through the spring. When a sound wave passes through air, the movement of the particles is in a pattern that consists of regions of high pressure (compression) and regions of low pressure (rarefaction). Sound is a mechanical wave and therefore needs a medium to travel through, but the medium does not have to be air – it can also be a solid or a liquid. In fact, because sound needs particles to vibrate in order for it to travel, sound travels faster through solids, where the particles are close together. It can't travel at all through a vacuum (where there are no particles).

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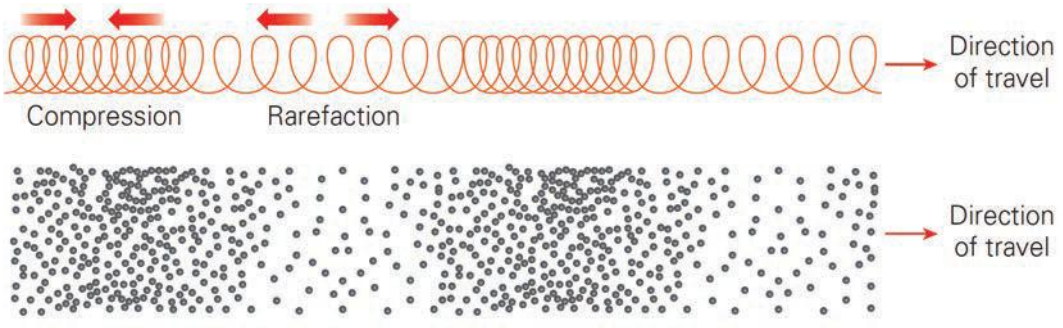


Figure 8.22 Longitudinal waves in a slinky can model longitudinal sound waves.

Try this 8.5

Visualising sound

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

Explore! 8.5

Sound waves and the didjeridu

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

Conduct some research on the didjeridu to answer the following questions.

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



Figure 8.23 The didjeridu is made of bamboo or tree trunks that have been hollowed out by termites or other insects.

Quick check 8.7

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

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Practical 8.3

Making sound

Aim

To hear and observe vibrations in the air.

Materials

- water
- tuning fork
- rubber stopper
- 100 mL beaker

Method

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

Results

Record your observations.

Discussion

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

Properties of sound waves

In the same way that we can describe the properties of the transverse waves of the electromagnetic spectrum, we can also describe the properties of the longitudinal waves of sound. First, let's recap the terms 'wavelength', 'frequency' and 'amplitude'.

- Wavelength (unit = metre) is the distance between two compressions or rarefactions of a wave. The greater the distance between two points of maximum compression, the longer the wavelength.
- Frequency (unit = hertz) is the number of cycles (complete waves or vibrations) that pass a point each second. The more cycles or wavelengths that pass in a second, the higher the frequency.
- Amplitude (unit = metre) is the maximum displacement of air particles from their undisturbed position. This is the displacement amplitude. In a sound wave, which has regions of high and low pressure, the amplitude is the difference between the maximum pressure in a compression and atmospheric pressure.

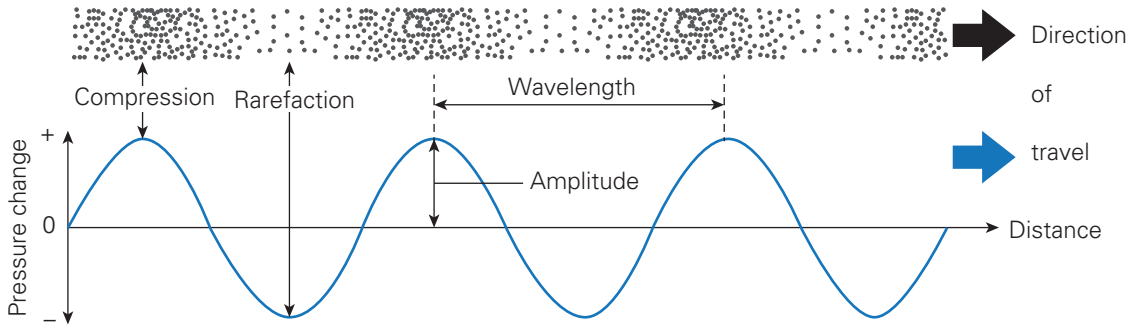


Figure 8.24 A sound wave represented as a graph of change in air pressure over distance. The air pressure change with no sound is 0, and + /– represents increase / decrease in pressure. Above the graph is a diagram showing the space between the air molecules and the regions of compression and rarefaction. Amplitude and wavelength now appear like they do for a transverse wave. Note that the graph is the same shape whether air pressure or air pressure change is plotted.

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

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

The energy of a wave depends on its amplitude as well as its frequency. If you look at water waves, you might notice that not all waves look the same: some waves are bigger than others. Amplitude is the maximum height of a wave from its resting position. If you were able to see sound waves, you would notice that loud sounds have a higher amplitude than soft sounds. This amplitude is often measured in decibels (dB) for sound.When a drum is hit harder with more energy, it sounds louder – the loudness of the sound is a measure of the amount of sound energy.

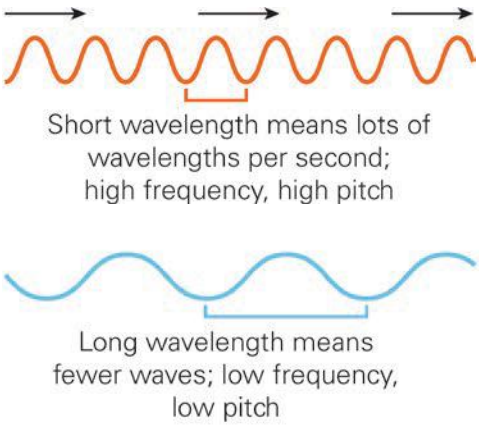


Figure 8.25a Which of the two waves do you think would be a whistle and which would be a bass guitar?

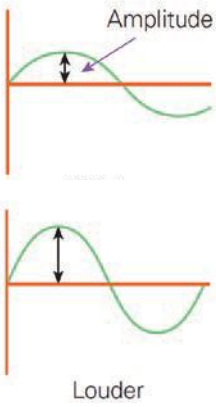


Figure 8.25b The amplitude of a sound wave is an indication of the loudness of the sound.

Quick check 8.8

1 Define the terms 'frequency', 'wavelength' and 'amplitude'. Include the units.

2 Look at these sound waves, shown as pressure against time, and answer the questions below.



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

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WIDGET
Lightning speeds

Explore! 8.6

During a storm, it usually takes a few seconds for the sound to travel from the lightning flash to your ears. This is because light travels about 1 000 000 times faster than sound, which travels at around 340 metres per second in air.

Figure 8.26 shows the relationship between the distance to the flash of lightning and the time delay before hearing the sound. Do you see any pattern in the graph?

Look carefully, and you will see that the line of the graph runs close to the points (3, 1000), (6, 2000) and (9, 3000).

This gives a simple rule for calculating the distance to a lightning strike: every 3 seconds is about 1000 m or 1 km.

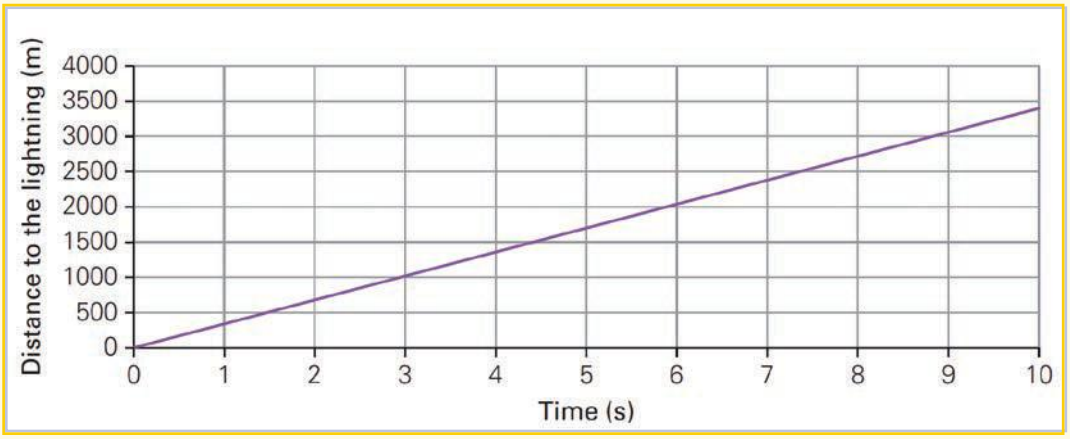


Figure 8.26 Graph of the time between seeing lightning and hearing thunder versus distance to the lightning

Try this 8.6

How far away is the storm?

One way to determine the distance to a lightning strike is to make a movie of the thunderstorm.

Using a mobile device, record a video (from somewhere indoors) during a thunderstorm.

Analyse the video of the storm to accurately determine the time between the flash of lightning and the beginning of the sound of the thunder.

Use the graph in Figure 8.26 to estimate the distance to the lightning.

Stay safe: Record your movie from a place indoors, at a safe distance behind a window. This will work well for recording your video and you will not get wet. It is not safe to be outside during a thunderstorm in case the lightning hits you.



Figure 8.27 Lightning strikes over Perth city

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Surface waves

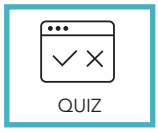
Surface waves are a combination of transverse and longitudinal waves. The particles move both perpendicular to (like a transverse wave) and parallel to (like a longitudinal wave) the direction of wave motion. The result of those two directions is that individual particles move in a circle. Surface waves typically move at the surface of a medium, such as the waves seen in the ocean.

Summary: comparison between wave and particle models

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

Table 8.3 Comparison between waves and particles

Section 8.2 questions



Remembering

1 **State** the types of electromagnetic radiation that are outside the visible spectrum.
2 **Identify** the wavelength range of radio waves.
3 **Recall** the terms for the high-pressure and low-pressure areas of a sound wave.
4 **Identify** the correct words to complete the following sentences.
   a Pitch is determined by the _____ of a sound wave.
   b Loudness is determined by the _____ of a sound wave.

Understanding

5 The speed of light in air is 299 704 645 metres per second. **Calculate** how long it would take (in seconds) for light to reach the following destinations from Perth. Hints: Convert the distances to metres. Divide each distance by the speed of light.
   a Adelaide (2134 km)
   b Brisbane (3607 km)
   c Sydney (3295 km)
   d Melbourne (2730 km)
6 If you see a flash of lightning and 20 seconds later hear the thunder, **calculate** how far away the storm is.

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Applying

7 **Explain** how microwaves heat up food.

8 **Explain** what is meant by the term 'longitudinal wave'.

9 **Explain** why sound cannot travel through the vacuum of space.

10 **Explain** why you see the flash of lightning first before you hear the thunder.

Analysing

11 A sound wave has a frequency of 5 Hz and a wavelength of 3 m. **Interpret** what this means.

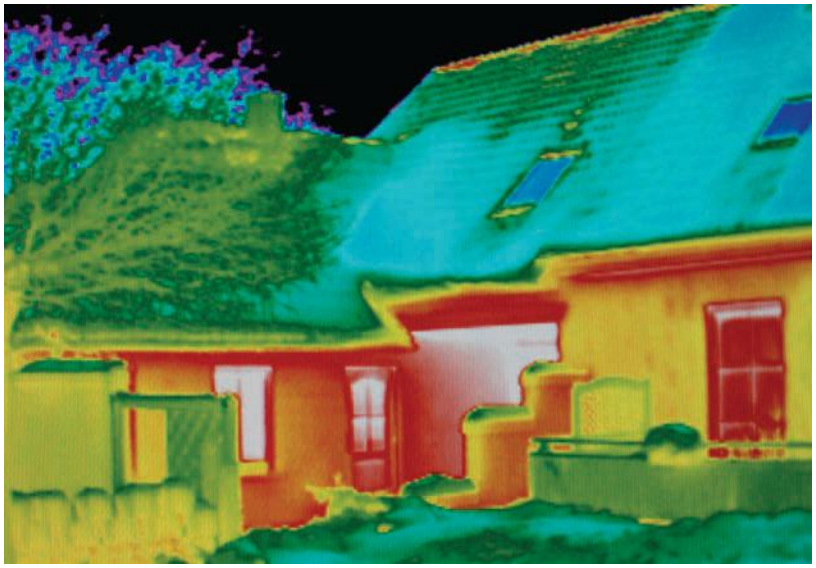
12 **Compare** microwaves and gamma rays in terms of energy, wavelength and frequency.

Evaluating

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



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



15 **Decide** why it is important to find a balance between getting too much and too little UV radiation exposure.

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8.3 Seeing and hearing

Learning goals

1 To be able to label diagrams of the human eye and ear.
2 To discuss the use of corrective technology in vision and hearing loss.

WORKSHEET

How the eye works

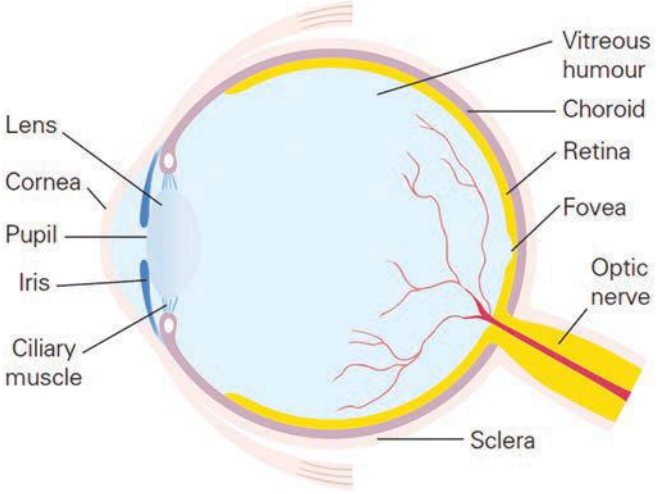
You already know that eyes are amazing, and ever since you were little you have probably been told to protect your eyes. This is because you only have one set of eyes and they may not repair themselves if they suffer certain types of damage.

The structure of the human eye is illustrated in Figure 8.28. Light enters the human eye through the **cornea** and then through the small hole at the front called the **pupil**. The size of the pupil is controlled by the **iris** muscles, which form the coloured part of the eye.

cornea
the transparent outer covering of the eye

pupil
the circular black area in the centre of the eye through which light enters

iris
the coloured circular part of the eye that surrounds the pupil



Cornea: clear protective covering in front of the iris
Pupil: a gap in the front of the eye where light enters
Iris: muscles that change the size of the pupil to control the amount of light entering the eye
Lens: a convex shape that is flexible and helps to focus light on the retina
Ciliary muscles: muscles that control the focus of the lens by changing its shape
Vitreous humour: clear jelly-like substance in the eyeball through which light passes
Choroid: contains the blood vessels that supply the retina
Retina: light-sensitive lining at the back of the eye that converts light into electrical signals
Fovea: the most sensitive part of the retina where the lens aims to focus the vision
Optic nerve: carries the information from the retina to the brain
Sclera: the white outer layer of the eyeball of the eye

VIDEO
Eye evolution

Figure 8.28 The structure of the human eye, side-on cross-section view

If you are somewhere dark, the pupil's size will increase to let in as much light as possible. On a bright sunny day, the pupil's size will reduce to limit the amount of light that enters in order to protect the eye. Just behind the iris is the **lens**, which focuses the light on to the **fovea**, a small area on the **retina** at the back of the eye. The retina is covered in a thin layer of specialised light-receptor cells that send impulses to the brain about the light they receive via the **optic nerve**. The image we see on the retina is upside down. Our brain turns the image the correct way up.

When you change what you are looking at, the lens automatically adjusts to become more curved for near objects and less curved for distant objects. The ciliary muscles adjust lens focus and are controlled by the autonomous nervous system which you met in Chapter 3. This means you do not have to think about focusing when you lift your eyes from a book to look at a distant tree. This process of adjustment is called **accommodation**.

lens (eye)
a small disc of transparent tissue behind the pupil that allows near and far objects to be focused on

fovea
a small part of the retina that contains the most light-sensitive cells

retina
an area of tissue at the back of the eye that contains cells that detect light and colour

optic nerve
the nerve that connects the eye with the brain

accommodation
automatic adjustments made by the eye when looking at objects at different distances

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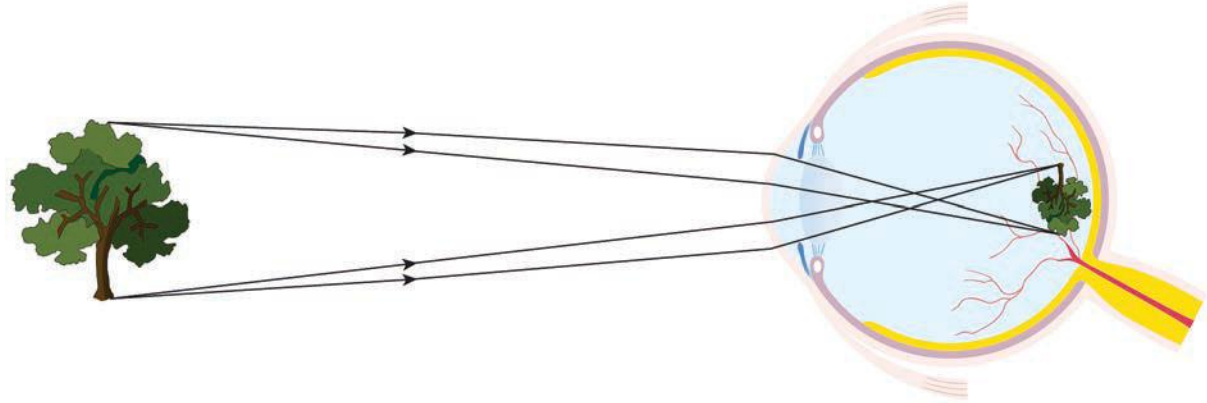


Figure 8.29 The light coming from the tree passes through the pupil and the lens to form an image on the retina.

Practical 8.4

Eye dominance vs. hand dominance

Most of us have a dominant hand, that is, the hand we prefer to use for more precise performance. Just like a dominant hand, most of us have a dominant eye. This is the eye that our brain prefers when processing visual input. Visual information is still gathered through both eyes, but more precise visual information comes from the dominant eye. This is the eye that we should use in activities that involve aiming.

Aim

To determine if eye dominance is related to hand dominance.

Planning

Will an individual's eye dominance always be the same as their hand dominance? Propose a hypothesis.

Materials

An object on a wall or far away that can be the subject of focus.

Method

1 Draw the results table below.

2 Use your dominant hand to create a 'monocular' with your fingers as shown.



3 Find an object in the distance, such as a clock. With both eyes open, try to view it through the hole.

4 Once you can clearly view the object through the hole, close your left eye so you are only looking at it with your right eye. If you can see the object through your hand, then you are right-eye dominant. If you cannot see it, then close your right eye so you are only looking with your left eye. You should now be able to see it through your hand and it means you are left-eye dominant.

continued…

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…continued

5 Survey your entire class. Out of those who are right-eye dominant, how many are right-handed? How many are left-handed? Out of those who are left-eye dominant, how many are left-handed? How many are right-handed? Fill out the results table.

Results

	Right-eye dominant	Left-eye dominant	Total
Right-hand dominant			
Left-hand dominant			
Total			

Discussion

1 Out of the entire class, calculate the percentage that are right-hand dominant. What percentage are left-hand dominant? Identify if the proportions are even.
2 Out of the entire class, calculate the percentage that are right-eye dominant. What percentage are left-eye dominant? Identify if the proportions are even.
3 Determine if all right-hand dominant individuals are right-eye dominant as well. Do the same for left-eye dominance.
4 Does your data support your hypothesis?

Conclusion

Draw a conclusion from this experiment on eye dominance, supporting your statement with data.

Explore! 8.7

Different eyes

Not all eyes are the same. Some organisms' eyes are very different to human eyes. In fact, most animals see very differently to one another; their eye structure varies according to the type of animal and how they live. A bee sees the world very differently to how we see it! Use a search engine of your choice to explore the following questions:

1 How does an earthworm see?
2 How are scallop's eyes different to those of almost every other animal on the planet?
3 How does the position of the eyes on the face differ between animals? How does this change their view of the world?

Quick check 8.9

1 Draw a flow chart to summarise the path of light from outside the eye to the retina.
2 Identify the missing information in the table below.

Part of the eye	Function
Cornea	
	To focus light onto the retina
Retina	
Optic nerve	

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Science as a human endeavour 8.2

Different-shaped windows for seeing

Researchers have found that an animal's ecological niche (the role that an organism plays in an ecosystem) determines the shape of its pupil. Remember, the pupil is the hole through which light is let into the eye. In humans, the pupil is round. Some animals, such as cats, have slits for pupils. This is typical of animals that are active in both the daytime and the night-time. Grazing animals, such as sheep, have horizontally elongated pupils in order to easily survey the landscape for predators.



Figure 8.30 Close-up view of a sheep's eye. The pupil is a horizontal slit.

Corrective technology

Sometimes the eye needs a bit of help. For example, the lens in a person's eye may be unable to curve sufficiently or the eyeball may be abnormally short. In both of these cases, this causes the image to be formed behind the retina, allowing the person to see distant objects clearly but making near objects blurry. We call this condition **long-sightedness**, and it can be corrected with a convex lens that converges the light rays entering the eye. Because the activity most associated with close-up vision is reading, the glasses used to treat long-sightedness are often called reading glasses. Reading glasses are essentially a support for the lens, helping by adding a little bit of extra curvature to the lens.

long-sighted
able to see distant things clearly, but not things that are close

short-sighted
able to see close things clearly, but not things that are far away

People who are **short-sighted** have an eyeball that is abnormally long, or a lens that is too thick. This means the image is formed in front of the retina, giving the ability to see near objects clearly, but distant objects are blurred. Concave lenses can be used to cancel some of the effect of the curved lens in the eye by diverging the light rays entering the eye, allowing the person to see distant objects clearly.

VIDEO
Lens demonstration

Condition	Cause	Solution
Long-sighted	The lens in the eye is not curved enough	Convex lenses worn as glasses to provide extra curvature
Short-sighted	The lens in the eye is too curved	Concave lenses worn as glasses to cancel some of the curvature

Table 8.4 Causes and solutions for long-sightedness and short-sightedness

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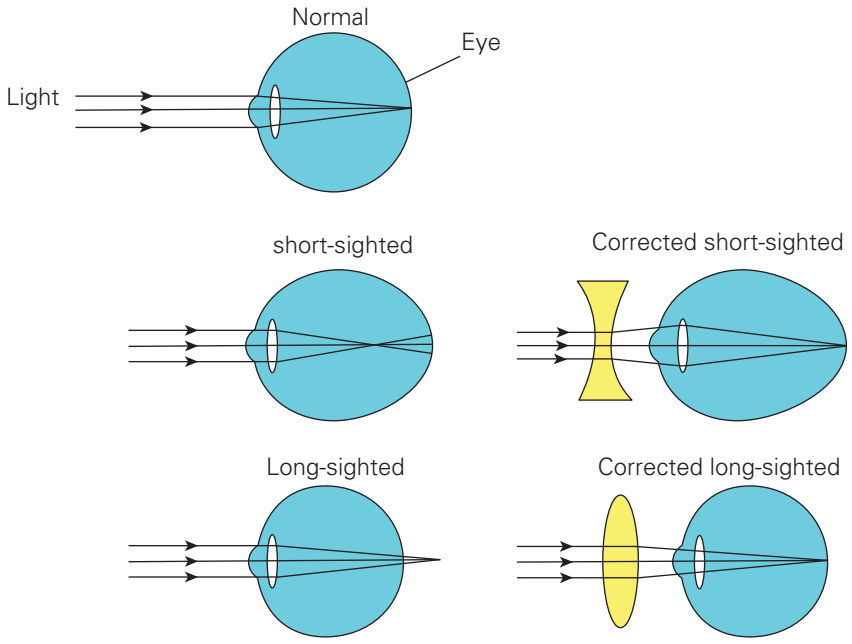


Figure 8.31 The diagram shows how the light is not focused correctly in short-sighted and long-sighted eyes, but this problem can be overcome by correction lenses.

Explore! 8.8

Correcting sight

People can have a number of problems with their sight. Some problems can be corrected with the use of a bionic eye. Research the bionic eye to answer the following questions.

1. What does 'bionic' mean?
2. What is a bionic eye?
3. How does it work?
4. Who will it help?
5. What might someone who has a bionic eye see?
   (There are apps available that simulate the sort of vision a person with a bionic eye might experience).

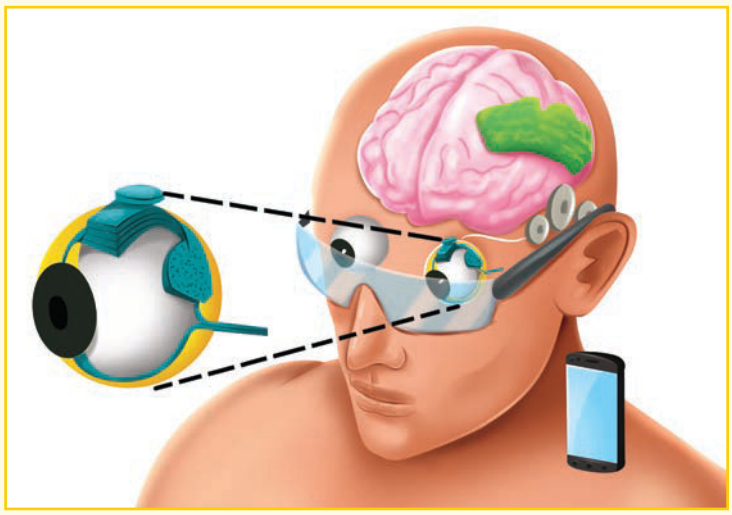


Figure 8.32 The bionic eye can be used to solve some sight problems.

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Quick check 8.10

1 Explain what the terms 'long-sightedness' and 'short-sightedness' mean.
2 Explain how reading glasses help long-sighted people.

How the ear works

Like the eye, the ear is amazing! How does it turn vibrating air particles into messages our brain understands as sound? Let's have a look at the structure of the ear.

In order for us to hear a sound, the energy from the sound needs to be transmitted from our outer ear to our inner ear. However, it must pass through a number of structures before it gets there. The part of the ear that you can see has the job of funnelling sound waves from the environment into the ear. The sound waves travel through the **ear canal** and arrive at the **eardrum**. As you know, sound waves are the vibration of particles – these vibrations cause the eardrum to vibrate. The vibrations are passed on to three tiny bones called the hammer, anvil and stirrup – also known as the malleus, incus, and stapes, respectively. These three bones together are part of the middle ear. The eardrum causes these three bones to vibrate, and in turn this causes the vibration of fluids in the **cochlea**. This part of the ear is the inner ear.

ear canal
a tube that connects the outer ear and the middle ear

eardrum
a thin piece of membrane inside the ear that moves backwards and forwards very quickly (vibrates) when sound waves reach it

cochlea
a spiral tube inside the inner ear that is the main organ of hearing

auditory nerve
the nerve which connects the ear with the brain

Finally, in the cochlea, the vibrations are converted into electrical impulses, which travel along the **auditory nerve** to the brain, where they are interpreted as sound.

You have already learned that the loudness of a sound depends on the amplitude of the sound wave. The unit of measurement for loudness of sound is the decibel (dB). Carrying on a normal conversation with someone is usually around 60 dB. A rock concert is around 105 dB. Humans can hear sounds as low as 0 dB – this limit is called the threshold of hearing. Meanwhile, anything at around 85 dB can start to damage your hearing. Sounds louder than 120 dB can quickly cause irreversible damage.

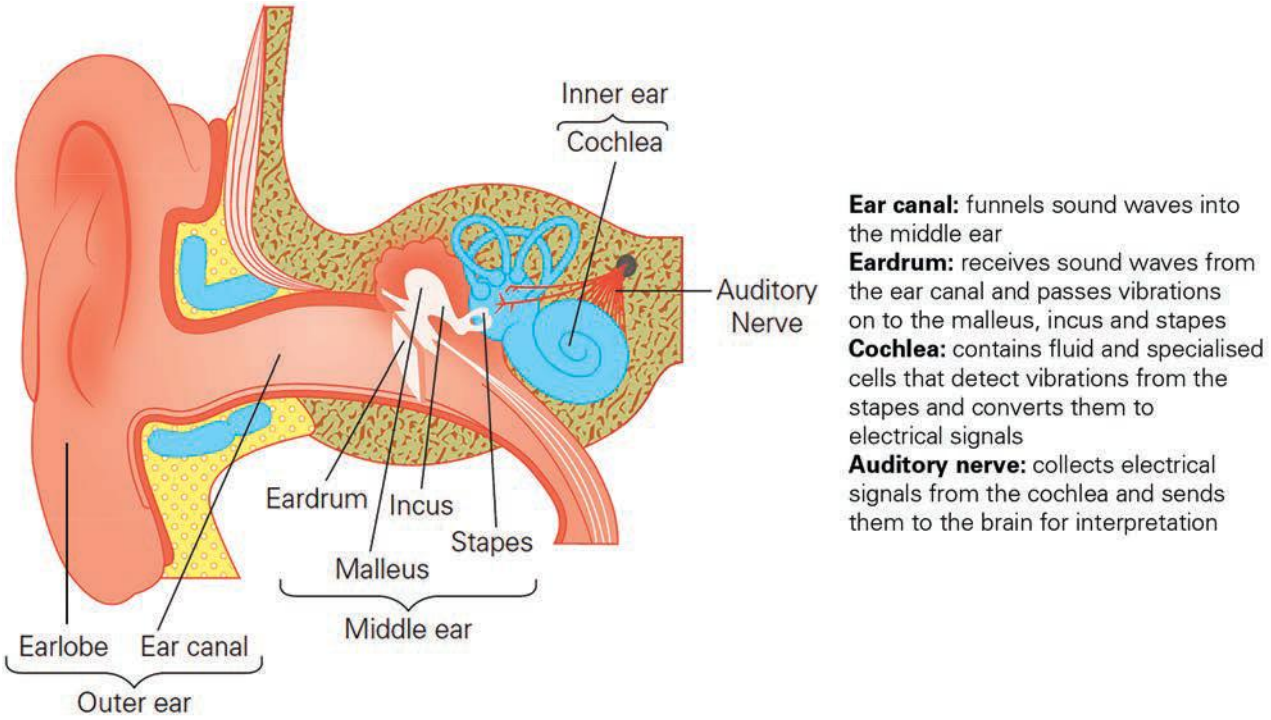


Figure 8.33 The structure of the human ear

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Corrective technology

Some people who experience mild hearing loss wear a hearing aid. Hearing aids make sounds louder so people with hearing loss can participate in everyday life more effectively. However, some people have severely impaired hearing and cannot hear any sounds at all. This kind of impairment can sometimes be solved with a cochlear implant.

Unlike a hearing aid, which is worn outside the ear, a cochlear implant is surgically placed inside the ear. It consists of a microphone worn outside the ear to detect sounds and a processor that can be worn in a pocket that converts the sound into electrical signals. These signals are sent to the implant in the cochlea, which stimulates the auditory nerve.

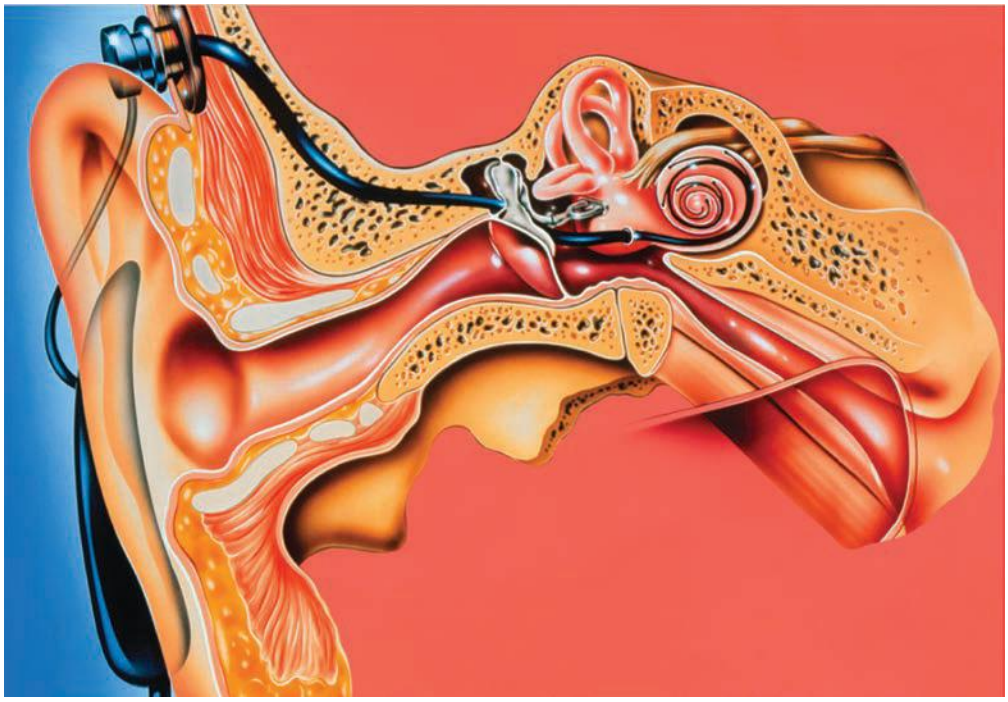


Figure 8.34 A cochlear implant. A microphone outside the ear can be seen. The transmitter behind the ear sends electrical signals through to the implant in the cochlea.



Figure 8.35 Left: A person wearing a hearing aid. Right: A person fitted with a cochlear implant

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Quick check 8.11

1 Identify the missing information in the table below.

Part of the ear	Function
	Contains fluid and specialised cells that detect vibrations from the middle ear and converts these to electrical signals
Eardrum	
Ear canal	
	Collects electrical signals from the cochlea and sends them to the brain for interpretation

2 Recall the threshold of human hearing.

Did you know? 8.4

Protecting our hearing

Excessive noise can damage the delicate hearing cells in the inner ear. People who work with noisy machinery can be exposed to sounds above 85 dB, which can damage their hearing over time. If the delicate hair cells that detect sound in the inner ear are damaged, they cannot be replaced. This can cause hearing loss or a disorder called tinnitus, where a person permanently hears a ringing noise in their ears. To prevent this from occurring, people who are constantly exposed to loud sounds wear ear defenders to protect their hearing.



Figure 8.36 People who work with aircraft can be exposed to sounds above 140 dB, so they wear ear defenders.

Science as a human endeavour 8.3

Music to my ears

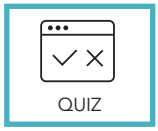
Although cochlea implants enable people to hear sounds when they wouldn't be able to otherwise, the sounds are not as clear as they would be for a person with normal hearing. The implants were designed to process speech, so listening to music is nearly impossible. Researchers are currently trying to develop music that listeners with cochlear implants can enjoy. The researchers are trying to isolate the parts of music that are most enjoyable, such as the vocals, in order to simplify it.

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Quick check 8.12

1 Recall one reason why someone can lose their hearing.
2 Contrast a hearing aid and a cochlear implant.

Section 8.3 questions



Remembering

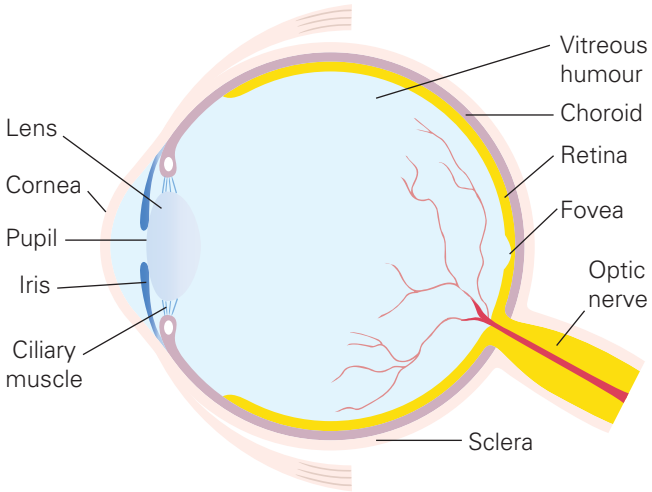
1 **State** which structure in the eye focuses light.
2 **Name** the type (shape) of lens that is in the human eye.
3 **Recall** the parts of the ear that make up the middle ear.
4 **Define** the term 'accommodation'.
5 **Recall** the purpose of the ear canal.
6 **Recall** which type of corrective lens a person with long-sightedness should be wearing.
7 **State** what will happen to your pupil in the following situations.
   a Standing outside on a sunny day
   b Walking into a dark room

Understanding

8 **Explain** how the iris and the pupil work together.
9 **Explain** which parts of the eye deteriorate over time, causing long-sightedness.
10 **Illustrate** a diagram showing how light enters the eye and is focused on the retina.

Applying

11 **Explain** how the shape of the lens changes if an object is:
   a up close
   b far away.
12 **Describe** the shape of the pupil of animals that need to watch the landscape for predators.
13 'Retinal detachment' occurs when the retina becomes separated from the back of the eye. It is a medical emergency. Apply your knowledge of the retina to **explain** why it is an emergency. Use the figure right showing a human eye in side-on view to help you.



Analysing

14 **Compare** the kinds of corrective technology needed for long-sightedness versus short-sightedness. Explain the reasons for the difference.

Evaluating

15 **Decide** why people need to return to the optometrist every 1-2 years to get their eyes checked.
16 **Discuss** what may happen to a person's ability to hear if their eardrum has burst.
17 **Propose** what might happen to a person's hearing if they had to get their outer ear removed.

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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria	Linked question	Check
8.1 I can distinguish between temperature and thermal energy.	2	
8.1 I can compare the transfer of energy by conduction, convection and radiation.	16	
8.2 I can distinguish between mechanical and electromagnetic waves.	3	
8.2 I can identify the different parts of a wave, including the wavelength, amplitude, trough and crest.	5	
8.2 I can recall the different parts of the electromagnetic spectrum.	13	
8.2 I can describe compression and rarefaction in longitudinal waves.	6	
8.3 I can describe the structure and function of the eye.	8	
8.3 I can describe the structure and function of the ear.	19	

Review questions

SCORCHER

Remembering

1 **State** the unit of frequency of waves, and describe what it measures.
2 **Define** temperature and thermal energy.
3 **Identify** the correct words related to the direction of wave travel to complete the following sentence.
Sound waves are _____ waves, whereas electromagnetic radiation is made up of _____ waves.
4 **State** which types of electromagnetic radiation have a higher frequency than visible light.
5 **Define** the following terms: wavelength, frequency, amplitude, pitch.

Understanding

6 **Describe** the difference between compression and rarefaction.
7 **Explain** what is necessary for a sound wave to travel from one place to another.
8 **Explain** why the image formed on our retina is upside down, and suggest why we do not see the world upside down.
9 **Explain** how wearing glasses can help correct sight problems such as long- and short-sightedness.
10 Using your knowledge of infrared radiation, **explain** how night vision goggles work.

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11 Two astronauts are completing a space walk outside the International Space Station.
   a **Explain** why radios are necessary for communication between the two astronauts.
   b Imagine that the radios were broken. **Describe** some other ways the astronauts could communicate.

Applying

12 **Identify** whether altering the frequency or the amplitude would be required in the following situations.
   a Singing a higher pitched note
   b Going from a high note to a low note on the guitar
   c Changing from talking to whispering

13 **Identify** some examples of objects that are similar in size to the wavelengths of the following types of radiation. One has been completed for you.

Type of radiation	Wavelength	Object
Radio waves	1 metre to a few kilometres	Buildings
Microwaves	1 millimetre (mm) to 1 m	
Infrared	0.7 micrometres (μm) to 1 mm	
Visible light	400 nanometres (nm) to 700 nm	
Ultraviolet	10 nm to 400 nm	
X-rays	10 picometres (pm) to 10 nm	
Gamma rays	shorter than 10 pm	

Analysing

14 The figure below depicts a group of four participating in a Mexican wave. **Analyse** the figure to work out whether a Mexican wave is an example of a transverse wave or a longitudinal wave. Justify your response.



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15 **Compare** the particle model and wave model in terms of energy transfer and how they travel through matter.

16 **Contrast** the transfer of thermal energy (conduction, convection and radiation), light and sound energy. You may choose to do so in a table as shown.

	Convection and conduction	Radiation	Light	Sound
Medium				
Particle or wave model				
Type of wave				
Direction of energy transfer				

Evaluating

17 A person standing 1 km away shoots a gun. You see the flash of light to indicate that the gun has been fired but you do not hear anything immediately.

a **State** why this is the case.

b If it takes 3 seconds after you see the gun fire to hear the gunshot, **calculate** the speed of the sound.

c **Discuss** how close this value is to the actual speed of sound in air.

d **Propose** some reasons why it may be different.

18 The table shows the average smallest distance at which a person can see a clear image, at different ages. Use the table to answer the questions that follow.

Age	Smallest distance (mm)
10	7.5
20	9.0
30	12.0
40	18.0
50	40.0
60	90.0

a **Suggest** some reasons why sight changes with age.

b **Propose** whether an older person is more likely to need convex or concave lenses to correct an eyesight problem. Justify your proposition.

19 Suggest some occupations that could give workers excessive exposure to loud noises. Then **propose** some policies that could be put in place to prevent permanent hearing loss.

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Data questions

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

The audiogram results for the 20-year-old and the 80-year-old are illustrated in Figure 8.37. Hearing is considered normal if you can hear sound volumes over 30 dB at a particular frequency. Hearing loss is considered moderate if you require volumes of 30 dB to 60 dB, and is severe if you can only hear sound volumes over 60 dB.

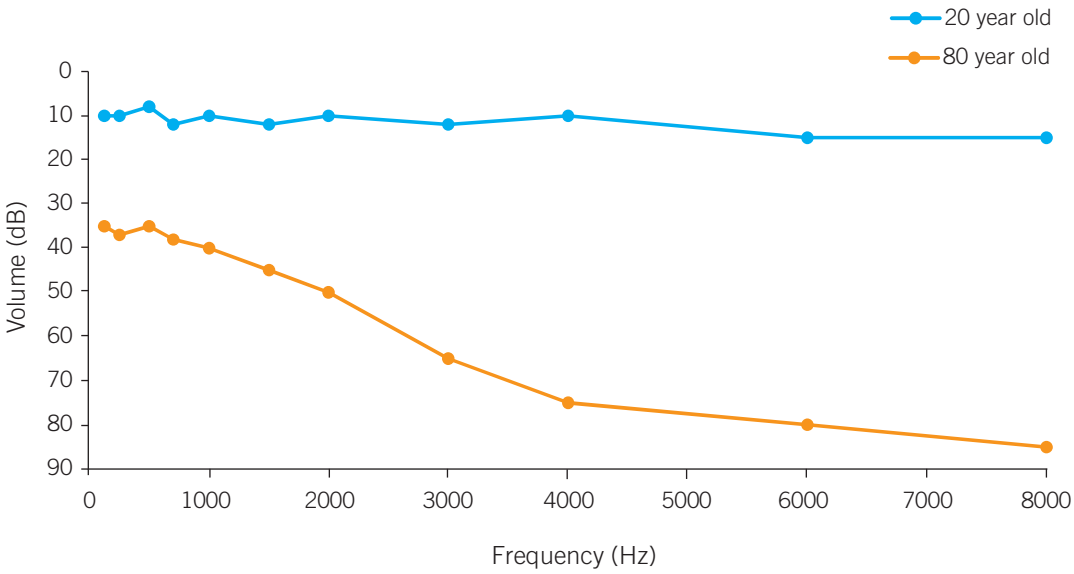


Figure 8.37 Audiogram for a 20-year-old and 80-year-old

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

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STEM activity: Accessible musical instruments

Background information

Music is part of most people's lives. Whether you listen to music, play an instrument or even create your own music, it is something that most people encounter every day. Music can be defined as sounds that are organised in time and vary in pitch (the frequency of the sound), dynamics (loudness and softness) and timbre (the tone of the sound).

All musical instruments have three main components:

- a primary vibrator that produces the sound (for example, a violin string when you draw a bow across it, or a flute mouthpiece when you blow across it)
- a primary resonator that amplifies the sound (for example, the space inside a violin or a flute)
- an opening for the sound to effuse (flow out) from (for example, the f-holes of a violin or the open end of a flute).

Pitch is varied in different ways depending on the type of instrument. In a wind instrument, the pitch is varied by changing the length of the tube (usually by opening and closing holes). In a stringed instrument, the pitch can be varied by changing the tension in the string, the length of the string or the mass (thickness) of the string.

Musical instruments have been developed by every human culture in history – the desire to make music is a universal human trait. Studies have shown that listening to music can reduce anxiety, depression and even pain, and it can improve memory, mood and even sleep. Learning to play an instrument has positive effects on the brain, which translate to other areas of learning. Because music strengthens neural pathways, it can also help to delay ageing of the brain.

Traditionally, people with a disability have been limited in the ways they can engage with music, because of the fine motor skills usually associated with learning to play an instrument. Engineers have been able to modify existing instruments or design new ones so that people with disabilities can engage with music.





Figure 8.38 In musical instruments, vibration produces sound, and this sound is often amplified in the body of the instrument.

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Design brief: Design and build an accessible musical instrument from recycled materials.

Activity instructions

In small groups your task is to design and build a musical instrument that is accessible either to elderly people or to people with a disability. The first step will be to decide what type of condition you would like to cater for. You may need to do some research into the condition to help understand the potential challenges that elderly people or people with a disability may encounter in using traditional instruments.

Suggested materials

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

Research and feasibility

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

Design and sustainability

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

Create

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

Evaluate and modify

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

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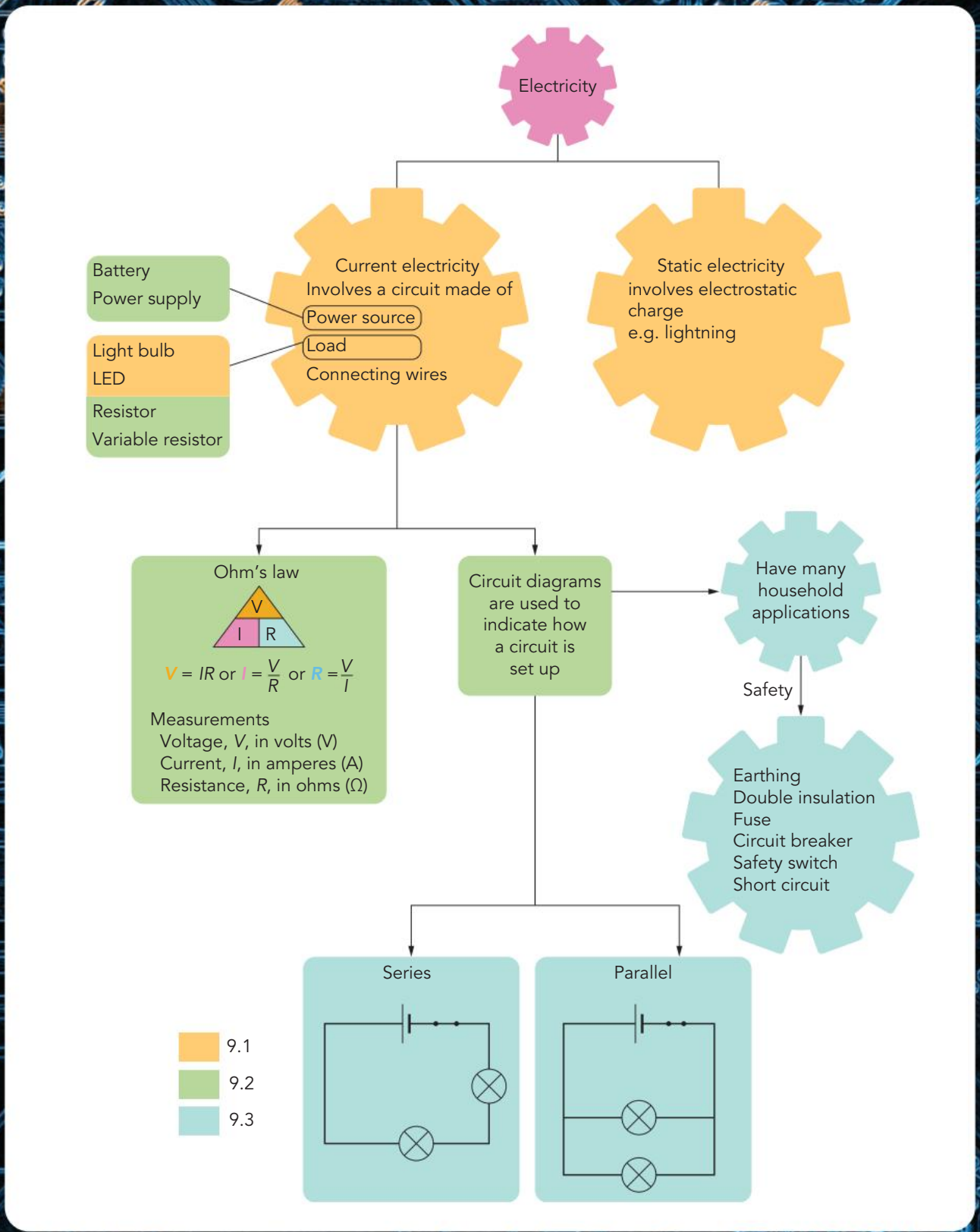
Chapter 9
Electricity

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.

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Chapter map



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9.1 What is electricity?

WORKSHEET

VIDEO
Electricity

Learning goal

1 To be able to define electricity, static electricity and current 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 (–). 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.

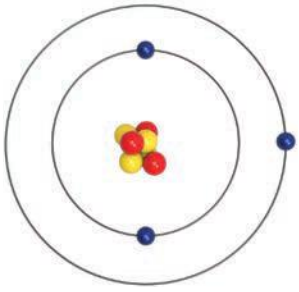


Figure 9.1 The modern Bohr model of a lithium atom with 4 neutrons (yellow), 3 positively charged protons (red) and 3 negatively charged electrons (blue). The net charge is neutral, but if it loses an electron, the atom becomes positively charged.

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. 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.

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

static electricity
an imbalance of charge on objects

electrostatic charge
charge that stays on an object

Explore! 9.1

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 becomes negatively charged. Eventually, the attraction between the charges becomes too great and a discharge of electrical energy occurs between them, producing lightning in the cloud. Sometimes the lightning moves from the cloud to the ground. Use the search engine of your choosing to research the following:



Figure 9.2 When the difference in electrical charge becomes too great, lightning will discharge between clouds.

1 Approximately how many people are hit by lightning each year in Australia? Is the answer what you expected?
2 Look up at least one Indigenous Australian story about lightning and write it down. What phenomenon does it explain?
3 Explain what the lightning 30–30 rule is.

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To demonstrate aspects of static electricity, a Van de Graaff generator may be used, as shown in Figure 9.3c. 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 (that is, by your Science teacher or at a science museum).

VIDEO Example of static electricity at work



Figure 9.3 (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 now has a positive 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.

Did you know? 9.1

History of static electricity

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

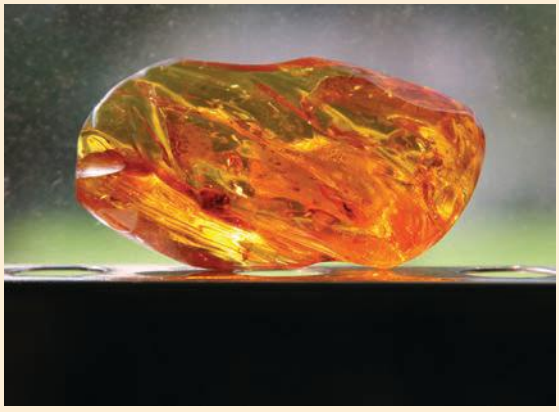


Figure 9.4 Amber was rubbed on fur to produce static electricity.

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 (see Figure 9.5).

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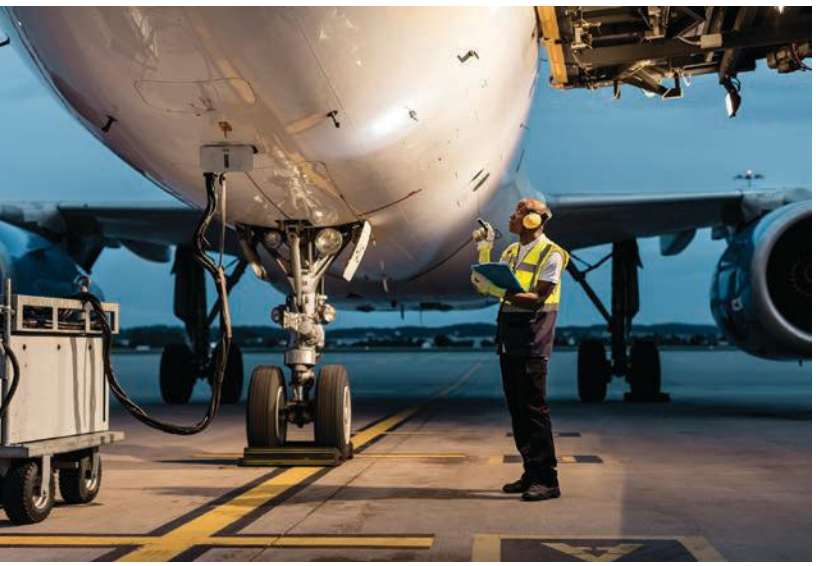


Figure 9.5 The aeroplane is connected to earthing wires during refuelling to avoid sparks and a possible explosion.

Quick check 9.1

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

Try this 9.1

Exploring static electricity

Explore the effects of static electricity using the following items.

- 2 inflated balloons with strings attached
- empty aluminium soft-drink can
- woollen fabric
- your hair
- mirror

Instructions

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.

Questions

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.

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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 charges pass through electrical **components**, such as a light bulb, they transfer energy to that component. Depending on what the component is, it converts that energy into other forms of energy like movement, light and heat.

Try this 9.2



Figure 9.6 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.

It is current electricity that moves in a circuit. If there is a break in the loop, then the electricity stops flowing. Electrons need a path out of and back to the power source to continue moving around the circuit. An electrical circuit always has these three components:

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

component
part of a circuit

circuit
structure through which charges can move

load
something that uses energy in a circuit

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Power source

cell
a single electrical energy source that produces a current; two or more cells joined together are called a battery

battery
a portable source of power

dry cell
a battery in which the electrolyte is absorbed in a solid to form a paste

Figure 9.7 shows the symbol for a cell, 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 two terminals are connected via a circuit, electrons flow from the negative to the positive terminal. The **cell** supplies the energy to the electrons, which are then pushed around the circuit. An everyday **battery**, like you might have in a torch, is an electrochemical cell. Technically, a battery is made up of two or more cells. An example is a car battery – it is bigger and lasts longer than a single cell. A power pack is a bank of multi-cell batteries. In this text, we use battery in a general sense to mean a portable source of power (so, including cells).

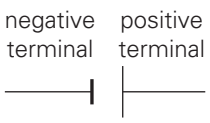


Figure 9.7 The symbol that represents the power source in a circuit has two parallel lines. The shorter line represents the negative terminal, while the longer line represents the positive terminal of the power source.

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

Did you know? 9.2

What happens to used batteries?

Australians use approximately 350 million batteries every year. Around 80% of these (amounting to 6000 tonnes) are alkaline batteries, which are the most commonly used **dry cell**. Most people do not use 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 and corrosive chemicals. When buried in landfills, these toxic metals corrode the battery casing and are released into the water supply.

Let's all do our part and recycle disposable batteries!

Load

Electrons moving through a circuit carry energy from the power source to components that can transform that energy into other forms of energy as the electrons pass. For example, in light bulbs, the energy being carried by the electrons is transformed into light and thermal energy.

Figure 9.8 An older style light bulb transforms electrical energy into light and thermal energy. These are typically only 3–4% efficient in transforming electrical energy into light.

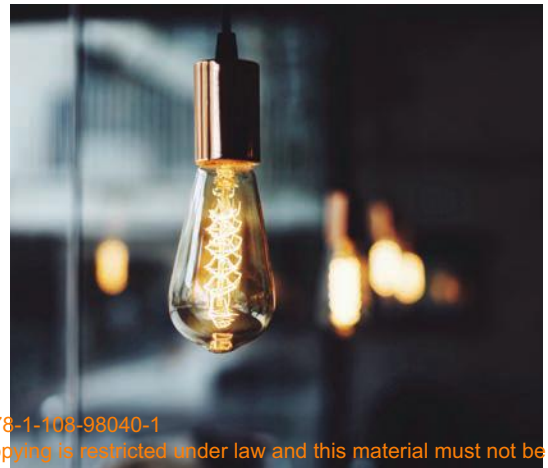


Figure 9.9 shows the most common circuit symbol for an incandescent light bulb. Only a small amount of the energy is transformed into light energy – around 96% is wasted as thermal energy. Light bulbs that are not very energy efficient can get quite hot!

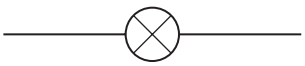


Figure 9.9 One of the circuit symbols for an incandescent light bulb is a circle with a cross in the middle.

LEDs

Light emitting diodes (LEDs) are tiny light bulbs that fit into electric circuits, as shown in Figure 9.10. They transform electrical energy into light energy much more efficiently than light bulbs, with only 20% of the energy lost as thermal energy. The lifespan of LEDs is also much longer than that of incandescent light

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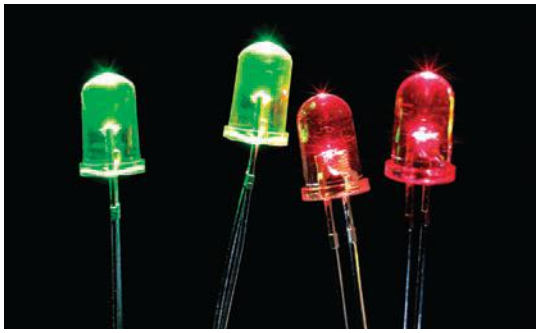


Figure 9.10 LEDs (light emitting diodes) are tiny light bulbs that fit into electric circuits.

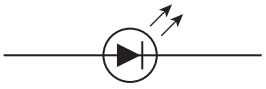


Figure 9.11 The two arrows on the circuit symbol for an LED indicate that light is being emitted.

bulbs. LEDs are often used in appliances such as watches, microwaves, calculators, traffic lights and TV screens. The symbol for an LED is shown in Figure 9.11.

Connecting wires

Current is the name given to the electrons flowing through the connecting wires in a circuit. While we know that it is the negatively charged electrons that move, the current is shown in circuit diagrams as going in the opposite direction; that is, in the imagined direction of a positively charged particle moving from the positive to the negative terminal of the power source. This is called conventional current, and follows the direction defined in the 1700s. At that time, electricity was first being experimented with, and electrons were unknown. So scientists at the time assumed it was the positive charges moving, not negative ones (electrons).

An **alternating current (AC)** electricity source (like an AC power pack) reverses the direction of the current around 50 times every second. This is the power supply most used with appliances. A battery, on the other hand, produces a **direct current (DC)**, which flows only in one direction. In this chapter you will mainly be using DC sources.

alternating current (AC)
a form of electricity where the current reverses direction in regular cycles

direct current (DC)
a form of electricity where the current flows in one direction

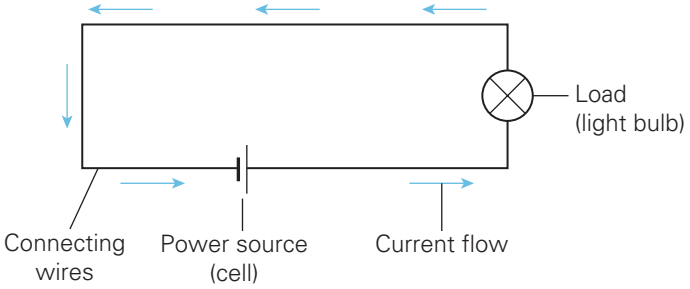


Figure 9.12 Conventional current is indicated in this simple circuit as flowing from the positive terminal to the negative terminal of a cell. The connecting wires are drawn as straight lines.

Quick check 9.2

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

Try this 9.3

Using a 2.5 volt (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 bulb 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 the batteries could be flattened or damaged. Draw a circuit diagram for each successful arrangement.

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Science as a human endeavour 9.1

Electric cars

There are many reasons why electric cars are becoming more mainstream worldwide.

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

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

While electric cars are ideal for city and suburban runs (having a typical range of approximately 200–300 kilometres [km]), most cannot yet manage long-distance journeys. Petrol and diesel cars can typically do 500–800 km on a tank and can be refilled in 10 minutes at numerous petrol stations along the highways. Electric recharge stations are still few and far between in Australia, especially when you think that the first Australian-built electric car began production 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 (from 15 to 60 minutes for a fast recharge).

A Perth to Port Hedland car trip (approximately 1600 km) might involve three 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 9.13 Fast charging an electric car. The 85 kWh battery pack has a mass of 540 kilograms (kg) and contains 7104 lithium-ion battery cells in 16 modules wired in series.

Section 9.1 questions

QUIZ

Remembering

1 **Recall** the electric charge on a neutron, an electron, a proton and an atom.
2 **Name** the charged particles that carry an electric current through a circuit.

Understanding

3 **Define** the following terms.
   a Direct current
   b Conventional current
4 **State** the role of the connecting wires in an electric circuit.

Applying

5 **Explain** how rubbing amber produces electric sparks.
6 **Draw** a simple circuit diagram that shows a battery and an LED so the LED will light up.

Analysing

7 **Contrast** static and current electricity, and give examples of each.

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Evaluating

8 It is often difficult to completely empty the plastic bag that contains breakfast muesli as small flakes of oats seem to get stuck to the inside of the bag. **Propose** a possible explanation for this effect.

9 Lightning bolts contain large amounts of electrical energy. **Propose** reasons why the electricity from lightning bolts is not captured for our electrical needs.

9.2 Simple circuits

Learning goals

1 To be able to construct a circuit diagram using correct symbols for components.
2 To define voltage, current and resistance and their units.
3 To use Ohm's law to calculate voltage, current or resistance in a circuit.

WORKSHEET

Circuit diagrams

The circuit in Figure 9.14 shows a battery pack connected to a light bulb with connecting wires and a switch. When the switch is pressed down, it completes the circuit, so electrons can flow from the negative terminal of the battery through the circuit and back to the positive terminal.

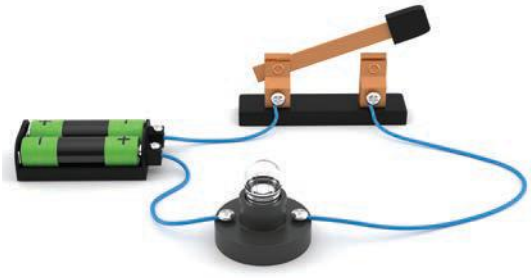


Figure 9.14 A simple circuit can be made with a power source, light bulb and switch.

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 9.15 shows the circuit from Figure 9.14 in the form of a circuit diagram using symbols.

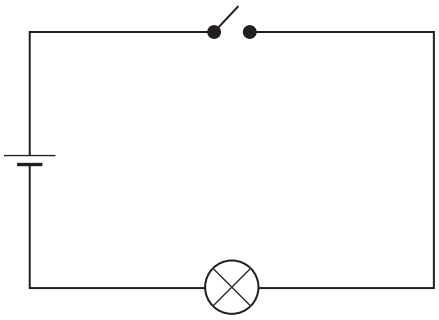


Figure 9.15 To create a diagram of the simple circuit shown in Figure 9.14, join the symbols for a power source (left), a light bulb (bottom) and a switch (top) together with straight lines that represent the wires.

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Science as a human endeavour 9.2

Crystal circuits

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

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

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

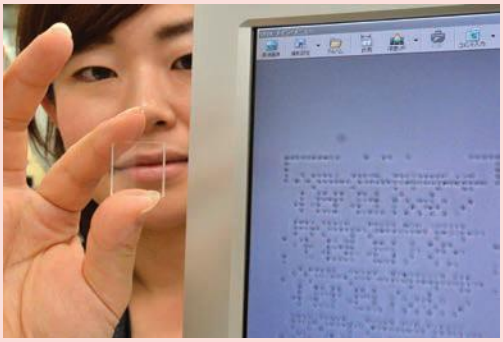


Figure 9.16 Laser beams create dots on glass in order to store data. Electrical circuits in crystals are the next step!

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 9.1 shows several useful electrical components and their circuit symbols.

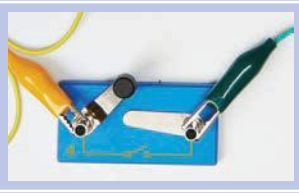
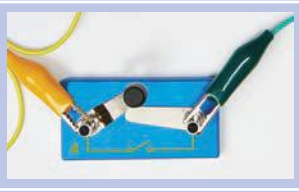
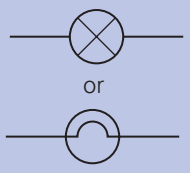
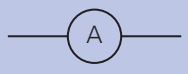
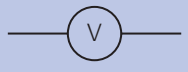
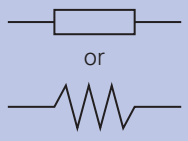
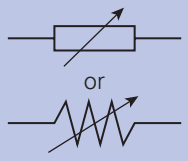
Component	Image	Symbol
Connecting wire		
Switch open		
Switch closed		
Cell		

Table 9.1 Some common electrical components and their circuit symbols

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Component	Image	Symbol
Power supply or battery pack		
Load (e.g. light bulb)		
Ammeter		
Voltmeter		
Resistor		
Variable resistor		

ammeter
a device for measuring electric current

voltmeter
a device for measuring voltage between two points on an electric circuit

resistor
a component which provides resistance to limit the flow of electrical current in a circuit

variable resistor
a type of resistor in which the resistance value can be adjusted

Table 9.1 *(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.

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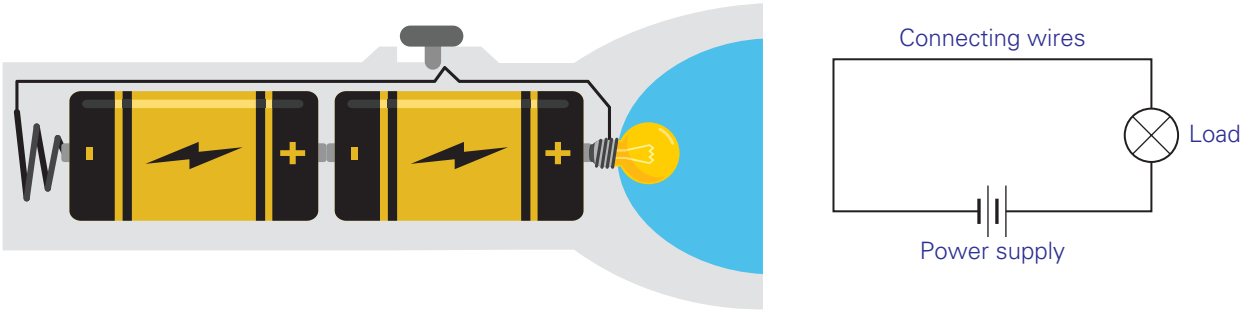
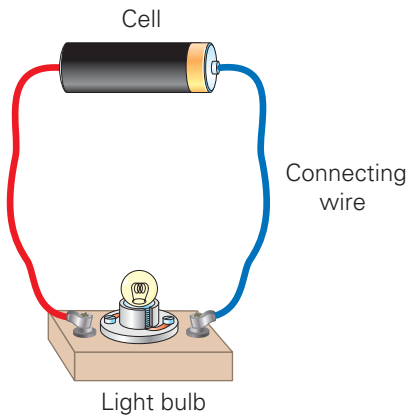


Figure 9.17 The left drawing shows the inside of a torch, but you use a simplified diagram like the right one to represent the circuit. The batteries are the energy source and the light bulb is the load. Can you think of one component that needs to be added to the diagram?

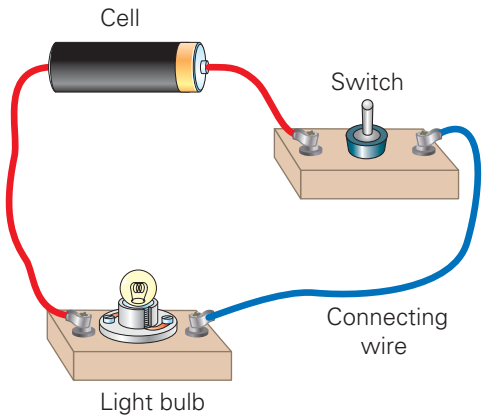
Try this 9.4

Draw circuit diagrams for the following circuits.

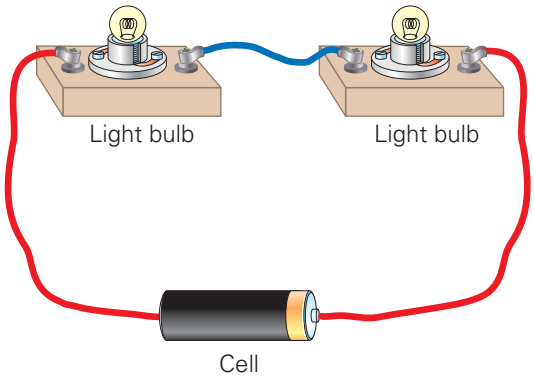
a



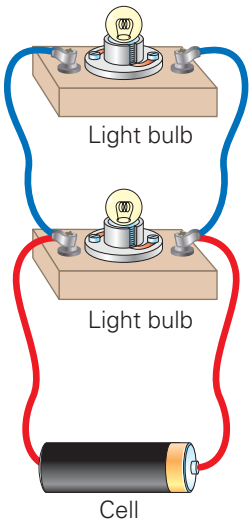
b



c



d



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Quick check 9.3

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

Voltage

Voltage measures the energy difference for each electron (charge) between two points, and has units of **volts (V)**. For example, a 1.5 V battery supplies 1.5 joules of energy to each unit of charge (remember that a joule [J] is a unit of energy). Components such as light bulbs 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 bulb or speaker is also a voltage, and commonly 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 using a voltmeter. A voltmeter can measure the voltage provided by the power supply or the voltage drop across components of the circuit. In a circuit, a voltmeter must be connected to the start and the end of the component whose voltage you are measuring so as to measure the voltage drop **across** the component. This is called connecting in parallel to the circuit. The circuit symbol for a voltmeter is shown in Figure 9.18.

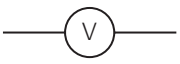


Figure 9.18 The circuit symbol for a voltmeter is a circle with a capital V in the middle.

Current

The **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 1 second and use that number as a measure of the current (in electrons per second). The unit of current is defined this way: 1 **coulomb** per second is 1 **ampere (A)**, or amp for short. A coulomb can be therefore described as the amount of charge transferred in 1 second with a current of 1 amp. You can increase the electric current flowing through a circuit by increasing the voltage or energy supplied to each charge.

voltage
the difference in energy per unit charge, measured between two points

volt (V)
the unit of voltage, equal to one joule per coulomb

voltage drop
the *decrease* in energy per unit charge, measured across a load

current
the amount of charge which moves past a point each second

coulomb (C)
the unit of charge

ampere (A)
the unit of current, equal to one coulomb per second

To measure the current in specific locations of a circuit, an ammeter is used. An ammeter is connected in line to measure the current **through** a circuit. This is called connecting in series with the circuit. The circuit symbol for an ammeter is shown in Figure 9.19.

An ammeter can measure current in amperes (A) or in milliamperes (mA):

$$1\text{ A} = 1000\text{ mA};\quad 1\text{ mA} = \frac{1}{1000}\text{ A}$$



Figure 9.19 The circuit symbol for an ammeter is a circle with a capital A in the middle.

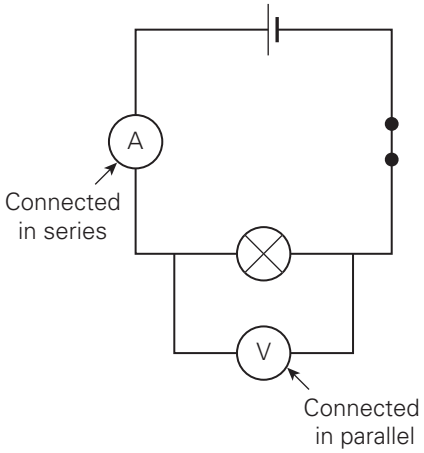


Figure 9.20 When building a circuit, ammeters need to be placed in series and voltmeters need to be placed in parallel.

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Quick check 9.4

1 Define the following terms.
   a Voltage
   b Voltage drop
   c Voltmeter
   d Current
   e Ampere
   f Ammeter
2 How does current differ in a circuit when the switch is open and closed? Explain your answer.

Resistance

The **resistance** in an electric circuit is how difficult it is for the current to flow through a material or component. Resistance is measured using the unit **ohm (Ω)**. The unit symbol for ohms is the symbol for the last letter in the Greek alphabet – omega Ω.

Conductors

If the current can flow easily through a material, you say that the material has a low resistance. Low-resistance materials are called **conductors**. Metals are a good example of conductors.

Some metals are much better at conducting electricity than others. Copper is an excellent conductor of electricity. It is used in electrical wiring, electrical motors, telecommunications and electric cars. Gold is also an excellent conductor of electricity. It is, however, much more expensive than copper. Because it does not easily oxidise and therefore deteriorate, gold is used in small amounts in critical electronic components such as computer chips and spacecraft electronics. Aluminium is another very good low-resistance conductor. It's not as good a conductor as copper, but it is much lighter. This makes it suitable for conducting electricity in the high voltage transmission lines that criss-cross the country.

resistance
the degree to which a substance resists the flow of an electric current through it

ohm (Ω)
the unit of resistance

conductor (electricity)
a material that allows electric current to flow easily

Figure 9.21 High-voltage (up to 500 000 V) power lines distributing electricity most often use aluminium wires as their main conductor.



A digital multimeter is a tool often used to measure current, voltage and resistance.



Figure 9.22 Digital multimeters can measure current, voltage and resistance.

Did you know? 9.3

Saving lives

A defibrillator is a device that treats life-threatening heart problems by delivering a measured dose of electric current to the heart. When the heart does not beat as it should, blood is not circulated around the body. To get the heart pumping, an electric shock is delivered to the heart. An automatic external defibrillator (AED) can be used by untrained people and significantly improve survival rates in people having a heart attack.



Figure 9.23 An AED can increase the chance of survival during a heart attack.

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Insulators

High resistance means that it is difficult for electrons to pass through the material.

Some materials have such high resistance that they block electric current almost completely. Such materials are called **insulators**. Examples of good electrical insulators are various plastics, glass, ceramics, wood and rubber.

insulator
a material through which current cannot flow easily

Explore! 9.2

Electrical engineering as a career



Figure 9.24 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 questions.

1. Identify the material used in insulators for high-voltage power transmissions.
2. Some electric utilities have begun converting to polymer composite materials for some types of insulators. Identify what these are made of and deduce why they are useful as an alternative to other insulators.

Quick check 9.5

1. Define the term 'resistance'.
2. Explain what a conductor and an insulator are and give an example of each.

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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 in volts (V) and I is the current in amperes (A).

Ohm's law
the law stating that the electrical current through a conductor is proportional to the voltage applied, and inversely proportional to its resistance

$$V = IR \text{ or } I = \frac{V}{R} \text{ or } R = \frac{V}{I}$$

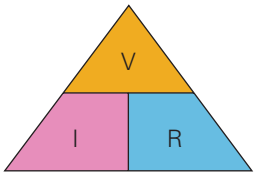


Figure 9.25 The Ohm's law triangle is a useful way to remember the relationship between voltage, current and resistance. Compare this triangle to the equations for Ohm's law.

For example, if you have a circuit with a 2.5 V power source and a 1 Ω resistor, the current would be $I = \frac{2.5\text{ V}}{1\,\Omega} = 2.5$ A. If the resistor is changed to having 2 Ω resistance while keeping the voltage the same at 2.5 V, then the current is decreased to $I = \frac{2.5\text{ V}}{2\,\Omega} = 1.25$ 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.

Quick check 9.6

1 Explain the relationship between current and voltage as stated in Ohm's law.
2 Using the formula $V = IR$, calculate the following.
   a The resistance of a circuit where the voltage supplied is 6 V and the current is 2 A
   b The current in a circuit where the resistance is 50 Ω and the voltage is 25 V
   c The voltage in a circuit where the resistance is 100 Ω and the current in the circuit is 0.5 A

Practical 9.1: Investigation

Investigating resistance

Aim
To investigate how the length of a wire affects its resistance.

Materials
- DC power supply (6 V)
- 6 connecting leads
- resistance wire such as constantan or nichrome
- alligator clips
- ammeter
- voltmeter
- metre ruler

Be careful
Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

Planning
1 Write a rationale about the factors that affect resistance.
2 Create a relevant and specific research question for this investigation.
3 Identify the independent, dependent and controlled variables for this investigation.

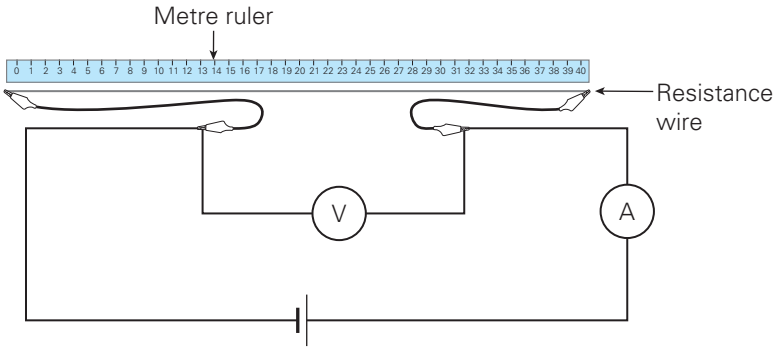
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Method

1 Connect the circuit shown in the diagram. For ease, follow these instructions.
   - i Start on the positive side of the power supply.
   - ii Connect a lead from the positive socket to the positive side of the ammeter.
   - iii Connect a lead from the negative side of the ammeter to the alligator clip attached to the resistance wire at the zero end of the ruler.
   - iv Connect another lead from the other alligator clip to the negative side of the battery. This lead will be used to connect to the other side of the resistance wire and disconnect the power supply between taking readings.
   - v Connect a lead from the positive side of the voltmeter to the alligator clip that you connected to the ammeter.
   - vi Connect a lead from the negative side of the voltmeter to the other alligator clip attached to the switch lead.



2 Draw a suitable results table. Hint: you should have four columns.
3 Record the length of the wire between the alligator clips, and the readings on the ammeter and voltmeter in your results table.
4 Move the alligator clip attached to the disconnection lead to different points on the resistance wire, recording the ammeter and voltmeter readings at each length of wire. The voltmeter readings may not change.

Results

1 Record your results in your results table.
2 Calculate and record the resistance for each length of wire using the Ohm's Law equation.
3 Plot a graph of length of wire in meters (m), against the resistance in ohms (Ω), including a straight line of best fit.

Discussion

1 Identify any trends, patterns or relationships in your results.
2 Explain your results using your own scientific knowledge.
3 Your line of best fit may not go through the origin. Explain where the extra resistance came from.

Conclusion

Draw a conclusion from this experiment regarding length of wire and resistance, using data to support your statement.

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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 9.26 and 9.27, respectively.



Figure 9.26 Fixed resistors have coloured bands that indicate their value.

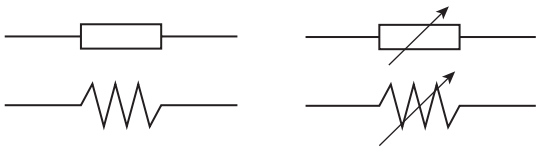


Figure 9.27 The symbol for a fixed resistor (left) is either a rectangle or a zigzag line. The symbol for a variable resistor (right) is the same, but with an arrow through it.

A light-dependent resistor (LDR) is a special type of variable resistor because its resistance changes depending on the amount of light falling on it. As light intensity increases, resistance decreases. LDRs are used in light-sensitive electronic circuits and act as light-sensitive switches; for example, they are used for lights that turn on automatically when it gets dark.

Thermistors, another special type of variable resistor, act in the same way except that their resistance changes as the temperature increases or decreases. Thermistors regulate the temperature in air conditioners and refrigerators using the relationship between voltage and resistance.

Practical 9.2

Current and resistance

Aim

To investigate the relationship between current and resistance using a variable resistor.

Materials

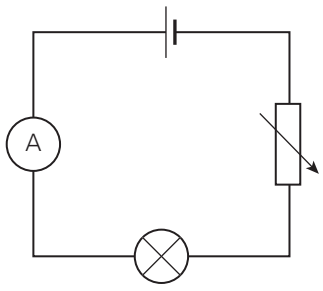
- 6 V power supply
- 6 V light bulb
- variable resistor
- 4 connecting wires and connectors
- ammeter

Be careful

Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.

Method

1. Draw the results table below.
2. Set up the circuit as shown in the diagram at right and set the power supply to 6 V.
3. Adjust the variable resistor so that the light bulb is at its brightest. Record the current shown.
4. Adjust the variable resistor so that the light bulb gets dimmer and dimmer, recording the current at various points until it is at its dimmest.



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Results

Brightness of bulb	Current (A)
Brightest	
Bright	
Dim	
Dimmest	

Discussion

1 Describe what happens to the current in the circuit as the resistance of the variable resistor increases.
2 Describe what happens to the brightness of the bulb as the resistance is increased.
3 Predict what is happening to the voltage across the bulb as it gets dimmer.

Conclusion

Draw a conclusion from this experiment regarding current and resistance.

Quick check 9.7

Explain how a variable resistor works and give an example of how it may be used in your home.

Explore! 9.3

Robotic sensors

Humans have five main senses: sight, smell, touch, hearing and taste. Engineers take a lot of inspiration from these senses and incorporate them into other pieces of technology, such as robots. For example, there are now robotic vacuum cleaners with sensors that tell the robot what part of the room it is in and where it has already vacuumed.



Figure 9.28 The Roomba vacuum cleaner has sensors that tell it where it has already cleaned.

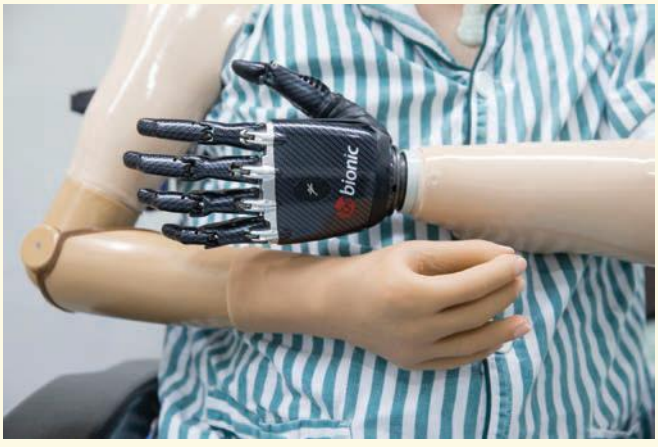


Figure 9.29 Bionic hands need to be able to replicate the senses in a working human hand to operate effectively.

1 Research how sensors are being used in robots.
2 How can the study of human senses help people in the medical field?

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Section 9.2 questions

QUIZ

Remembering

1 **Define** the following terms and give an example of each.
   - a Conductor
   - b Insulator
   - c Resistor
   - d Variable resistor

2 **Recall** the device that measures current.

3 **Recall** the device that measures voltage.

4 **State** Ohm's law.

Understanding

5 **Draw** the symbols for the following electrical components.
   - a Single cell
   - b Three cells in a row
   - c Open switch
   - d Resistor
   - e Bulb

6 a **Explain** why an ammeter must be connected in line with the other components of a circuit (this is called being 'in series').
   b **Explain** why a voltmeter must be connected across the component whose voltage you are measuring in a circuit (this is called being 'in parallel').

7 **Summarise** how a variable resistor works.

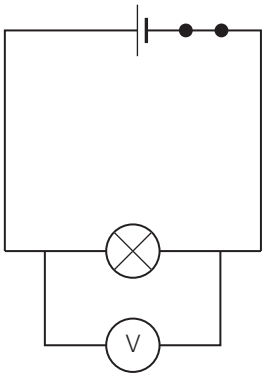
Applying

8 Both aluminium and copper conduct electricity. **Identify** which one of these two conducting metals you would be most likely to find in the following. Give reasons why.
   - a Household wiring
   - b High-voltage transmission lines

9 **Contrast** the terms 'voltage' and 'voltage drop'.

Analysing

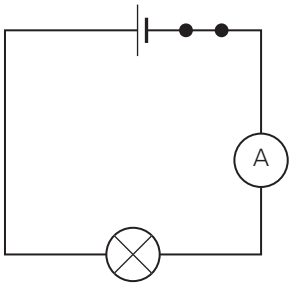
10 The circuit below was constructed by a student using a 6 V battery, a switch, a 6 V bulb and a voltmeter.



   - a **Identify** each of the electrical components on the diagram.
   - b **Identify** which side of the battery is positive on the diagram.
   - c **Deduce** the voltage across each component when the switch is open (off) and closed (on).

Component	Switch open voltage (V)	Switch closed voltage (V)
Battery		
Switch		
Bulb		

11 The following circuit has been constructed using a 6 V battery, a switch, a 6 V light bulb with a resistance of 5 Ω and an ammeter.



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Deduce 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 (A)	Switch closed current (A)
Between power source and switch		
Between switch and bulb		
Between bulb and power		

Evaluating

12 Use your knowledge of light-dependent resistors to **propose** a household appliance that uses them.

13 Research and **discuss** measures that could 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.

9.3 More circuits and their applications

Learning goals

1 To be able to draw series and parallel circuits.

2 To explore the safety aspects of household electricity.



Series circuits

A torch circuit where the batteries, the switch and the bulb are all connected one after the other is an example of a **series circuit** (see Figure 9.30).

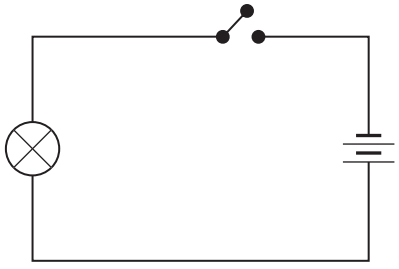


Figure 9.30 A series circuit diagram of a torch contains the symbols for a power source, light bulb and switch.

series circuit
a circuit in which the batteries and other components are all connected one after the other

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 bulb 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 bulb burned out? Both headlights would stop working. This would be extremely dangerous if you were travelling at 80 kilometres per hour around a corner on a country road on a dark night.

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In a series circuit, the voltage is shared among the load. For example, in the following circuit, if the light bulbs are identical, the voltage across each is half that of the power source. The current is the same throughout the circuit.

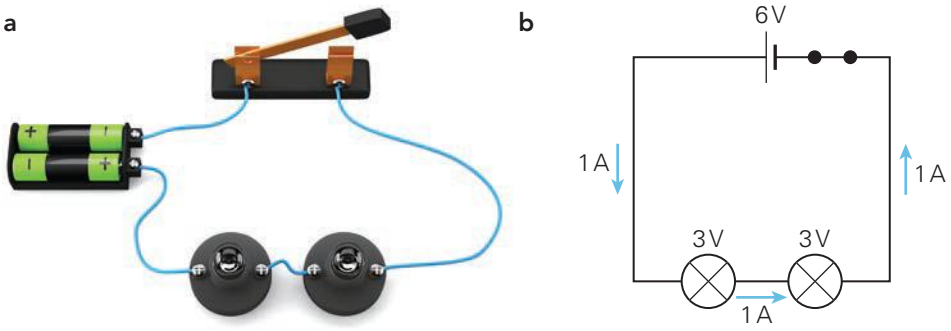


Figure 9.31 (a) Car headlight circuit modelled as a series circuit. **(b)** Matching circuit diagram with a 6 V power source and identical bulbs.

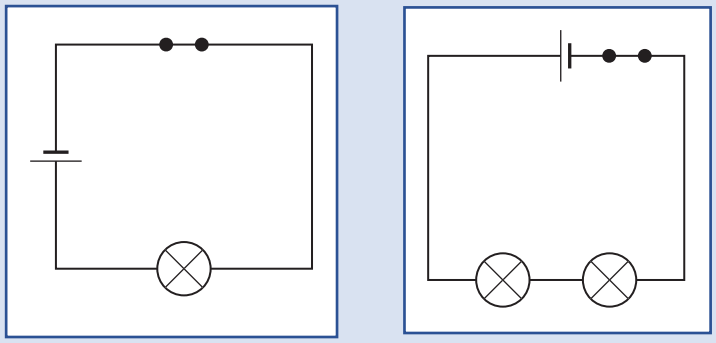
Try this 9.5

Series circuits

Two circuits have been set up for you by your teacher.

Circuit 1 is shown below. Note the brightness of the bulb.

Now look at circuit 2 where the two bulbs are connected in series.



Circuit 1 – Single bulb

Circuit 2 – Two bulbs in series

1. Do the bulbs in circuit 2 glow as brightly as the bulb in circuit 1? Explain why or why not.
2. Predict what will happen if you disconnect the lead between the two bulbs in the circuit.
3. Disconnect the lead and note what happens. Explain what you observe.
4. What happens if you add another bulb in series? Explain what you observe.

Parallel circuits

An alternative car headlight circuit could be constructed using the same components as you used previously, but in a way that will prevent both lights from turning off if one blows. In this instance, you will model the headlight circuit using a **parallel circuit**, as shown in Figure 9.32.

parallel circuit
a circuit in which each component is connected in a separate conducting path

In a parallel circuit, the current is split at each branching. For example, if the light bulbs in Figure 9.32 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.

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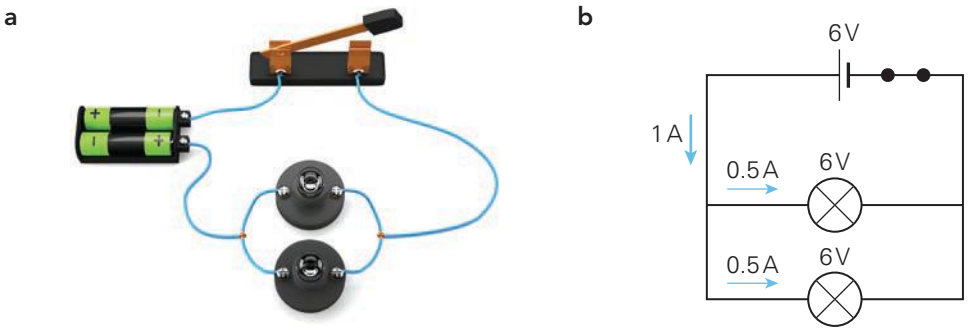


Figure 9.32 (a) Car headlight circuit modelled as a parallel circuit. **(b)** Matching circuit diagram with the blue arrows indicating current split.

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.

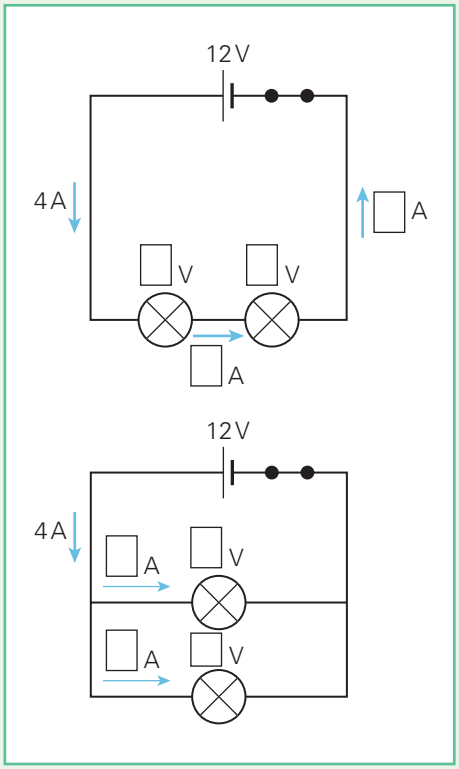
In a parallel circuit, therefore, each component is connected in a separate conducting path. This means that if one load component of the circuit is faulty, the other load components will still work. Most modern Christmas tree lights are connected in parallel. If one of the 200 fairy light bulbs fails, then the other 199 bulbs will still glow. In older style Christmas tree lights, all the bulbs were connected in series. This meant that if one bulb failed, then none of the bulbs would glow. Each individual bulb had to be taken out one by one and replaced with a working bulb until the whole circuit lit up again when the faulty one was found!



Figure 9.33 Modern Christmas tree fairy lights are wired in a parallel circuit.

Quick check 9.8

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 bulbs compare in series and parallel circuits?
4. Assuming that each light bulb is identical, copy and complete the values in the following diagrams.





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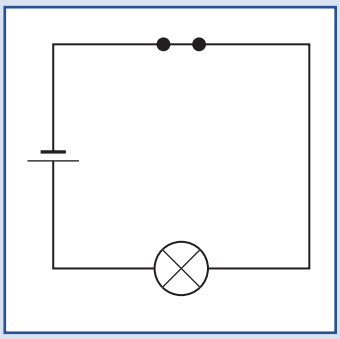
Try this 9.6

Parallel circuits

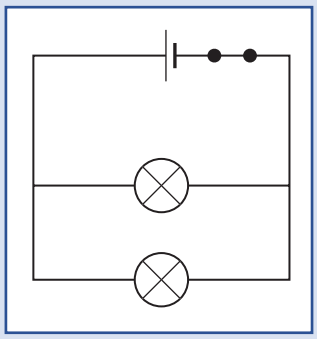
Two circuits have been set up for you by your teacher.

Circuit 1 is shown below. Note the brightness of the bulb.

Then look at circuit 2 where the two bulbs are connected in parallel.



Circuit 1 – Single bulb



Circuit 2 – Two bulbs in parallel

1 Are the bulbs in circuit 2 glowing as brightly as the bulbs in circuit 1? Explain what you observe.
2 Predict what will happen if you disconnect the bottom bulb in circuit 2.
3 Disconnect the lead. What happens to the brightness of the other bulb? Explain what you observe.
4 What happens if you add another bulb in parallel? Explain what you observe.
5 What happens if you add another bulb in series with the bottom bulb? Explain what you observe.

Practical 9.3

Series and parallel circuits

Aim

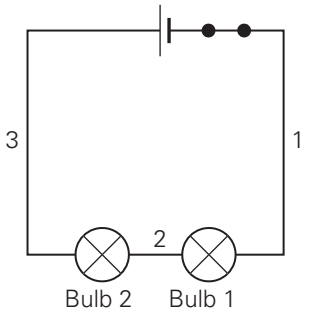
To observe and compare the values of current and voltage in series and parallel circuits.

Materials

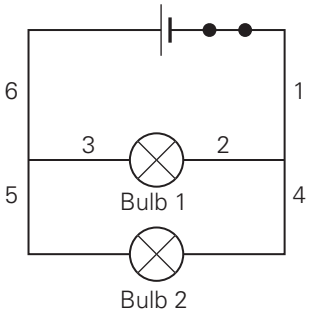
- DC power supply (6 V)
- 2 × 6 V light bulbs and 2 × 6 V bulb holders
- connecting leads (alligator clips)
- ammeter
- voltmeter

Be careful

Electrical shocks may occur. Ensure the voltage output is not exceeded. Power supply is to be turned off when changing the circuit.



Circuit 1 – Two bulbs in series



Circuit 2 – Two bulbs in parallel

continued...

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Method

Draw the results tables below.

Series

1 Set up circuit 1 so that the two bulbs are connected in series.
2 Measure the current at the three numbered positions. Then measure the voltage across the power pack, across bulb 1 and across bulb 2. Record the readings in your results tables.

Parallel

1 Set up circuit 2 so that the two bulbs are connected in parallel.
2 Measure and record the current at the six numbered positions. Then measure the voltage across each bulb. Record the readings in your results tables.

Results

Current

Series circuit	
Position	**Current (A)**
1	
2	
3	
Parallel circuit	
Position	**Current (A)**
1	
2	
3	
4	
5	
6	

Voltage

Series circuit	
Component	**Voltage (V)**
Power source	
Bulb 1	
Bulb 2	
Parallel circuit	
Component	**Voltage (V)**
Power source	
Bulb 1	
Bulb 2	

Discussion

1 Explain your observations regarding the current values in the series circuit.
2 Explain your observations regarding the current values in the parallel circuit.
3 Explain your observations regarding the voltage values in the series circuit.
4 Explain your observations regarding the voltage values in the parallel circuit.

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Household electricity

In your household, all your electrical appliances and lights transform the electrical energy into other forms of energy as the electrons flow through the different components. Power stations supply AC to homes. In Australia, electricity is supplied to homes at a voltage of 230 V and is referred to as the **mains electricity**.

mains electricity
the electricity that is supplied to homes

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

earthed
having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

Power points (sockets) in the home have three slots: active, neutral and earth. When you plug in an electrical device and switch the power on, current flows between slots at the top through the appliance (between the active and the neutral via the appliance). The third slot is the earth slot. It is normally connected to a metal pipe in the ground; that is, directly connected locally to the earth.



Figure 9.34 An Australian power point has three slots: active, neutral and earth.

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 insulated** and only require a connection between the active and neutral pins. These appliances use a 2-pin plug. You might have a laptop computer at home with a 2-pin plug. Other electrical appliances must be **earthed** to protect the user from stray current. These appliances use a 3-pin plug. You might have a toaster with a 3-pin plug at home.



Figure 9.35 Power cords in Australia have either a 2-pin plug (left) or a 3-pin plug (right).

Explore! 9.4

Smart homes

Research shows that around 480 million 'smart' home products will be connected by 2025. 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!

continued…

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…continued

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.



Figure 9.36 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, and there is a fault in the appliance, the metal casing might accidently become 'live'. Then, because the bottom earth pin fits into the earth socket, the electric current will flow via the earth pin to the ground. This prevents the current going through the body of a person who might be touching the metal case of the toaster.

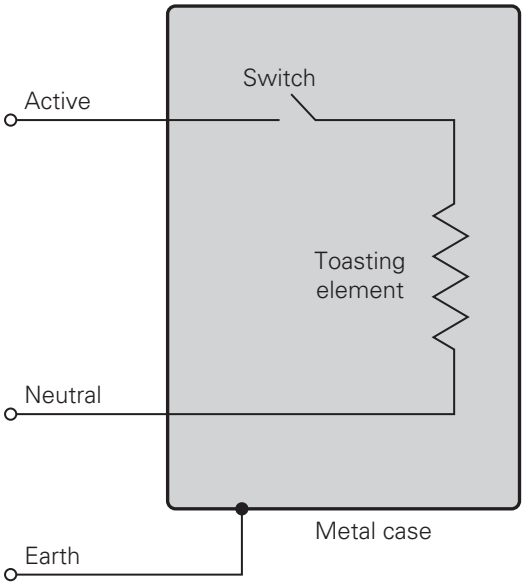


Figure 9.37 In an earthed appliance will like this toaster, any metal parts that can come into contact with the active part of the circuit and become 'live', which means that current could run through it, which could cause an electrocution injury or death. If this occurs, a large current can run to earth and blow a fuse or trip a circuit breaker. This is much better than having the current run through the user of the appliance!

Did you know? 9.4

Electrical wiring

In Australia, the following modern colour code is used for electrical wiring. Some older electrical appliances may still have the old colour code (described in brackets).

The active wire, at the mains voltage of 230 V, is coloured brown (it used to be red – a colour normally associated with danger).

The neutral wire, nominally at 0 V, is coloured blue (it used to be black).

The earth wire, connected to the earth, is striped green and yellow (it used to be plain green).

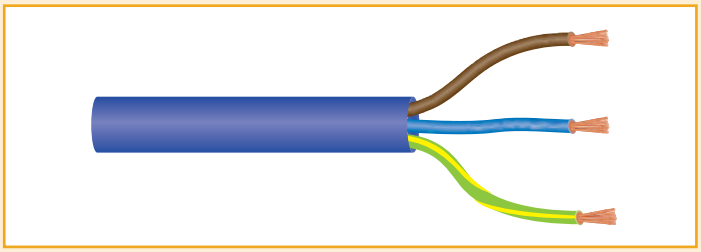


Figure 9.38 Modern colour code for electrical wires: brown for the active wire, blue for the neutral, and green and yellow for the earth.

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 9.39.

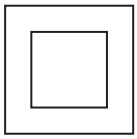


Figure 9.39 An appliance with this symbol on it is double insulated.

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So, the primary difference between an electric drill with a 3-pin and one with a 2-pin plug electric is the case material. If the drill case is made of conductive material (for example, metal), then it must have an earth pin (3-pin plug). Industrial appliances generally have three pins as they may encounter rougher treatment in an industrial environment. In contrast, a domestic appliance is more likely to have double insulation and two pins.

Try this 9.7

Household electrical devices and appliances

Work in a small group of three or four students.

1 Create a table with the following headings and add 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].

2 The characteristics of four electrical devices are shown in the table above. Brainstorm in your group four other electrical devices commonly used in and around the home. Place them in 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 p.m. 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 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 plastic-covered active, neutral and earth wires inside. If the plastic coatings are cracked, you could come in direct contact with a bare active wire. As Table 9.2 shows, the human body is very sensitive to relatively small currents. You can feel one thousandth of an amp (1 mA), and a current of only 20 mA involuntarily contracts your muscles – you cannot let go of the wire! If someone grabs you to save you, they will most likely paralyse their muscles as well, placing two people at risk of electrocution.

electrocution
electric current passing through the body

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Figure 9.40 Electrical hazard symbols are placed where there is a risk of deadly electric shock.

Most modern homes have quick-acting special safety switches that can cut the current off in less than one-thirtieth of a heartbeat!

With appropriate care and caution, many of these unfortunate electrical incidents can easily be avoided.

Current (mA)	Effect on the human body
1	Can be felt
10	Causes pain
20	Paralysed muscles – very difficult to let go
50	Severe shock
90	Breathing is affected
150	Breathing is very difficult
200	Death is likely
500	Serious burning, breathing stops, death inevitable

Table 9.2 The size of the current determines the effect it has on the human body.

Fuses and circuit breakers

fuse
a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

circuit breaker
carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

A **fuse** is a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit. Many fuses used in cars are designed this way. Look at Figure 9.41 – notice the fuse on the right no longer provides an electrical connection.

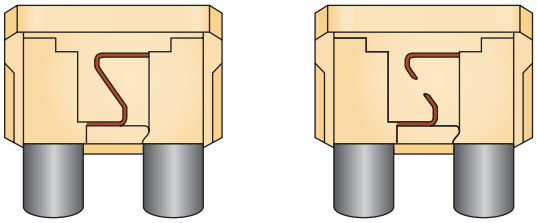


Figure 9.41 The wire inside a fuse will break if the current passing through it gets too high.

Most modern houses have replaced fuses with circuit breakers. A **circuit breaker** (see Figure 9.42) carries out the same function as a fuse by breaking the circuit when the current exceeds some safety limit, such as 20 A.

Safety switches (also known as residual current devices, RCDs) are different to circuit breakers. RCDs detect when current 'leaks' from circuits, possibly into a person. When 30 mA leaks from a circuit, these devices trip the power, preventing an electric shock.

VIDEO
Residual current device (RCD)

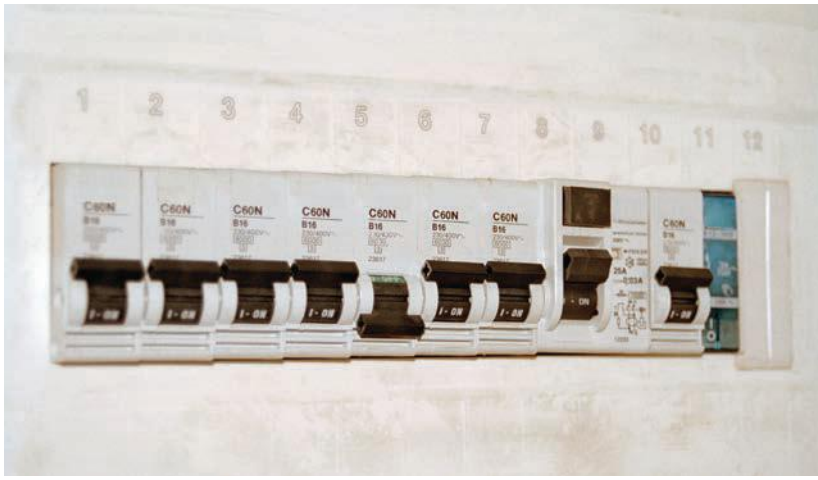


Figure 9.42 Circuit breakers protect electrical systems in the house and safety switches protect people against electric shock.

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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 9.43 A short circuit can cause a fire.

Science as a human endeavour 9.3

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 50 000 V shock do to a person's brain? Research has found that this electric shock can impair a person's ability to process and remember information. Cognitive function greatly declines immediately after being tasered, which can pose problems for those who are being questioned by law enforcement shortly after being subjected to the electric shock. This newfound knowledge may change the protocols surrounding taser use, which is now heavily regulated.



Figure 9.44 Taser use by law enforcement is regulated more now than it was in the past.

Quick check 9.9

1 Recall the voltage of mains electricity in Australia.
2 State the purpose of the third pin in the earth socket.
3 Explain why some appliances do not have the earth socket.

Section 9.3 questions

QUIZ

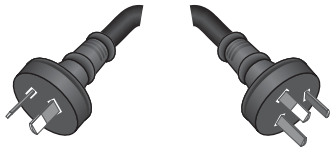
Remembering

1 Using the labels *switch*, *earth*, *active* and *neutral*, redraw and then correctly **identify** the parts of the electrical power point shown.



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2 Using the labels *2-pin*, *3-pin*, *earth*, *active* and *neutral*, redraw and then correctly **identify** the parts of the electrical plugs shown below.



Understanding

3 **Describe** the differences between series and parallel circuits.

4 a **Describe** the main disadvantage of a series circuit.

b **Describe** two advantages of a parallel circuit.

5 **Explain** why some electrical appliances are earthed.

6 **Explain** why some electrical appliances are not earthed.

7 **Draw** a diagram to show how four 1.5 V batteries can be connected in parallel. What is the total voltage provided by this battery circuit? Label the positive and negative terminals of each battery.

Applying

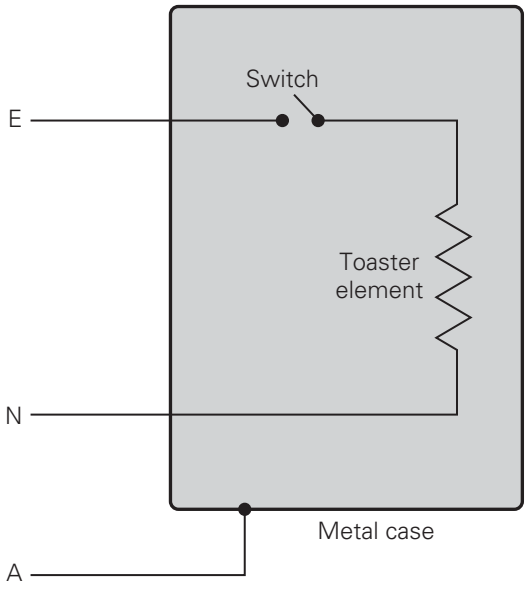
8 a **Explain** what happens to your muscles when you experience a current of 20 mA from a live wire from the mains electricity.

b **Explain** the reasons why you should not grab a person who is being electrocuted by a current of 20 mA or more.

9 **Explain** the function of a safety switch in an electrical circuit.

10 A circuit breaker in your home fuse box continually trips OFF when you are using your toaster. **Explain** what this means and what you should do next.

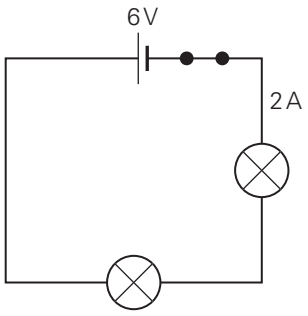
11 **Explain** what would happen if a red-green colour-blind electrician using the old colour code for electrical wiring had connected the metal case of the toaster to the active wire (A – old colour red), and the toaster element to the neutral wire (N – old colour black) and the earth wire (E – old colour green), as shown in the diagram of an incorrectly wired toaster.



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Analysing

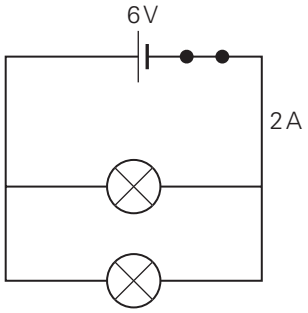
12 A student constructs circuit 1 as shown using a 6 V battery and two identical bulbs, and measures the current through the circuit as 2 A.



Circuit 1

a **Identify** whether this a series or parallel circuit. Explain your answer.
b **Determine** the voltage drop across each bulb.
c **Calculate** the resistance of one bulb.

13 A student constructs circuit 2 as shown below. The circuit contains a 6 V battery and two identical bulbs of higher resistance than in question **12**.



Circuit 2

a **Identify** if this is a series or a parallel circuit. Explain your answer.
b **Determine** the voltage drop across each bulb.
c **Calculate** the resistance of one bulb.

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 **Discuss** why household circuits supplying your lights, television, computers, washing machines and suchlike, are wired in parallel, while the fuses (and circuit breakers) to these circuits are wired in series with the circuits.

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Chapter review

Chapter checklist

In the Interactive Textbook, the success criteria are linked to the review questions and will be automatically ticked when answers are correct. Alternatively, you can download this checklist from the Interactive Textbook to complete it.

Success criteria		Linked question	Check
9.1	I can define electricity, static electricity and current electricity.	2	
9.2	I can construct circuit diagrams using the correct symbols.	5	
9.2	I can define voltage, current and resistance.	4	
9.2	I can calculate the voltage, current or resistance of a circuit using the Ohm's law	8	
9.3	I can distinguish between series and parallel circuits.	12, 13	
9.3	I can describe the safety aspects of household electricity.	14	

Review questions

SCORCHER

Remembering

1 **State** whether the following statements are true or false. If they are false, explain why.
   a Static electricity can be produced by rubbing amber on fur.
   b The nucleus of an atom contains protons, neutrons and electrons.
   c The unit of charge is the volt.
   d Six thousand tonnes of disposable batteries are sent to landfill annually in Australia.
   e Tasers can be very dangerous.
2 **Name** the two types of current electricity.
3 **Recall** the three components that an electricity circuit needs.
4 For a certain electrical circuit, 20 coulombs of charge flow past a point in 5 seconds. **Define** the term 'current' and **calculate** the current in amperes.

Understanding

5 **Draw** these electrical components: switch open, switch closed, ammeter, voltmeter, battery, incandescent light bulb, LED, resistor.
6 **Describe** the energy transfers that occur in a working electrical circuit containing a cell and a light bulb.
7 **Explain** how a safety switch can protect you from stray current.

Applying

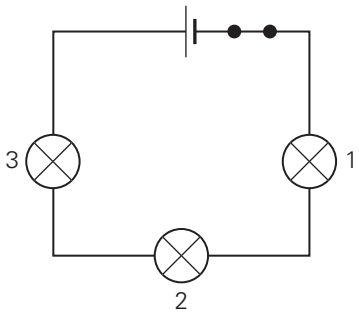
8 A 12 volt car battery has an internal resistance of 0.02 Ω. **Calculate** the current passing through this circuit.
9 **Explain** what a good electrical insulator is and give an example of where it may be used.
10 **Explain** why electrical wires made from gold or silver are not used for sending power from the power stations into households.

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Analysing

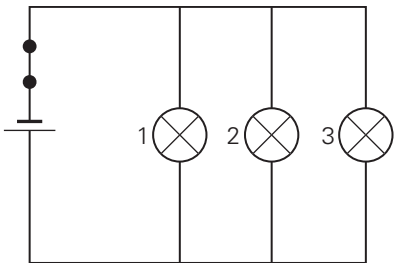
11 **Contrast** how an ammeter and a voltmeter would be connected in a circuit.

12 a If one or more of the bulbs were broken in the circuit on the right, **identify** how would it affect the other bulbs. Copy and complete the following table regarding the circuit.



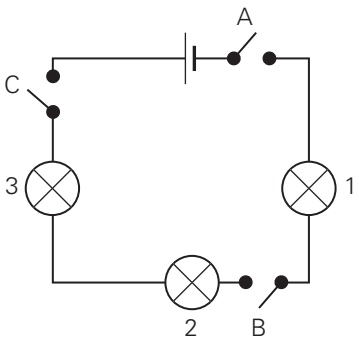
Bulb broken	Bulb 1 (on/off)	Bulb 2 (on/off)	Bulb 3 (on/off)
Bulb 1			
Bulb 2			
Bulbs 2 and 3			

b If one or more of the bulbs were broken in the circuit on the right, **identify** how would it affect the other bulbs. Copy and complete the following table regarding the circuit.



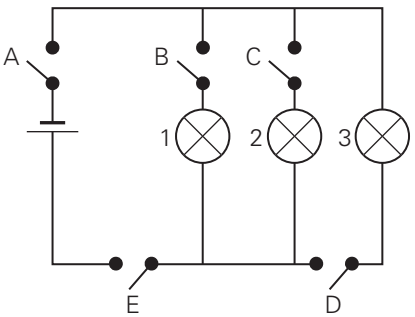
Bulb broken	Bulb 1 (on/off)	Bulb 2 (on/off)	Bulb 3 (on/off)
Bulb 1			
Bulb 2			
Bulb 3			
Bulbs 2 and 3			

13 *a* If one or more of the switches were open in the circuit, **identify** how would it affect the bulbs. Copy and complete the following table regarding the circuit shown on the right.



Switches turned on	Bulb 1 (on/off)	Bulb 2 (on/off)	Bulb 3 (on/off)
A			
B and C			
A, B and C			

b If one or more of the switches were open in the circuit, **identify** how would it affect the bulbs. Copy and complete the following table regarding the circuit shown on the right.



Switches turned on	Bulb 1 (on/off)	Bulb 2 (on/off)	Bulb 3 (on/off)
A, B, C and D			
A, B and E			
A, C, D and E			
A, B, D and E			

Evaluating

14 **Propose** reasons why:

a household electrical wires are coated in plastic

b many household appliances are double insulated.

15 **Decide** whether solar energy is a suitable source of electrical power for domestic use.

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Data questions

A group of students is testing the advertising claims of 10 different AA battery brands. Normally, a fresh AA battery should provide at least 1.50 V. The initial voltage for three new batteries for each brand was recorded by preparing a circuit with a multimeter, and the data is presented in Table 9.3.

Battery brand	Initial voltage of first battery (V)	Initial voltage of second battery (V)	Initial voltage of third battery (V)
1	1.63	1.60	1.61
2	1.57	1.55	1.57
3	1.24	1.29	1.45
4	1.48	1.50	1.47
5	1.52	1.50	1.51
6	1.53	1.53	1.53
7	1.50	1.55	1.50
8	1.60	1.61	1.64
9	1.65	1.65	1.65
10	1.61	1.62	1.60

Table 9.3 Recorded voltage for three new AA batteries of different brands

1. **Identify** the battery with the highest initial voltage.
2. A 'flat' AA battery can be considered, in this case, to have a voltage of less than 1.3 V. **Determine** whether any of the newly purchased AA batteries are already flat.
3. For the first battery tested of each brand, remove any flat batteries as outliers and **calculate** the mean initial AA battery voltage.
4. With respect to the initial voltage claim of at least 1.5 V, **identify** any patterns that appear in the observed initial voltages.
5. **Classify** the battery brands as those that meet their claim of an initial voltage of 1.5 V and those that don't consistently meet their claim.
6. Now **determine** the battery brands that do meet their claim into those with an initial voltage much higher than the claim (1.60 V+) and those consistently just above the claim (1.50–1.59 V).
7. Battery brand 9 also claims to have the 'longest lasting AA battery'. **Justify** whether the data in Table 9.3 supports this claim.
8. After complaints to battery brand 3 about the quality of their batteries, a spokesperson revealed that there was a 10% chance of a battery in their packs being sold with a voltage of less than 1.5 V. **Justify** this claim with respect to the reliability of the data presented in Table 9.3.
9. Based on the data presented in Table 9.3, **predict** whether a fourth battery of brand 3 is likely to meet the claim of an initial voltage of 1.5 V.

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STEM activity: Can you see the renewables?

Background information

In this chapter, you learned 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 tiny 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 grams (g) of carbon dioxide into the atmosphere. The number might seem small, but, imagine the emission from today's nearly 5 billion connected devices!

People and governments have recently started to invest in renewable and sustainable energy sources because our planet has gone through environmental change over centuries. Still, some people in our society need help in understanding that the energy resources of our planet are finite. Now, more than ever, it is important that we all do our very best to change our current practices into more sustainable ones.

There are many ways to showcase this message to the world. One of the most powerful of them all involves storytelling. Good stories have the power to bring us together and encourage us to understand and empathise with many causes. Recently, digital storytelling has been used by many professionals (including famous YouTubers) to tell (or sell) their ideas, opinions or products.



Figure 9.45 Even tablets and smartphones contribute to carbon dioxide levels in the atmosphere.

Design brief: Design and create a 60-second infomercial promoting the use of renewable energy to be shared in your local area.

Activity instructions

In teams (maximum of 4 people), you will use the digital storytelling process (described below) to create a short 60-second video to answer a specific scenario. You and your colleagues should 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.

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Suggested materials

- mobile device, camera to record footage
- laptop or tablet with a video editor
- paper to create a storyboard
- your imagination!

Research and feasibility

1 Discuss within your group who your target group is going to be. Include thinking about the people who live in your local area.

2 Research advantages of renewable energy over non-renewable energy that should be communicated to your audience through the infomercial, and make a table to rank them in order of importance for your project.

	Rank of importance	Comments when considering target audience
Advantages of renewable energy		
Disadvantages of non-renewable energy		

3 Research the population of your local area. Discuss and then list important information about your target audience. Considering this information about your target audience, add comments to your advantages and disadvantages research.

Design and sustainability

4 As a group, decide the key issues you are going to present in your infomercial. Then write the script for the video, assign roles to individual members and reflect on what is required to achieve the goal.

5 Design a storyboard to put the script together with a visual representation.

Create

6 Create the video by recording the storyboard sections. As a group, gather short clips and images, and/or record your own video using a mobile device.

7 Put it all together using video-editing tools such as iMovie, Windows Movie Maker or Adobe Spark (recommended) to put your ideas into video format.

Evaluate and modify

8 Discuss with your group members the challenges you encountered throughout this project. List the strategies or actions that allowed you to overcome each challenge.

9 Evaluate the effectiveness of your infomercial by sharing with your target audience.

10 Create a range of evaluative questions to use to gauge the success of your informercial. After showing your infomercial to a target audience, use the questions to test its effectiveness.

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Glossary

Chapter 1

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

controlled variable any variable that may influence the outcome of an experiment and is therefore kept constant

dependent variable the variable that is measured to see whether it is affected by the independent variable

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

independent variable the variable that is purposely changed (manipulated) during an experiment

linear a straight line plotted on a graph

mean the result you get by adding two or more values together and dividing the total by the number of values

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

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

outlier an extreme data point – a number that is very different to the other numbers collected

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

qualitative data data that is descriptive and non-numerical

quantitative data data values that are numerical

secondary data data that has been previously collected for another purpose

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 a substance that inhibits the growth of bacteria inside the body

antibody also called immunoglobulin; a protective protein produced by the immune system in response to the presence of a foreign substance (called an antigen)

antigen a substance that induces an immune response in the body; can be foreign (non-self) 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; it 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

capillaries (singular: capillary) the smallest vessels that contain oxygenated blood and enable red blood cells to deliver oxygen to the tissues on a cellular level

carbohydrate biological molecule made of carbon, hydrogen and oxygen which can be broken down with the release of energy in the body

cellular respiration an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy

effector a muscle, gland or organ capable of responding to a response signal from the modulator

enzyme a biological catalyst that increases the rate of a chemical reaction without itself being changed by the reaction

eukaryote an organism with a nucleus and membrane-bound organelles

fermentation a chemical process by which energy is produced in the absence of oxygen

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

germ theory the theory that some diseases are caused by pathogens

glucagon a hormone secreted by the pancreas that triggers the liver and muscle cells to convert glygogen into glucose, raising 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 cells to take up glucose from the bloodstream and the liver to store glucose as glycogen, lowering blood glucose levels

lipid a chemical substance such as a fat or oil that can be used as an energy source

lymphocyte white blood cell that is involved with flighting disease; some produce antibodies

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

multicellular composed of more than one cell

nephron the functional unit of the kidney, involved in filtering the blood to produce urine

non-specific immunity immunity provided by the branch of the immune system that does not depend on recognition of the pathogen; includes the first and second lines of defence such as physical barriers, inflammation and fever

osmoregulation the regulation of water levels in the blood/body

pathogen an infectious agent, such as a bacterium, virus, prion or parasite, that can cause disease

phagocytosis a cellular process where a white blood cell engulfs and ingests a cell or large particle to break it down using enzymes

prokaryote a single-celled organism with no membrane-bound organelles (such as a nucleus), e.g. a bacterial cell

protein a chemical substance composed of amino acids, with structural and regulatory functions; can also be used as an energy source

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

septic describes a wound infected with a harmful pathogen

specific immunity immunity provided by the branch of the immune system that is specific to each particular pathogen; the third line of defence

spontaneous generation the idea that disease can arise from non-living matter

stimulus (plural: stimuli) any object or event that elicits a sensory or behavioural response in an organism

unicellular composed of a single cell

vaccine a chemical substance composed of a dead or weakened version of a pathogen that is injected or ingested to make a person immune against that pathogen

virus an extremely small non-cellular pathogen composed 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

autonomic nervous system the part of the peripheral nervous system involved in involuntary physiological processes such as heart rate and digestion

axon long fine fibres that conduct nerve impulses from cell bodies to synapses, which form nerves when bundled

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

dendrites fine branching fibres which receive nerve impulses from synapses and conduct them to the body of a neuron

effector something which produces an action in response to a signal

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 (sensory and motor) a representation of body parts where size relates to the area of the cerebral cortex devoted to processing sensory or motor signals

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) between sensory and motor neurons

motor neuron a nerve cell that transmits messages from the central nervous system to the effectors

myelin sheath insulating substance around axons to prevent nerve impulses from leaking out into the surroundings

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

neuron an individual nerve cell specialised to carry signals

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

receptor something which detects and passes on a signal; a sensory receptor is a neuron or part of a neuron that detects a stimulus

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

sensory neuron a nerve cell that detects and transmits sensory information to the central nervous system

somatic nervous system the part of the peripheral nervous system involved with the voluntary control of body movements



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synapse the junction between two neurons

synaptic cleft a gap between the membranes of two neurons at a synapse, into which complex molecules project to facilitate and control the action of neurotransmitters

target cell a cell affected by a specific hormone

Chapter 4

abiotic non-living factors, such as temperature, pH, salinity, rocks and water

apex predator the highest level consumer in a food chain

ATP adenosine triphosphate: a molecule that provides useable energy in cells

autotroph also known as a producer, an organism capable of making its own food

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

biosphere total region of Earth containing biomes

biotic living factors, such as plants, animals and bacteria

capture–mark–recapture method a method for estimating animal population sizes that involves capturing, tagging, releasing and recapturing a sample of the population

carrying capacity the maximum population size a particular environment can support

cellular respiration an energy-releasing process in which glucose reacts with oxygen, producing carbon dioxide and water and releasing energy in the form of ATP

commensalism a symbiotic relationship where one organism benefits and the other neither benefits nor is harmed

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

consumer also known as a heterotroph, an organism that must eat or consume other plants or animals as a source of energy

ecological niche the role and space that an organism fills in an ecosystem, including all its interactions with the biotic and abiotic factors of its environment

ecosystem an ecological unit made up of living components, non-living components and the interactions between them

emigration the movement of individuals out of the population

eutrophication high levels of nutrients in water bodies that results in excessive growth of algae and oxygen depletion of the water

exponential growth a rapidly accelerating increase in population size

food chain the flow of energy from organism to organism in an ecosystem

food web a series of interconnected food chains

habitat the environment an organism lives in

heterotroph also known as a consumer, an organism that must consume plants or animals as a source of energy

immigration the movement of individuals into the population

interspecific competition competition for food or resources between members of different species

intraspecific competition competition for food or resources between members of the same species

limiting factor a biotic or abiotic factor that prevents a population from growing

logistic growth population growth that increases initially and then plateaus (flattens out) once it has 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 some organisms make their own food

pollinator an organism, such as an insect, that carries pollen from one plant, or part of a plant, to another

population members of one species living in a particular area at a given time

predator an animal that hunts other animals as its source of food

prey a living animal that is captured and eaten by a predator

primary consumer the consumer who eats the producer in a food chain

producer also known as an autotroph, an organism capable of making its own food

quadrat a tool used to measure species abundance

quaternary consumer the consumer who eats the tertiary consumer

random sampling a sampling technique where each sample has an equal chance of being selected

secondary consumer the consumer who eats the primary consumer

symbiotic relationship any type of close and long-term relationship between two types of living organism

systematic sampling a sampling technique where each sample is taken at fixed intervals that have been previously decided upon

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tertiary consumer the consumer who eats the secondary consumer

trophic level the position an organism occupies within a food chain

tundra plains of frozen soil and sparse tree growth in the Arctic region

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 of protons in an atom of an element

beta particle a charged particle (electron) that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom

bioplastic a type of plastic made from renewable resources like plants

compound chemical combination of two or more different elements combined in a fixed and definite proportion by weight

electromagnetic spectrum the range of all possible forms that electromagnetic radiation can take, plotted out in terms of lowest to highest frequency

electron a subatomic particle with a negative charge found orbiting the nucleus

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

ion a charged version of an atom that has either gained or lost electrons

isotopes atoms of the same element with the same number of protons but a different number of neutrons

mass number the sum of the protons and neutrons in the nucleus of an atom

molecule a chemical species generally made up of two or more non-metal atoms. A molecule can be elemental or a compound.

neutron a subatomic particle with a neutral charge found in the nucleus of an atom

nucleus (plural: nuclei) the central part of the atom containing its protons and neutrons

proton a subatomic particle with a positive charge found in the nucleus of an atom

radioactive decay when an unstable nucleus emits radiation (alpha and beta particles or gamma rays) and breaks down to form another element

subatomic particle one of the particles that make up an atom

Chapter 6

acid a substance that, when dissolved in water, has a pH of less than 7

base a substance that has a pH greater than 7 and that can react with an acid to form a salt and water; known as an alkali if it can dissolve in water

chemical change a rearrangement of atoms

chemical reaction a process in which the structure of atoms or compounds that make up a substance are changed

coefficient the number placed in front of a chemical symbol to balance a chemical equation

combustion the reaction of a fuel with oxygen, usually producing heat and light

conservation of mass a law that states that matter can neither be created nor destroyed in chemical reactions

effervescence bubbles or fizzing in a solution

endothermic an absorption of heat in a chemical reaction characterised by a decrease in surrounding temperature

enthalpy internal energy of a system

exothermic heat is released from a reaction characterised by an increase in surrounding temperature

kinetic energy the energy of moving matter

neutralisation a reaction between an acid and a base, forming a solution that has a pH of 7

photosynthesis the chemical reaction by which some organisms make their own food

potential energy (chemical) the energy stored in the chemical bonds of a substance

product substance formed in a chemical reaction

reactant substance that undergoes change in a chemical reaction

reaction conditions factors required for a chemical reaction to proceed

rearrange move things into a different order

respiration a chemical reaction which converts glucose and oxygen into carbon dioxide and water as well as energy

salt a product formed when an acid reacts with a metal, base or carbonate; usually made up of a metal and a non-metal

Chapter 7

asthenosphere the softer layer of rock under the lithosphere

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



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convection currents movement of rock within Earth's mantle due to temperature differences between the upper and lower layers

core the inner part of Earth's structure

crust the top layer of Earth, which supports all life on Earth

destructive (convergent) a type of plate boundary that occurs when plates move towards one another

epicentre the location on Earth's surface directly above the focus of an earthquake

focus the exact point under the surface of the Earth where the earthquake occurs

geoid a model of the Earth's surface approximating the height of sea level as it would be if affected by gravity alone (and not by currents or tides)

GPS Global Positioning System, 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 of an earthquake

lava molten rock that has reached the surface

lithosphere the solid outer layer of Earth consisting of the crust and top layer of the upper mantle. It is split into giant slabs called tectonic plates.

magma hot liquid rock found just below the surface of the Earth

mantle the layer of the Earth underneath the crust, which is made up of mostly solid rock and is where convection currents take place

Pangaea the original supercontinent which has since broken into pieces and drifted apart

plate boundaries the edges where two tectonic plates meet

plate tectonics the theory that the Earth's lithosphere is broken up into many pieces called tectonic plates and that they are moved by convection currents in the mantle

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 waves waves that moves through Earth during an earthquake

seismogram the pattern produced when seismic activity is recorded by a seismometer

seismometer an instrument that measures the intensity and duration of seismic waves during an earthquake

subduction when the denser oceanic plate sinks underneath less dense continental plate

tectonic plates gigantic slabs of rigid rock which float on the Earth's asthenosphere

transform a type of plate boundary that occurs when plates move parallel to one another

tsunami a great wave produced by an earthquake in the ocean

Chapter 8

accommodation automatic adjustments made by the eye when looking at objects at different distances

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

auditory nerve the nerve which connects the ear with the brain

cochlea a spiral tube inside the inner ear that is the main organ of hearing

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

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

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

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

cornea the transparent outer covering of the eye

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

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

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

ear canal a tube that connects the outer ear and the middle ear

eardrum a thin piece of membrane inside the ear that moves backwards and forwards very quickly (vibrates) when sound waves reach it

electromagnetic radiation transfer of energy by electromagnetic waves

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

fovea a small part of the retina that contains the most light-sensitive cells

free electron an electron that is not attached to an atom

frequency the number of cycles of a wave per second

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

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

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

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

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

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

iris the coloured circular part of the eye that surrounds the pupil

kinetic energy the energy of moving matter

lens (eye) a small disc of transparent tissue behind the pupil that allows near and far objects to be focused on

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

long-sighted able to see distant things clearly, but not things that are close

mechanical wave a disturbance in a medium that transfers energy through that medium

medium the matter through which a mechanical wave travels

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

optic nerve the nerve that connects the eye with the brain

oscillating moving back and forth with periodic motion somewhat like vibration

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

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

pupil the circular black area in the centre of the eye through which light enters

radiation transfer of energy without the presence of particles

radio waves electromagnetic radiation that has the longest wavelength

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

retina an area of tissue at the back of the eye that contains cells that detect light and colour

seismic wave waves that moves through Earth during an earthquake

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

short-sighted able to see close things clearly, but not things that are far away

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

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

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

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

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

vacuum a space totally devoid of matter

visible light the part of the electromagnetic spectrum that we can see

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

wavelength the distance from one wave crest to the next

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

Chapter 9

alternating current (AC) a form of electricity where the current reverses direction in regular cycles

ammeter a device for measuring electric current

ampere (A) the unit of current, equal to one coulomb per second

battery a portable source of power

cell a single electrical energy source that produces a current; two or more cells joined together are called a battery

circuit structure through which charges can move

circuit breaker carries out the same function as a fuse by breaking the circuit when the current through it exceeds a certain threshold

component part of a circuit

conductor (electricity) a material that allows electric current to flow easily

coulomb (C) the unit of charge

current the amount of charge which moves past a point each second

direct current (DC) a form of electricity where the current flows in one direction



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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 having an earth pin in a plug through which the electric current will flow to the ground in the case of a fault

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

electrocution electric current passing through the body

electrostatic charge charge that stays on an object

fuse a short length of conducting wire or strip of metal that melts when the current through it reaches a certain value, breaking the circuit

insulator a material through which current cannot flow easily

load something that uses energy in a circuit

mains electricity the electricity that is supplied to homes

ohm (Ω) the unit of resistance

Ohm's law the law stating that the electrical current through a conductor is proportional to the voltage applied, and inversely proportional to its resistance

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

resistor component which provides resistance to limit the flow of electrical current in a circuit

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

variable resistor a type of resistor in which the resistance value can be adjusted

volt (V) the unit of voltage, equal to one joule per coulomb

voltage the difference in energy per unit charge, measured between two points

voltage drop the *decrease* in energy per unit charge, measured across a load

voltmeter a device for measuring voltage between two points on an electric circuit

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