OXFORD INSIGHT SCIENCE

FOR NSW STAGE 5

MELINDA **MESTRE**
LILY **OKATI**
TIMOTHY **SLOANE**
HELEN **SILVESTER**

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FOR NSW STAGE 5

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Indexed by Neil Daly
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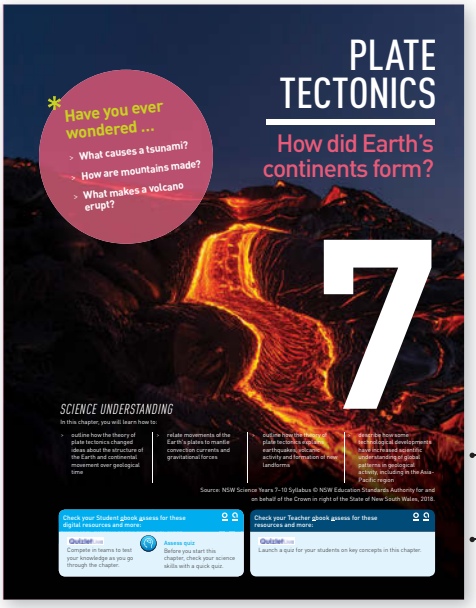
USING OXFORD INSIGHT SCIENCE FOR NSW STAGE 5

Oxford Insight Science for NSW is a series developed to meet the requirements of the NSW Syllabus for the Australian Curriculum: Science across Stages 4 and 5. Taking a concept development approach, each double-page topic of *Insight Science* represents one concept and one lesson, encouraging accretive acquisition of learning and, by the end of each chapter, complete understanding.

The series also includes standalone 'Working scientifically' and 'Student research project' chapters to equip students with key science skills and support assessment.

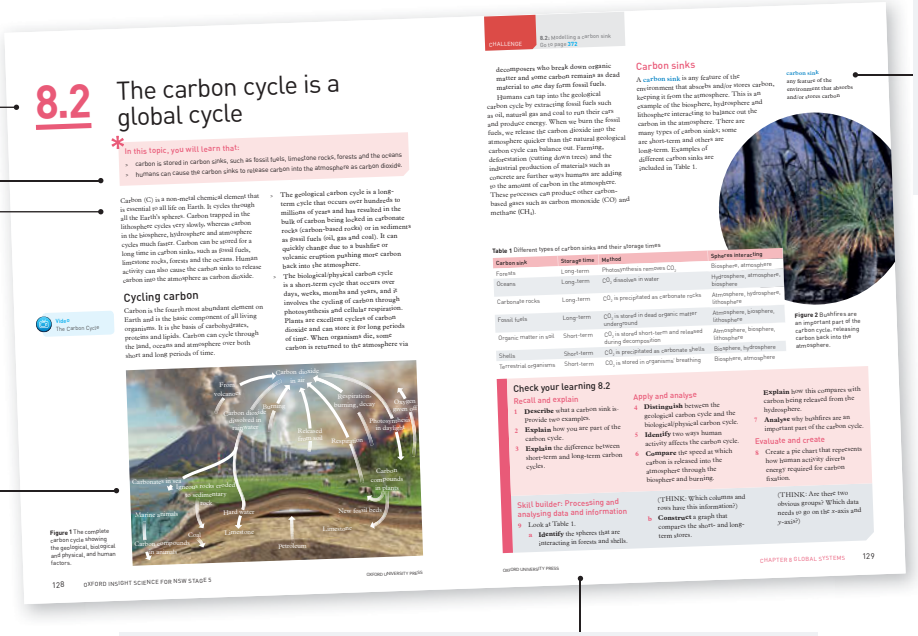
KEY FEATURES OF THE STUDENT BOOK:

- 'Have you ever wondered' questions encourage inquiry and early engagement.



- Each chapter begins with an overarching inquiry question.
- All syllabus outcomes covered in the chapter are clearly mapped.
- Quizzes for each chapter on Quizlet allow students to compete against each other.

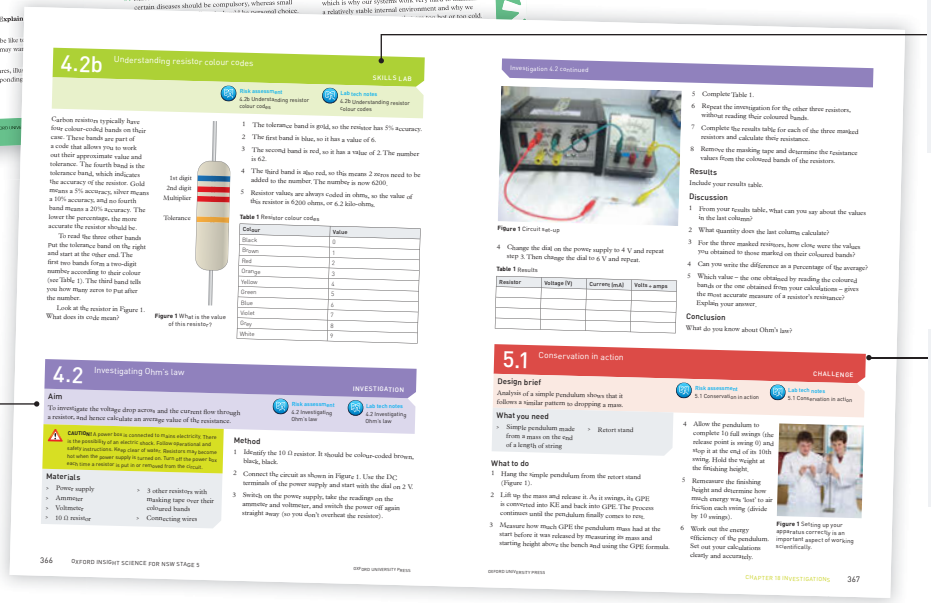
- The topic heading introduces the concept.
- Each topic begins with a dot point summary of key ideas.
- Body text elaborates on the concept in clear and accessible language.



- Glossary definitions for key terms in the margin enhance student understanding and support science literacy.
- Diagrams and photos are used to illustrate the concept and engage students.
- Every topic ends with 'Check your learning' questions, allowing students to consolidate their understanding. Questions are graded according to Bloom's taxonomy – catering for a range of abilities and learning styles.
- 'Skill builder' questions are included in every topic to scaffold and practise Working scientifically skills in the lead up to Stage 6.
- Digital links signpost the availability of additional digital resources at the point of learning.

- Review questions test students' understanding of syllabus content, including 'Critical thinking' and 'Going further' questions for extension.
- Research topics provide a springboard for larger research projects, or inspiration for the Student Research Project.
- Students are encouraged to reflect and self-assess their learning, and are directed back to specific topics if they are not yet confident on the content.

- Investigations are organised at the end of the book in an extended chapter, rather than being confined to each double-page spread.
- Investigations provide opportunities for students to conduct practical investigations to apply and further their understanding of key concepts.



- Skill labs give students the opportunity to practise discrete lab and science skills.
- Challenges ask students to apply critical thinking and design solutions.

obook assess

obook assess provides a complete digital version of the Student book in an easy-to-read format. It also features a range of engaging and relevant resources to support learning including:

- videos and interactive activities
- interactive, auto-correcting multiple choice quizzes
- access to reading, homework or tests assigned by teachers.

Assess quiz
Chapter 3

Quizlet Live
Each chapter of the Student book is supported by Quizlet. By accessing Quizlet via web browser or app, students have access to different interactive learning tools, including flashcards, multiple choice questions and Quizletlive.

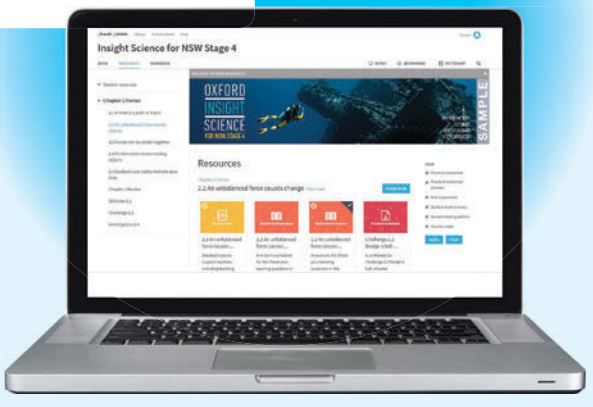
Video
DNA

Resource:
STEM activity
Wallabat evolution

Teacher obook assess

In addition to the student resources, teachers also receive:

- teaching programs and lesson ideas
- answers to all activities (including mock data for investigations)
- printable and editable sample assessments and differentiated worksheets (including answers)
- the ability to manage classes by assigning work and tracking progress with the markbook.



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WORKING SCIENTIFICALLY

How do scientists manage experiments that have gone wrong?

Have you ever wondered ...

- How do scientists test claims?
- What is a risk assessment?
- How is research conducted?

1

SCIENCE UNDERSTANDING

This chapter will help you to practise the six key skills you will need to master throughout Stage 5 science. These skills include:

- questioning and predicting
- planning investigations
- conducting investigations
- processing and analysing data and information
- problem solving
- communicating

Remember you can come back to this chapter at any point during Stage 5.

Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

1.1 Scientists ask questions and test hypotheses

In this topic, you will learn that:

- scientists use the scientific method to test claims
- the scientific method creates empirical evidence, which scientists use to support or refute a theory.

claim
a statement that asserts that something is the case, without necessarily providing proof

hypothesis
a proposed explanation for phenomena that can be tested

Think about the things you eat, drink and use each day. At breakfast, you might have had vitamin-boosting juice, and maybe you then got on a bus to get to school. At home, you get light by flicking a switch, and if you get a headache, you might take some medicine. Each of these has been scientifically tested.

Scientists continuously test hypotheses, theories and claims. Some are more obvious in your everyday life. Others are clearly scientific, such as testing claims about natural phenomena like earthquakes. Scientists never seek to prove a claim, rather they seek evidence to support or refute it. Regardless of the claim, the scientific method is always used to test it.

The scientific method at work

In the Case study, Jenny and Anna were sure of their results because they followed the scientific method.

Hypotheses

The scientific method involves developing a plan to test a **claim** or **hypothesis** that arises as a result of a 'what if' question.

In the Case study, the claim was:

'blackcurrants in Ribena contain four times the vitamin C of oranges'.

The 'what if' question was:

'*What if* the vitamin C content of Ribena was compared with other fruit juice drinks'.

This then became a hypothesis using the words 'if' and 'then' and 'because':

'*If* the vitamin C content of Ribena was compared with other fruit juice drinks, *then* Ribena will have more vitamin C per millilitre *because* the manufacturers claim this'.

A hypothesis should be based on some underlying suspicion, prediction or idea that is based on previous observations. It must be very specific so that it can be tested.

Case study: Testing claims

Several years ago, two New Zealand science students, Jenny Suo and Anna Devathasan, exposed a startling fact about the fruit juice drink Ribena while performing research for their school's science fair. Jenny and Anna decided to compare the vitamin C content of different fruit juice drinks to see if the manufacturer's claims on the labels were correct. The label on Ribena, which contains blackcurrant juice, implied that it had a much higher vitamin C content than the other fruit juice drinks they tested. It said: 'The blackcurrants in Ribena contain four times the vitamin C of oranges'. The students therefore predicted that Ribena would have four times the vitamin C content of orange fruit juice drinks.

Jenny and Anna then analysed the vitamin C content of Ribena and several other fruit juice drinks, using the scientific method. They ensured that their tests were fair and objective. The only difference between the drinks during their tests was the brands. Jenny and Anna performed three trials to ensure the accuracy of their results. After each trial, they re-examined their data.

The students were surprised to find that the vitamin C content of Ribena was far lower than most other brands. However, because they had followed the scientific method, they were confident that their results were reliable. For this reason, they contacted the manufacturer about the misleading labelling and advertising. When no response was received, they brought their case to a national consumer affairs program.

After their case was broadcast, and after further testing of Ribena, the New Zealand Commerce Commission brought 15 charges against the manufacturer under the *Fair Trading Act*.

Figure 1 Ribena was found to contain less vitamin C than its competition, despite the manufacturer's claims.

Variables

A hypothesis should be tested in an objective way. For example, for a fair comparison of the fruit juice drinks, Jenny and Anna needed to design an experiment that identified all the **variables** that would be operating. The variables in an experiment are the factors that will affect the results in some way. These could include the volume of the fruit juice drinks tested, the age and temperature of the fruit juice drinks, and the quality of the chemicals used in the testing.

To test the hypothesis, all of the variables should be controlled except for the one being tested. This is known as the **independent variable**, and in Jenny and Anna's case, it was the brand of the fruit juice being tested. The variable being measured is the **dependent variable**, such as the amount of vitamin C in a fruit juice drink.

Method

When reporting an experiment, a scientist describes the materials and equipment they used, including the concentrations and brands they tested. Diagrams are also useful to illustrate the steps taken. Remember to label all equipment in the diagram and to give the diagram a title.

The number of times you repeat an entire experiment is referred to as repetition. The greater the number of times an experiment is repeated and the results are averaged, the more likely it is that the results are reliable.

The **sample size** refers to the number of subjects being tested or used in the experiment. The greater the sample size, the more reliable the results will be, and the stronger the evidence available to support the conclusion.

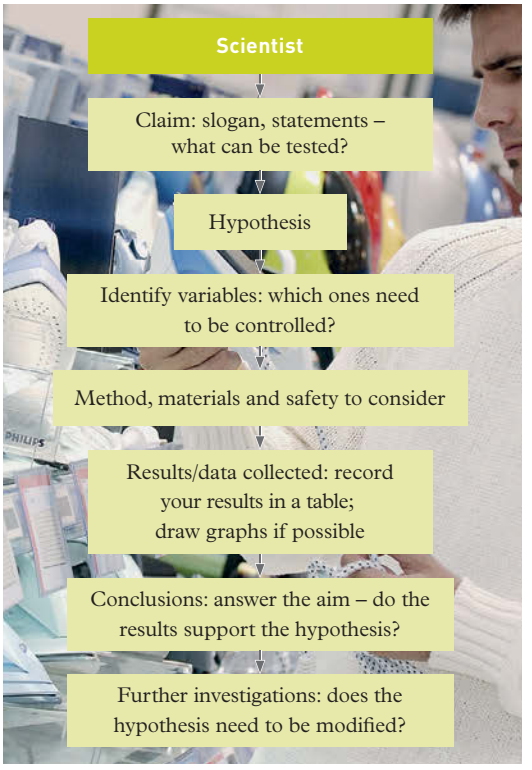


Figure 2 Using the scientific method to test claims and hypotheses

variable
anything that can change the outcome or result of an experiment

independent variable
the variable that is deliberately changed or tested during an experiment

dependent variable
the variable being tested in an experiment

Results

The observations (or data) that you make during your experiment are written down as the results. All observations should be what you *actually* see and not what you *expect* to see. Data can be organised into a table format and a graph to make it easier to understand.

Conclusion

A conclusion should answer the initial question asked about the experiment. It should provide evidence that supports or refutes the hypothesis. Any further investigations that may need to be done can be outlined here.

sample size
the number of subjects being tested or used in an experiment

Check your learning 1.1

Recall and explain

1 **Explain** if an increased sample size gives greater validity to an experiment. **Justify** your answer.

2 A local business claims that their conditioner will make your hair shinier than other conditioners because it contains flaxseed.
   - **a** Decide what the 'what if' question is.
   - **b** Write this as a hypothesis using the words 'if' and 'then' and 'because'.

3 **Explain** what a hypothesis is.

Apply and analyse

4 In the following hypotheses, **identify** the independent and dependent variables.
   - **a** If the heat of a stove is increased, then butter will melt faster because the stove is warmer.
   - **b** If the battery life of today's laptops was compared with the battery life of laptops from 10 years ago, today's laptop batteries will last for two hours longer because technology has improved.

Evaluate and create

5 **Assess** whether the following is a 'good' hypothesis. Ask if it is testable and if it has a clear independent variable. 'An increase in carbon dioxide in an apartment complex would be seen if surrounding trees were removed during construction.'

1.2 Scientists carefully plan investigations to record accurate results

In this topic, you will learn that:

- scientists use devices with specific purposes to gain appropriate results
- there are three key types of error: reading error, parallax error and zero error
- scientists use significant figures and SI units to ensure everyone can understand their research.

Figure 1 A burette is a laboratory instrument used to accurately measure the volumes of liquids.

parallax error
an error that occurs when the reader's eye is not placed directly opposite a mark

reading error
an error that occurs when markings on a scale are not read correctly

zero error
an error that occurs when an instrument has not been adjusted to zero before the measurement was taken

Scientists plan and conduct experiments to test theories. In scientific investigation, measurements can only show that a hypothesis is correct if the measurements are accurate. To achieve maximum accuracy, the measurement must be carefully taken with the most suitable measuring device. This device must have a scale appropriate to the accuracy that you require.

Choosing the right device

Choosing the right instrument is the first step in achieving accuracy. For example, if you need to accurately measure the volume of a liquid, then you would use a burette or a measuring cylinder but not a beaker. A burette has a more accurate scale than a measuring cylinder. A beaker often has no scale.

Errors and accuracy

Choosing the right instrument is only part of the job a scientist must do. It is very important to take care with your measurements. The most common errors in measurement are parallax errors, zero errors and reading errors.

Scientists will often repeat measurements and then find an average measurement to improve their accuracy.

A **reading error** can result when guesswork is involved when taking a reading. For example, when a reading lies between the divisions on a scale, a guess of the actual reading can result in a reading error (Figure 2).

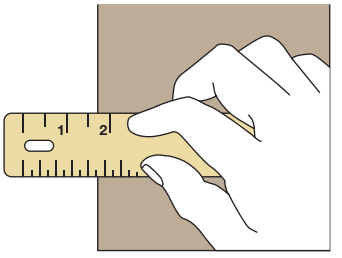


Figure 2 Guessing the measurement between units of measurement (e.g. between 1.5 and 2) can produce a reading error.

A **parallax error** occurs when the eye is not placed directly opposite the scale when the reading is being taken. You can avoid parallax errors by ensuring that your eye is placed in the correct position when taking the reading. For example, when reading the level of a liquid in a measuring cylinder, place the cylinder on the bench and line up your eye with the bottom of the meniscus (Figure 3).

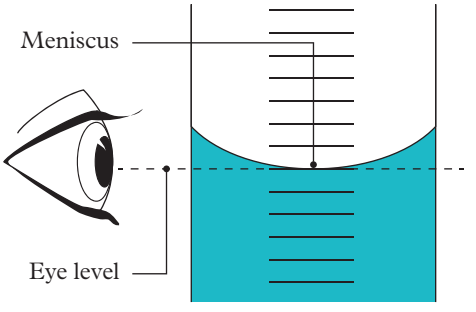


Figure 3 To avoid parallax error, make sure your eye is correctly lined up with the bottom of the meniscus.

A **zero error** happens when an instrument has not been correctly adjusted to zero or the reading has not taken into account the weight of empty containers. For example, scales must be set to zero correctly before making a weight measurement of substances.

Mathematical accuracy

When conducting a scientific investigation, mathematical accuracy is very important. Not only must your equipment be appropriate and precise to avoid errors, but your calculations must also be mathematically accurate. When taking a reading, you should quote the maximum allowed number of **significant figures**. This can represent the accuracy of a measurement or reading. When results are recorded, it is important to know the number of significant figures the instrument allows. The final answer can only be quoted correct to the number of significant figures present in the least accurate result. For example, if one measuring device measures to 0.22 and a second device measures to 0.345, the final answer should only have two figures after the decimal point. This might require a **rounding off** procedure.

Measurements and units

Scientists measure fundamental quantities (such as mass, time and length) in a standard unit that has been agreed upon by scientists across the world. The international system of units, known as the **SI system** of units, is based on the metric system. Table 1 shows some SI units. Other measurements, such as volume, are calculated from those basic units and so are termed **derived units**.

Although the SI unit for mass is the kilogram, this is not always the most suitable unit to use. Some objects are too heavy or too light for this to be the most convenient unit. The measurement would have too many zeroes in it. For example, masses of 0.000 000 007 43 kg or 850 000 000 kg are very inconvenient to write. So, scientists and mathematicians choose a unit that requires as few zeroes as possible. They denote this by using a system of prefixes before the basic measurement unit, as shown in Table 2.

Table 1 SI units

Physical quantity	SI unit	Abbreviation or symbol
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Thermodynamic temperature	Kelvin	K
Amount of substance	Mole	mol
Electric current	Ampere	A

significant figures
the number of digits that contribute to the overall value of a number

Notice that when the number is larger than the basic measurement, the prefix is a capital letter. When it is only a fraction of the basic measurement, the prefix is a small (i.e. lower case) letter. For example, a megalitre, which is a million litres, is written as ML, whereas a millilitre, which is one-thousandth of a litre, is written as mL. Kilograms is an exception to this general rule. A kilogram is 1000 grams, and its symbol is kg.

rounding off
reducing the number of significant figures by increasing or decreasing to the nearest significant figure; for example, 7.6 cm is rounded up to 8 cm, 7.2 cm is rounded down to 7 cm

Table 2 Standard prefixes and meanings

Name	Symbol	Value	Meaning
peta	P	10^{15}	One thousand million million
tera	T	10^{12}	One thousand million
giga	G	10^{9}	One billion
mega	M	10^{6}	One million
kilo	k	10^{3}	One thousand
centi	c	10^{-2}	One-hundredth
milli	m	10^{-3}	One-thousandth
micro	μ	10^{-6}	One-millionth
nano	n	10^{-9}	One-billionth
pico	p	10^{-12}	One-millionth of one million

Check your learning 1.2

Recall and explain

1 **Identify** three types of errors that can occur during an experiment.
2 **Explain** how each of the errors identified in question 1 can be reduced to improve accuracy.
3 **Recall** why scientists often repeat experiments and then take an average of the results.
4 **Identify** the symbol you would write for:
   a millionths of a gram
   b billions of litres
   c thousandths of an ampere
   d thousands of metres.

Apply and analyse

5 **Identify** the number of significant figures in each of the following measurements.
   a 45.22 mL
   b 9.0 s
   c 8000 L
   d 3.005 m
6 A student took the following measurements for an experiment: 5.6 volts, 2.97 amperes, 3000 seconds. How many significant figures should the final answer be stated to? **Justify** your answer.

1.3 Scientists conduct experiments safely

In this topic, you will learn that:

- Safety Data Sheets (SDSs) note any chemicals that are a hazard and how to use this chemical safely
- a risk assessment acknowledges all associated risks of an investigation and records ways to manage this risk.

Safety Data Sheet (SDS) a document that anticipates, recognises and controls any chemical safety hazards in an experiment

When scientists conduct experiments, they take measures to ensure that investigations are safe. A **Safety Data Sheet (SDS)** is an important tool for maintaining safety in a science laboratory. It contains information about a chemical such as its various names, the dangers involved in its use, and the precautions scientists should take when handling the chemical. SDSs should be prepared for all the reactants used and the products produced during science experiments.

Anticipate, recognise and eliminate

Scientists work with many hazardous materials when completing experiments. As a result, they need to be aware of anything that might affect their health or safety in the laboratory. The laboratory is a safe place provided hazards are:

- anticipated
- recognised
- eliminated.

A Safety Data Sheet (SDS) provides scientists and emergency personnel with information on how to use a particular substance. An SDS also helps scientists understand more about how the chemical is used during the experiment.

Risk assessments

risk assessment undertaken by scientists before conducting research and recognises any hazards and how to manage these safely

As you conduct experiments, keep these safety measures in mind. You may also be asked to conduct a **risk assessment**. A risk assessment looks at all chemicals and equipment being used, and details how these risks can be anticipated, recognised and eliminated. Risk assessments will need to be checked by your teacher or school's laboratory technician.

For example, in a risk assessment, you may need to consider whether you will be using a Bunsen burner and note how this can be done safely. You need to think about the naked flame, and ensure that the air hole of the Bunsen burner is closed appropriately and that items are handled appropriately near the flame, for example with tongs and heat-protective gloves. You should also consider what chemicals may react with the flame and make sure these are not included in your experiment.

Figure 1 Emergency workers in sealed positive-pressure protective suits communicating with each other.

MATERIAL SAFETY DATA SHEET

Sodium Chloride: Hazardous chemical

Section 1 - Chemical Product and Company Identification	
MSDS name:	Sodium Chloride
Synonyms:	Common salt; Halite; Rock salt; Saline; Salt; Sea salt; Table salt.
Company identification:	Chemical company
Section 2 - Hazards Identification	
Eye and skin:	May cause eye irritation.
Ingestion:	Ingestion of large amounts may cause gastrointestinal irritation. Ingestion of large amounts may cause nausea and vomiting, rigidity or convulsions.
Inhalation:	May cause respiratory tract irritation.
Section 3 - Handling and Storage	
Handling:	Use with adequate ventilation. Minimise dust generation and accumulation. Avoid contact with eyes, skin and clothing. Keep container tightly closed. Store in a cool, dry, well-ventilated area away from incompatible substances. Store protected from moisture.
Section 4 - Exposure Controls, Personal Protection	
Engineering controls:	Good general ventilation should be used.
Personal protective equipment	
Eyes:	Wear safety glasses with side shields.
Skin:	Wear appropriate gloves to prevent skin exposure.
Clothing:	Wear appropriate protective clothing to minimise contact with skin.
Section 5 - First Aid Measures	
Eyes:	Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.
Skin:	Flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes. Get medical aid if irritation develops or persists. Wash clothing before reuse.
Ingestion:	If victim is conscious and alert, give 2-4 cupsful water. Get medical aid. Wash mouth out with water.
Inhalation:	Remove from exposure to fresh air immediately. If breathing is difficult, give oxygen. Get medical aid if cough or other symptoms appear.
Section 6 - Physical and Chemical Properties	
Physical state:	Solid
Appearance:	Colourless or white
Odour:	Odourless
Boiling point:	1413 deg C
Freezing/melting point:	801 deg C
Solubility:	Soluble
Specific gravity/density:	2.165
Molecular formula:	NaCl
Molecular weight:	58
Section 7 - Accidental Release Measures	
Spills/leaks:	Vacuum or sweep up material and place into a suitable disposal container. Clean up spills immediately, observing precautions in the Protective Equipment section. Avoid generating dusty conditions. Provide ventilation.
Section 8 - Fire Fighting Measures	
General information:	Water runoff can cause environmental damage. Collect water used to fight fire. Wear appropriate protective clothing to prevent contact with skin and eyes. Wear a self-contained breathing apparatus (SCBA) to prevent contact with thermal decomposition products. Substance is noncombustible.

Figure 2 Example of an SDS from a manufacturer or certified provider

Safety Data Sheets

The information on a Safety Data Sheet includes the following.

- **The various names of the chemical:** This includes its chemical name and its common generic name, its concentration and structure. For example, DL-threo-2-(methylamino)-1-phenylpropan-1-ol is also called pseudoephedrine or Sudafed.
- **The contact details of the manufacturer**
- **The hazard level of the chemical:** All chemicals should contain labels relating to their particular dangers. This may include their flammability, corrosive ability, toxicity and ability to cause long-term damage such as cancers. The hazards can be shown using descriptions or symbols.
- **Usage instructions and restrictions:** Some chemicals may form a dust that can explode. For example, workers in flour mills need to be especially aware of flour dust.
- **Protective measures:** The SDS should contain information on the eye and face protection needed, the type of gloves or skin protection required, and the possible need for masks.
- **The physical and chemical properties of the chemical:** Everyone in a laboratory should be able to easily identify the chemical. The SDS should include the colour, smell, pH, flammability, solubility, and melting and boiling points of the chemical.
- **What to do in the case of a spill (in the laboratory or in the environment):** This includes first aid measures, any antidotes, symptoms that might result from exposure, and whether personal protective equipment (PPE) is recommended for first aiders. Advice may be needed on how to cover drains to prevent the chemical making its way into groundwater.
- **Fire-fighting measures:** Some chemicals produce toxic fumes or are highly flammable. Other chemicals become more dangerous if they are exposed to water. Firefighters may need special equipment.
- **How to dispose of the chemical safely:** This section should include what disposal containers should be used, the effects of sewage disposal, and the special precautions that may be needed to ensure safety for both individuals and the environment.
- **How to transport the chemical:** This information should include any special precautions for transporting this chemical. This may include the Hazchem code (the code provided by the government for each class of chemical).
- **An Australian telephone number of the Office of Chemical Safety**
- **The date the SDS was last reviewed**

Figure 3 SDSs are used in many industries, including the mining industry.

Table 1 lists some possible equipment and how you can control associated risks.

In all laboratory work you should be familiar with your school's first aid procedures, the location of water in the laboratory, and how to dispose of equipment and chemicals. If ever in doubt, check with your teacher.

You should also refer to Chapter 18 for a list of laboratory safety *Do*s and *Don't*s. Protective safety equipment (laboratory coat, safety glasses, gloves) should be worn at all times, long hair should be tied back, closed shoes should be worn, and food and drink should not be consumed in the laboratory. You should never conduct an experiment on your own or without supervision.

Assessing the ethics of research

Scientists also assess the ethics of research. Ethics are moral values about whether something is right or wrong. Before an experiment that impacts an ecosystem or involves animals or humans is conducted by a scientist, they must get ethical approval. When thinking about ethics, scientists consider the following.

- The materials and methods being used in the research. Does the research impact the environment? Are there living things involved?
- The implications of the research. Will this research have negative impacts on a group or area?
- Cultural sensitivity. Is the research disrespectful to a system of beliefs? Can the research be conducted somewhere else?
- Political and social issues. Is this research needed for today's world? Could it change policy? Do I need to seek higher approval?

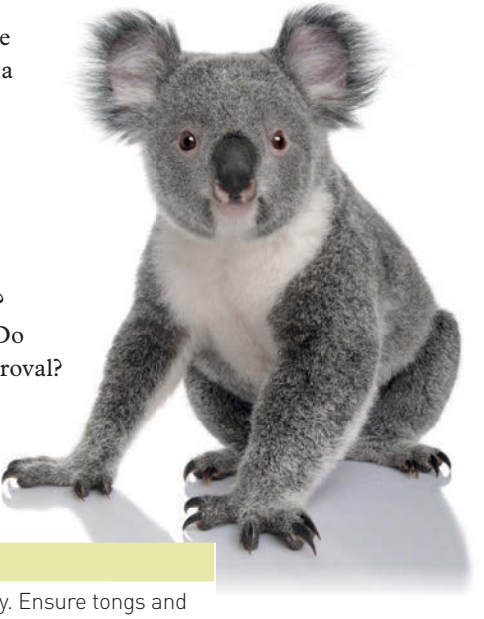


Figure 4 Before scientific research is conducted, scientists must consider impacts on ecosystems and society.

Table 1 Examples of safety measures in the laboratory

Risk	Safety measure
Bunsen burner – naked flame	Ensure that the air hole of the Bunsen burner is closed correctly. Ensure tongs and heat-protective gloves are used. Wear safety glasses and a laboratory coat.
Exposed electrical wires	Exposed wires can give electric shocks. Always check wires before you use any electricity. Check with your teacher.
Glass – broken glass	Broken glass is sharp and can cut you. Make sure you are familiar with your classroom's first aid kit and how to dispose of glass.
Scalpel – sharp edge	Be careful with handling sharp scalpels. Never grasp the blade in your hand. Be familiar with your classroom's first aid kit.

Check your learning 1.3

Recall and explain

1. **Recall** what SDS stands for.
2. **Explain** why it is important to prepare an SDS before starting an experiment.
3. **Explain** why it is important to have all the various names of a chemical on the SDS.
4. **Identify** two pieces of equipment in the laboratory that may pose a risk, and **propose** a way of removing the risk.

Apply and analyse

5. Saki is conducting an experiment in the school laboratory. Saki is mixing two unknown chemicals and plans to heat them over a Bunsen burner. **Identify** the risks Saki is taking and suggest how these could be removed.
6. A scientist wants to see if using smartphones is decreasing memory capacity in humans. The scientist is aware that they will need to be ethical because of working with humans, but they are trying to determine what the effects of this research would be on society. **Identify** two possible impacts on society and **explain** why these might be ethical considerations.

1.4 Scientists record data and information

In this topic, you will learn that:

- a logbook should record all information associated with your investigative work.

Your science logbook is used to record all the details of any laboratory work, fieldwork or research. Your logbook is where you keep information that you may otherwise forget. It provides evidence of your planning, research and results for an investigation.

Setting up your logbook

All scientists have basic rules when using a logbook.

logbook
a book used to record all information relating to experiments or investigations

1. A **logbook** should be a bound notebook specifically for your laboratory work or research. If you use loose sheets of paper, you might lose them, and using a computer is only successful if you make continuous back-ups of your data.
2. Your logbook should include your name, your phone number, your school and your teacher's name. This way, if you misplace your logbook, you reduce the risk of losing all your data.
3. Your logbook should contain a table of contents on the second page. This will help you navigate your way through experiments and research when it comes time for your Student Research Project (see Chapter 17). An example table of contents may look like Table 1.
4. Use a consistent style for recording your notes and data.
5. Every entry in your logbook should be dated.
6. You should record everything in your logbook in pen. If you make a mistake, simply cross it out. Never use liquid paper or white-out tape – this ensures that everything is true and not forged (including results!).
7. Entries should be clear and concise. You don't even need to use full sentences.
8. If you do use any loose paper or images, glue or sticky tape these in so they can't be lost.
9. If you change anything about your research or an experiment, write this down. This will help you see where you might have gone wrong and how you fixed it.
10. Record any observations you make during an experiment. This will help you write your final report.

The more detailed and accurate your logbook is, the better it will be for helping you write your Student Research Project or the report for an investigation.

Table 1 An example table of contents for your logbook

Science area (e.g. Living world)	Experiment title	Page number

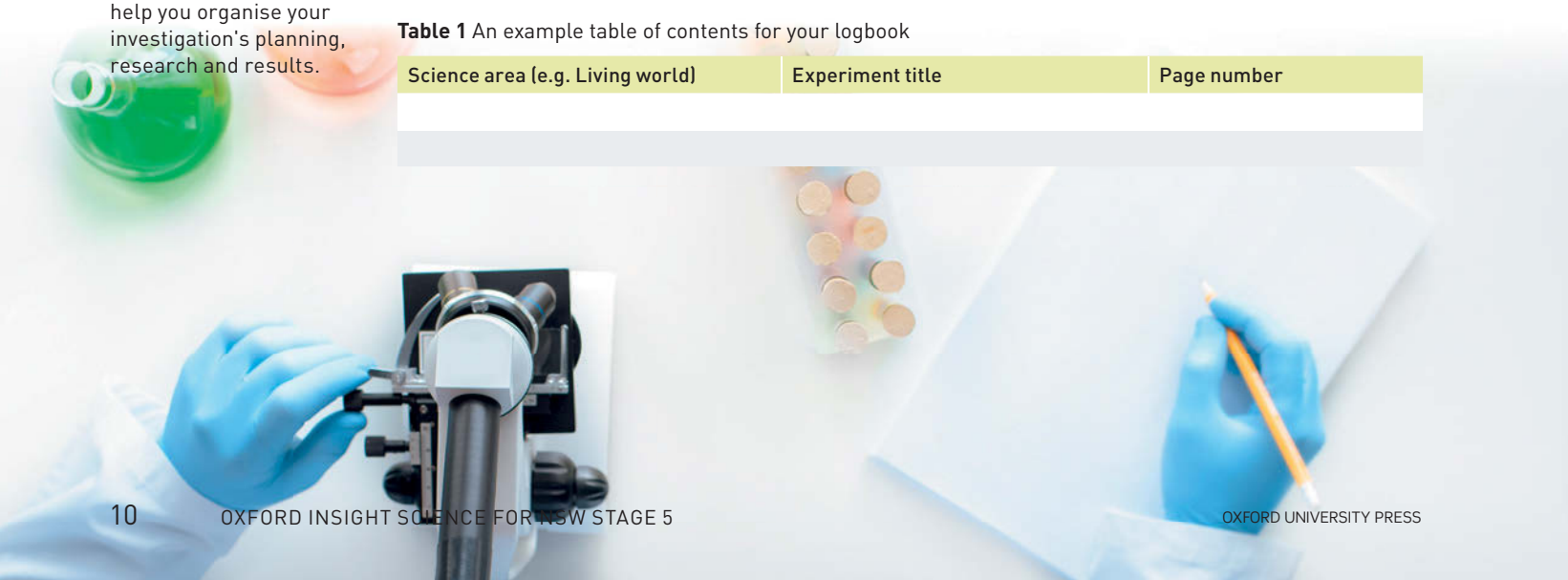


Figure 1 Logbooks help you organise your investigation's planning, research and results.

1 February 2016

Aim

To determine the relationship between the distance elastic is pulled back and the distance a marshmallow moves.

Method

Refer to page 159 of Oxford Science 8. Please note: 1 cm wide elastic was tied around the base of the chairs from Experiment 1.4.

Measurements

Distance marshmallow has moved

Distance elastic pulled back	Attempt 1	Attempt 2	Attempt 3	Average
1 cm	20 cm 3 mm	23.4 cm	19.9 cm	21.2 cm
2 cm				
3 cm				
4 cm				

20.3
23.4
+ 19.9
63.6
63.6 ÷ 3 = 21.2 cm

Observations

The elastic came undone after the third attempt so we had to do it up again. We tried to make it the same tightness as before.

Conclusion

When the elastic was pulled back, more elastic gained more energy. This energy went into the marshmallow so that it could move further when released.

We should have tested with the elastic pulled back ~~more~~ different distances.

Next time the same person should do the pulling back.

Figure 2 A sample logbook

Figure 3 Scientists record what they see during experimental research in a logbook.

Check your learning 1.4

Recall and explain

1 **Explain** why you should use a logbook.

2 From the following list, **identify** anything you shouldn't include in your logbook.

- **a** A change to your research plan
- **b** When you have removed outliers
- **c** Describing a flower as beautiful rather than describing what happened to the flower
- **d** Every result, including inaccurate data
- **e** How you adjusted your experiment to increase accuracy

3 **Recall** what you can use a logbook for.

Apply and analyse

4 **Construct** your own logbook. Select a bound notebook and nominate pages for your table of contents.

1.5 Scientists present their data accurately

In this topic, you will learn that:

- outliers are anomalies in data
- the mean, median and mode can determine whether an outlier can be removed
- correlation does not equal causation.

The results section is often the most important part of a scientific report. It must present an accurate picture of the findings. Outliers are values that are very different from the main group of data. Outliers can affect the mean (average) of the overall results. The median (middle number of data when placed in increasing order) or the mode (most common result) are less affected by outliers. Positive correlation of data does not mean one event caused another event.

Outliers

Occasionally the data that scientists collect contains a value that is far away from the main group of data. These values are called **outliers** and may be due to inaccurate measurements or experimental errors.

outlier
a value that is outside the normal range of all other results

median
the middle data in a set that has been ordered by increasing value

For example, an outlier may occur when measuring the height of seedlings after 3 weeks of growth (see Table 1).

Table 1 Seedling growth

Seedling number	Height (cm)
1	3.6
2	4.0
3	4.1
4	4.0
5	0.1
6	3.5
7	4.3

Figure 1 How can scientists accurately represent data from a seedling experiment?

All seedlings except seedling 5 grew between 3.5 and 4.3 cm. The average (or **mean**) growth of the seedlings (including seedling 5) was 3.4 cm. This average is well below the growth of any of the seedlings other than seedling 5. This shows how one outlier can present an artificial result of the seedling growth.

mean
the average of a set of data

If the average (mean) is determined without using seedling 5, the average becomes 3.9 cm. This is a closer representation of the actual growth. However, is it fair to discard any results that we don't like?

Are the results 'pure' if some are left out? For this reason, an outlier is only excluded if the researcher explains how the results are modified and the reason for doing so. For example, the discussion might include the statement that 'Seedling 5 was excluded from the analysis due to a fungal infection that affected its growth'.

Median

The **median** is the middle value of the data after all numbers have been placed in increasing order. For the previous data, the median is found as shown in Figure 2.

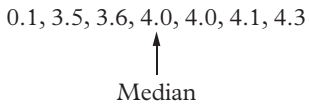


Figure 2 Finding the median for the data in Table 1

The median amount the seedlings grew was 4.0 cm. If the outlier is removed, the median growth is still 4.0 cm. So, the median value of the data is not affected as much by outliers as the mean (average).

Mode

The **mode** is the most common number in the set of data. In our set of data, the number 4.0 occurs twice (Seedlings 2 and 4).

This means the mode or most common amount the seedlings grew was 4.0 cm. If the outlier was removed, the mode of the seedling growth would still be 4.0 cm. An outlier does not affect the mode value.

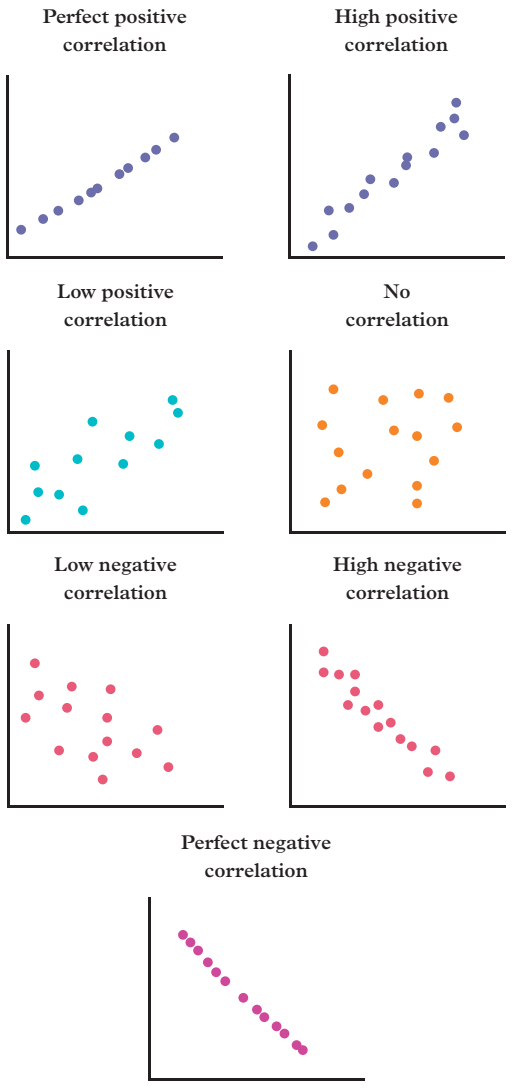
Correlation of data

When two sets of data are strongly linked (i.e. as one changes, the other changes a similar amount), the data has a strong correlation. When both values increase at the same rate, it is called a positive correlation. If one value increases as the other decreases, then it has a negative correlation. This can be shown on a graph (Figure 3). It is important to remember that correlation does not mean causation.

Checklist

When you are presenting your data, check the following list off in your head.

- Are my table and graph for the same set of data? If yes, they should have the same name.
- Have I plotted each set of data on my graph?
- Can I explain why I removed an outlier from my data set?
- Have I labelled the *x*-axis and *y*-axis correctly? Remember that the independent variable should be on the *x*-axis.



mode
the most frequently occurring data in a set

Figure 3
Correlation of data

Check your learning 1.5

Recall and explain

1 **Explain** why it is best to present your data in table form.
2 **Recall** what an outlier is.
3 In your own words **define**:
   a mean
   b median
   c mode.

Apply and analyse

4 **Explain** whether outliers should be included in data. **Justify** your answer.
5 Draw a graph of the set of data in Table 2.
   a Is there any correlation between the daily temperature and ice-cream sales?
   b Could you say that the daily temperature has an effect on the number of ice-creams sold that day?
   c What would you expect to happen to ice-cream sales if the daily temperature was to increase to 40°C?

Table 2 Ice-cream sales and daily temperature

Temperature (°C)	Sales ($)
14.2	215
16.4	325
11.9	185
15.2	332
18.5	406
22.1	522
19.4	412
25.1	614
23.4	544
18.1	421
22.6	445
17.2	408

1.6 Scientists review past research to solve problems

In this topic, you will learn that:

- new theories are formed from existing research
- scientists trust credible sources, such as scientific journals.

Before conducting a new investigation or experiment, scientists research previous experiments and information about the current topic. This helps scientists formulate research questions and hypotheses, and it ensures they are building in their field.

Good background research involves using all available resources relevant to your topic, being able to identify good research, and not just relying on any information you find on the internet. There are a few tips that will help you decide whether the information you are reading is useful or trustworthy.

Recognising reliable sources

The internet is full of accessible information. This provides a great source of facts, but it also creates a realm of inaccurate information. This information may not have been tested scientifically, and it is not likely to have been peer reviewed. To identify whether research is reliable, you should think about the following.

- Once you read something, check it against other sources to make sure it is accurate.

Figure 1 It is important to review the sources you use to ensure the information is accurate.

- Check if the author of the information you are reading is recognised. A quick Google search will typically let you know if the author is considered an expert in their field.
- Who published the information? Information published by journals, universities, the government and specific organisations are usually more credible because the information is peer reviewed. Peer-reviewed information has been checked by experts in the field.

Keep track of your resources in your logbook

Similar to recording your experimental data, it is important to record any research you do. When you are researching and find something interesting, write down the reference for this information. There are specific ways to reference books and journal articles. You should always make sure you write down the following.

- The title of the information
- The author's (or authors') surname and initials
- The date it was published – this can just be the year
- Who published it and where it was published (e.g. Oxford University Press, Melbourne or CSIRO, Melbourne)
- The page reference of the information you want to include

If you decide to use this information in a report, you need to make sure you reference this information. At the end of your report you should include a reference list. This list should include anyone you quote or cite in your report, as well as any background information you found. In your report, if you quote someone, you need to state the author's

surname and the year it was published. Your teacher will specify how they want this information presented.

By keeping a reference list this ensures that your research is considered credible. It also means that your research can be repeated and checked to see if it is **valid** (accurate; did it measure what it was supposed to?) and **reliable** (consistent; if someone repeats your research, will they get the same results?).

Problem solving

Scientists use research and information to solve problems. Some methods they may use include:

- Writing a pros and cons list
- Conducting a SWOT analysis
- Creating cause-and-effect diagrams.

A pros and cons list can help a scientist be clear on the benefits or potential harm of their research.

Figure 2 Scientists record all research in a logbook.

valid
a test, research or experiment that correctly tests what it was designed to test

reliable
a test, research or experiment that consistently achieves the same results

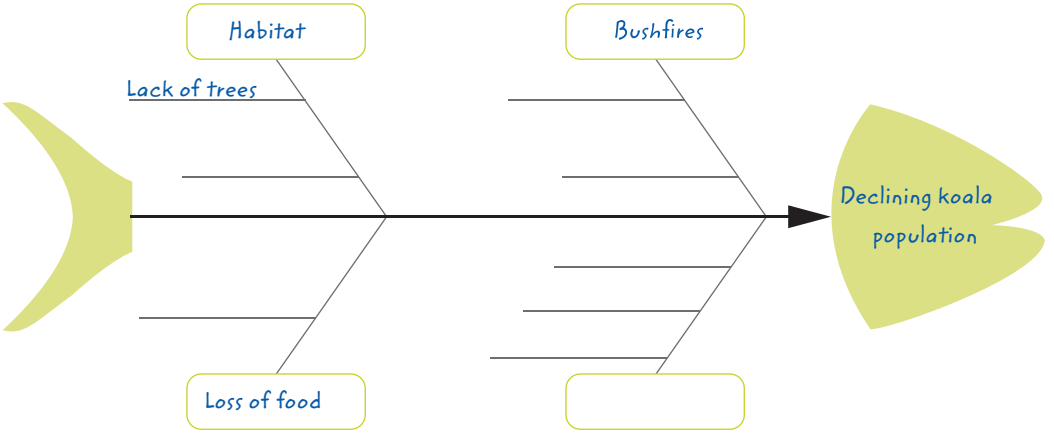


Figure 3 A cause-and-effect diagram

SWOT analyses look at the **S**trengths, **W**eaknesses, **O**pportunities and **T**hreats of a solution to a problem. The strengths of a solution are the things that can be solved well, whereas the weaknesses are things that cannot be solved well with the suggested solution. Opportunities identify areas that can benefit from the solution, whereas threats are external, for example government restrictions.

A cause-and-effect diagram focuses on identifying the problem, for example climate change. It then identifies the main causes of the problem, for example, human impact. Once the main causes are identified, sub causes are identified, for example human reliance on fossil fuels, deforestation. These are often drawn as a fishbone diagram.

Check your learning 1.6

Recall and explain

1 **Identify** three things you need to include in a reference.
2 **Explain** what reliable data is.
3 **Describe** valid data.
4 **Recall** two places where you would find reliable research. **Explain** why these are reliable.

1.7 Scientists communicate concisely

In this topic, you will learn that:

- research is presented in a scientific report
- scientists use clear and concise language.

Resource
STEM activity: Scientific Representations

When scientists make discoveries, they report these to the public, to companies and to the government. Scientists can present their findings as a report, a presentation or a poster.

Regardless of the format, all scientific information is presented consistently so that scientists around the world can read and understand the findings.

Writing a scientific report

Understanding how to write a scientific report will also help you read research. Scientific reports always include the following information.

1 Title of the research, date of the research and the name of the researchers (this might be an individual, for example, if you did the research on your own, or it might be several names, for example, if you did the research collaboratively as a group).

2 **Abstract:** This is presented on its own page at the start of a report. It offers a brief summary (no more than 250 words) about the aim, results and conclusion of an experiment. (Hint: You can read this to determine if research is relevant to your topic.)

3 **Introduction:** The introduction explains any background research that the scientists conducted before they started their experiment. It offers an explanation of how they reached their hypothesis. The hypothesis is included in the introduction. The aim of the experiment is also included in the introduction.

4 **Method:** The method includes all relevant information so that another scientist can conduct your research exactly the way you did. It includes the following.
   - All materials used. This section should be as specific as possible (e.g. 250 mL beaker, 175 mL of water).

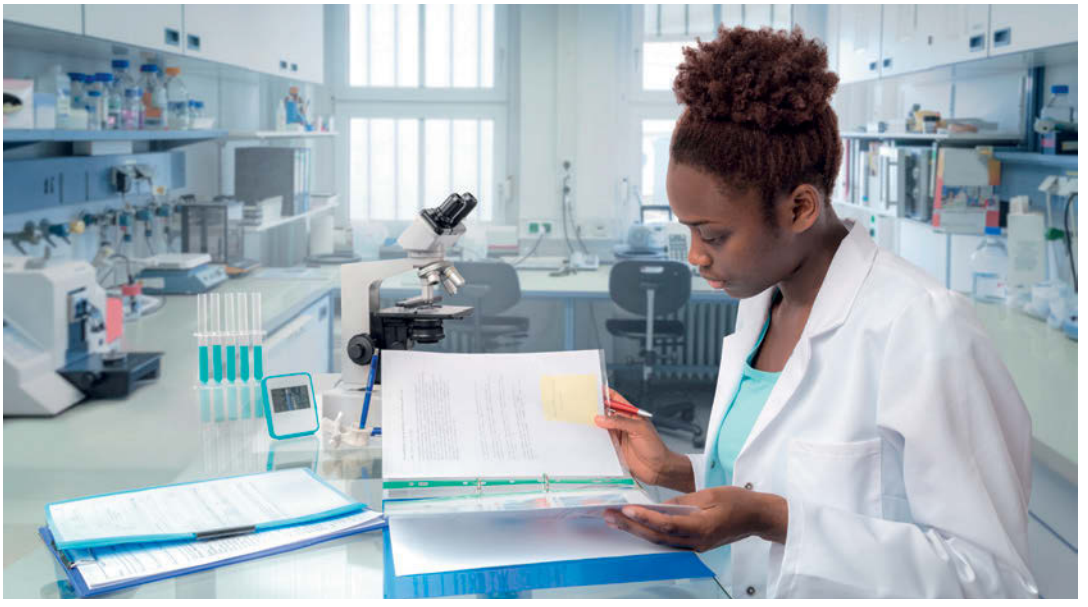


Figure 1 Scientists structure their reports in a consistent manner so that results can be shared easily.

- Each step taken in the experiment. This should include how you set up materials and equipment, as well as how you recorded and analysed your results. This should be written as step-by-step instructions. If you washed the beaker before you put liquid in, this should be noted so that other scientists achieve the same results.

5 **Results:** In this section, the results are presented as tables and graphs. You should also show any calculations you had to perform on the results. Scientists do not discuss the implications of their results in this section – they state the facts of their results.

6 **Discussion:** Scientists discuss the implications of their results, and they offer strengths and limitations in their findings. For example, if you accidentally added 180 mL of water and this skewed your results, this should be discussed here, along with a way to resolve this in future experiments (i.e. avoiding parallax error).

7 **Conclusion:** Scientists summarise their study's findings and offer paths for new research.

When scientists present their information in a presentation or poster, the format changes but each of these steps is still included.

Writing scientifically

Writing scientifically is different to writing an English essay. For example, look at the next two sentences:

Descriptive:

The flower was pink with very soft delicate petals. It smelt like spring and filled the laboratory with a lovely scent as it got warmer. As it got hotter, the flower's petals wilted in the steam.

Scientific:

A beaker containing a rose and water was placed above a Bunsen burner to heat the water. As the water reached its boiling point, it evaporated causing the rose to wilt.

The descriptive sentence tells us all that was happening, but it does not give a scientific explanation for the behaviour of the flower. The scientific description offers a summary of what was done to the flower and why the flower reacted.

It is important that you are concise when writing for science and that you do not include information irrelevant to the research.

Figure 2 When scientists make discoveries, they present their findings consistently so that other scientists around the world can read and understand them.

Check your learning 1.7

Recall and explain

1 **Outline** the correct order for the following terms in a report.
- Discussion
- Method
- Results
- Abstract
- Introduction
- Conclusion

2 **Explain** what might happen if a scientist left a step out of their method.

3 **Explain** what might happen if a scientist included an extra piece of equipment or material in their materials list.

Apply and analyse

4 Read the following two sentences. **Assess** which sentence uses scientific writing, and **explain** why it is scientific.

a At 40°C, icy poles were softened in their packets, and vanilla ice cream was melted.

b On a very hot summer day, Sally noticed her delicious vanilla ice cream was completely melted and was almost like a milkshake. She also noticed that her fingers were sticky holding onto a lemonade icy pole for her brother.

1.8 Understanding the syllabus

In this topic, you will learn that:

- understanding task words will help you correctly answer questions.

As you work through Stage 5 science, and continue into HSC, you will notice that questions are asked in a particular way.

Your teachers, schools and assessments have a list of key words to ask questions about what you have learnt and check that you understand the content in different ways.

You might be asked to 'describe', 'summarise', 'distinguish' or 'assess'. Each of these words requires a different answer.

Understanding what each of these words mean will give you a better chance at answering a question correctly. You can see these key words in Table 1.

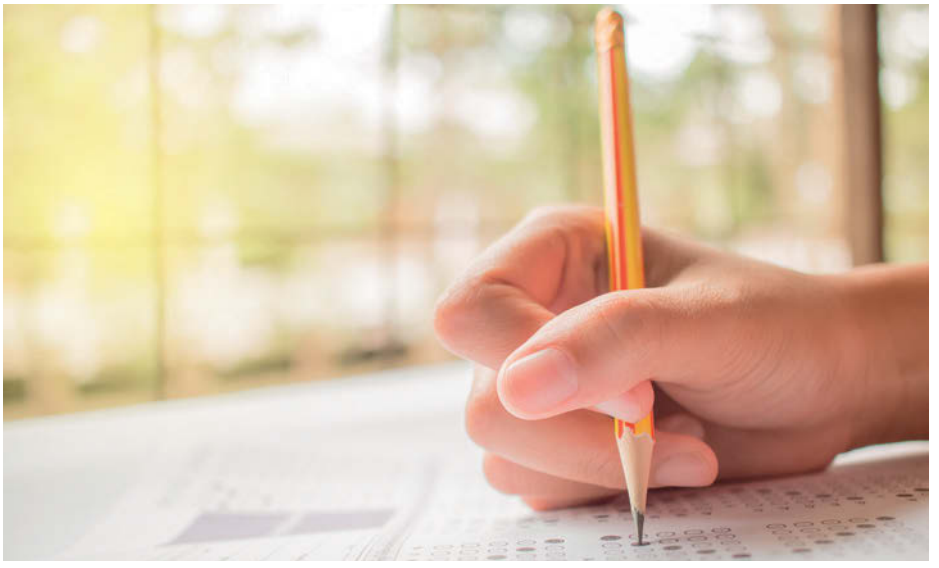


Figure 1 Understanding the syllabus is key to assessment success in Stage 5 and into your HSC.

Table 1 Key words

Key word	Definition
Account	Account for: state reasons for, report on. Give an account of: narrate a series of events or transactions
Analyse	Identify components and the relationship between them; draw out and relate implications
Apply	Use, utilise, employ in a particular situation
Appreciate	Make a judgement about the value of
Assess	Make a judgement of value, quality, outcomes, results or size
Calculate	Ascertain/determine from given facts, figures or information
Clarify	Make clear or plain
Classify	Arrange or include in classes/categories
Compare	Show how things are similar or different
Construct	Make; build; put together items or arguments
Contrast	Show how things are different or opposite
Critically (analyse/evaluate)	Add a degree or level of accuracy depth, knowledge and understanding, logic, questioning, reflection and quality to (analyse/evaluate)
Deduce	Draw conclusions
Define	State meaning and identify essential qualities
Demonstrate	Show by example
Describe	Provide characteristics and features
Discuss	Identify issues and provide points for and/or against
Distinguish	Recognise or note/indicate as being distinct or different from; to note differences between
Evaluate	Make a judgement based on criteria; determine the value of
Examine	Inquire into
Explain	Relate cause and effect; make the relationships between things evident; provide why and/or how
Extract	Choose relevant and/or appropriate details
Extrapolate	Infer from what is known
Identify	Recognise and name
Interpret	Draw meaning from
Investigate	Plan, inquire into and draw conclusions about
Justify	Support an argument or conclusion
Outline	Sketch in general terms; indicate the main features of
Predict	Suggest what may happen based on available information
Propose	Put forward (for example a point of view, idea, argument, suggestion) for consideration or action
Recall	Present remembered ideas, facts or experiences
Recommend	Provide reasons in favour
Recount	Retell a series of events
Summarise	Express, concisely, the relevant details
Synthesise	Putting together various elements to make a whole

Source: A glossary of key words © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

Check your learning 1.8

Recall and explain

1 **Explain** the difference between 'describe' and 'apply'.
2 **Recall** why it is important to understand the differences between each key word.
3 **Recommend** how you could learn these definitions.

REVIEW

Multiple choice

1 **Identify** the independent variable in this hypothesis: 'An increase in the amount of garlic on bread will see a decrease in bacterial growth because the garlic inhibits growth.'

- **A** Garlic
- **B** Bread
- **C** Bacterial growth
- **D** Cooking time

2 **Explain** how parallax error occurs.

- **A** When your eye is directly opposite the scale
- **B** When you guess a reading
- **C** When an instrument has not been adjusted to zero before the measurement was taken
- **D** When your eye is not placed directly opposite the scale at the time of measurement

3 A Safety Data Sheet will not include information about:

- **A** manufacturer contact details
- **B** when to add the chemical to your experiment
- **C** instructions and restrictions for use
- **D** how to safely dispose of a chemical.

Recall and explain

4 **Identify** the steps used when conducting an experimental investigation using the scientific method.

5 **Explain** what a variable is.

6 **Explain** why scientists are more interested in what can be observed and tested rather than claims made by brands.

7 **Identify** the measures scientists take to ensure investigations are conducted safely.

8 Suppose you are conducting a fair experiment in which you have identified six variables. **Explain** how you can be sure of the effect of one particular variable.

9 **Recall** why beakers aren't used to measure volumes.

10 **Summarise** the difference between zero error and parallax error.

11 **Define** the following prefixes in your own words:

- **a** mega
- **b** micro
- **c** kilo

12 **Recall** the SI unit for each of the following:

- **a** time
- **b** mass
- **c** length.

13 **Explain** why scientists use an internationally agreed system of units.

14 **Recall** what you should include in your logbook.

15 **Identify** what makes something 'good' research.

Apply and analyse

16 A consumer scientist wanted to test the effect of a lotion for treating acne. At first, the scientist tested the lotion on a group of 20 teenagers (all aged 15), but then they decided to conduct some more tests. The scientist then tested 100 teenagers (all aged 15).

- **a** Is this an example of experimental repetition or increasing the sample size?
- **b** Which result is likely to lead to the most reliable conclusion? **Justify** your answer.

Figure 1 What is the effect of a lotion for treating acne?

17 A scientist was commissioned by a jeans manufacturer to test various denims. The manufacturer wanted a more durable fabric than the one they were currently using. **Explain** how the scientist might test a fabric for its durability in a fair and objective way. **Assess** why this is important.

Figure 2 The durability of fabrics can vary.

18 State the number of significant figures in each of the following measurements.

- **a** 65.301 g
- **b** 0.006 420 kg
- **c** 40 L

19 Consider the following set of data:
15, 13, 18, 16, 14, 17, 12, 14, 19

- **a** **Calculate** the mean, median and mode for this data.
- **b** Plot the data on a graph.
- **c** **Identify** the type of correlation this data has.

20 A lipstick manufacturer claims that their brand of high-gloss lipstick will stay on for at least 6 hours, even during eating and drinking. Design an experiment based on the scientific method to test this claim. First state your hypothesis, and then **identify** the variables you will be considering. **Explain** the measures that you will take and how you will ensure that these measures are accurate.

Figure 3 Can a lipstick last for 6 hours?

21 For the experiment you designed in question 20, **outline** the results you would expect to obtain if your stated hypothesis was correct.

Evaluate and create

22 For the experiment you designed in question 20, **assess** how accurate your results might be and **propose** what further investigation you could take to improve the reliability of your conclusion.

23 For the experiment you designed in question 20, assuming you found that the manufacturer's claim was correct, **construct** a scientifically accurate slogan or advertisement for the lipstick based on your findings.

24 One source of information for consumers is *CHOICE* magazine. The magazine reports the results of testing a variety of brands of consumer products. If a consumer scientist was reading a report on the safety of children's pyjamas, **identify** the evidence that they might look for to see if the report was fair and objective. If they conclude that it is, **explain** how the public might be convinced to read such reports before purchasing pyjamas.

Critical thinking

25 Rhiannon had been working on an experiment to determine the optimum amount of water to use when growing flowers on her deck. Rhiannon used four pot plants in her trial. In the abstract to Rhiannon's research, her hypothesis stated that 'flowers receiving 15 mL of water four times a day will grow more than flowers that are watered once a day and receive 30 mL because they won't have as much hydration'.

- **a** **Explain** whether this should have been included in her abstract.

Figure 4 Rhiannon's pot plants

- **b** **Assess** whether Rhiannon's hypothesis could be improved.

Go further

26 Set up a logbook for your practical work. Follow the steps outlined in section 1.4.

Figure 5 A bound lined notebook will help you set up your logbook.

Research

27 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Mobile phone safety

Research is continuing into the safety of mobile phones, although most people in the Western world have one or use one. Imagine you are an advisor to the Minister of Communications and Technology. Produce a report, of at least 10 points, detailing any research that has taken place into mobile phone safety. Make sure to include the outcomes or conclusions reached in any of these studies.

»Artificial colourings and flavourings in foods

Some people claim that certain artificial colourings and flavourings in foods can cause problems, such as hyperactivity in children. Use the internet and other resources to investigate this issue. What is the meaning of the term 'opposing evidence'? Are there warnings based on anecdotal evidence or scientific evidence? Can anecdotal evidence be of value to scientists? Discuss.

»Bottled water

Many people in Australia spend a lot of money on bottled drinking water. Are they doing this because of the way the water is marketed, or are there scientifically supported health benefits in drinking bottled water rather than tap water? Is tap water unsafe to drink? Have there been any cases where water bottlers have been fraudulent in their claims about the water they are selling? Investigate this issue. Find out what dentists and medical experts say about bottled water. What scientific tests are performed to check that the claims are correct and what results have been obtained? After researching and comparing a range of evidence, what is your conclusion? Should we drink bottled water here in Australia and not tap water? Or does this depend on where you live?

Figure 6 Artificial food colourings in food can cause hyperactivity in some people.

Reflect

During Stage 5, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Make predictions and hypotheses based on observations and scientific knowledge.	☐	☐ Go to pages 2-3
Plan investigations including determining equipment and a methodology, and conducting background research.	☐	☐ Go to pages 4-5
Conduct investigations using the correct equipment to record accurate and reliable measurements.	☐	☐ Go to pages 6-9
Participate in investigations safely by conducting ethical and risk assessments.	☐	☐ Go to pages 10-11
Process and analyse primary and secondary sources of data to develop an evidence-based argument.	☐	☐ Go to pages 12-13
Evaluate and solve problems by applying scientific understanding to them.	☐	☐ Go to pages 14-15
Present scientific ideas for specific audiences using correct language, diagrams and representations.	☐	☐ Go to pages 16-17

WAVE AND PARTICLE MODELS

How does energy move?

Have you ever wondered ...

- How does a heater warm your classroom?
- How can you hear people on the other side of a room?
- How does energy from the Sun reach the Earth?

2

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- explain, in terms of the particle model, the processes underlying convection and conduction of heat energy
- identify situations where waves transfer energy
- describe, using the wave model, the features of waves including wavelength, frequency and speed
- explain, using the particle model, the transmission of sound in different mediums
- relate the properties of different types of radiation in the electromagnetic spectrum to their uses in everyday life, including communications technology
- describe the occurrence and some applications of absorption, reflection and refraction in everyday situations

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

2.1 The particle model can explain heat energy

In this topic, you will learn that:

- energy is never lost or gained – it is transformed from one form to another or transferred from one object to another
- the law of conservation of energy states that the total amount of energy stays exactly the same *when energy is transferred or transformed*
- the law of conservation of energy states that the total amount of energy stays exactly the same *in a closed system*.

Heat (also called thermal energy) is a form of energy. It describes the total vibrational and kinetic energy of all particles in an object. Energy is never lost or used up, but it is transformed (changed from one form to another) or transferred from one object to another. According to the law of conservation of energy, the total amount of energy stays exactly the same. Thermal energy moves spontaneously from a hotter substance to a cooler substance. It can be transferred by conduction, convection or radiation. Conduction is a way of transferring heat energy without transferring matter. Convection occurs by transferring matter. Radiation is a mechanism of transferring heat without any need for matter.

Heating by conduction

conduction
transfer of thermal energy involving direct contact with no movement of material

convection
the transfer of heat energy through particles

radiation
the transfer of energy through waves

Heat transfer by **conduction** is the transfer of thermal energy from matter that is warmer to matter that is cooler. This happens spontaneously when two solid objects make direct contact with each other and reach thermal equilibrium.

If you heat one end of a metal rod, after a while the other end also becomes hotter. How does heat reach the other end of the metal rod? The atoms of the hot end of the metal rod have more kinetic energy. As the atoms in a solid (e.g. the metal rod) are in close contact with each other, they bump into their neighbouring atoms and transfer some of their energy to them, causing them to vibrate faster. These quickly vibrating atoms in the rod bump into nearby atoms, transferring energy to them making them vibrate faster. This process continues all through the metal rod, and heat energy reaches the other end of it. Although the energy moved through the metal rod, the atoms in the metal did not leave their positions. During heat conduction, it is the vibrations, and therefore the energy, of the individual atoms that are passed on.

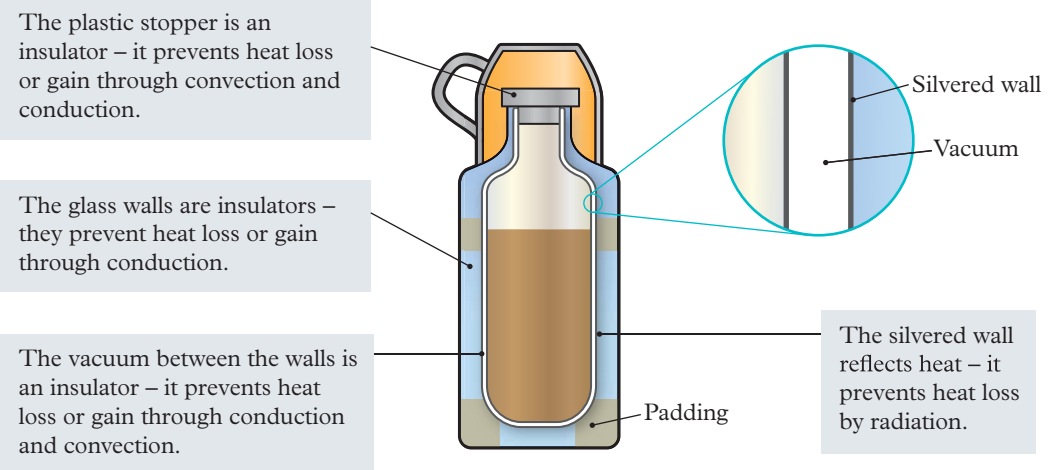


Figure 1 The structure of a vacuum flask. Vacuum flasks are designed to keep hot substances hot and cold substances cold. To do this, they must prevent the contents from losing or gaining heat – conduction, convection and radiation must be minimised. Careful choice of materials and clever design make this possible.

INVESTIGATION
2.1: Investigating heating by convection
Go to page **353**

Conductors and insulators

The conduction of heat occurs at different speeds in different materials. Some materials that quickly transfer heat energy are good conductors of heat energy. Metals are good thermal conductors because they have some free electrons in their structure that can transfer heat energy in a metal. Materials that slow down the transfer of thermal energy by conduction are thermal insulators. Glass, plastic and wood are some examples of thermal insulators.

Heating by convection

Heat transfer by conduction occurs faster in material in which atoms are in close contact with each other. In liquids and gases, the atoms are further apart so they are not good conductors of heat energy. In liquids and gases, thermal energy moves by **convection**, which is the transfer of heat by transferring particles. If you heat your house using a heater, the particles of air next to the heater become hotter and less dense. They rise and the denser air particles take their place. The heated particles transfer heat energy with them. The movement of hotter or colder particles within a liquid or gas is called the convection current.

This process of convection in the air is what drives the weather on Earth.

Heating by radiation

Heat transfer through **radiation** is very different from how heat transfers through conduction and convection. You feel heat radiation many times in winter when you stand in front of a fireplace or a heater. The heat transfers to you without the rising and falling of particles (as in convection) and without the solid material (as in conduction). Radiation also occurs when the Sun's light reaches the Earth and heats the Earth. When you stand outside in the sunlight, it is warmer than standing in the shade. This is due to the radiation of the heat given off by the Sun. The energy from the Sun must travel through space to reach the Earth.

Figure 2 Convection currents are created in a saucepan of water when it is heated. The heated water molecules (shown in red) rise while the cooler ones (shown in blue) sink.

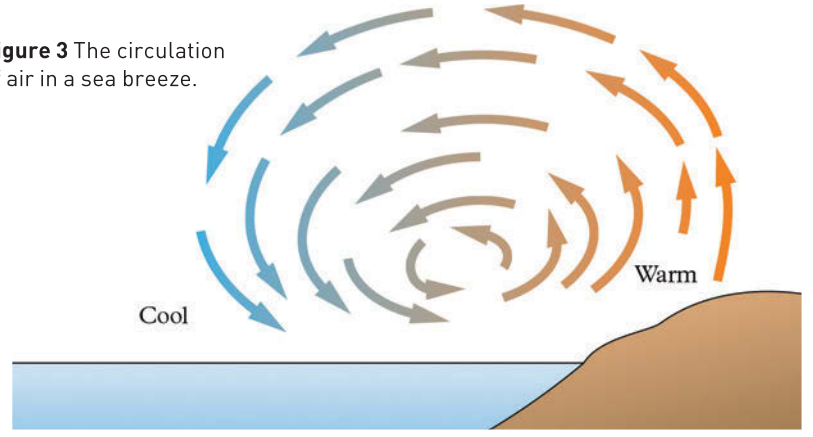


Figure 3 The circulation of air in a sea breeze.

Check your learning 2.1

Recall and explain

1 **Explain** what happens to molecules when they are heated.

2 From your everyday experience, **identify** some examples of where good thermal insulators are needed, and **identify** the materials used in each situation. Now give some examples of where good thermal conductors are needed, and **identify** the materials used.

Apply and analyse

3 **Compare** conduction with convection and radiation.

4 **Explain** how land and sea breezes are formed.

5 If you are to fry some onions, which pot is more effective: a glass pot or a metal pot? **Justify** your answer.

6 **Explain** how particle theory relates to the heating and cooling of substances.

Evaluate and create

7 **Construct** a labelled diagram to explain heating by convection.

Skill builder: Problem solving

8 The following materials are used to make the bottom, handle or lid of a saucepan.
Write a pros and cons list for using each of the following. (THINK: What are the advantages? What would be the disadvantages? How would each material be affected by heat energy?)

- **a** Plastic for the handle
- **b** Copper as the lid
- **c** Glass as the bottom

9 Based on your pros and cons list in question 8, **identify** which material should be used for each part of a saucepan. (THINK: What do you need to touch? What holds the food being cooked?)

2.2 Waves transfer sound

In this topic, you will learn that:

- waves carry sound energy through compressions (particles of air coming together) and rarefactions (particles of air moving apart) of a longitudinal wave
- the distance a particle of air moves *from its rest position* is called the amplitude of the wave, the length between successive compressions or successive rarefactions is called the wavelength, and the number of waves that pass a point in one second is the frequency of the wave.

compression
a part of a sound wave where air particles are forced close together

rarefaction
a part of a sound wave where air particles are forced apart

longitudinal wave
a type of (sound) wave where the particles move in the direction of travel of the wave

amplitude
the distance a particle moves from its position of rest

wavelength
the distance between two crests or troughs of a wave

Modelling sound waves

We know that sound energy travels because we can often hear it a long way from its source. Consider the example of a drum being played. The drum skin vibrates (moves up and down) when it is hit. It transfers its energy to the surrounding air particles. As a result, the air particles are pushed closer together in one place and further apart in another. In this way, the air around the drum is made to vibrate too. This causes the particles further away to vibrate and so on, until the air close to your ears eventually vibrates and causes your eardrum to vibrate too, and that's when you hear the sound.

The region with the particles forced close together is called a **compression**, and the less dense region is called a **rarefaction**. Sound waves travel as a **longitudinal wave**. The air particles move back and forth in the same direction as the transfer of energy. The distance a particle of air moves from its rest position is called the **amplitude** of the wave.

Sound waves with a large amplitude mean the air particles move faster and the wave contains more energy. This makes the sound seem louder to our ears. An example of this is when musicians use amplifiers to increase the loudness of their music. Amplifiers increase the distance air particles move during compression and rarefaction.

A sound wave moves out in all directions from the place where the vibration began (Figure 1).

Describing sound

You can sing high. You can sing low. You can talk in a funny voice if you want to because you can alter the number of vibrations coming from your vocal cords every second.

The distance between successive compressions or successive rarefactions is called the **wavelength**. Short wavelengths mean more vibrations hit your eardrum each second.

When the waves travel close together, then they are considered more frequent.

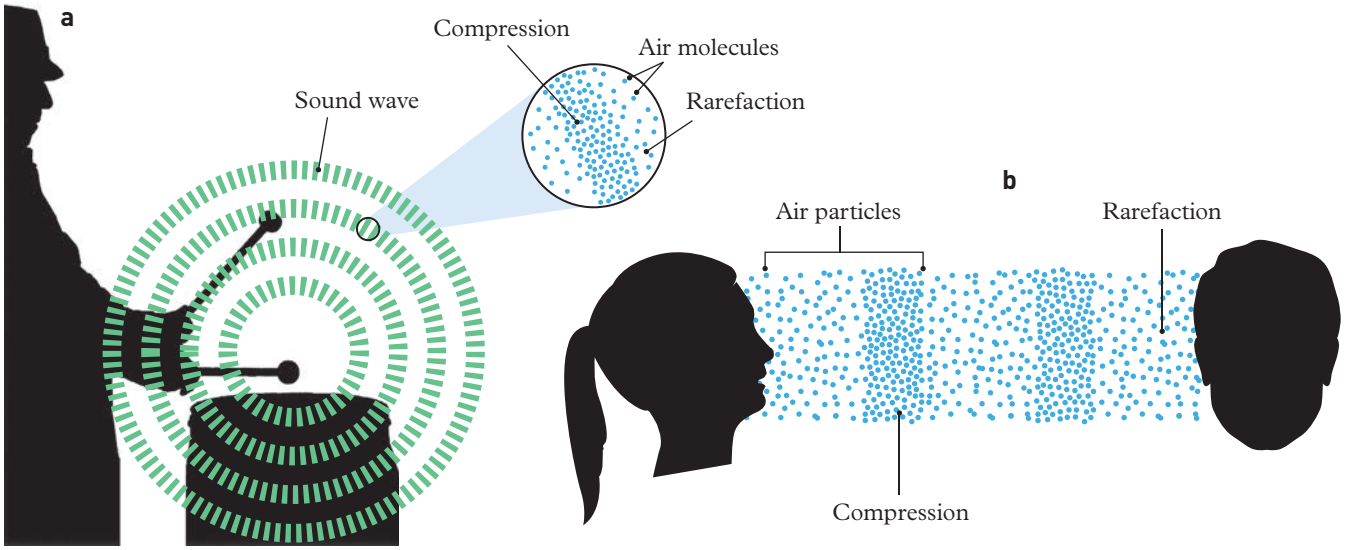


Figure 1 a When a drummer hits a drum skin, a sound wave is produced. **b** When a person talks, a sound wave is also produced.

The number of waves that pass a point each second is called the **frequency** of the wave. This is measured in the unit **hertz** (symbol Hz). We hear different frequencies as different pitches. For example, a soprano sings the high notes in an opera. These notes are considered high pitch. The sound waves for these notes have very short wavelengths and therefore high frequency. A deep bass singer is able to sing very low-pitched notes. These notes have long wavelengths and few of them can pass a point each second. Therefore, they have a low frequency.

As the waves move further away from their source, their energy is shared between more air particles and eventually fades out. As neighbours will confirm, the closer you live to a drummer, the louder they seem!

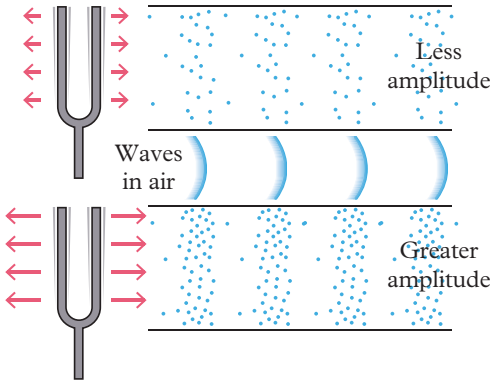


Figure 2 The red arrows indicate how far a particle in a sound wave moves.

frequency
the number of waves that pass a point every second; measured in hertz

hertz
the unit used to measure frequency

Figure 3 Middle C (shown in red) played on a piano has a wavelength of 1.33 metres and creates vibrations at a frequency of 256 vibrations every second or 256 Hz.

Check your learning 2.2

Recall and explain

1 **Explain** how particles in the air are arranged in a:
   - **a** compression
   - **b** rarefaction.

2 Work with a partner. **Explain** to your partner how the sound waves created by hitting a cymbal reach your ears. Use the following terms: compression, rarefaction, sound wave, spread out, air particles, ear.

3 Consider the two springs shown in Figure 4. **Identify** the string that demonstrates:
   - **a** lower frequency
   - **b** smaller wavelength.

Apply and analyse

4 Imagine you have three tuning forks of frequencies 250, 500 and 1000 Hz. **Deduce** which one would have the:
   - **a** shortest wavelength
   - **b** highest pitch.

5 Energy is transferred by a sound wave without transferring particles. **Account** for this statement.

6 If a nearby star was to explode, **explain** why we wouldn't hear the noise of the explosion on Earth.

Evaluate and create

7 **Investigate** the speed of sound in air.

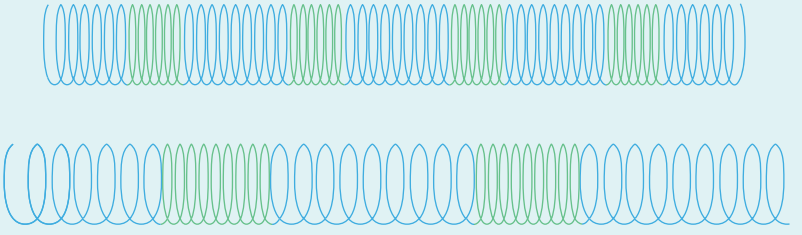


Figure 4 Two different springs

Skill builder: Communicating

8 Sometimes, using a diagram is the best way to explain a scientific concept.
   - **a** **Construct** a diagram of a longitudinal wave. (THINK: What does a longitudinal wave represent? What does a wave diagram look like? Is my diagram scientifically accurate?)
   - **b** Label the following on the diagram: compression, rarefaction, wavelength. (THINK: Have I put the correct labels on the right parts of the diagram?)

2.3 Sound can travel at different speeds

In this topic, you will learn that:

- the speed of sound varies according to the temperature and material through which it travels
- sound travels faster at higher temperatures as the particles can compress more easily.

Sound travels through air at 340 m/s at sea level at 20°C. The speed of sound varies according to the temperature and material through which it travels. At higher temperatures, particles have more kinetic energy so they can compress more easily. Therefore, sound travels faster at higher temperatures. The more closely packed the particles in a substance, the faster the sound wave travels.

Speed of sound

speed of sound
the speed that a sound wave travels through a medium at a certain temperature

The **speed of sound** is affected by the closeness of the particles in a material and how far they can move. For example, the particles in water are much closer together than in air so they collide more easily. Thus, they transfer energy more quickly. This means a sound wave can travel faster through water. The particles in a solid are packed even closer together. Therefore, at a constant temperature, sound waves travel the fastest through solids and the slowest through gases (see Table 1).

Table 1 Speed of sound in different materials and at different temperatures

Material	State	Temperature (°C)	Speed (m/s)
Air	Gas	0	331
Air	Gas	20	343
Water	Liquid	20	1482
Lead	Solid	20	1960
Glass	Solid	20	5640
Steel	Solid	20	5960

Speed of silence

If you are a drummer, you have probably been told more than once to 'keep the noise down!' But is there somewhere you could play your drum kit as hard and as loud as possible with absolutely no sound being heard? The answer is 'yes', but it is not a place you can get to easily.

Figure 1 Whales communicate with clicks, whistles and pulsed calls under water.

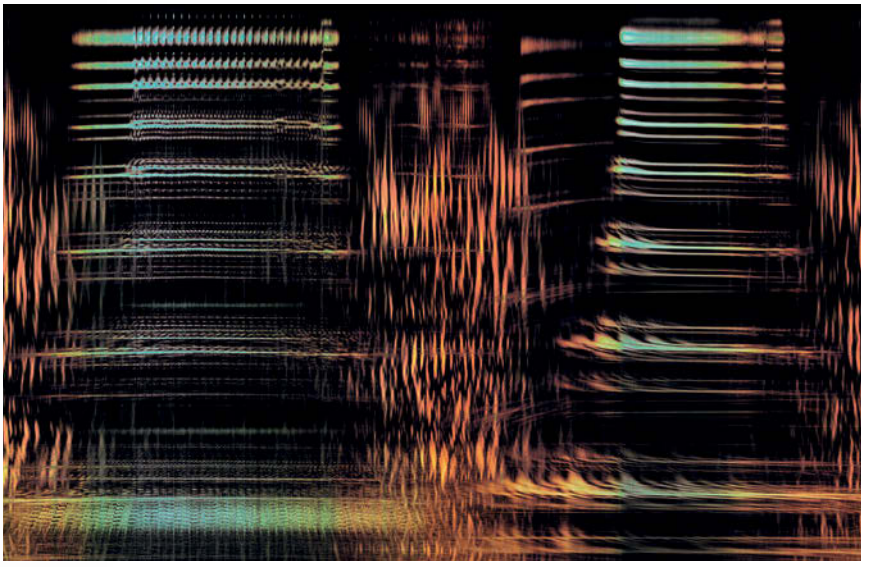


Figure 2 The sound of whales travels almost five times faster under water than in the air. Blue whales sing to each other in a series of moans and pulses (shown) that can travel thousands of kilometres underwater.

CHALLENGE **2.3a:** The speed of sound
Go to page **354**

CHALLENGE **2.3b:** Racing dominoes
Go to your **obook**

A famous sci-fi movie was advertised with the tagline 'In space, no one can hear you scream.' The moviemakers were right. In outer space, you can play your drum kit without anyone hearing a sound – but you wouldn't hear it either. You could even see an explosion without hearing a thing. This is because sound needs something to travel through; it needs a substance (or **medium**) that contains particles that can be compressed to create the sound waves. The medium could be a solid, a liquid or a gas.

Sonar

When a wave reaches a boundary between two media, it might return into its original medium. The returning of a wave into its original medium is called reflection of wave. In all wars since World War I, reflected waves have been used to detect enemy submarines under water. In a similar way to radar (which sends out radio waves), **sonar** sends out sound waves and records how long the sound takes to reflect or echo back after striking an object. The longer the sound takes to return, the further away the object is. An exact location can be calculated by knowing how fast sound travels in water.

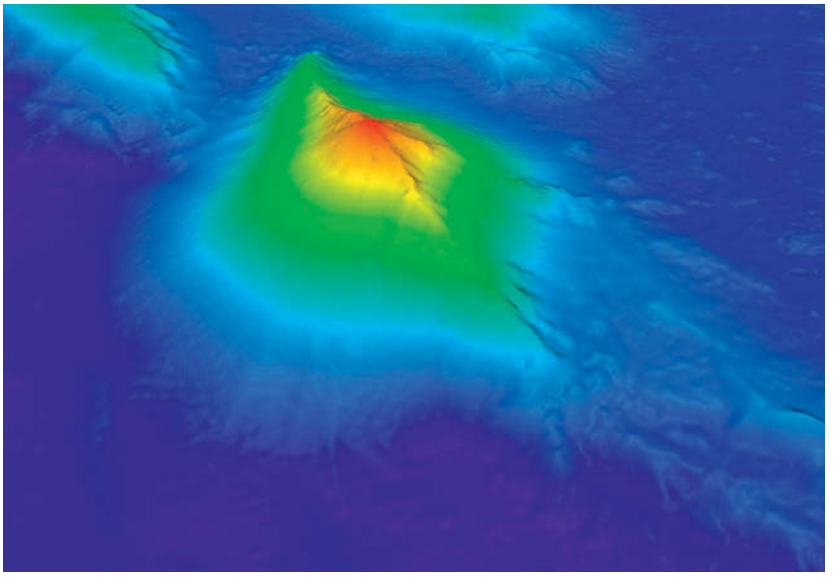


Figure 3 Sonar is used to map volcanoes on the ocean floor.

This information, along with the time taken for the sound to return, allows the exact location of a submarine to be determined.

Sonar is widely used today and can help map the ocean floor, check the depth of water and locate schools of fish.

sonar
the recoding of how long it takes a sound wave to reflect or echo back to its starting point after it hits an object; it is used to detect the location of things, for example, a submarine

Check your learning 2.3

Recall and explain

1 **Identify** which of the following materials will allow sound to travel the fastest.
   - **a** Water
   - **b** Lead
   - **c** Air
   - **d** Glass

2 **Describe** how sonar works.

3 **Define** the term 'medium'.

Apply and analyse

4 **Explain** how sonar is similar to light striking a mirror.

5 **Explain** why sound travels faster in warmer air.

6 If a nearby star were to explode, **account** for why we wouldn't hear the noise of the explosion here on Earth.

7 Movies sometimes show people tapping SOS on water pipes to get help. **Explain** why tapping on water pipes is a quicker way of passing on a message than yelling.

Evaluate and create

8 Bats navigate by echolocation. **Investigate** how echolocation works. **Compare** it to how sonar works.

Skill builder: Planning investigations

9 Music is a series of sound waves. Different musical instruments produce sounds of different frequencies and wavelengths to produce different notes.
   - **a** Research two different types of musical instruments, and **explain** how each produces sounds at different frequencies and wavelengths. (THINK: What part of the instrument causes sound and how?)
   - **b** Select one instrument and **identify** equipment you may need to investigate how it produces sound.

2.4 Visible light is a small part of the electromagnetic spectrum

In this topic, you will learn that:

- the electromagnetic spectrum is a way of describing all the different forms of light, including the light we see
- all forms of light travel at the same speed through a vacuum and are transverse waves.

Resource
STEM activity: Soundproofing

Ancient civilisations believed that light was emitted from the eye and this enabled us to see. We now know that we see by light entering our eyes. Like sound, light is a form of energy, which can behave like a wave. There are many different types of light, with a very wide range of wavelengths. Together, these forms of light are called the electromagnetic spectrum.

Electromagnetic spectrum

The **electromagnetic spectrum** includes the energy that transmits music on your radio, the picture on your television, and the heat to cook popcorn in your microwave.

Our eyes can only see a small amount of these electromagnetic waves called visible light. All these different types of light (electromagnetic waves) have common features.

They all travel at the same speed in a vacuum – the speed of light. However, they have an obvious difference. They have different wavelengths and therefore different frequencies and energy.

As you have already learned, sound waves need a medium to travel, so how does sunlight reach the Earth and keep you warm without a medium? Electromagnetic waves do not need a medium to travel. They can travel from the Sun to our Earth through a vacuum. In addition, as electromagnetic waves can travel through a vacuum (which has no particles), there is no loss of energy due to the friction between particles. Thus, they travel a longer distance compared with sound waves.

electromagnetic spectrum
a range of electromagnetic waves with different wavelengths and energies

transverse wave
a type of wave where the vibrations are at right angles to the direction of the wave

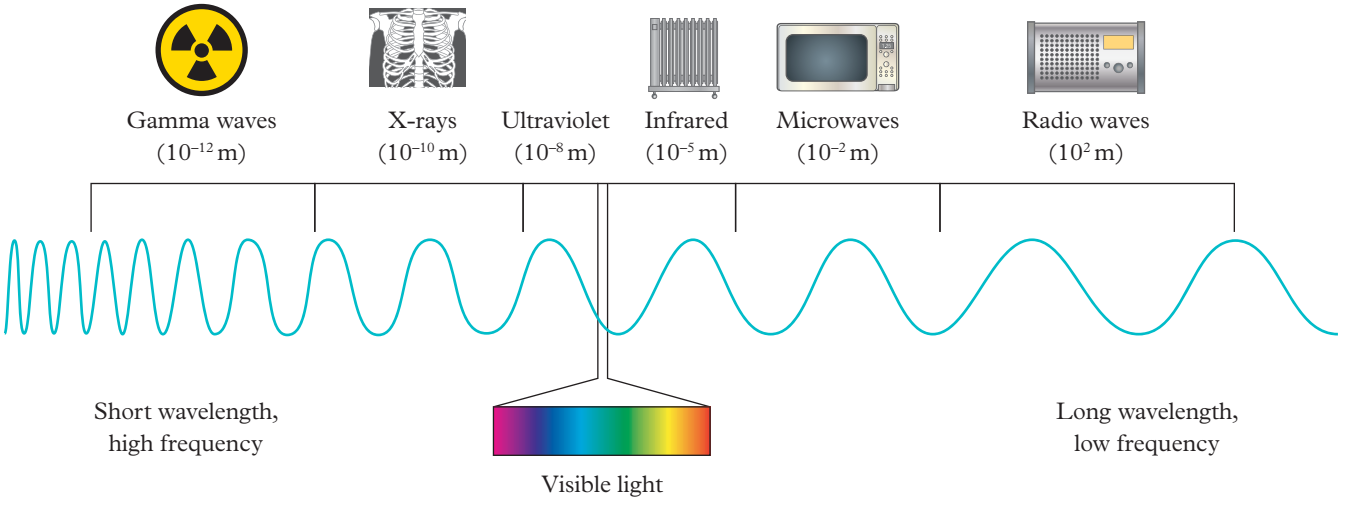


Figure 1 The electromagnetic spectrum

Transverse waves

Light waves are different from sound waves. Sound waves exist as longitudinal waves – the vibrations of the air particles are in the same direction as the direction of travel of the wave. In light waves, the vibrations are at right angles to the direction of travel of the wave. We call these waves **transverse waves**. The highest and lowest points in a transverse wave are called crests and troughs, respectively.

The distance between two neighbouring crests or two neighbouring troughs on a transverse wave is called the wavelength. It is the same as the distance between any two consecutive matching points on the wave. The standard unit of wavelength is the metre (m). At a different wavelength, the nature of the light wave changes. In the region of visible light, this change of wavelength is seen as different colours. For example, red light has a longer wavelength (lower frequency) than that of blue light.

Because light waves have different wavelengths, they also have different frequencies. As with sound waves, the frequency of a light wave is a measure of the number of waves that pass a point each second (unit Hz). Amplitude is a measure of how far a particle moves from its place of rest (see Figure 3).

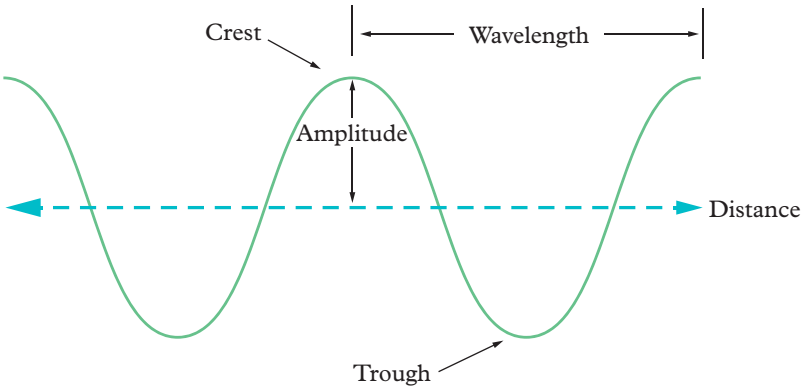


Figure 2 Vibrations in a transverse wave are at right angles to the wave's direction of travel.

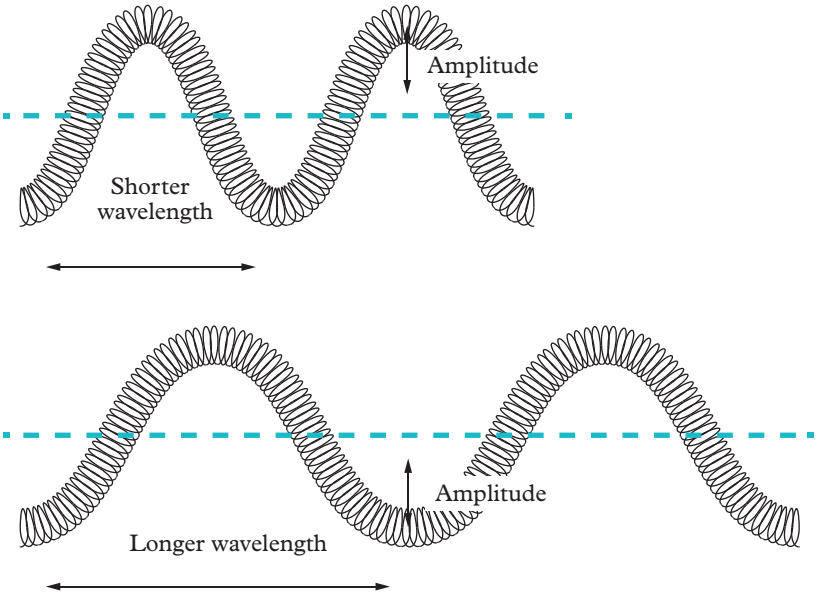


Figure 3 The wavelength of a wave is measured from any point on the wave (usually a peak or trough) to the next corresponding point.

Check your learning 2.4

Recall and explain

1 **Describe** a transverse wave.
2 **Explain** what the electromagnetic spectrum is.
3 **Identify** the unit used to measure wavelength.
4 **Identify** the speed of light in a vacuum.

Apply and analyse

5 Draw a diagram of a transverse wave and label a crest, a trough, a wavelength and an amplitude.
6 Sound is a wave but sound cannot travel through a vacuum (empty space). Light can travel in a vacuum. **Explain** why.
7 **Explain** why you can see the light of a distant car but you cannot hear its sound.
8 In terms of wavelength and frequency, **identify** the difference between ultraviolet light and infrared radiation.

Skill builder: Questioning and predicting

9 The relationship between wavelength and frequency is described as an inverse or reciprocal relationship. This can be confirmed by asking questions and making predictions.
a Write a scientific question that may help you test this. (THINK: What am I measuring? What am I changing?)
b **Predict** what the outcome of your question might be. (THINK: Why do I think this would happen? What scientific theory is this?)

2.5 Light reflects off a mirror

*

In this topic, you will learn that:

- light can travel through transparent objects and is blocked by opaque objects
- translucent objects allow some light energy through
- opaque objects do not allow light to pass through them at all
- the law of reflection states that the angle of incidence equals the angle of reflection.

Light behaves in different ways with different objects. Light can reflect off a glass window, but most of the light is transmitted and passes through. This is because the glass in the window is transparent. Some types of frosted glass prevent us seeing through them clearly. They are **translucent**. If an **opaque** material doesn't allow any light to pass through it and if it is shiny enough or has a shiny coating, it will reflect the light and allow us to see the clear image. The best example of this is a mirror.

translucent
a substance that allows light through, but it diffuses so that objects cannot be seen clearly

opaque
a substance that does not allow light to pass through

normal
an imaginary line that is drawn at right angles to the surface of a reflective or refractive material

angle of incidence
the angle between the incident ray and the normal (the line drawn at right angles to a reflective surface)

angle of reflection
the angle between the reflected ray and the normal (the line drawn at right angles to a reflective surface)

virtual image
an image that appears in a mirror; it cannot be captured on a screen

Reflection

Reflection is the bouncing of light off a solid material. The reflection of light from a mirror is shown in Figure 1. Light always follows particular rules when it reflects from a surface, no matter how rough or how smooth the surface is. The **normal** is an imaginary line that can be drawn at 90° (or perpendicular) to the mirror's surface. It is usually drawn as a dotted line.

The incident ray represents the incoming light and strikes the mirror at the base of the normal. The **angle of incidence** is the angle between the incident ray and the normal. The reflected ray leaves the mirror from the base of the normal at the same angle as the incidence ray. The **angle of reflection** is the angle between the reflected ray and the normal. An arrow is always used to indicate which line is the incident ray and which is the reflected ray. The law of reflection states that the angle of incidence (symbol i) equals the angle of reflection (symbol r).

Angle of incidence (i) = angle of reflection (r)

When we look in a plane mirror, we see a picture (or image) of ourselves. In the case of a plane mirror (i.e. a flat mirror), the image is always a **virtual image**. This means it cannot be captured on a piece of paper or on a screen like a movie projector. The image always forms where the reflected light rays or their extensions cross. The image we see in a plane mirror is also laterally inverted.

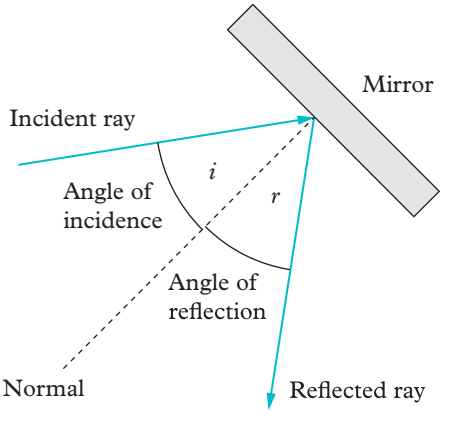


Figure 1 The angle of incidence (i) and the angle of reflection (r) are the same.

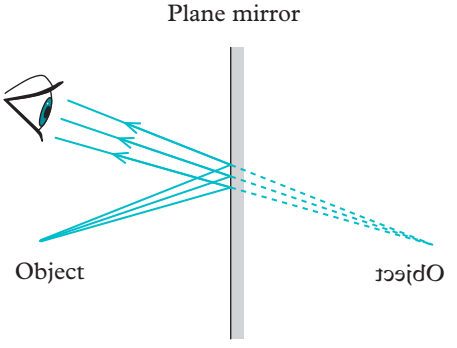


Figure 2 The image in a plane mirror is virtual, laterally inverted, the same size as the object and the same distance from the mirror.

CHALLENGE 2.5a: Mirror writing
Go to your obook

CHALLENGE 2.5b: Using curved mirrors
Go to page 356

If we raise our left hand in front of a mirror, our image looks as if it is raising its right hand. The image is also the same distance behind the mirror as the object is in front of it.

Not all mirrors are necessarily plane mirrors (i.e. flat). If you have ever been to a circus or fun park, there are usually curved mirrors that make your body appear long, short or otherwise distorted. Curved mirrors are not as predictable as plane mirrors. They can change the size and nature of the object's image. Curved mirrors can be convex, where the centre sticks out, or concave, where the centre goes in (like a cave).

Reflections off curved mirrors still obey the law of reflection that the angle of incidence is equal to the angle of reflection. However, because the surface is no longer flat, there are many different angles that the incidence ray is reflected at due to the normal constantly changing around the curve of the mirror.

Concave mirrors cause the reflected light to bend towards a central point. They are used in reflecting telescopes. **Convex mirrors** scatter the light of an object which means you can generally see more than you typically would with a plane mirror. They are typically used in passenger side mirrors of cars.

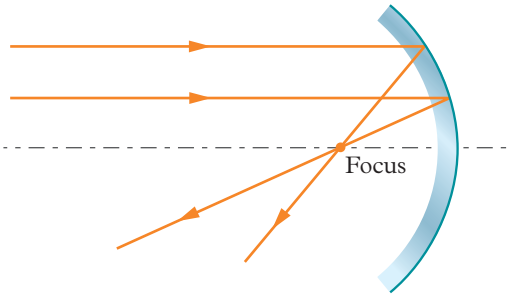


Figure 3 A concave mirror. The orange lines show the path of the light. The incident rays are coming into the mirror, and the mirror reflects them through a point where they converge. This point on a concave mirror is called the focus.

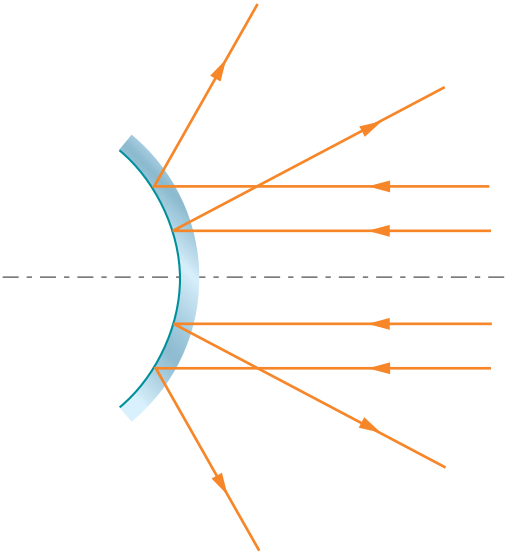


Figure 4 A convex mirror. The orange lines show the path of the light with the incident rays coming towards the mirror, while the reflected rays leave the surface of the mirror.

concave mirror
a mirror in which the centre goes in, and it converges the incident rays

convex mirror
a mirror in which the centre sticks out, and it diverges the incident rays

Check your learning 2.5

Recall and explain

1 **Summarise** the meanings of 'transparent', 'translucent' and 'opaque', and give two material examples of each.

2 **Explain** why light fittings are often translucent.

3 Create a table to **explain** the meaning of the following: normal, incident ray, angle of incidence, reflected ray, angle of reflection.

Apply and analyse

4 **Distinguish** between a convex mirror and a concave mirror.

5 **Recall** what plane mirrors and convex mirrors have in common.

Evaluate and create

6 View the image in Figure 5. If a is the incident ray, **identify** which one of the rays (b or c) is the reflected ray.

7 A ray of light hits a plane mirror at an angle of 30°. Draw a labelled diagram of the mirror and show the incident ray, reflected ray, normal, angle of incidence and the angle of reflection.

8 **Investigate** some uses of concave and convex mirrors.

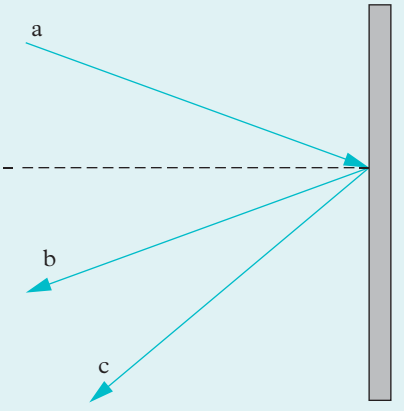


Figure 5 Reflection of an incident ray

Skill builder: Processing and analysing data and information

9 The way data is represented can help people understand your findings. In this task, you need to create a table to **summarise** the information from this section. In your table, include:

- information about reflection
- the difference between concave and convex mirrors.

(THINK: What is the best structure for your table? What information is important? Can you structure it to compare information?)

2.6 Light refracts when moving in and out of substances

In this topic, you will learn that:

- refraction is the bending of light as it enters from one medium to another
- reflection occurs from shiny surfaces, but when light strikes a transparent material, it enters the material and may change direction.

refraction
the bending of light as a result of light speeding up or slowing down

medium
a substance or material through which light can move

refractive index
a measure of the bending of light as it passes from one medium to another

refracted ray
a ray of light that has bent as a result of light speeding up or slowing down

angle of refraction
the angle between the refracted ray and the normal (the line drawn at right angles to a refractive surface)

Have you ever wondered why a spoon in a glass looks broken? **Refraction** is the bending of light as it passes from one transparent **medium** (i.e. substance or material) into another. Often when light is refracted, our view is distorted. You might be familiar with this effect when looking through water.

The amount of bending depends on the optical density or **refractive index** of the material and has the symbol *n*. The bent ray is called the **refracted ray** and its angle with the normal is the **angle of refraction** (symbol *r*). The higher the optical density, the slower the light travels through it. When a light ray enters a denser medium, such as from air into water, it slows down and consequently bends closer to the normal.

Figure 1 Water refracts light and distorts images.

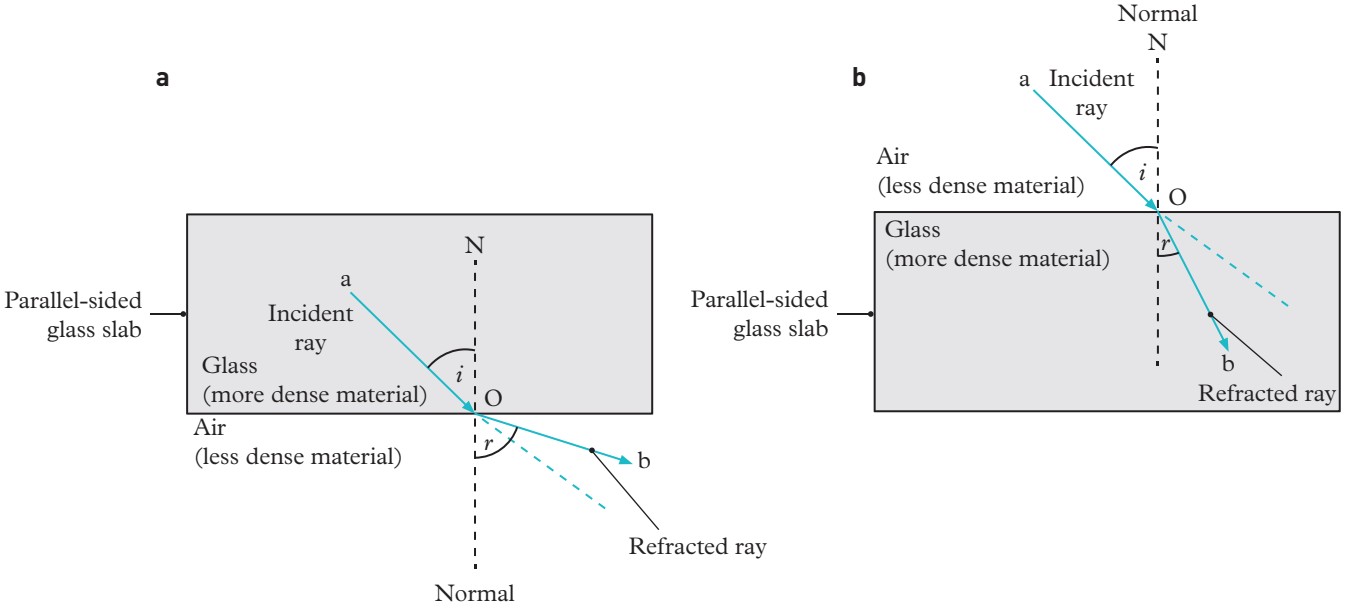


Figure 2 a Light entering a less dense medium bends away from the normal. **b** Light entering a denser medium bends towards the normal.

INVESTIGATION 2.6a: Bending of light
Go to page 356

INVESTIGATION 2.6b: Creating images with convex lenses
Go to page 357

When the light ray leaves the denser medium and moves into a less dense medium, it is able to speed up. When this happens, the light ray bends away from the normal.

Generally, liquids have a higher refractive index than gases as they are more dense. Similarly, solids have a higher refractive index than liquids because they are more dense. Light bends because it changes speed. The lower the refractive index, the faster the light travels in the medium.

The only time that light does not refract is when it enters a new medium along the normal (90° to the surface). It still changes speed, but there is no bending of the light.

Refraction in everyday life

Refraction explains a lot of everyday phenomena (see Figures 5–7). Refraction also explains how lenses work.

Lenses

A **lens** is usually a curved piece of transparent material, such as glass or plastic. Convex lenses are thicker in the centre than at the edges, and concave lenses are thinner in the centre than at the edges. They work in a similar way to convex and concave mirrors but use refraction to change the direction of light and form an image.

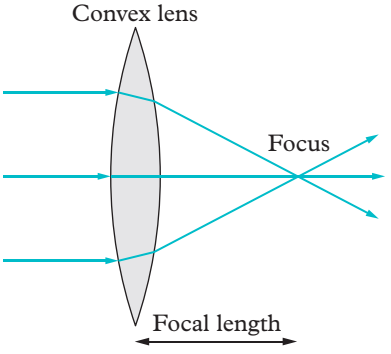


Figure 3 Parallel rays converge to a focal point with convex lenses.

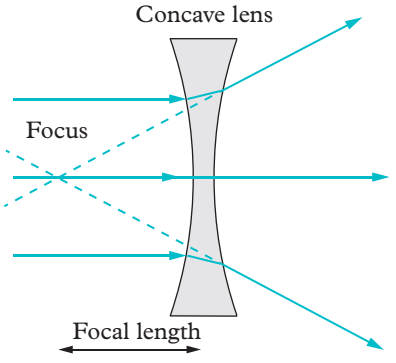


Figure 4 Parallel rays diverge from a focus with concave lenses.

Figure 5 Swimming pools and the ocean look shallower than they really are. The depth we see is the *apparent depth*. This person looks shorter in the water because the apparent depth is less.

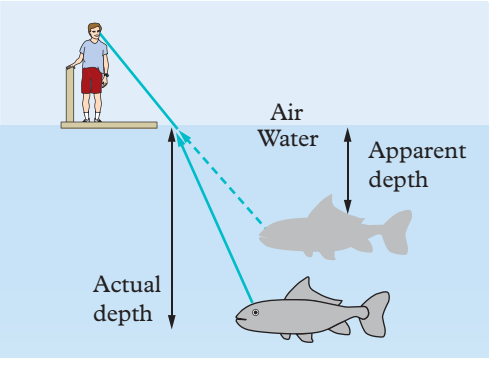


Figure 6 Refraction makes underwater objects appear closer to the surface than they really are. The fish looks closer than it really is because the light has left a denser medium.

Figure 7 Refraction makes straight objects appear disconnected. This pencil looks bent because its apparent position is different from its real position.

lens
a curved piece of transparent material

Lenses are essential components of nearly all optical instruments, including spectacles, magnifying glasses, binoculars, microscopes, telescopes and cameras.

Convex lenses cause light rays to **converge** (or focus). The **focus** (or focal point) is the point where the rays cross, and the **focal length** is the distance from the focus to the middle of the lens.

Concave lenses cause light rays to **diverge** (or spread out). The focus is on the other side of the lens, and to find it the diverging rays are extended back until they cross at the apparent source. The focus can therefore be described as a **virtual focus** because the light rays do not really come from this point.

converge
when rays of light move towards a single point

focus
the point where rays of light cross

focal length
the distance from the middle of the lens to the focus

diverge
when rays of light move away from each other

virtual focus
the point from which the rays of light seem to come

Total internal reflection

Optic fibres have revolutionised communications systems. Instead of always relying on copper wires to carry electrical signals, we now use bundles of optic fibres to carry light signals for landline telephone calls, the internet and networking of computers. They work on the basis of total internal reflection.

As you have learned, when light passes from a more dense medium to a less dense medium, it is refracted away from the normal. As the angle of incidence increases, the refracted ray may be refracted so much that it travels along the surface between the two mediums, known as the interface, at an angle of 90° to the normal. The angle of incidence at which this occurs is called the **critical angle** (symbol θ_c or i_c). If the angle of incidence is increased further, the light is totally internally reflected from the interface back into the more dense medium. This is known as **total internal reflection** (often abbreviated to TIR). It only occurs when light attempts to travel from a more dense medium into a less dense medium and only for angles greater than the critical angle.

optic fibre
a thin fibre of glass or plastic that carries information and/or data in the form of light

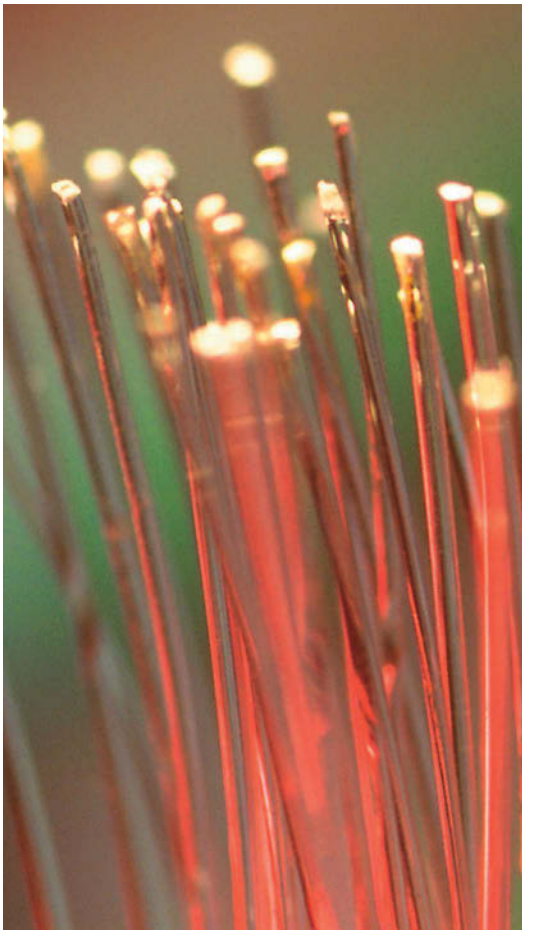


Figure 8 Optic fibres are used to carry digital light signals, and they have various applications.

critical angle
the angle of incidence when the refracted angle is 90°

total internal reflection
when a light ray passes from a more dense material at a large angle, it can be reflected back into the dense medium

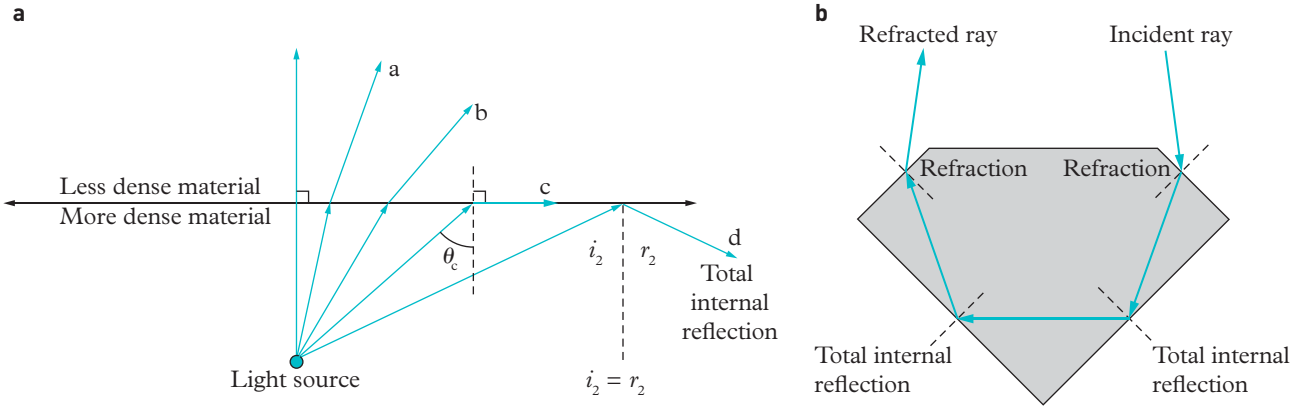


Figure 9 a Rays a and b are refracted because the angle of incidence is less than the critical angle. Ray c occurs when the critical angle is reached. Ray d is reflected when the angle of incidence is greater than the critical angle. **b** Total internal reflection.

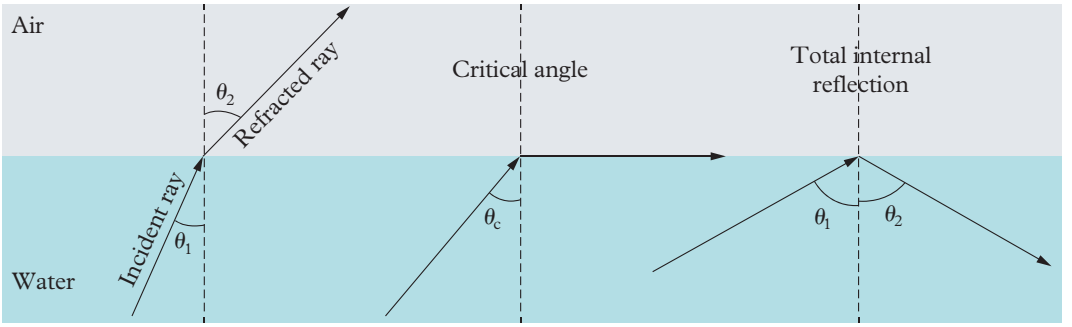


Figure 10 When light refracts, the refraction angle depends on the angel between the incident light and the boundary. At the critical angle, light bends to a point that it can be seen parallel to the boundary between the two materials.

Optic fibres work on the basis that the light passing through the fibres is totally internally reflected within the core of the fibre. This means there is minimal signal loss, and information is transferred at the speed of light. A single optic fibre carries much more data than a copper cable. Optic fibres do not generate heat like the current in a copper wire and are non-electrical, so they don't pose a fire risk and can be used around high voltages. Optic fibres are often found in HDMI cables.

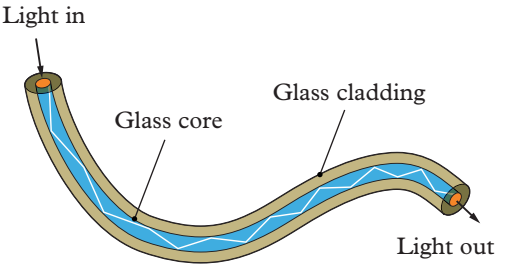


Figure 11 Light zigzags along inside an optic fibre at the boundary of the core and the cladding.

Check your learning 2.6

Recall and explain

1 Write a list to **identify** the similarities and differences between reflection and refraction.

2 **Identify** three everyday examples where refraction takes place.

3 **Recall** the name given to the point where light converges in a concave lens.

4 **Identify** the ways in which total internal reflection is similar to and different from reflection from a plane mirror.

5 **Recall** the principle behind optic fibres.

6 **Recall** the advantage of using optic fibres instead of copper wire for telecommunications.

Apply and analyse

7 The refractive index of water is 1.33 and that of diamond is 2.42. Draw a labelled diagram to show how a light ray bends when it travels from water into diamond.

8 The refractive index of glass is 1.52 and that of air is 1.00. Draw a labelled diagram to show how a light ray bends when it travels from glass to air.

9 **Distinguish** between convex and concave lenses.

Evaluate and create

10 **Investigate** some uses of convex and concave lenses.

11 **Explain** why total internal reflection can't occur for a light passing from a less dense material into a denser material.

Skill builder: Conducting investigations

12 It is important that any practical work is safe. To ensure safety, scientists perform risk assessments. An experiment designed to investigate convex lenses lists the following materials: light box kit, candle, matches, convex lenses.

- **a** **Identify** risks associated with these materials. (THINK: Could these cause injury or harm? Might they have risks with electricity or reactions?)
- **b** Suggest how these risks can be controlled. (THINK: Is there protective equipment you can wear? Can you substitute something?)

2.7 Different wavelengths of light are different colours

In this topic, you will learn that:

- visible light can be separated into the colours of the visible spectrum
- each colour of the visible spectrum has a different wavelength
- objects appear coloured when some colours are absorbed and others are reflected into our eyes.

visible spectrum
the variety of colours or wavelengths of light that can be seen by the human eye

primary colours of light
the three colours of light (red, blue and green) that can be mixed to create white light

secondary colours of light
the colours of light (magenta, cyan and yellow) that result from the mixing of two primary colours of light

White light can be separated into a range of different colours and shades, but there are generally considered to be six (or seven) basic colours – red, orange, yellow, green, blue, (indigo) and violet. This range of colours is called the **visible spectrum**. The process used to produce these colours is called dispersion.

Each colour of the visible spectrum has a different wavelength (i.e. the length of one complete cycle of a wave) and is refracted by a different range of wavelengths within the visible spectrum. This produces the separation of colours. A rainbow is an example of dispersion (and total internal reflection) caused by the refraction of light through water droplets. Three of the six basic colours are called **primary colours of light**. These are red, green and blue. This is because these three alone can be mixed to produce white light. When two of the primary colours are mixed, they form **secondary colours of light**.

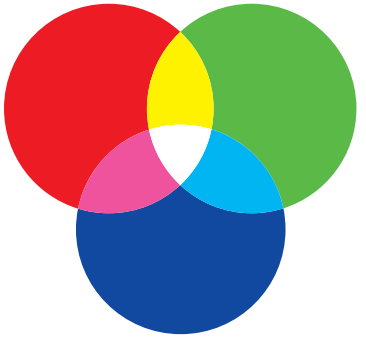
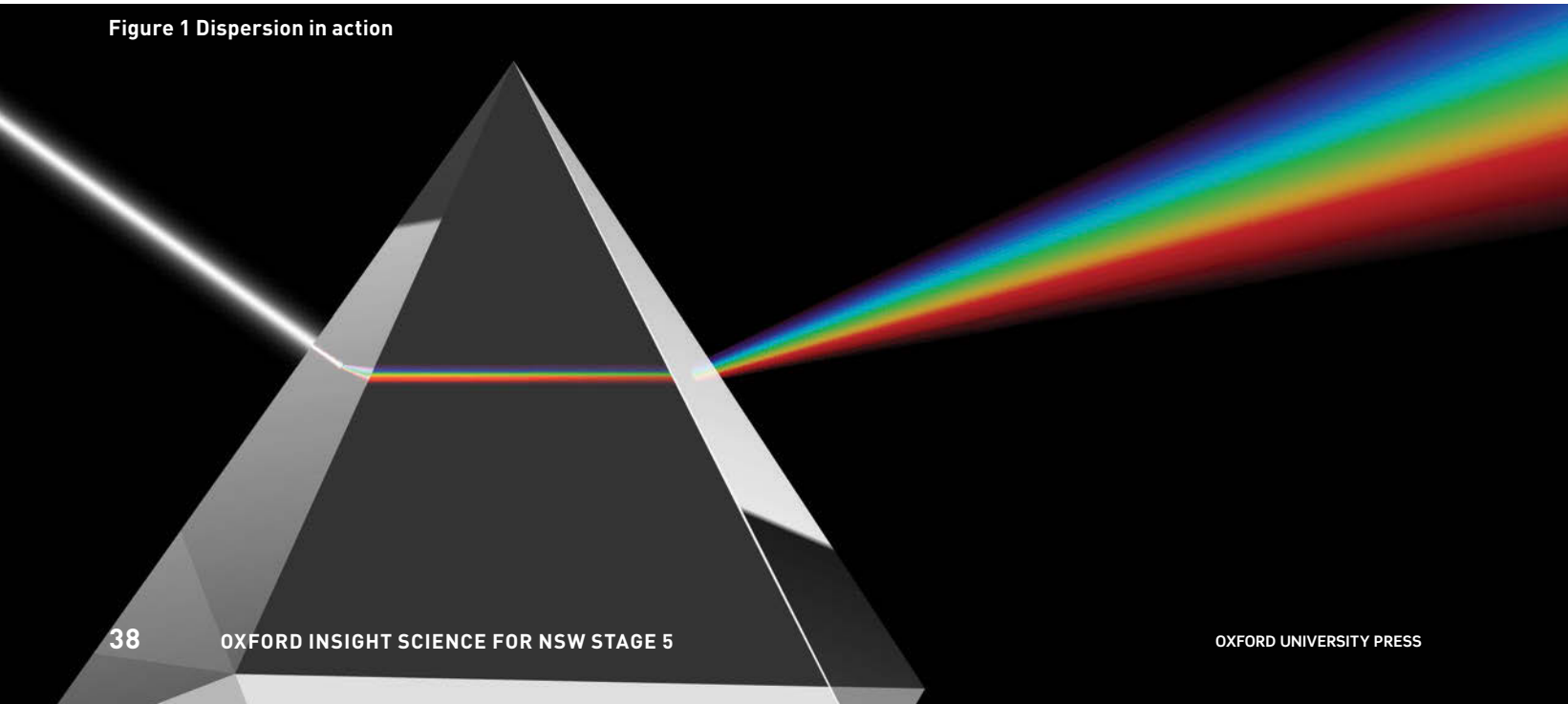


Figure 2 Where the red, green and blue lights overlap, white light is produced. The secondary colours are formed by the overlap of two of the primary colours.

For example, red light and blue light make a red–blue light called magenta. These rules are different for paints, so if you are an art student, you will need to think differently when considering mixtures of light compared to mixtures of paint!

Figure 1 Dispersion in action



Colour of opaque objects

So, why do coloured objects appear coloured? When white light (or sunlight) falls on an opaque object, some colours may be reflected while others are absorbed (or soaked up or subtracted from the white light). The colour the object appears to be depends on the mix of colours that reflect into our eyes. In most cases, it is easier to consider white light as just made up of red, green and blue light.

If some colours are absorbed and some are reflected, the object will appear to be the colour of the mix it reflects. This rule is the same for objects illuminated by coloured light. So, a red shirt appears red because red light is reflected from the red surface back to our eyes. Grass is green because the red and blue wavelengths are absorbed and the green wavelength is reflected back to our eyes.

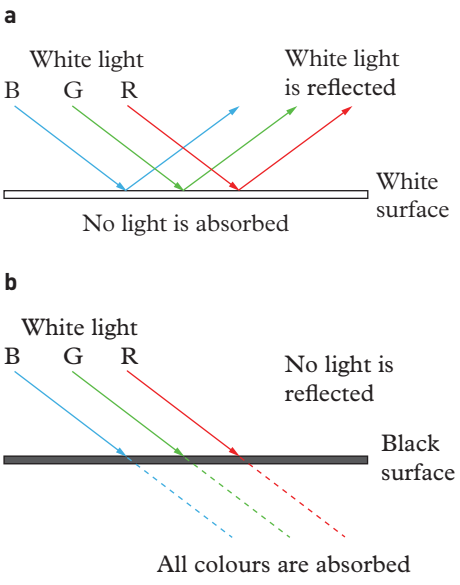


Figure 3 a A white surface reflects all colours and so looks white. **b** A black surface absorbs all colours and so looks black – no colours are reflected.

Colour of transparent objects

Transparent objects, such as the coloured **filters** in the Hodson light box kits or coloured cellophane, **transmit** (allow to pass) and absorb colours in the same general way that blue objects appear blue to us. If the blue colour is transmitted while the red and green colours are absorbed, then the filter appears to be blue. For example, a red filter appears red because the blue light and green light are absorbed and red light passes through. Therefore, we see the red light from the filter.

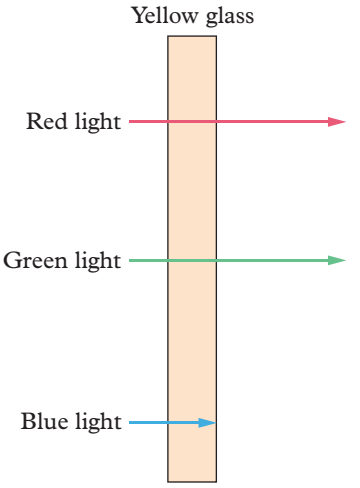


Figure 4 A filter that transmits red and green light and absorbs blue light will appear yellow.

filter
a transparent material that allows some wavelengths of light to pass through

transmit
to allow light to pass through

Check your learning 2.7

Recall and explain

1 **Identify** the result when green and red lights are mixed.
2 **Identify** what a green surface appears like under red light. **Explain** why it appears this way.
3 **Identify** what you would see if you looked at a white light through a yellow filter. **Explain** your answer.

Apply and analyse

4 **Distinguish** between primary and secondary colours of light.
5 If white light is a mixture of all the primary colours of light, **deduce** what black light is.
6 A white light is shone over an object. The blue light is reflected from it and the rest of the light is absorbed. **Identify** the colour of the object.

Evaluate and create

7 **Investigate** how astronauts use the colour of stars to find out about their temperatures.
8 **Predict** what would happen if red and blue lights are mixed. Then, write a hypothesis that would test this. **Identify** the independent variable and dependent variable in your hypothesis and **propose** any variables you would need to control.

Skill builder: Communicating

9 When scientists conduct investigations, they need to present their findings to a range of audiences. This involves using clear and concise language.

a **Investigate** the formation of rainbows.
(THINK: What key words should I use? Is the source of information credible?)

b Write a paragraph using scientific language to **explain** how rainbows are formed.
(THINK: Is my language too descriptive? Am I explaining the scientific concept or describing a rainbow?)

2.8 The electromagnetic spectrum has many uses

In this topic, you will learn that:

- the electromagnetic spectrum is a range of electromagnetic waves with different wavelengths and energies
- electromagnetic waves from the highest to the lowest wavelength (and the lowest to the highest energy) are radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

Electromagnetic spectrum

Radio waves

Radio waves are a part of the electromagnetic spectrum with a long wavelength and low energy. This part of the electromagnetic spectrum is used in communications such as radios and televisions. For example, radio waves are sent by radio stations and you receive them using your radio.

Microwaves

microwaves
a part of the electromagnetic spectrum

Microwaves are one small part of the electromagnetic spectrum. The wavelengths of microwaves are usually 1 mm to 1 m in length. Microwaves have many uses from communication (mobile phones) to cooking, from global positioning systems (GPSs) to radar. Microwaves can be focused into narrower beams than radio waves. This allows them to be used for person-to-person communication on Earth or even between Earth and the International Space Station.

The electromagnetic waves in a microwave oven provide energy to make the water molecules in food move. The increased movement of the water molecules causes friction between the other molecules in the food. This friction between all the molecules causes the food to heat up.

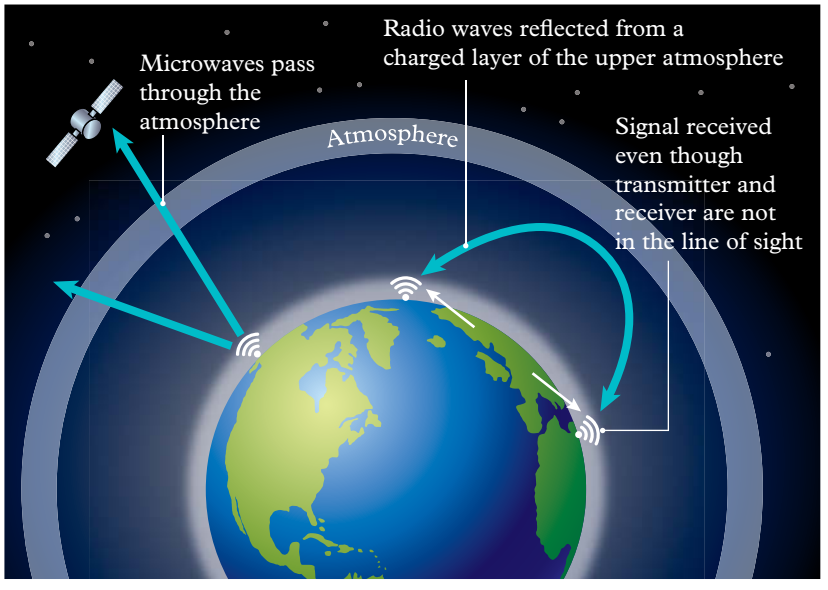


Figure 1 Electromagnetic waves with different wavelengths behave differently in the Earth's atmosphere.

Infrared rays

Infrared (IR) rays are another part of the electromagnetic spectrum. Infrared rays have a wavelength less than that of microwaves. The bodies of humans and other animals emit infrared rays, which cannot be seen, but can be felt as heat. Night vision goggles and infrared cameras transform longer wavelength infrared rays into visible rays to allow heat to be 'seen' and measured.

Infrared radiation has many uses. For example, it can be used in electronic remote controls, in sensors that can measure the temperature of the skin, and for thermal imaging.

Visible light

Visible light is the only part of the electromagnetic spectrum that you can see. Visible light helps you to see the world around you. It has a shorter wavelength (approximately 380–700 nanometres) and more energy than that of infrared rays. All of the colours of the rainbow are contained in visible light. From highest to lowest energy are violet, indigo, blue, green, yellow, orange and red.

Astronomers use the colour of the stars to determine the temperature of the stars. For example, a blue star is hotter than a red star. Our Sun is yellow and its surface temperature is approximately 5500°C.

Ultraviolet radiation

Ultraviolet (UV) radiation has more energy than visible light and your eyes cannot see it. It has many applications such as sterilising surgical equipment in hospitals, and UV curing adhesive is used to bond plastics and glasses. A small amount of ultraviolet radiation is useful for your body because it triggers the production of vitamin D. However, long exposure to it leads to skin cancer, sunburn and skin aging. The ozone layer in the upper atmosphere absorbs most of the UV rays emitted by the Sun.

X-rays

X-rays have shorter wavelengths than UV radiation. They are used for medical purposes. For example, doctors and dentists use them to image your bones and teeth. X-rays help them diagnose many health problems without a need for surgery. In industry, X-rays are used to find cracks in welds and joints.

Gamma rays

Gamma rays have the highest energy in the electromagnetic spectrum. Very hot stars, such as neutron stars, emit gamma rays. Gamma rays can penetrate through most types of materials, though a lead block or thick block of concrete can stop gamma rays. As gamma rays are particularly energetic, they can be used to kill bacteria or to destroy cancer cells.

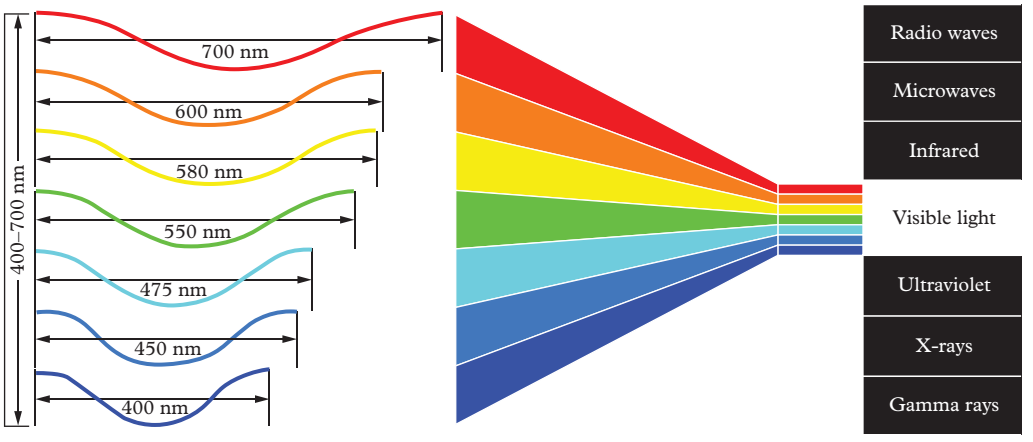


Figure 2 Different colours of visible lights have different energy. Violet with the shortest wavelength has the highest energy, and red with the longest wavelength has the lowest energy.

Check your learning 2.8

Recall and explain

1 **Classify** electromagnetic waves from highest energy to the lowest energy.
2 **Explain** how a microwave oven works.

Apply and analyse

3 **Explain** why long exposure to ultraviolet radiation is dangerous but we are not worried about our exposure to visible light.
4 **Recall** the order of the colours of visible light in order of increasing energy.

Evaluate and create

5 **Investigate** why the amount of water in food is important when cooking in a microwave, and **explain** how this relates to the electromagnetic spectrum.
6 **Investigate** more uses for electromagnetic waves.

Skill builder: Questioning and predicting

7 Making predictions helps scientists think of outcomes for their experiments.

a A scientist has suggested that people will not be able to see a wavelength of 410 nanometres. **Explain** why this scientist's prediction is wrong. (THINK: Is this wavelength in the visual spectrum?)

b A different scientist predicts that different animals may be able to see more of the visual spectrum than humans. Write a scientific question about this. (THINK: Can you test your question? Can you measure your question?)

REVIEW

Multiple choice

1 **Identify** how thermal energy is transferred from a warm object to a cooler object.
- **A** Radiation
- **B** Conduction
- **C** Convection
- **D** Heat

2 **Identify** the type of wave that sound is.
- **A** Transverse wave
- **B** Hertz wave
- **C** Concave wave
- **D** Longitudinal wave

3 **Identify** the wavelength that humans can see.
- **A** 100 nm
- **B** 650 nm
- **C** 200 nm
- **D** 300 nm

Recall and explain

4 Complete the following paragraph by inserting the missing words. The first letter of each missing word is given.

Sound is created by v_____. The v_____ create c_____ and r_____ due to the movement of the particles as the sound w_____ passes through. The w_____ travels through the substance and is known as a l_____ wave. The greater the vibration of the particles, the greater the a_____ of the sound. Sound waves must have a m_____ to pass through.

5 **Define** the frequency of a sound and **identify** its unit.

6 **Explain** why sound travels faster in solids than in air.

7 **Compare** sound waves and electromagnetic waves.

Figure 1 Infrared rays can be used in thermal imaging.

8 **Explain** how sound pitch and frequency are related. Is there a difference between the two terms?

Apply and analyse

9 **Describe**, in terms of particle motion, why neither convection nor conduction can transfer energy through empty space.

10 **Distinguish** between the primary colours of light and the primary colours of paint.

11 If radio communication between astronauts broke down on the Moon, would it help if they shouted at each other with their helmets touching? **Justify** your answer.

12 **Describe** the appearance of the Australian flag when viewed in:
- **a** blue light
- **b** red light
- **c** green light.

13 **Explain** why a fish appears to be closer than it really is when underwater.

14 **Compare** a convex lens and a convex mirror.

15 Use a labelled diagram to **explain** total internal reflection.

16 **Explain** why the word 'Ambulance' is written in reverse on ambulances.

Evaluate and create

17 Butchers sometimes use red lights to illuminate their meat in the shop window. **Explain** why they might choose this colour.

18 **Evaluate** if black is a colour. **Explain** your reasoning.

19 A grand piano can be played with the lid opened or closed. Most often, concert pianists will play with the lid open towards the audience. **Explain** why you think they would choose to do this. **Explain** what effect this may have on the sound produced by the piano.

20 Consider the data in Table 1 and answer the following questions.

Table 1 The speed of sound at different temperatures

Air temperature (°C)	Speed of sound (m/s)
0	330
10	336
20	342
30	348
40	354

- **a** Using graph paper, draw a graph of the speed of sound (vertical axis, y) at various air temperatures (horizontal axis, x). Start the scale at 320 m/s on the vertical axis.

b **Summarise** what happens to the speed of sound as the temperature increases.

c Use your graph to **deduce** the speed of sound at 5°C.

d Use your graph to **calculate** the temperature of the air if the speed of sound is 351 m/s.

21 **Investigate** the differences and similarities between audible sound, ultrasound and infrasound. Display your answer using a Venn diagram.

22 Astronauts in space can still see each other even if they cannot hear each other.

a What does this say about the mechanism that light uses to travel compared to how sound travels?

b What can you infer about the ability of light energy to travel through outer space?

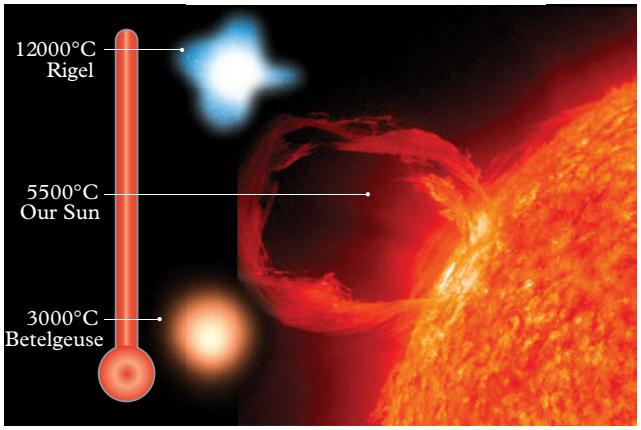


Figure 2 The temperature of stars. Blue stars, like Rigel, are hotter than red stars, like Betelgeuse. Rigel is the seventh brightest star in the sky.

Critical thinking

23 A physicist wanted to investigate whether humans could see different colours better at night, to confirm the use of blue and red lights on emergency vehicles. They predicted that people would pick up blue light better at night and red light during the day. Create a scientific question to investigate this.

Figure 3 Why are lights on ambulances blue and red?

Go further

24 You might have had orthodontic work on your teeth. As part of this, it is likely that you had X-rays taken of your mouth so that your orthodontist could track the movement of your teeth.

a There are other scanning methods used by medical professionals. **Investigate** how MRI and PET scans work, and if they are using a type of wave.

b Write a reference for each source of information you have used.

c **Evaluate** the use of each technology.

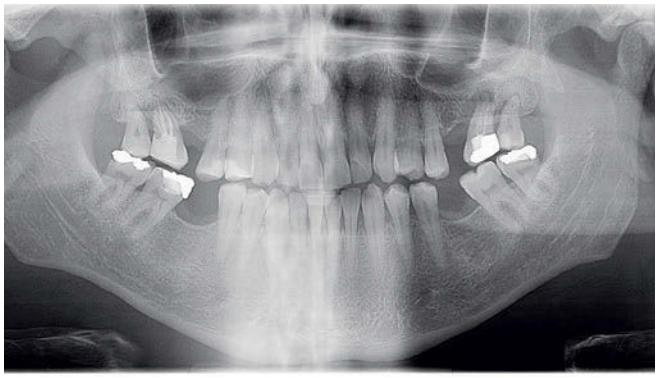


Figure 4 X-ray of a mouth showing fillings (the white marks on the teeth).

25 In space, there is no sound. **Investigate** this phenomenon, and **explain** whether you would hear a collision between two meteors.

26 Gamma rays have the highest energy in the Electromagnetic spectrum, which means they can be used to kill cancer cells. Research other medical uses of gamma rays. **Identify** the medical purpose and **explain** why gamma rays are used for this.

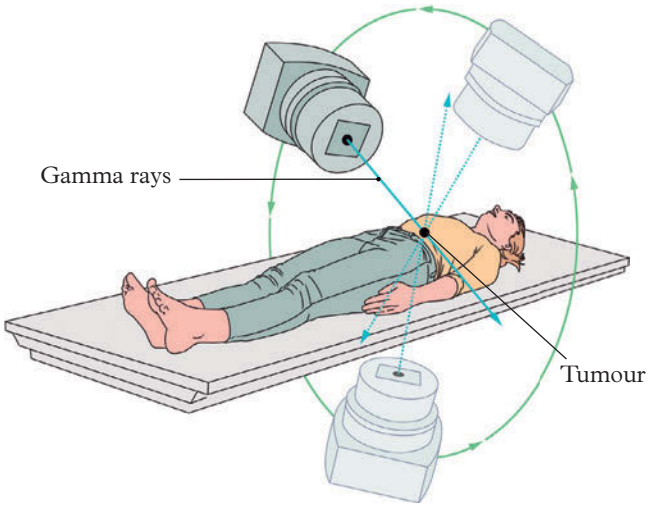


Figure 5 Gamma rays have very high energy and are used to kill cancer cells.

Research

26 Choose one of the following topics for a research project. A few guiding questions have been provided, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting. One component of your report must include a demonstration of sound (e.g. if you make an instrument, it needs to be played). In a multimedia presentation, sound must be part of the presentation. If you interview someone as part of your research, you must present a recording of your interview with your report.

»Hearing technologies

Some people find it difficult to hear; Australian scientists invented the cochlear ear to assist with this. What would it be like to wear a bionic ear? What does 'sound' sound like with a bionic ear? What sound technologies are being developed right now? What other non-hearing technologies are being developed through our knowledge of sound energy?

»Vision defects

Some people find it difficult to focus on near or distant objects. This type of defect is reasonably common. Find out what causes both types and how it can be corrected. What other vision defects are quite common and how are they treated?

»Speed of light

The speed of light is used as a measurement for time in space. What is the speed of light? Why can't objects travel faster than the speed of light? What if they could? How is it measured and how was it discovered? What applications does it have in science?

»Night vision goggles

Night vision goggles allow soldiers to see at night and spot the enemy before they are spotted themselves. They give an army a tactical advantage, but how do they work? Will they work in a totally dark environment? Do they have any disadvantages to the soldiers operating them?

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Explain, in terms of the particle model, the processes underlying convection and conduction of heat energy.	☐	☐	Go to pages 24-25
Identify situations where waves transfer energy.	☐	☐	Go to pages 26-27
Describe, using the wave model, the features of waves including wavelength, frequency and speed.	☐	☐	Go to pages 28-29
Explain, using the particle model, the transmission of sound in different mediums.	☐	☐	Go to pages 28-29
Relate the properties of different types of radiation in the electromagnetic spectrum to their uses in everyday life, including communications technology.	☐	☐	Go to pages 40-41
Describe the occurrence and some applications of absorption, reflection and refraction in everyday situations.	☐	☐	Go to pages 32-37

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OBJECTS IN MOTION

Are velocity and speed the same thing?

Have you ever wondered ...

- What is the difference between displacement and distance?
- What are Newton's laws and why is he so famous?

3

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- describe the relationship between force, mass and acceleration
- explain the relationship between distance, speed and time
- relate acceleration to a change in speed and/or direction as a result of a net force
- analyse everyday situations involving motion in terms of Newton's laws

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

3.1 Displacement is change in position with direction

In this topic, you will learn that:

- distance is how far an object has travelled in a set time
- displacement is the final distance and direction of an object from its starting point
- displacement is a vector quantity.

distance
how far an object has travelled in a set time

displacement
a vector quantity that measures the change in position of an object and its direction over a certain period of time

scalar quantity
quantity that has magnitude (size)

magnitude
the size or extent of something

vector quantity
quantity that has size and direction (e.g. velocity, displacement)

Distance describes how far an object travels in a set time. **Displacement** describes the final distance and direction of an object from its starting point. Distance is known as a **scalar quantity** because it only has **magnitude** (size) and no direction. Displacement is known as a **vector quantity** because it has both size and direction. The movement of an object can be shown on position–time graphs or distance and displacement diagrams.

Distance and displacement

During a normal day, you may cover a considerable distance – on the way to school, on the way home, or around school from classroom to classroom. However, at the end of the day, you will most likely end up in exactly the same place as where you started the day: bed! So, you could say that you haven't really gone anywhere at all.

Distance is how far an object travels over a certain period of time. Displacement describes the change in position of an object and its direction over a certain period of time. Displacement only compares the end position with the starting position, not all the in-between movements. If you end up back in bed after a whole day of moving, then your displacement is zero. We use the symbol d for distance and the symbol s for displacement, and the standard unit (or SI unit) is the metre (m). Distance is known as a scalar quantity because it only has size (or magnitude) and no direction. Displacement is known as a vector quantity because it has size and direction. The direction part can be a compass direction (north, south, east, west) or a bearing, or it may be as simple as left, right, up, down, forwards or backwards.

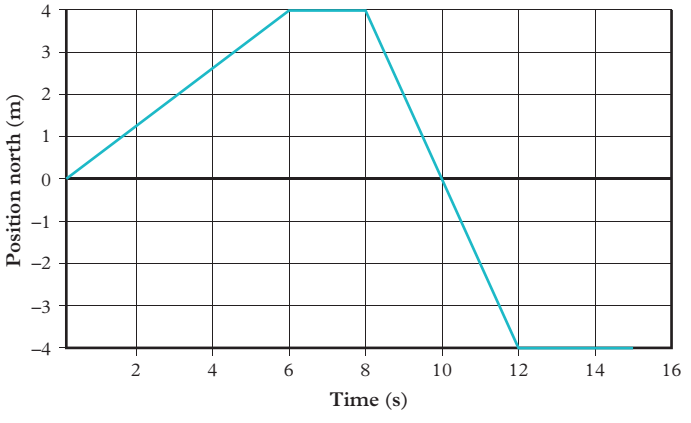

Figure 1 This position–time graph shows the position of a person walking north from the starting point for 6 seconds, stopping for 2 seconds and then walking south for 4 seconds. Their final position was 4 metres south of the starting point.

Position–time graphs

Have you ever seen a movie or read a book where a cryptic code is used to find the buried treasure or precious artefact? These codes often contain instructions such as 'walk 15 paces south and then 20 paces west', which could lead to a very different outcome depending on how big (or small) your steps are.

Motion graphs are a model or visual representation of a movement and can take many forms. The simplest is a position–time graph (also called a displacement–time graph). A position–time graph is a picture of the motion of an object. Position–time graphs are really only useful when the motion is linear; that is, in the same line, such as north–south or east–west or up–down. Time is always on the x-axis and position is always on the y-axis (see Figure 1 for an example). Always remember to mark the units (e.g. seconds, metres) on the graph.

Distance and displacement diagrams

The distance an object travels can also be represented by diagrams. Distance and displacement diagrams (as opposed to graphs) are most useful when the movement changes from linear to two dimensions. We can use arrows to show the directions and a scale to show the distances. North commonly points towards the top of the page. For example, Figure 2 shows a diagram of a person walking 5 metres north, then 4 metres west and then 2 metres south. This gives a total distance covered of 11 metres. However, this is not their displacement. Their displacement only compares where they finish to where they started.

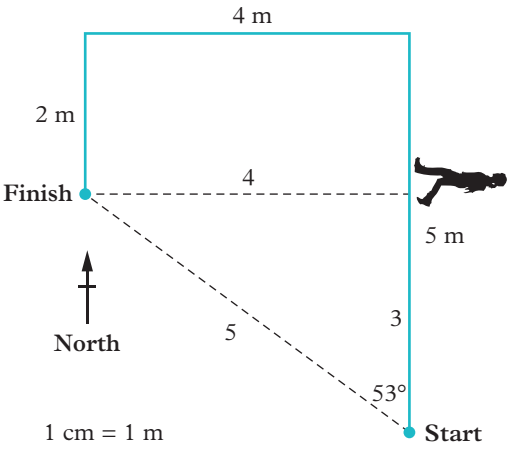

Figure 2 This person walks a total of 11 metres. The displacement can be calculated by drawing a right-angled triangle and using Pythagoras' theorem. The final position of the person is 5 m north 53° west or 5 m on a bearing of 307°.

Resource
STEM activity: Roller coaster

Check your learning 3.1

Recall and explain

1 **Describe** a motion that has zero displacement.

2 **Compare** distance and displacement.

3 An object has moved 14 metres north and then 14 metres south. **Calculate** the distance it has covered and its displacement.

Apply and analyse

4 **Distinguish** between a vector quantity and a scalar quantity.

5 A person runs 50 metres north, then 20 metres south and then 30 metres west. **Calculate** the total distance covered and the person's displacement.

6 A car travels north for 100 metres in 10 seconds, then stops for 10 seconds before moving north another 150 metres in 15 seconds. On a piece of paper, draw this movement as a position–time graph.

Evaluate and create

7 The position of a person at different times is shown in Table 1.

Table 1 The position of a person at different times

Time (s)	Distance (m)
0	0
2	4
4	8
6	12
7	14

a **Construct** a distance–time graph.

b Use your graph to **predict** how far the person will travel after 8 seconds.

c **Calculate** the gradient of the graph.

Skill builder: Processing and analysing data and information

8 Graphs can be used to represent data. Consider the position–time graph shown in Figure 3.

a **Describe** the motion shown.
(THINK: Where is the movement?)

b **Calculate** the distance covered in the graph.
(THINK: What is the distance? Which part of the graph do I need to include?)

c What is the displacement shown?
(THINK: What do I need to calculate? Is there a formula I can use?)

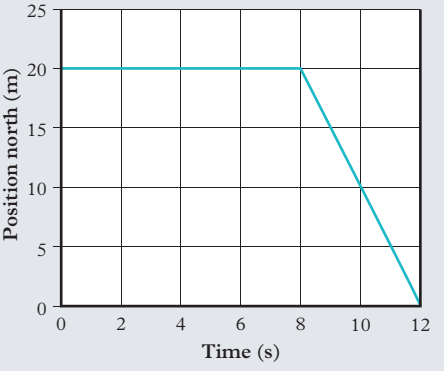

Figure 3 A position–time graph

3.2 Velocity is speed with direction

In this topic, you will learn that:

- speed is a scalar quantity that measures how fast an object is travelling
- average speed is the total distance travelled divided by the total time taken
- instantaneous speed is the speed an object is travelling at a specific point in time
- velocity is a vector quantity and is the speed in a particular direction
- average velocity is the displacement divided by the total time taken.

speed
the distance travelled per unit of time

velocity
the vector quantity that measures speed in a particular direction

The media often reports the speed or velocity of a car. However, speed is a scalar quantity that measures distance travelled in a set time. Velocity is a vector quantity, which measures the change in position over time. They aren't the same thing.

Speed

Speed is a measure of how fast a car or a person or any moving object is travelling. It is measured in SI units of metres per second (m/s or m s^{-1}) – although, kilometres per hour (km/h or km h^{-1}) is often used instead, especially for cars and planes. Speed is defined as the distance travelled per unit of time. Hence, a speed of 5 m/s means the object travels 5 metres in every second of its motion. Speed is a scalar quantity because it only has size and no direction.

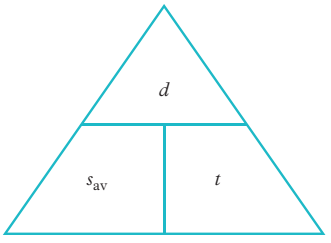

Figure 1 The average speed triangle is used to work out the formula for average speed. Cover the quantity you want to calculate with your finger and the other two quantities will form the formula.

Average speed

Often it is more convenient to work out (or calculate) an object's average speed. To calculate average speed (s_{av}), divide the total distance travelled (d) by the total time taken (t). The units for speed depend on the units of distance and time. The formula for calculating the average speed is:

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

This rule (or formula) can also be expressed in a triangle as shown in Figure 1. The triangle is a good memory tool to help you work out three formulas from the one diagram.

Average speed can also be determined by the gradient (or slope) of a position–time graph.

$$\text{Gradient} = \frac{\text{change in position}}{\text{change in time}}$$
$$= \frac{\text{rise}}{\text{run}}$$
$$= \frac{4\text{ m}}{6\text{ s}}$$
$$= 0.67\text{ m/s}$$

Instantaneous speed

Over the course of a bus or car trip, your speed changes. The speedometer in the vehicle gives the instantaneous speed in km/h. This is the speed at each moment of the trip.

Velocity

Pilots and sailors need to know both the speed of the wind and its direction. **Velocity** is speed in a particular direction and is therefore a vector quantity (a measurement of both size and direction). It has the same unit (m/s) as speed. The average velocity (v_{av}) of an object is calculated in a similar way to average speed, but displacement (s) is used instead of distance (see Figure 2). The direction of the average velocity is the same as the direction of the displacement. The formula for calculating the average velocity is:

$$\text{Average velocity} = \frac{\text{displacement}}{\text{time}}$$

where v is the v_{av} is the average velocity, s is the displacement, and t is the time. This rule (or formula) can also be expressed in a triangle as shown in Figure 2.

Like speed, average velocity can be determined from the gradient of a position–time graph, but the nature of the gradient indicates the direction.

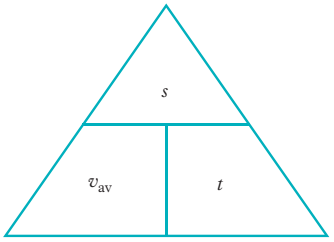

Figure 2 The average velocity triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

INVESTIGATION **3.2:** The ticker timer
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SKILLS LAB **3.2:** Using a motion sensor
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For example, if the gradient is positive (sloping upwards) in the north direction, then the velocity will be positive in the north direction (see Figure 3).

If the gradient is negative (sloping downwards), then the velocity will be negative in the south direction.

Figure 3 shows position–time graph for object A. It shows that object A covers a distance of 4 metres. The final displacement of object A is 4 metres north. The slope of the graph between 0 and 6 seconds is positive, so the velocity is at the positive direction (north). Between 6 and 8 seconds the slope of the graph is zero, which means the velocity is zero.

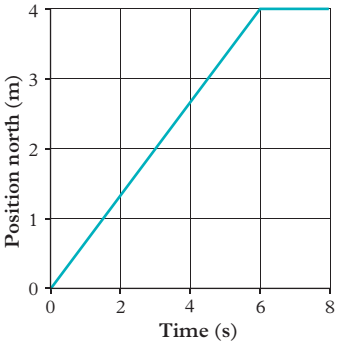

Figure 3 A position–time graph for object A.

Graphing speed

It is useful to represent an object's speed graphically. This is called a speed–time graph. In these graphs, speed is plotted on the *y*-axis and time on the *x*-axis. The area under the graph determines the distance travelled in that time.

Unit conversion

The basic unit of speed is metres per second (m/s); however, kilometres per hour (km/h) is also commonly used. Most vehicle speedometers use km/h. To convert m/s to km/h, multiply by 3.6. To convert km/h to m/s, divide by 3.6.

The 3.6 arises because there are 60 seconds in a minute and 60 minutes in an hour, giving $60 \times 60 = 3600$ seconds in an hour. Also, there are 1000 metres in a kilometre, so $3600 \div 1000 = 3.6$.

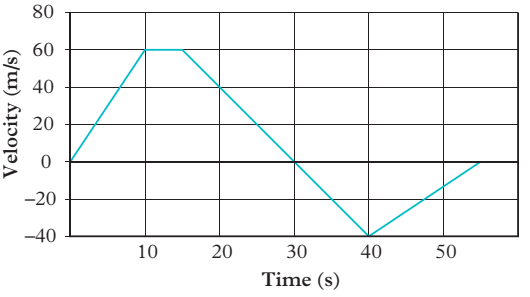

Figure 4 This velocity–time graph shows an object with changing velocity. The object increases its velocity from 0 m/s to 60 m/s in the first 10 seconds. It then travels at a constant 60 m/s for 5 seconds before slowing down. At 30 seconds, it has stopped, and then it starts travelling in the opposite (negative) direction before eventually slowing to a stop. The area under the graph describes the displacement as 1050 metres in the positive direction and 500 metres in the negative direction. The total displacement will be 550 metres in the positive direction.

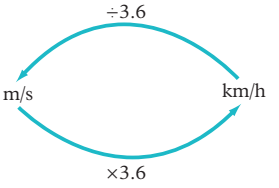

Figure 5 To convert from one unit to the other, follow the arrows.

Check your learning 3.2

Recall and explain

1 Is 4 m/s a speed or a velocity? **Explain** your answer.

2 Use the average velocity triangle to write three different formulas.

Apply and analyse

3 Convert 80 km/h to m/s.

4 An object travels 40 km in 5 hours. **Calculate** its average speed.

Evaluate and create

5 Create a story that describes the motion of a person moving according to the graph in Figure 6. **Calculate** their displacement from the point of origin.

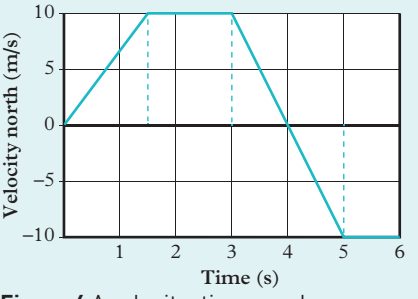

Figure 6 A velocity–time graph

Skill builder: Conducting investigations

6 Scientists make predictions based on information and data. Using the right unit to record measurements is important to producing accurate data.

a **Identify** units that are used to measure speed.
(THINK: Do different speeds have different measurements? Does the distance affect the unit used?)

b **Explain** why using the correct unit of measurement is important in an investigation.
(THINK: How accurately can you record results? What if the unit is too big to be specific?)

3.3 Acceleration is change in velocity over time

In this topic, you will learn that:

- acceleration is the rate the velocity of an object changes
- acceleration can be due to change in speed or change of direction
- deceleration is slowing down.

acceleration
rate of change of velocity; rate of change of speed if the motion is in a constant direction

deceleration
slowing down; also known as negative acceleration

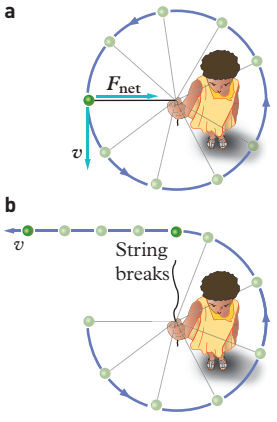

Figure 1 a The green ball is accelerating due to the changing direction of its velocity (v). **b** When the force applied by the string (F_{net}) is removed, the ball travels away in a straight line. Newton's first law says its velocity will now remain constant unless another force acts on it.

Acceleration is measured in m/s^2. **Deceleration** is the rate the speed slows down. An object travelling at a constant, unchanging speed and in the same direction has an acceleration of zero. Gravitational acceleration is the increase in the speed of an object as it falls under the sole influence of gravity. This is calculated as 9.8 m/s^2 down. Acceleration is a vector quantity, which means it has size and direction.

Acceleration

Velocity is a vector quantity – it changes due to change in its size or direction. Pressing the accelerator pedal in a car makes the car move forwards and increase in speed. This is the same as saying the car accelerates.

A car that travels at a constant speed but changes its direction accelerates. Its acceleration is due to the change in direction. Acceleration is the rate of change of velocity. The term 'rate' in this case refers to time, so acceleration is the change of velocity over time. Just as the accelerator pedal causes a car to speed up, the brake pedal causes a car to slow down. This is called deceleration (or negative acceleration).

Acceleration is measured in units of metres per second per second (m/s/s) or metres per second squared (m/s^2 or m s^{-2}) because velocity is usually measured in metres per second and time is usually measured in seconds. Acceleration is the rate of change in velocity (in metres per second) every second, therefore the change in metres per second per second.

We will only discuss objects travelling in one direction in a straight line and under constant acceleration. Consider a falling object, such as the rock shown in Figure 2.

When held out to one side and dropped vertically (not thrown), the rock starts at rest and increases in speed as it falls. If it were dropped from high enough, the rock may accelerate to quite a high speed.

After 1 second, it should reach a speed of almost 10 m/s due to gravity (actually, it is 9.8 m/s, which is very close to 10). We say it has accelerated at a rate of 10 metres per second in 1 second or at 10 metres per second per second (written as 10 m/s/s or 10 m/s^2 or 10 m s^{-2}).

After another second at the same rate, the rock would reach a speed of almost 20 m/s.

After 3 seconds, it would reach a speed of almost 30 m/s. Of course, this analysis ignores the effects of air resistance, which would prevent the rock from reaching a speed of 30 m/s after 3 seconds.

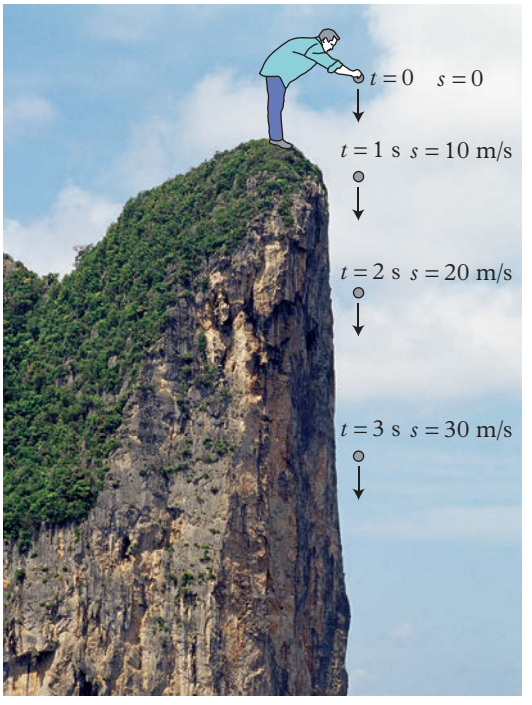

Figure 2 Each second, the speed of the falling rock increases by almost 10 m/s, ignoring air resistance. This means the acceleration is 10 m/s^2 down.

The acceleration value of 10 m/s² is called **acceleration due to gravity** and is given the special symbol of *g*.

Calculating acceleration

The formula for calculating acceleration is:

$$a = \frac{\Delta v}{\Delta t}$$

where *a* is acceleration and Δ is the Greek letter 'delta' and means 'change in' so Δv is change in velocity and Δt is change in time. This can also be seen in the acceleration triangle (Figure 3).

This can also be written as:

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

where *v* is the final speed and *u* is the initial (or starting) speed.

Acceleration is indicated by the gradient of a velocity–time graph. The size of the gradient indicates the size of the acceleration (Figure 4).

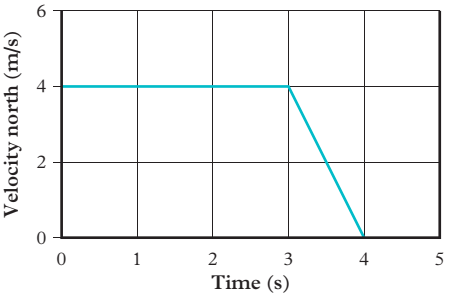

Figure 5 The object in this graph is travelling at a constant velocity of 4 m/s north for the first 3 seconds. Its gradient (and hence its acceleration) is zero. The object then slows down to 0 m/s in the last 1 second. Its acceleration according to the acceleration triangle is –4 m/s². The negative number indicates the object has decelerated.

acceleration due to gravity
the acceleration of an object due to a planet's gravitational field; on Earth, g = 9.8 or 10 m/s²

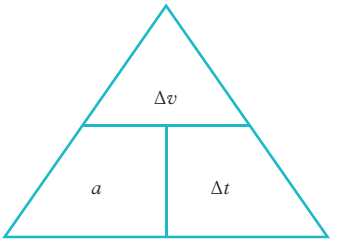

Figure 3 The acceleration triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

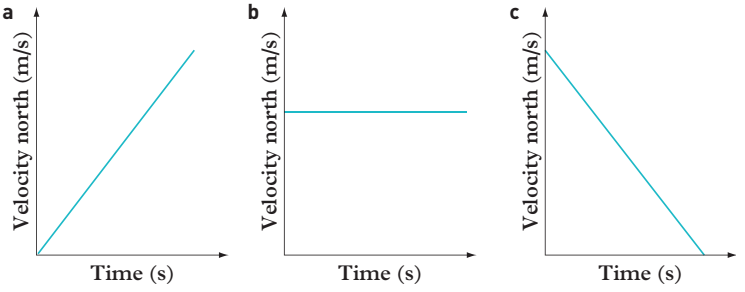

Figure 4 Velocity–time graphs showing **a** constant positive acceleration (i.e. speeding up), **b** zero acceleration and **c** negative acceleration (i.e. slowing down or decelerating).

Figure 6 Timing how long an object takes to fall also provides a practical way to measure distance. You can calculate the depth of a well by dropping a rock into the well and measuring the time required for it to reach the bottom. The depth (*d*) can be calculated using the formula $d = \frac{1}{2} g t^2$.

Check your learning 3.3

Recall and explain

1 Use the acceleration triangle to write three different formulas.

2 **Explain** what is meant by the term 'deceleration'.

3 **Explain** what the acceleration of an object is if its velocity is constant.

Apply and analyse

4 An object starts from rest and accelerates at a rate of 4 m/s². **Calculate** its speed after each second for 5 seconds.

Evaluate and create

5 Consider the data in Table 1 and answer the following questions.

a **Construct** the velocity–time graph of this object.

b **Calculate** the acceleration of the object by using the gradient of the graph.

Table 1 The velocity of an object at different times

Time (s)	Velocity (m/s) north
0	0
2	10
4	20
6	30
8	40
10	50

Skill builder: Questioning and predicting

6 Scientists make predictions about acceleration, to determine how quickly something may happen or the forces needed.

a Observe what happens when cars travelling at constant speed suddenly have to travel up a hill. Note these observations. (THINK: Was there a change at the hill?)

b **Predict** what will happen to the rate of acceleration if a car travelling at a constant speed of 5 m/s on flat ground has to climb a hill. (THINK: Would the hill impact speed? Why?)

3.4 Newton's first law

In this topic, you will learn that:

- Newton's first law states that an object at rest or at constant velocity will stay as such unless an unbalanced force acts on it.

Newton's first law
Newton's first law of motion states that an object will remain at rest and will not change its speed or direction, unless it is acted upon by an outside, unbalanced force; also known as the law of inertia

inertia
the tendency of an object to resist changes in its motion while either at rest or in constant motion

force
a push or pull that acts on an object as a result of interacting with another object; a vector quantity

Newton's first law (of **inertia**) states: 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.' The greater the mass of an object, the larger the inertia. This means an object will remain at rest until an outside force acts on it. An object that is moving at a constant velocity will not change its speed or direction unless an outside force acts on it.

In relation to motion, a force is something that can change an object's motion. A force is not necessarily needed to keep an object moving, but most objects slow down because of the force of friction. A **force** is a push or a pull acting upon an object as a result of its interaction with another object. Force is a vector quantity and has the symbol F and is measured in newtons (N).

Newton's first law

English scientist Isaac Newton (1642–1727) formulated three laws of motion. In his book the *Philosophiae Naturalis Principia Mathematica*, Newton outlined his laws of motion and his law of universal gravitation. Newton's formulation of his second law of motion and his law of universal gravitation led to nearly all the important advances in physics in the areas of magnetic, electrical and atomic forces for the next 200 years.

Figure 1 Newton is famous for the story of the apple falling from a tree as he sat in his family orchard. Although the story is fictional, Newton himself is responsible for its creation.

The law of inertia

Newton's first law, also known as the law of inertia, has two applications. A stationary object, such as someone sitting on a chair (Figure 2), has the force of gravity (their weight force) acting on it to pull them down. It doesn't move because there is another force, equal in magnitude (strength) to the weight force but acting in the opposite direction, pushing up on the object from the surface. Because these two forces are equal in magnitude and opposite in direction, and because they both act on the same object, we say that the object has zero **net force** (or zero resultant force) acting on it. The two forces are balanced. The movement (or lack of movement) of an object will only change if another force is added (such as someone pushing the object). This will cause the forces to become unbalanced.

> Newton's first law states: 'An object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force.'

How Newton's first law applies if the object is already moving

Think of any motion you have experienced today, maybe in a car, bus, train or tram, or even on a bike. In constant motion, you sometimes hardly notice you are moving, but if you stop or start suddenly or turn a sharp corner, your body may move unexpectedly.

If you are a passenger in a car and not wearing a seatbelt and the car comes to a very sudden stop, your body will continue moving forwards. This is due to inertia. Inertia is the property of matter that keeps it in its existing state of motion (Figure 4).

Figure 2 Zero net force. This person will not move until a new force acts on them.

CHALLENGE **3.4a:** Making an accelerometer
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CHALLENGE **3.4b:** Half-full water bottles
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Figure 3 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.

The friction of the brakes apply a stopping (decelerating) force to the car, but they do not apply a force to you. Your seatbelt is the only thing stopping you moving at 60–100 km/h. If you are not wearing your seatbelt, Newton's first law says that you will keep moving at the same speed, through the windscreen and onto the road. The same thing also happens in a bus, train or tram, especially if you are standing up and not holding on to something. The larger the mass of the object, the more inertia it has and the harder it will be to change its motion.

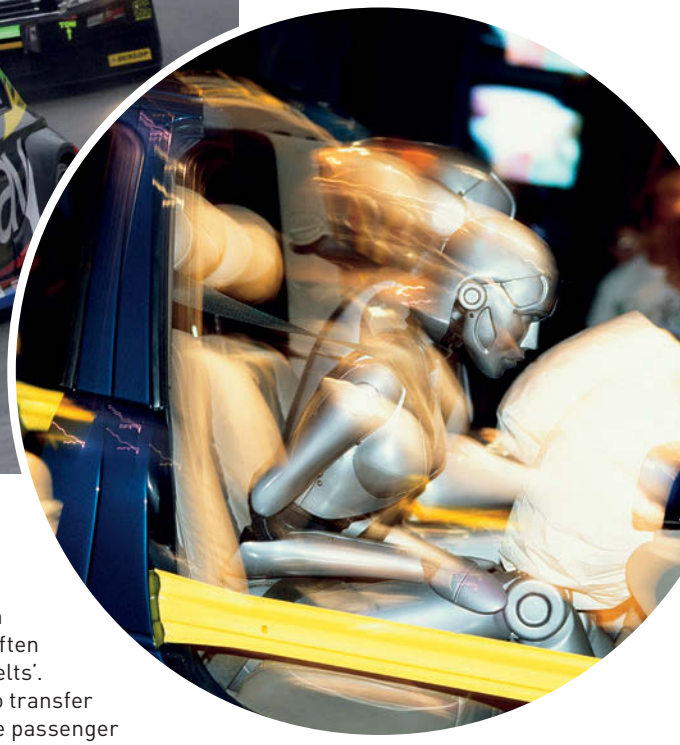

Figure 4 Seatbelts are an inertia device. They are often called 'inertia reel seatbelts'. The aim of a seatbelt is to transfer the force on the car to the passenger wearing the seatbelt so that the person moves with the car. You start moving when the car starts moving and, when wearing your seatbelt, you stop moving when the car stops moving.

net force
the vector sum of all the forces acting on an object; also known as resultant force

Check your learning 3.4

Recall and explain

1 **Explain** what is meant by the term 'net force'.
2 **Describe** what happens to a stationary object with zero net force acting on it.
3 **Summarise** what happens to a moving object with zero net force acting on it.
4 **Explain** what inertia is, and provide an example.

Apply and analyse

5 Provide an example of how inertia affects your motion inside a car, bus, tram or train.
6 **Explain** why people lurch backwards in a tram when it starts moving suddenly.

Evaluate and create

7 Create a brochure to **explain** how a seatbelt protects people in car accidents. You may also want to include information on how other features such as crumple zones and airbags assist with inertia.

Skill builder: Communicating

8 Scientists explain information to a range of people. Imagine that you are explaining Newton's first law to a group of year 7 science students.

a **Identify** the key information that students would need to understand.
(THINK: Can you define Newton's first law? Can you explain its implications?)

b **Construct** a brief discussion of Newton's first law that is appropriate for year 7 students.
(THINK: Is the language level appropriate? Have I used simple scientific language? Is all the information required?)

3.5 Newton's second law

*

In this topic, you will learn that:

- if an object has a net force acting on it, then the object will change its speed, direction or both
- Newton's second law states that 'the acceleration of an object is directly related to the magnitude and direction of the net force acting on the object, and inversely related to the mass of the object.'

Newton's second law
Newton's second law of motion describes how the mass of an object affects the way it moves when acted upon by one or more forces. It is often expressed as $F = ma$ (F = total force on the object; m = mass of the object; a = acceleration)

Figure 1 a Pedalling provides the thrust force when riding a bike. **b** Braking provides a drag force.

Newton's second law

Newton's second law states: 'The acceleration of an object is directly related to the magnitude and direction of the net force acting on the object, and inversely related to the mass of the object: $F = ma$.' This means a heavy object (with a lot of mass) needs a greater force to start moving than a lighter object. Weight is a measure of the gravitational force acting on an object. It is measured in newtons (N).

> Newton's second law states: 'The acceleration of an object is directly related to the magnitude and direction of the force acting on the object, and inversely related to the mass of the object.'

Force affects acceleration

If an object experiences an unbalanced net force, the object will change its speed, direction or both. A moving object will speed up (accelerate) if the net force acts on it in the same direction it is moving in. A bike will speed up if you pedal harder to increase the driving force (known as thrust; see Figure 1a).

When the net force acts in the opposite direction, the moving object will slow down (decelerate) and eventually stop. The brake adds a friction force to a moving bike. This means there is a net force in the opposite direction to the bike's movement. This net force causes the bike to change its speed. It decelerates or slows down (Figure 1b).

Force and mass

Would you need more push force to start moving a car or to start moving a bike? A car has a greater mass than a bike; therefore, it needs a greater force to change its motion. A bike, with less mass, needs less force to change its speed.

We can express this relationship in a simple equation:

$$\text{Net force} = \text{mass} \times \text{acceleration}$$

$$F_{net} = m \times a$$

This relationship can also be expressed in a force triangle (Figure 2). You need a larger force to accelerate a heavy object from rest than to accelerate a lighter object from rest.

When mass is in kilograms (kg) and the acceleration is in metres per second squared (m/s^2), the net force will be in newtons (N). Acceleration and net force are both vectors and always act in the same direction.

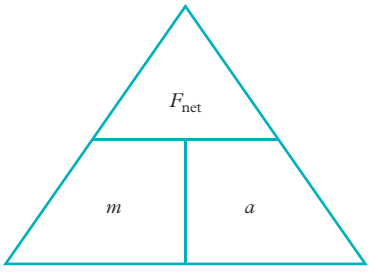

Figure 2 The net force equation can be written as a triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

You need to consider all the individual forces acting on an object in order to work out the net force. Consider the cyclist and bike with a mass of 90 kg shown in Figure 3. The forwards acting thrust force is 400 N and the total drag force from air resistance and friction is 300 N

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INVESTIGATION 3.5b: Accelerating masses
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backwards. As a result, the net force is 100 N forwards. This would produce an acceleration of 1.11 m/s² (100 N ÷ 90 kg). The cyclist would increase his speed by 1.11 m/s every second.

Mass or weight

Newton's second law also connects an object's mass to its weight. We often use the term 'weight' to indicate how much mass something has in kilograms but, strictly speaking in physics, weight is a force not a mass. Weight acting on an object's mass is the force of gravity acting on an object. Because it is a force, weight is measured in newtons. For example, gravity on the Moon is approximately 1.6 m/s² and on the Earth is approximately 10 m/s². This means an object with a mass of 100 kg would have a weight of 160 N (100 kg × 1.6 m/s²) on the Moon and 1000 N (100 kg × 10 m/s²) on the Earth. An object on the Moon will have less weight (N) but the same mass (kg).

Weight = mass × gravitational acceleration

$W = m \times g$

Figure 3 Various forces act on a cyclist.

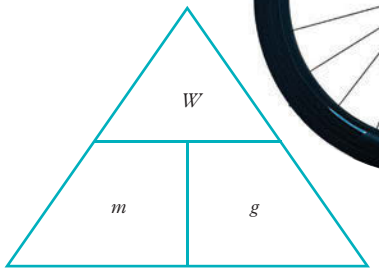

Figure 4 Weight is the force of gravity acting on an object's mass. Weight (force) = mass × acceleration due to gravity.

Check your learning 3.5

Recall and explain

1 **Explain** what is meant by the term 'weight force'.

2 **Explain** what happens to a moving object if it is acted on by a net force in the same direction as its motion.

3 **Describe** what happens to a moving object if it is acted on by a net force in the opposite direction to its motion.

Apply and analyse

4 **Compare** the acceleration of a bus full of passengers with that of an empty bus for the same net force.

5 **Explain** why a bike slows down on a level road when the rider stops pedalling.

6 A net force causes a mass of 10 kg to accelerate at 2 m/s². **Calculate** the magnitude of the net force.

Evaluate and create

7 A group of students want to investigate how a change of mass will affect the acceleration of an object.

- **a** Write a hypothesis for this investigation.
- **b** **Outline** the independent, dependent and controlled variables.
- **c** Write a step-by-step method to test the hypothesis.
- **d** If the results of the investigation are as shown in Table 1, **construct** a force–mass graph for these results.
- **e** **Calculate** the gradient of the graph.

Table 1 Results from the investigation

Mass (g)	Force (N)
50	1
100	2
150	3
200	4
250	5
300	6

Skill builder: Problem solving

8 A car company has been having problems with a claim one of their drivers made. The driver claimed that the car driving down a hill was speeding up too much. Use a cause and effect diagram to help **explain** the relationships between force and acceleration. (THINK: What is the problem? What are the main causes of this problem? Are there any specific sub-causes?)

3.6 Newton's third law

In this topic, you will learn that:

- Newton's third law states that 'for every action force, there is an equal and opposite reaction force.'

Newton's third law
Newton's third law states that for every action force, there is an equal and opposite reaction force

Newton's third law states: 'For every action force, there is an equal and opposite reaction force on the other object.' Action–reaction *force* pairs always act on different objects and cancel each other out. However, the effect on the motion of the two objects involved may be different depending on their mass (Newton's second law).

Newton's third law

If you blow up a balloon and let it go, it flies around the room like a crazy rocket. As the air is forced backwards out of the opening, the balloon is propelled forwards by the reaction force. These two forces are equal in magnitude and opposite in direction. They form an action–reaction pair and obey Newton's third law. The action force in this example is the rubber of the balloon contracting and pushing the air backwards. The reaction force is the force of the air rushing out, pushing forwards on the balloon.

Newton's third law states: 'For every action force, there is an equal and opposite reaction force on the other object.'

Action and reaction pairs always act on different objects. When you lean against a wall, you exert a force on the wall. The wall exerts a force on you – you can feel it pushing against your hands. Because these two forces act on different objects (you and the wall), they cannot be described as being balanced or cancelling each other out. A net force is balanced or zero when all the forces acting on a single object are equal and opposite. Action–reaction pairs act on different objects, so the effect they have on the net force of each object may be different.

When an insect hits a car windscreen, the action on the windscreen is equal and opposite to the reaction on the insect. The insect is much smaller, so its mass is less able to withstand the deceleration.

The motion of a girl on roller blades pushing off from another girl (Figure 2) works in a similar manner. The two girls experience an identical but opposite force. Newton's second law tells us that smaller masses have higher accelerations for the same force. So, if the two girls have different masses, the lighter girl will have a higher acceleration and will reach a higher speed while the force is acting.

Rockets, missiles and jet engines work on the action–reaction principle. For many years, it was thought that rocket ships would not be able to accelerate in space because there was very little air for the rocket to push against. However, rocket fuel undergoes a combustion reaction, producing exhaust gases. These gases are forced out of the back of the rocket, producing an opposite and equal reaction on the rocket. This moves the rocket forwards.

Figure 1 The rocket pushes exhaust gases back. As a result, the rocket is propelled forwards.

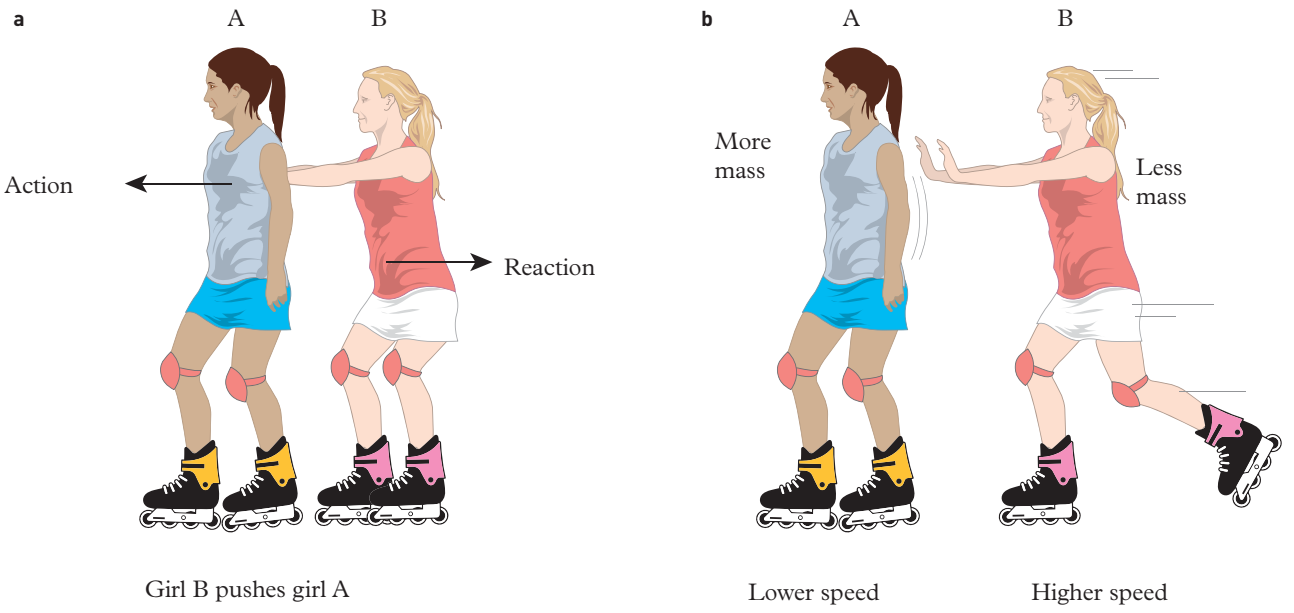

Figure 2 a Girl B pushes girl A forwards (action), and girl A pushes girl B backwards (reaction). Girl A moves forwards and girl B moves backwards. **b** Different masses have different accelerations and reach different speeds even though the forces shown by the arrows are equal in size.

Check your learning 3.6

Recall and explain

1 **Summarise** Newton's third law.

Apply and analyse

2 A person pushes forwards on an object with a force of 30 N. **Identify** the reaction force that acts on the person.

3 A boy of weight 500 N sits on a chair. **Identify** the reaction force that acts on the boy.

4 In space, an astronaut pushes on another astronaut with a force of 80 N. **Identify** the reaction force in this situation, and **explain** why the second astronaut might have a higher acceleration than the first astronaut.

5 **Identify** the action–reaction pair when a sprinter uses a set of starting blocks for the start of a sprint race.

6 **Identify** the action–reaction pair when a softball player hits a home run.

Evaluate and create

7 Draw a diagram to show action–reaction forces when you hold a bag.

Skill builder: Questioning and predicting

8 A student hypothesised that when two basketballs hit each other, the basketball thrown with more force would be more likely to rebound further.

a **Predict** whether this outcome is likely.
(THINK: Does this hypothesis apply Newton's laws correctly?)

b **Identify** which variable is being measured and which variable is being manipulated.
(THINK: Which variable depends on the action of the other?)

REVIEW

Multiple choice

1 The following sentence is most applicable to which of Newton's laws?

An object's acceleration directly relates to the magnitude and direction of the force acting on the object.

A First law
B Second law
C Third law
D Law of inertia

2 Charlie walked 1 km to the supermarket from her house, then 3 km to the florist and then 3 km back home again. Charlie's total displacement is:

A 7 km
B 0 km
C 21 km
D 14 km

3 Average speed is calculated by using which of the following formula?

A $\text{Average speed} = \dfrac{\text{total time taken}}{\text{total distance travelled}}$

B $\text{Average speed} = \dfrac{\text{total displacement}}{\text{total time taken}}$

C $\text{Average speed} = \dfrac{\text{total acceleration}}{\text{total displacement}}$

D $\text{Average speed} = \dfrac{\text{total distance travelled}}{\text{total time taken}}$

Recall and explain

4 **Identify** the correct definition for each of the terms in Table 1.

Table 1 Scientific terms

Term	Definition
Vector	Speed of an object at a moment in time
Average velocity	Rate at which an object's velocity changes
Average speed	Slope of a graph
Acceleration	Graph where speed is plotted against time
Distance	Quantity that has magnitude and direction
Instantaneous speed	Calculated by dividing distance by time
Gradient	How far an object has travelled
Speed–time graph	Calculated by dividing displacement by time

5 **Explain** what happens to an object's speed if it travels with zero acceleration.

6 **Explain** what happens to an object's speed if it travels with constant deceleration.

7 **Classify** each of the following statements as true or false.

a A force will only change an object's speed.
b A force is always needed to keep an object in motion.
c The quantity of weight is measured in kilograms.
d A force has magnitude and direction, making it a vector.
e Acceleration increases if the net force increases and the mass is kept constant.
f A stationary object can have several forces acting on it.
g Mass is a measure of how much space an object occupies.

8 **Assess** if the below quantities are vector or scalar.

a Force
b Speed
c Distance
d Displacement
e Velocity
f Acceleration

9 **Distinguish** between distance and displacement, and provide an example.

10 **Recall** what the gradient of a position–time graph indicates.

11 **Recall** what the area under a velocity–time graph indicates.

Apply and analyse

12 A car is driven along a straight road. Starting from rest, it takes 10 seconds of steady acceleration for the car to reach a speed of 20 m/s. The car then cruises for 60 seconds at 20 m/s, before slowing down to a halt over a period of 30 seconds.

a **Calculate** the maximum speed of the car in km/h.
b **Construct** a speed–time graph for the car using SI units.
c Use the graph to **calculate** the distance moved in metres and then in kilometres.

13 Nishara caught the train 10 km north to work in the city. After work, Nishara went to dinner at her parents' house – this was a 5 km walk east. She then decided to stay the night at her parents' house as it was getting late. **Calculate** Nishara's displacement for the day.

14 An object travels 100 m in 10 seconds, and it rests for the next 10 seconds. It then travels 200 m, which takes 15 seconds.
   a **Calculate** the average speed of the object.
   b **Construct** a distance–time graph for the object.
   c **Calculate** the average speed in the first 10 seconds using the graph.

15 A car travels 160 km, from Sydney to Newcastle, in 3 hours. It stops there for 5 hours and then returns to Sydney, which takes 2.5 hours.
   a **Calculate** the total distance travelled by the car.
   b **Calculate** its average speed in this journey.
   c **Calculate** its total displacement in this journey.
   d **Calculate** the velocity of the car in this journey.

16 A car travels at constant velocity of 20 m/s west. The driver suddenly sees a kangaroo on the road and immediately brakes. It takes the car 3 seconds to come to a complete stop. **Calculate** the acceleration (or deceleration) of the car.

17 For a car accelerating at 5 m/s^2, **construct** the:
   a acceleration–time graph
   b velocity–time graph
   c displacement–time graph.

18 Figure 1 shows two horizontal forces acting on an object. The object has a mass of 2 kg. **Calculate** its acceleration.

Figure 1 Two horizontal forces acting on an object

19 An object travels 80 m north and then 20 m south in 10 seconds. **Calculate** its average velocity.

20 **Explain** what accelerating and decelerating objects have in common.

Evaluate and create

21 On a wet Monday morning, a school bus that has to travel 24 km leaves its starting place at 7.35 am and only manages an average speed of 36 km/h on its trip to school. There is a clear section on the highway when the bus has a speed of 74 km/h. The bus then does various runs during the day and arrives back at the school in time to depart at 3.45 pm. It arrived back exactly at its starting place at 4.25 pm.
   a **Calculate** the displacement of the bus between 7.35 am and 4.25 pm
   b **Deduce** what time the bus will arrive at school in the morning.
   c **Calculate** the average velocity of the bus between 7.35 am and 4.25 pm.
   d The bus's average speed on the way to school is 36 km/h, but on one stretch the bus moves at 74 km/h. Use this data to **explain** the difference between 'average speed' and 'instantaneous speed'.

22 Rene catches a softball.
   a **Identify** the action.
   b **Describe** what the action does.
   c **Identify** the reaction.
   d **Describe** what the reaction does.

23 **Deduce** what mass object would accelerate at 3.5 m/s^2 under the influence of a net force of 70 N.

24 **Calculate** the acceleration of a 500 g object under the influence of a net force of 500 N.

25 Some objects or devices require high accelerations that are many times greater than 9.8 m/s^2 (the acceleration due to gravity). Think of an object or device in this category. Does it have an engine or some other propulsion mechanism? What fuel does it use? How does this enable it to achieve such a high acceleration?

26 Design a poster on motion that explains each of Newton's three laws. Include a detailed example (which is not already mentioned in the text) to **explain** each law.

Critical thinking

27 **Discuss** why physicists measure displacement and distance. Make sure you include the following in your discussion:
   - an introductory sentence
   - two key points
   - a concluding sentence.

28 Based on your understanding of Newton's laws, **evaluate** the following statement.
'Any car that encounters a force will stop, regardless of how strong the force is.'

Go further

29 When you go bowling, the force of your bowl is used to control the direction of the ball and how it impacts the pins.
   a **Explain** how Newton's laws apply to ten pin bowling.
   b **Evaluate** how the impact of a bowling ball causes the pins to fall.

Research

30 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Movement of an aircraft

Aircraft are the second fastest mode of transport after rockets. Find out about the different types of aircraft and how they move. Explain the interactions between lift, weight, thrust and drag in aircraft movement. What speeds can aircraft attain?

Figure 2 Commercial passenger jets can cruise at a speed of 885 to 933 kilometres per hour.

»Car safety

Each year, cars gain new features to keep drivers safe on the roads. Research one safety feature being used in cars and discuss how it works using Newton's laws.

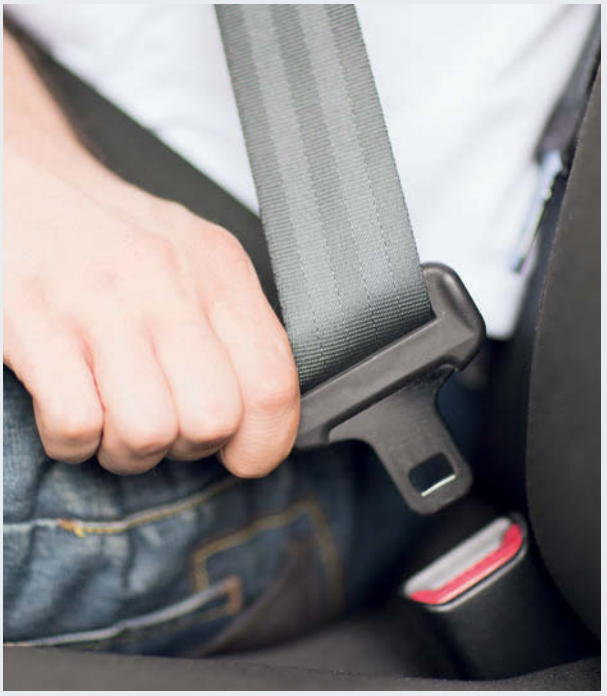

Figure 3 Seatbelts continue to be an important safety feature in cars.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Describe the relationship between force, mass and acceleration.	☐	☐	Go to pages 52-53
Explain the relationship between distance, speed and time.	☐	☐	Go to pages 46-47
Relate acceleration to a change in speed and/or direction as a result of a net force.	☐	☐	Go to pages 50-51
Analyse everyday situations involving motion in terms of Newton's laws.	☐	☐	Go to pages 52-57

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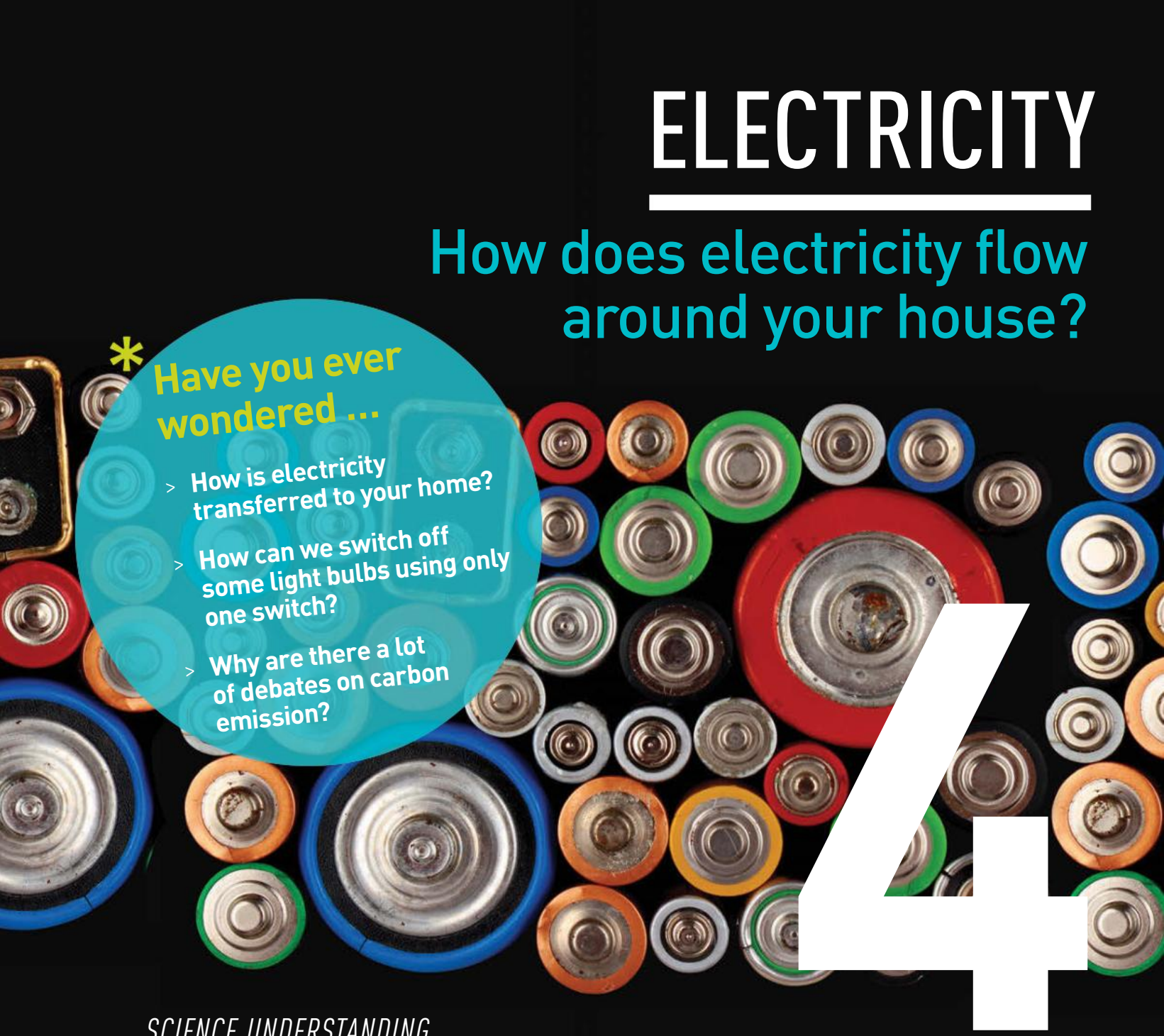
ELECTRICITY

How does electricity flow around your house?



Have you ever wondered ...

- How is electricity transferred to your home?
- How can we switch off some light bulbs using only one switch?
- Why are there a lot of debates on carbon emission?

4

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- describe voltage, current and resistance in terms of energy applied, carried and dissipated
- describe the relationship between voltage, resistance and current
- compare the characteristics and applications of series and parallel electrical circuits
- outline recent examples where scientific or technological developments have involved specialist teams from different branches of science, engineering and technology, e.g. low-emissions electricity generation and reduction in atmospheric pollution

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

4.1 The characteristics of energy change in series or parallel circuits

In this topic, you will learn that:

- electric currents travel through electric circuits, which are a closed loop
- an electric circuit contains an energy source, a pathway and a load
- in a series circuit, all the current passes through from start to finish
- in a parallel circuit there are two or more branches, and the electric current splits between the branches.

electric circuit
a closed pathway that conducts electrons in the form of electrical energy

ampere
unit of electric current; 1 ampere is equal to 1 coulomb of charge passing a given point in one second

series
the positioning of loads (e.g. lights) side by side in an electric circuit so that the electrical energy passes through one load at a time

parallel
the positioning of loads (e.g. lights) in an electric circuit so that they are connected to the battery separately; they are in parallel to each other

circuit diagram
a diagrammatic way to represent an electric circuit

An electric circuit contains an energy source (a battery), a pathway (usually wires) and a load, which transforms the electrical energy into other forms of energy. Current (measured in **amperes**) is a measure of the number of negative electrons that pass a point each second. The pathway of the charges can be represented by a circuit diagram.

In a **series** circuit, the loads (e.g. lights) are connected one after the other, and the current is the same throughout the circuit. In a **parallel** circuit, the loads are parallel to each other, and the current is shared between them.

Electric circuits

Charges travel through a closed loop, which is called an **electric circuit**. Electric circuits must have an energy source (often a battery), wires to carry the charges, and a load. The load converts the electrical energy into other forms of energy such as heat, light or kinetic energy. Many devices have gaps – these are called switches and are used to control the flow of electricity in a circuit.

Circuit diagrams represent how charges travel

We use **circuit diagrams** to represent these circuits. Each component of an electric circuit is represented by a symbol, as shown in Figure 1.

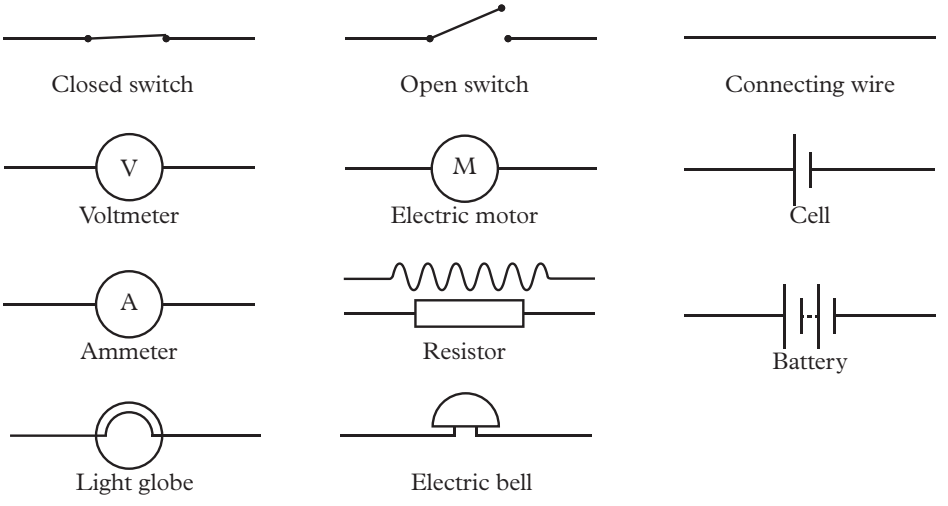

Figure 1 Common symbols used in circuit diagrams.

SKILLS LAB
4.1: Making series and parallel circuits
Go to page **365**

CHALLENGE
4.1: Short-circuiting an electric current
Go to your **obook**

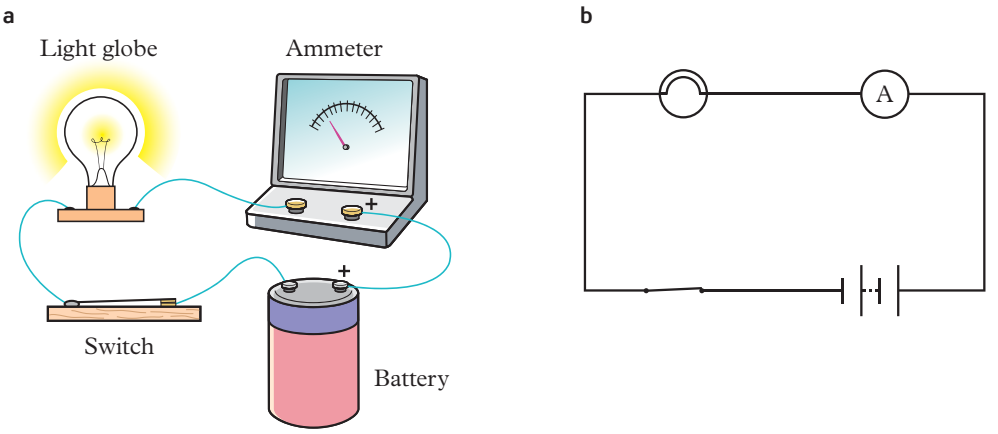

Figure 2 a An electric circuit and **b** the circuit diagram to represent this circuit

As you can see in Figure 2, in a circuit diagram, wires are usually drawn as straight lines and are usually joined at right angles (though there are exceptions to this). In Figure 2, the longer line on the battery symbol indicates the positive terminal, and the shorter line indicates the negative terminal – each terminal is where the wires are connected.

When you draw a circuit diagram, use a ruler and a pencil, and make sure all lines are connected to indicate there are no breaks in the circuit.

Types of electric circuits

When two or more globes are connected in a circuit, two different types of connection are possible. In a series circuit, the globes are connected side by side so that the current goes through one globe and then the second (Figure 3a). In a parallel circuit, the circuit has two or more branches and the current splits between the branches (Figure 3b) and comes back together afterwards.

Comparing series and parallel circuits

If two globes are connected in a circuit in series, then all the current (the electrons) passes through both globes. This means that the current is always the same at all points in a series circuit.

However, if two globes are connected in parallel, the current must split. This means that when the electrons reach where the wire splits, the current will travel down one path or the other. Part of the current passes through each globe and then joins together again after passing through the globes. This means that the current going through each globe must be added together to determine the total amount of current coming from the battery.

In a series circuit, a break at any point in the circuit (e.g. from a switch) affects all the globes in the circuit. In a parallel circuit, a break in one of the wire branches of the circuit affects only the current in that branch.

In a household, lights and appliances are connected in parallel so that:

- some appliances can be on while others are off (achieved by inserting switches)
- if one appliance fails, others will still work.

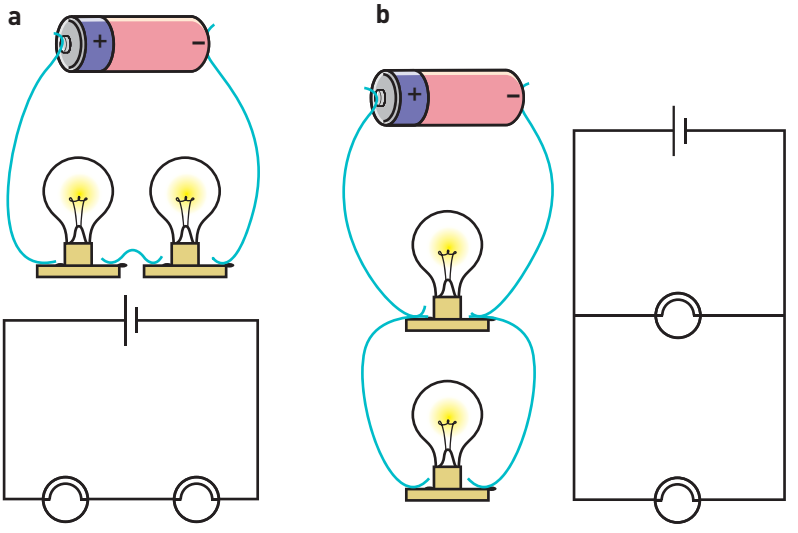

Figure 3 a In a series circuit, the current is the same anywhere in the circuit. **b** In a parallel circuit, the sum of the current going through each globe is equal to the total current from the battery.

Figure 4 Christmas tree lights are both series and parallel circuits.

Batteries in series and parallel

Batteries may be connected in series or parallel in a similar way to globes. When batteries are connected in series, an electron picks up a certain amount of energy as it passes through the first battery and then an additional amount as it passes through the second battery. This arrangement allows electrons to be given larger amounts of energy. For instance, a simple torch normally includes two 1.5 V batteries connected in series. As each electron passes through both batteries, it collects a total of 3.0 units of energy to light the torch globe.

When batteries are connected in parallel, each electron passes through either one battery or the other. So, each electron collects the same amount of energy as it would from one battery on its own. The advantage of this arrangement is that the two batteries last longer than either one of them would in the same circuit on their own.

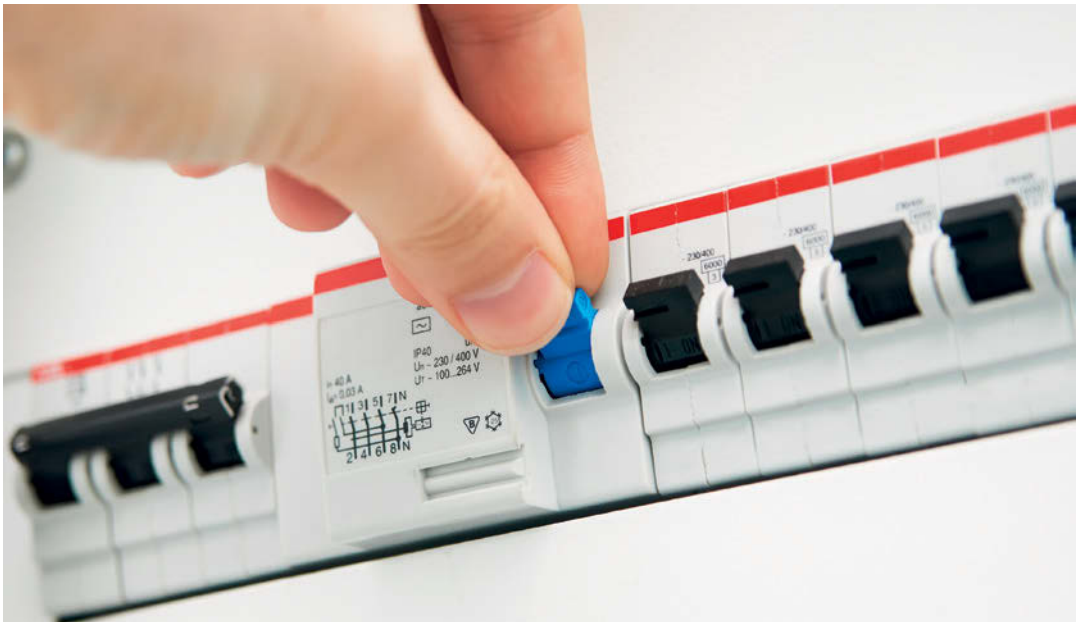

Figure 5 A sudden increase in current will cause fuses to break the circuit. This stops the current from flowing and may prevent electrocution.

Short circuit

A **short circuit** occurs when a current (moving electrons) flows along a different path from the one intended. Electric charges will take the path of least resistance, which means that large currents can flow in a short circuit, causing batteries to go flat quickly. Short circuits are dangerous because they can also lead to wires heating up, causing damage or even fire.

Fuse

A **fuse** is a switch or thin piece of wire that burns up quickly when current starts flowing too fast in a circuit. This causes a break in the circuit so that the electrical energy stops flowing. This is to prevent damage to appliances from the high current or loss of life.

short circuit
when electrical current flows along a different path from the one that was intended

fuse
a wire of high resistance; it will melt if too much current flows through the circuit

Check your learning 4.1

Recall and explain

1 **Recall** how energy is transferred in a simple circuit.

2 **Identify** the essential components of an electrical circuit.

3 **Describe** the similarities and differences between series and parallel circuits.

4 **Identify** the role of a switch in a circuit.

Apply and analyse

5 a Draw a circuit diagram containing a battery, a switch and two light bulbs connected in series.

b Is it possible to turn one of the light bulbs on while the other one is off? **Explain** your answer.

6 a Draw a circuit diagram containing a battery, a switch and two light bulbs connected in parallel.

b Is it possible to turn one of the light bulbs on while the other one is off? **Explain** your answer.

7 People often complain when they put up their Christmas tree lights that a whole row of them no longer works. Does this suggest the globes are connected in series or parallel? **Explain** your answer.

8 **Explain** what is 'used up' in an electric circuit: the current, the electrical potential, both or neither. **Justify** your answer.

9 Decide if a circuit can be made from a battery, a single piece of wire and a light bulb. **Justify** your answer.

Evaluate and create

10 **Investigate** and **describe** the following safety devices: circuit breakers and earth wires.

Skill builder: Planning investigations

11 Electricians and scientists use diagrams to explain how something needs to be set up. You have been asked to plan an investigation into the wiring of the apartment in Figure 7. **Apply** your understanding of circuit diagrams to draw one for the wiring of this apartment. You need to include the following:

- one light bulb and one switch in the kitchen
- two light bulbs and one switch in the bedroom
- two light bulbs and two switches in the living room
- one light bulb and one switch in the bathroom.

(THINK: How does each light bulb receive electricity? Have I drawn this scientifically? What are the correct symbols to use?)

Figure 7 An apartment floor plan

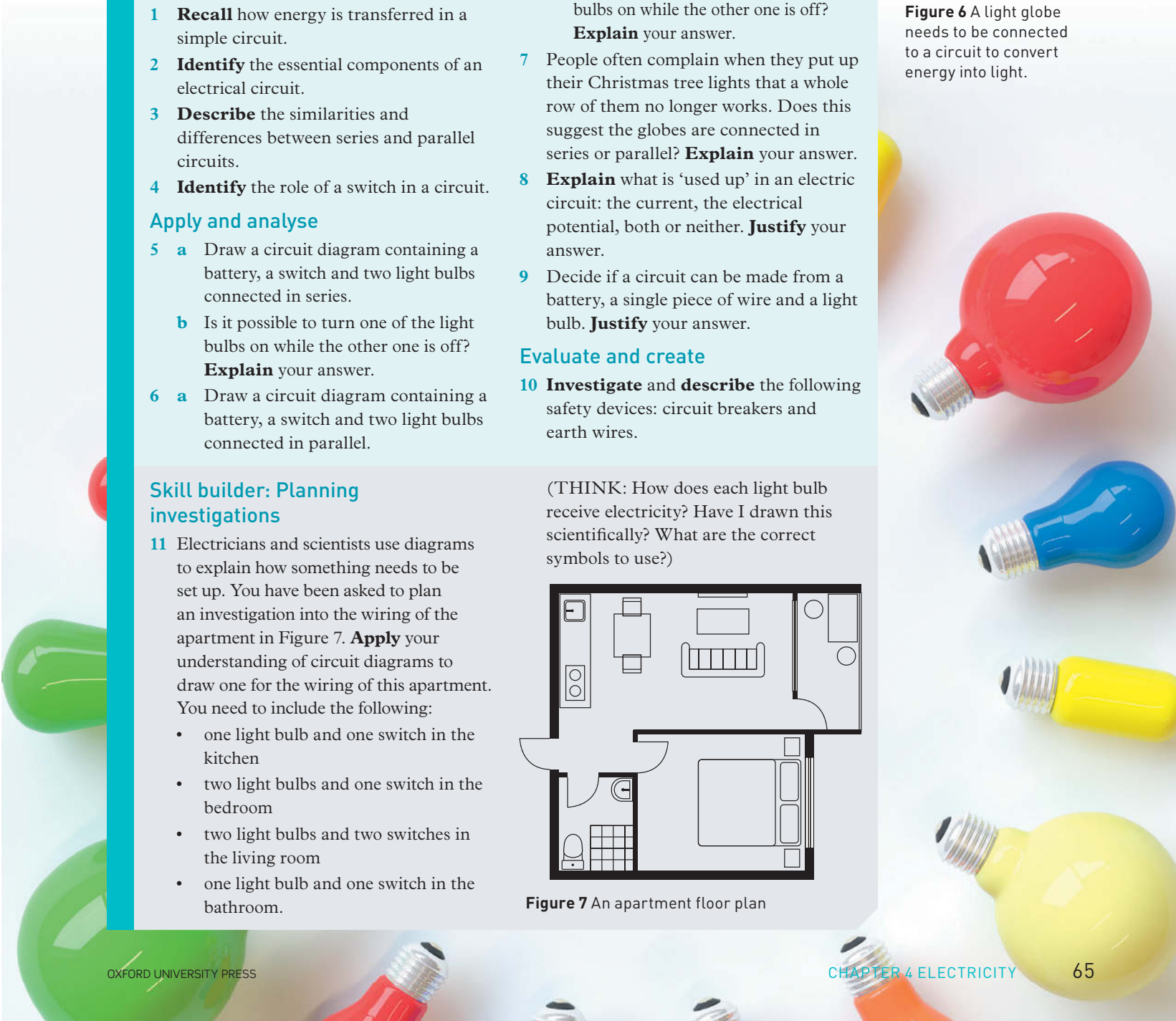

Figure 6 A light globe needs to be connected to a circuit to convert energy into light.

4.2 Energy circuits have different voltages, currents and resistance

In this topic, you will learn that:

- electric current is a measure of the amount of charge that goes past a point in the circuit in one second
- voltage is the difference in the electrical potential energy carried by charged particles at different points in a circuit
- the electrical resistance of a material is a measure of how difficult it is for charged particles to move through it.

electric current
the rate of motion carried from one part of a conductor to another

The difference in the electrical potential energy carried by charged particles at different points in a circuit is called the voltage. It can be measured using a voltmeter in parallel to the circuit. Resistance is a measure of how difficult it is for current to flow through part of the circuit – the higher the resistance, the lower the current at a given voltage.

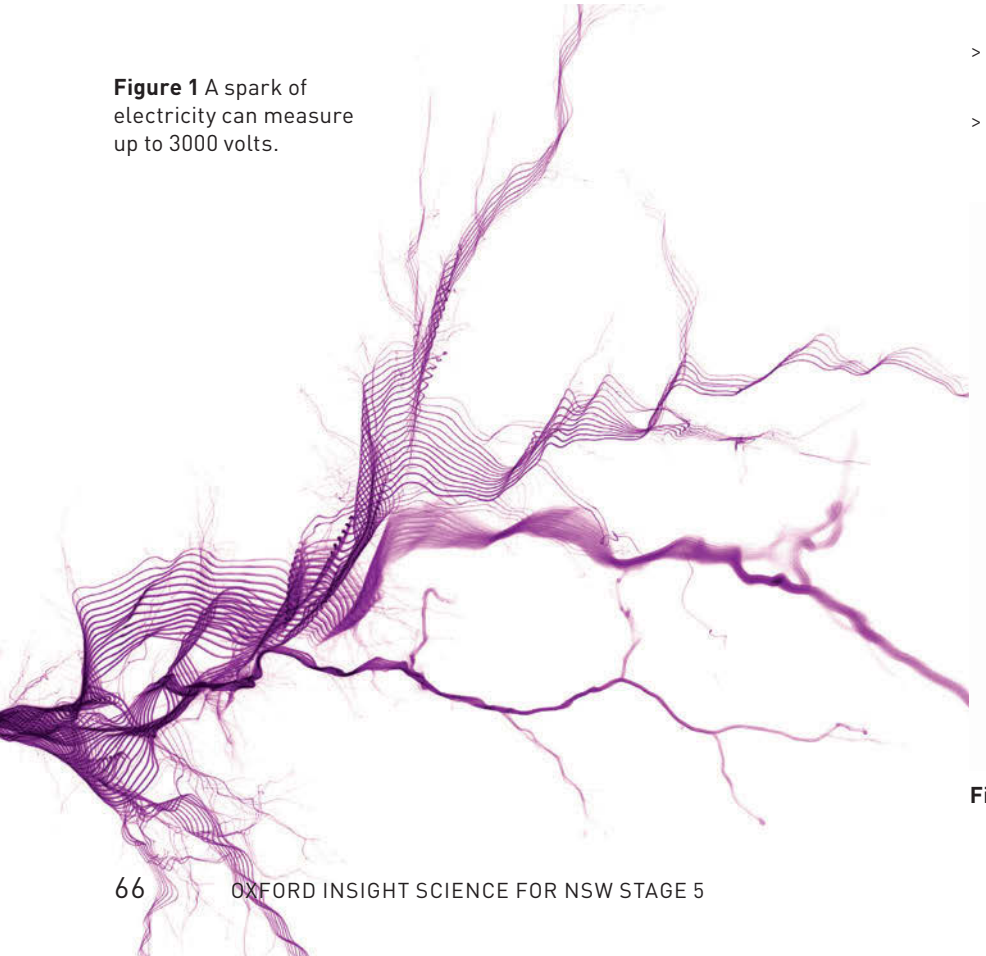

Figure 1 A spark of electricity can measure up to 3000 volts.

Current

Electric current is a measure of the amount of charge that goes past a point in the circuit in one second. Because electrons are tiny, a large number of them are likely to pass each point at any moment in time. Physicists use the following measurements to record what is passing in an electric circuit:

- 6.241×10^{18} electrons are known as 1 coulomb
- 1 coulomb passing a given point in 1 second is called an ampere (A)
- current is measured in amperes (also shortened to amps).

Figure 2 An ammeter is used to measure electric current.

SKILLS LAB
4.2a: Using Ohm's law to find resistance
Go to page **365**

SKILLS LAB
4.2b: Understanding resistor colour codes
Go to page **366**

Because the ampere is a relatively large quantity of current, sometimes smaller units such as the milliampere (mA) are used. 1 A is equivalent to 1000 mA. Physicists use a device called an **ammeter**. Ammeters measure the current travelling through a specific point in an electric circuit. They are connected to the circuit in series. This is so the current can flow through it. You can also think of an ammeter as an invisible ribbon that runners have to run through, being counted each time.

The electrons move, or are conducted, from the negative terminal of the energy source to the positive terminal. For historical reasons, the direction of the current is given as the flow of positive charges from the positive terminal of the energy source to the negative terminal. This flow of positive charges is referred to as a conventional current (Figure 3).

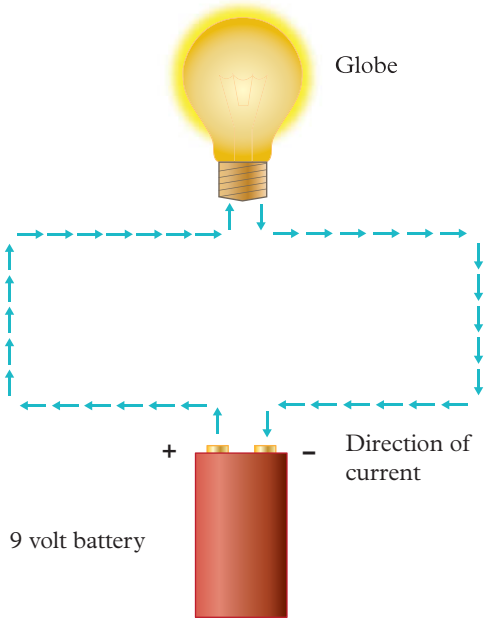

Figure 3 A conventional current in an electric circuit

Voltage

Each charged particle contains potential energy as it moves in an electric circuit. This energy can be transformed into different forms of energy. For example, it is transformed into sound as it moves through a speaker, or into light and heat if it moves through a globe. This means the charged particle (electron) will have different amounts of energy before and after the speaker or globe. This difference in energy is called **potential difference** or **voltage**.

Voltage is measured with a voltmeter in the unit volts (symbol V). To measure the potential difference between two points in a circuit, a voltmeter is set in parallel across the two points in the circuit (Figure 4).

Batteries add energy to the charged particles. The amount of energy added by the battery can be determined by connecting a voltmeter in parallel to the battery. In a 1.5 V battery, each unit of charge (coulomb) gets 1.5 J of energy as it passes through the battery. This potential energy is used up in the circuit, but only if there is a resistance.

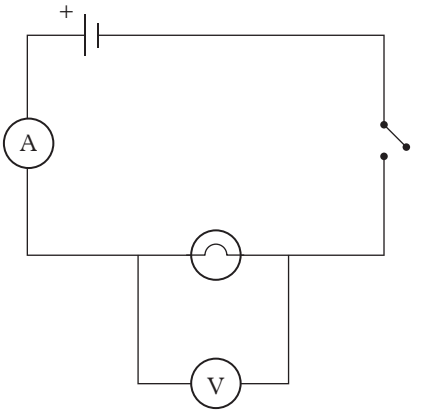

Figure 4 A voltmeter is used to measure voltage in a circuit.

Figure 5 Each unit of charge in this battery has 1.5 joules of energy.

ammeter
a device that measures the current travelling through a particular point in an electric circuit

Resource
STEM activity: Electrolyte up your life

potential difference
voltage; the difference in the electrical potential energy carried by charged particles at different points in a circuit

voltage
potential difference; the difference in the electrical potential energy carried by charged particles at different points in a circuit

Resistance

resistance
a measure of how difficult it is for the charged particles in an electric circuit to move

resistor
a device that has opposition to an electric current

The amount of current flowing in a circuit is determined by the **resistance** of the circuit. The electrical resistance of a material is a measure of how difficult it is for charged particles to move through it. Electrons collide with the atoms in the wires and the various other components of a circuit, and some of their electrical energy is converted into heat.

Figure 6 Many types of resistor are available. **a** The resistance of carbon resistors is indicated by the coloured bands on their plastic case. **b** The resistance of a light-dependent resistor (LDR) varies depending on the brightness of the light shining on it. This makes LDRs useful in sunset sensors that control automatic lighting circuits, like streetlights or security lights.

Most connecting wires are thick and made from good conductors. Consequently, they have very low resistance and hardly any energy is lost by the electrons. Sometimes, the heat generated by resistance is useful. For example, the wires in a toaster are designed so that a lot of the electrons' energy is transformed into heat – so much that the wires glow red-hot and brown our toast.

Resistors are devices that are placed deliberately in circuits to control or reduce the size of the current. Resistance is measured in units called ohms (symbol Ω).

Thermistors are temperature-dependent resistors. They are useful in thermostats for controlling devices that heat or cool, such as central heating and fridges.

A potentiometer is another type of variable resistor with a dial that rotates. A light dimmer is a potentiometer, as is the temperature control on an oven.

Ohm's law

Georg Ohm, a German physicist, discovered the relationship between voltage, current and resistance. Ohm found that the voltage drops across a fixed-value resistor (ohmic resistor) will always be directly proportional to the current through the resistor. This relationship is known as **Ohm's law** and is written as:

$$V = IR$$

This means for a certain amount of voltage, the higher the resistance, the lower the current. Insulators have very high resistance so the current flowing through them is almost zero.

If you plot a graph of current versus voltage, the graph is a straight line. Resistance equals one divided by the gradient of the current–voltage graph.

$$R = \frac{V}{I}$$

$$\text{Gradient} = \Delta V / \Delta I$$

$$R = \frac{1}{\text{gradient}}$$

An ohmic resistor has a constant resistance. The resistance of a non-ohmic resistor changes with temperature. Ohm's law applies only to ohmic resistors.

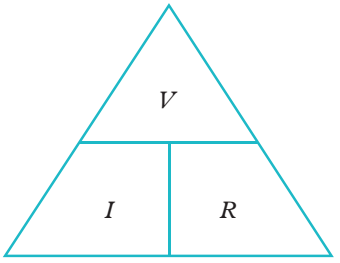

Figure 7 The Ohm's law triangle can be used to remember the equations for Ohm's law. To find resistance, cover the *R* – the other two letters show you the formula to use. The *V* is over the *I* so $R = V \div I$.

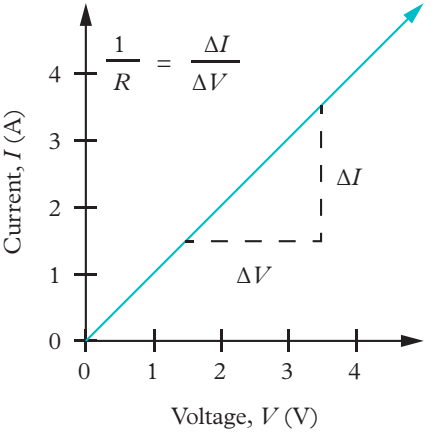

Figure 8 Graphical representation of Ohm's law

Ohm's law
a law stating that electric current is proportional to voltage and inversely proportional to resistance

Check your learning 4.2

Recall and explain

1 **Define** the following terms.
   - **a** Current
   - **b** Voltage
   - **c** Resistance

2 **Explain** what happens to the electrical energy carried by electrons as they flow around an electric circuit.

3 **Identify** the quantity that measures the electrical energy carried by each unit of charge in an electric circuit.

4 Write out the three equations that can be obtained by the Ohm's law triangle.

5 Complete the information in Table 1.

Table 1 Symbols and units for electric circuit terms

Term	Symbol	Unit
Current	*I*	
Voltage		V
Resistance		

Apply and analyse

6 **Calculate** the current flowing through a 44 Ω resistor when it has a voltage drop of 11 V across it.

7 **Calculate** the voltage drop across a 25 Ω resistor when a current of 50 mA flows through it.

8 **Calculate** the value of a resistor that has a voltage drop of 8 V across it when a current of 0.4 A flows through it.

9 **Compare** potential difference and resistance. **Explain** how they differ and why each is part of an energy circuit.

Evaluate and create

10 Students performed an experiment to determine the value of an unknown ohmic resistor. They made a simple circuit and measured the amount of current for different values of voltage. Their results are shown in Table 2.

Table 2 Experimental results for an electric circuit

Voltage (V)	Current (A)
0	0.0
2	0.1
4	0.2
6	0.3
8	0.4
10	0.5

- **a** Determine the independent, dependent and controlled variables.
- **b** Draw a current–voltage graph for the data in Table 2.
- **c** **Calculate** the resistance using the gradient of the graph.
- **d** Another group of students performed the same experiment but each time they changed the voltage and thickness of the connecting wires. **Evaluate** the validity of their experiment.

Skill builder: Conducting investigations

11 When you conduct investigations around electricity, there are different risks to consider compared with investigations involving chemicals. It is particularly important that your equipment is set up and assembled safely.

- **a** **Identify** risks associated with connecting the power source before you have set up your circuit. (THINK: What risks exist when wires aren't connected correctly?)
- **b** **Explain** why it is important that you check wires before commencing an investigation. (THINK: Would your results be impacted?)

4.3 Scientists work together to find new solutions for electricity use

In this topic, you will learn that:

- energy efficiency is a measure of how much energy is transformed into the desired energy type (called usable energy) compared to the initial energy amount
- scientists and engineers are working on developing alternative energy production.

energy efficiency
a measure of how much input energy is transformed, rather than lost (via sound or heat)

The world is striving to become energy efficient. The measure of how much an original amount of energy has transformed into the desired energy type is called **energy efficiency**. Australia, for example, has been phasing out the use of inefficient incandescent light bulbs. By increasing the use of energy-efficient products, the economy can make great savings and the world can become more environmentally sustainable. Moving to energy-efficient lighting was expected to save approximately 28 million tonnes of greenhouse gas emissions by 2020.

Coal is a form of non-renewable energy

Until recently, Australia has relied on coal to power the country. Burning coal has powered most of our home, business and school appliances. As coal burns, it produces carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2).

Each of these can cause environmental damage. Carbon dioxide contributes to the greenhouse effect, and sulfur dioxide and nitrogen dioxide damage the environment in the form of acid rain.

Coal is a cheap resource in Australia because we are able to produce it ourselves; Australians have been reluctant to switch to emerging renewable technologies, including solar power, hydropower and wind farms. Scientists are working on encouraging the use of these energy sources as well as trying to find more sustainable ways to continue to use coal.

As a society, the world is beginning to ask for more renewable energy sources to increase sustainability and to reject non-renewable (long-term-renewable) energy sources. Given that a range of factors need to be considered when considering energy generation (including convenience, the economy, personal costs, efficiency or a more sustainable future), the mix of renewable and long-term-renewable resources used in the future is an area of ongoing debate.

Figure 1 Mount Piper is a coal power station near Lithgow in New South Wales.

Coal can be treated to reduce environmental impacts

Some scientists have been investigating techniques to continue to use coal but reduce the environmental impact. One method is **coal washing**. Coal washing treats coal by removing unwanted chemicals from it. The coal is first crushed and then mixed with a liquid, allowing impurities to separate. When the coal is then burnt, the environment-damaging gases can be treated with limestone and water, which removes the sulfur dioxide. The nitrogen dioxides are reduced through burners that limit the oxygen involved in the combustion process.

Coal can be turned into gas

A system called the Integrated Gasification Combined Cycle (IGCC) transforms coal into gas that can be used to create energy. The IGCC uses steam and pressurised hot air to force the coal's carbon molecules apart. This method is more energy efficient than directly burning coal to heat water to turn a turbine.

Carbon capture and storage

When carbon dioxide is emitted from a power station, it can be captured and stored – a process referred to as CCS (carbon capture and storage). There are several methods that scientists have developed to capture carbon dioxide, and these include the following.

- Flue-gas separation: This method removes carbon dioxide by using steam, which is then condensed into a concentrated stream.
- Oxy-fuel combustion: This method involves burning coal in pure oxygen, which creates a gas that is mostly carbon dioxide and water (i.e. without sulfur dioxide and nitrogen dioxide). The carbon dioxide is then stored in a container that is either placed under the ocean or deep in the ground, where it dissolves.

In your daily life, you may make choices about the type of appliances you purchase and use. Some may require less energy to operate, and others will be more energy efficient. Teams of scientists including engineers, biologists, chemists and physicists are working together to create new sources of energy that offer greater environmental sustainability.

coal washing
the process of 'cleaning' coal with water and chemicals to remove sulfur and other impurities before it is burned at a coal power plant

Figure 2 Coal provides a form of non-renewable energy.

Check your learning 4.3

Recall and explain

1 **Define** energy efficiency.
2 **Identify** the two waste gases other than carbon dioxide that result from burning coal.
3 **Recall** one method of using coal that is more environmentally sustainable.

Apply and analyse

4 **Assess** why considering the appliances you use and selecting energy-efficient ones is important.
5 Imagine that you need to purchase one of the following for your family: a fridge, a dishwasher, a washing machine or a microwave. **Identify** what you and your family might prioritise when choosing the chosen appliance. Think about the following. Is it more efficient than other models or brands? Will it last longer? Does it need to be replaced frequently? **Investigate** several models and explain your choice in terms of cost, energy efficiency and features.
6 **Construct** a flow chart to show how coal can be converted into gas and how this gas is burnt to produce electricity.

Evaluate and create

7 A friend of yours is considering purchasing an appliance that only has a 2-star energy rating, because it is cheaper than a 5-star device. **Recommend** what your friend should do, and **identify** the advantages and disadvantages of both devices, making sure you think about the environmental and economic effects.

Skill builder: Problem solving

8 Scientists assess strategies that are identified as possible solutions to a problem.
An example of a problem and a possible solution is coal and coal washing. **Assess** the method of coal washing by writing a pros and cons list.
(THINK: What is the value of coal washing? What are the outcomes of coal washing? Are there better alternatives?)

REVIEW

Multiple choice

1 The units of voltage, current and resistance, respectively, are:

A amps, ohms, volts
B ohms, volts, amps
C volts, amps, ohms
D volts, ohms, amps

2 A 50 ohm resistor is connected to a 10 volt battery. The current flowing through it is _____ amps. If the voltage is doubled, then the current will be _____ amps.

A 5 A, 2.5 A
B 0.2 A, 0.1 A
C 5 A, 10 A
D 0.2 A, 0.4 A

3 A voltmeter is connected in _____ in a circuit, and an ammeter is connected in _____ in a circuit.

A Series, series
B Parallel, parallel
C Series, parallel
D Parallel, series

Recall and explain

4 Draw a circuit diagram, showing a power supply, a globe, several wires and a switch.

5 Label each component in the circuit you drew in question 4.

6 **Identify** what an ammeter is and what it measures.

7 **Identify** each symbol (ammeter, cell, globe or switch) in Figure 1.

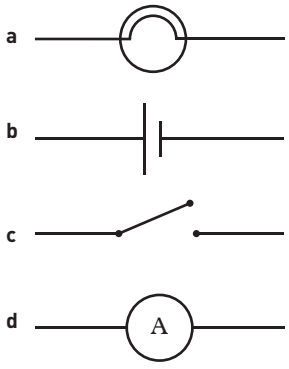

Figure 1 Circuit symbols

8 **Describe** how a fuse works.

9 **Explain** what resistance is.

10 In your own words, **describe** Ohm's law.

11 **Identify** the correct label for A, B and C in Figure 2.

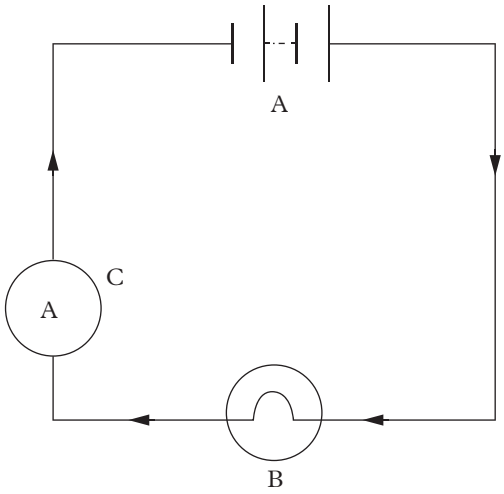

Figure 2 Circuit diagrams

Apply and analyse

12 Draw a circuit diagram showing a battery and a switch, with a globe on either side of the switch.

a Does it matter where in the circuit the switch is placed?
b Show the direction of electron flow and the direction of conventional current.

13 **Calculate** the current flowing through a 30 Ω resistor when it has a voltage drop of 12 V across it.

14 **Calculate** the voltage drop across a 50 Ω resistor when a current of 25 mA flows through it.

15 **Calculate** the value of a resistor that has a voltage drop of 18 V across it when a current of 0.3 A flows through it.

16 Draw a circuit diagram showing a battery, a switch that turns off all the circuit, and three globes. Two globes are in series, and the third globe is in parallel with the other two globes.

17 **Explain** why your home is wired in parallel.

Figure 3 Most modern homes have a switchboard to route electricity in the home.

18 **Assess** the use of coal in Australia to generate electricity.

19 **Calculate** the drop in voltage across a 200 Ω resistor when a current of 50 mA flows through it.

Evaluate and create

20 A storm has blown a tree over on the main power line to your neighbourhood. The electricity supply is cut. **Describe** your day without electricity.

Figure 4 A damaged power line

21 **Explain** why a voltmeter is connected in parallel and an ammeter is connected in series in a circuit.

22 **Evaluate** the claim: 'Resistance increases as voltage decreases.'

23 **Outline** the main features of the IGCC.

24 **a** **Explain** why Figure 5 is not an appropriate circuit diagram.

b **Construct** a scientific circuit diagram using the information you have learnt in this chapter.

c **Summarise** why it is important to use scientific diagrams.

d **Assess** what type of risks may occur if someone followed the circuit diagram in Figure 5.

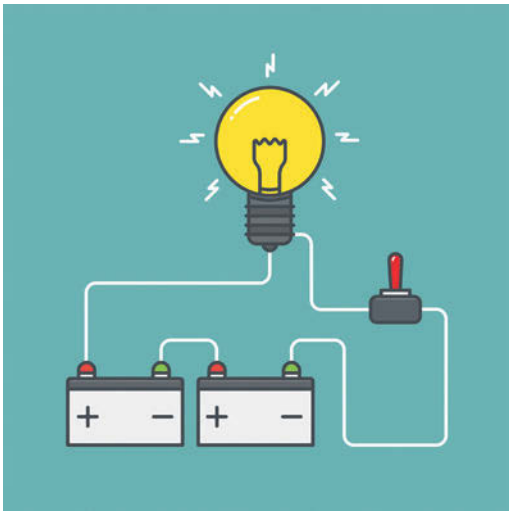

Figure 5 A circuit diagram

Critical thinking

25 **Investigate** two sources of information related to the use of coal in Australia. Then **investigate** two sources of information that provide an alternate energy source in Australia.

a Write down references for each source.

b **Discuss** whether one source was better than the other.

Figure 6 A coal power station in New South Wales

26 **Construct** a fair experiment to investigate the effect of increasing resistance on the current.

a Write a hypothesis for the experiment.

b Determine independent, dependent and controlled variables.

c Write a method for performing the experiment.

d Draw a labelled scientific diagram of the equipment set-up.

Go further

27 The use of coal in Australia causes debate among people. Coal has negative environmental impacts, and people sometimes suggest Australia should use renewable energy sources, specifically nuclear energy. This is suggested because Australia has one of the largest uranium stores on Earth.

a **Investigate** nuclear power as a source of energy.

b Create a table to **compare** nuclear energy and coal energy.

28 Someone may have asked you to switch your light off and all your power points before you leave a room. You might have informed them that you were only leaving for a minute. To complete this question, you will need to do some further research.

Deduce whether it is more energy efficient to turn a light off when you leave a room and turn it back on again, or whether it is more efficient to leave the light on the whole time.

Research

29 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Incandescent light globes

Incandescent light globes are traditional light globes. You are likely to see them around homes. What does 'incandescent' mean? What are incandescent light globes made of? Why must the filament be contained in an inert gas like argon? What temperature does the filament need to be heated to so that it gives off light? How efficient are incandescent light globes?

Figure 7 An incandescent light globe

»Generating electricity

Australia is powered via coal energy, which is created at coal power stations. Why do they need to burn coal? What is water steam used for? How can wind energy or any other renewable resources be used instead of coal?

»Energy-efficient housing

In previous societies, energy efficiency was important because people had limited access to the types of energy supplies and their applications that we have today. Research how civilisations in tropical areas designed their homes to keep them cool and damp-free. What different types of energy-efficiency practices have humans used through the ages?

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Describe voltage, current and resistance in terms of energy applied, carried and dissipated.	☐	☐	Go to pages 62-65
Describe the relationship between voltage, resistance and current.	☐	☐	Go to pages 66-69
Compare the characteristics and applications of series and parallel electrical circuits.	☐	☐	Go to pages 62-65
Outline recent examples where scientific or technological developments have involved specialist teams from different branches of science, engineering and technology, e.g. low-emissions electricity generation and reduction in atmospheric pollution.	☐	☐	Go to pages 70-71

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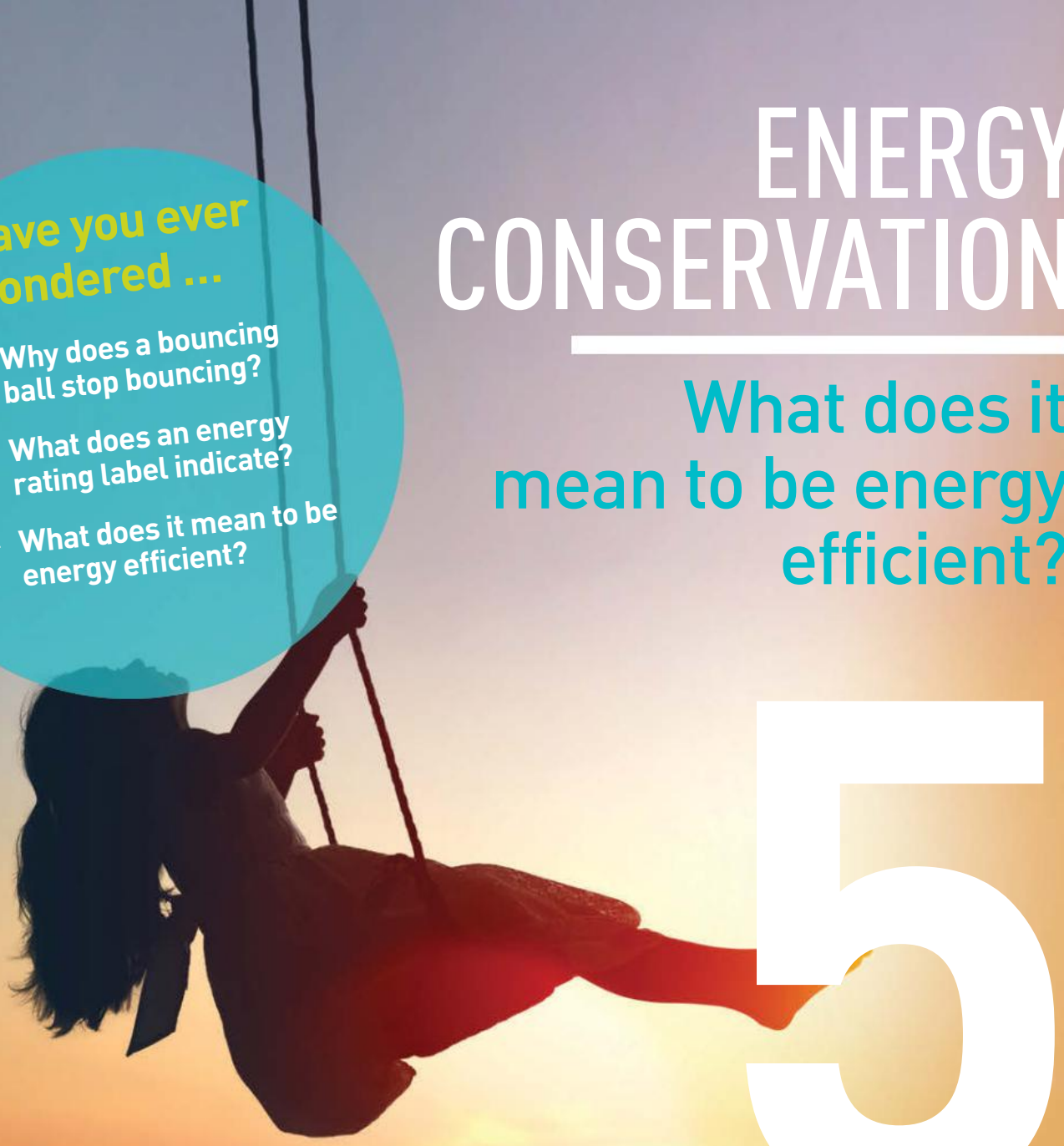
ENERGY CONSERVATION

What does it mean to be energy efficient?

Have you ever wondered ...

- Why does a bouncing ball stop bouncing?
- What does an energy rating label indicate?
- What does it mean to be energy efficient?



5

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- apply the law of conservation of energy to account for the total energy involved in energy transfers and transformations
- describe how, in energy transfers and transformations, a variety of processes can occur so that usable energy is reduced and the system is not 100% efficient
- discuss, using examples, how the values and needs of contemporary society can influence the focus of scientific research in the area of increasing efficiency of the use of electricity by individuals and society
- discuss viewpoints and choices that need to be considered in making decisions about the use of non-renewable energy resources

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

5.1 Energy is always conserved

*

In this topic, you will learn that:

- the law of conservation of energy states that energy cannot be created or destroyed
- energy transferred to an object can be released
- waste energy in the form of heat and sound can be formed in this transformation
- energy efficiency of the energy transformation can be calculated.

law of conservation of energy
a scientific law that states the total energy in a system is always constant and cannot be created or destroyed

Whenever energy is converted from one form into other forms, the total energy of the system is always constant because extra energy cannot be created, nor can energy be destroyed. This is called the **law of conservation of energy**.

Energy can be *transformed* (converted) into different forms – for example, kinetic energy can be converted to gravitational potential energy. Energy can also be transferred from one object to another object.

The law of conservation of energy is most obvious when you jump on a trampoline. When you are high above the trampoline, you have gravitational potential energy (GPE). As you start to move down, you gain velocity and therefore kinetic energy (KE). The closer to the ground you get, the less gravitational potential energy you have and the more kinetic energy you have. Just before you touch the trampoline, you are travelling at your fastest velocity. As soon as you start stretching the trampoline (as it caves in when you land), you start slowing down. Your kinetic energy is being transformed into elastic potential energy (EPE) in the trampoline. Eventually you will stop moving and the trampoline will be completely stretched. All the kinetic energy has been transformed into elastic potential energy. Eventually the elastic potential energy is transformed back into kinetic energy and gravitational potential energy, and you will start moving up into the air again.

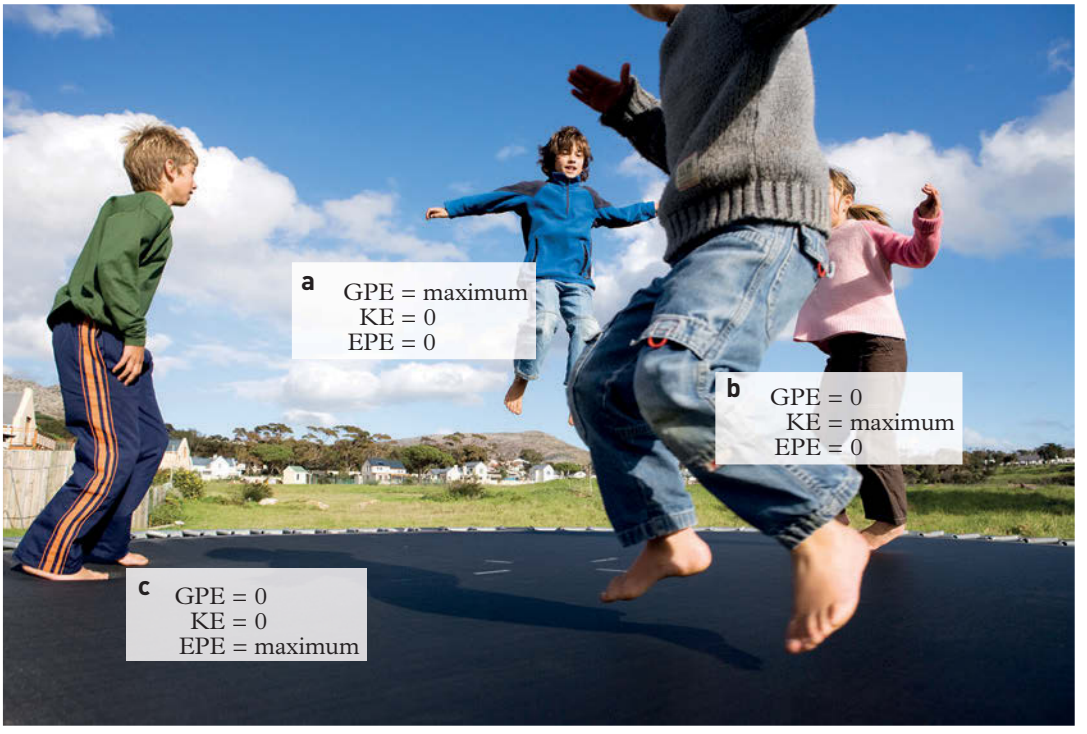

Figure 1 Although the individual energy quantities vary between the highest point **a**, through position **b** to the lowest position **c**, the total energy of the 'system' remains constant.

CHALLENGE
5.1: Conservation in action
Go to page **367**

Theoretically, the total amount of energy is constant when you jump on a trampoline. In reality, there may be a small amount of heat energy produced as you fall due to air resistance. This 'loss' of energy is not really a loss but rather just a transformation of energy to a non-usable form. The efficiency can be calculated by comparing how high above the trampoline you started and the height you reached on the rebound (usable final energy):

$$\text{Energy efficiency} = \frac{\text{amount of usable final energy}}{\text{amount of initial energy}} \times 100$$

Any difference in height is a result of heat or sound energy.

This transfer in energy also happens to run the appliances in your home. Energy is generated through coal mines or wind farms or through hydropower. This energy is then converted from the original source and runs through your home via electricity lines in your city and home.

Pendulums

A pendulum is a mass that is attached by a string to a pivot point. When the mass is drawn upwards, it gains gravitational potential energy. When the mass is let go, the force of gravity pulls it back to its original position, converting the gravitational potential energy to kinetic energy. The momentum built up by the moving mass causes the mass to then swing in the opposite direction. This means all the kinetic energy is converted back into gravitational potential energy. Pendulums (like a swing in a playground) are a good example of how energy efficiency can be measured. Some kinetic energy is always lost as waste energy, when it is transformed to heat and sound. This is evident when the pendulum does not quite reach the height at which it started.

Figure 2 A swing will not reach its original height because it loses energy as heat and sound energy.

Check your learning 5.1

Recall and explain

1 **Explain** the law of conservation of energy and give your own example.
2 **Explain** what waste energy is.
3 **Recall** the equation used to calculate energy efficiency.

Apply and analyse

4 Some people claim energy is lost. **Assess** if you agree with this statement. **Justify** your answer using the law of conservation of energy.
5 **Describe** the conservation of energy that occurs when you use a slinky.
6 The following statements are incorrect. Rewrite them to make them correct.
   a The energy efficiency of all systems is always 100%.
   b The law of conservation of energy doesn't always apply.
   c Pendulums always return to their original height.
   d A rollercoaster rolling down a ramp will stop at the bottom of the ramp.
7 **Calculate** the efficiency of a device if its input energy is 300 J and its waste energy is 100 J.

Evaluate and create

8 **Investigate** two uses of pendulums. Write a brief summary of how they can be used.

Skill builder: Questioning and predicting

9 Turning a scientific question into a hypothesis helps to structure an investigation.
You are presented with the research question: 'What happens to the amount of stored energy as a rubber band is stretched?'
   a Rewrite this question as a scientific question. (THINK: How can I make this measurable?)
   b **Identify** the dependent variable and the independent variable in your question. (THINK: What am I measuring? What am I changing?)
   c Write a hypothesis for stretching a rubber band. (THINK: Have I included both variables? Have I included a potential result?)

5.2 Energy can be transformed

*

In this topic, you will learn that:

- energy can be transformed into different forms, such as heat, sound, kinetic, gravitational potential and elastic potential
- energy can never be 100% efficient because in each transfer, energy is converted.

kinetic energy
the energy possessed by moving objects

gravitational potential energy
the energy possessed by objects raised to a height in a gravitational field

Resource
STEM activity: Energy transformation toy

Kinetic energy is the energy of an object as a result of its motion. This is affected by the object's speed and mass. **Gravitational potential energy** is a measure of how much energy is stored in an object because of its height above the ground. This is also affected by the mass of the object. **Elastic potential energy** is the energy stored in an object because of its shape or deformation.

Figure 1 The gravitational potential energy of a rollercoaster is transformed into kinetic energy.

Kinetic energy

Relative motion is needed for things to crash – the energy of this motion is called kinetic energy (KE). The larger the mass of an object, the greater its kinetic energy. Kinetic energy depends on the speed of the object, squared:

$$\text{Kinetic energy} = \frac{1}{2} \times \text{mass} \times \text{speed squared}$$

$$\text{KE} = \frac{1}{2} \times m \times v^2$$

where mass (m) is in kilograms (kg), speed (v) is in metres per second (m/s), and kinetic energy (KE) is in joules (J).

When a car brakes while driving, the kinetic energy is transformed to heat and released.

Gravitational potential energy

When we lift an object to a height, we use energy and the object gains gravitational potential energy (GPE). The larger the object, the more energy we use, and the more gravitational potential energy the object gains. The energy has been transferred from us to the object.

$$\text{Gravitational potential energy} = \text{mass} \times \text{gravity} \times \text{height}$$

$$\text{GPE} = m \times g \times h$$

where mass (m) is in kilograms (kg), height (h) is in metres (m), and gravitational potential energy (GPE) is in joules (J). Gravity has its normal value of 9.8 m/s^2.

For example, consider a rollercoaster. As the energy is transformed from gravitational potential to kinetic, some of the energy becomes sound energy (think of the cart on the tracks) and friction heat energy. Both of these transformations mean that the rollercoaster is not 100% efficient because some of the energy for momentum has been used as sound and heat.

CHALLENGE

5.2: Which is the more energy efficient?
Go to your **obook**

Elastic potential energy

Bouncing a ball requires energy, specifically gravitational potential energy, kinetic energy and elastic potential energy. As the ball hits the ground, it compresses and stores elastic energy. This energy transforms to kinetic energy when the ball returns to its natural state and is propelled upwards into the air.

$$\text{Elastic potential energy} = \frac{1}{2} \times \text{spring constant} \times \text{extension (or compression) squared}$$

$$\text{EPE} = \frac{1}{2} \times k \times x^2$$

where k is the spring constant (a measure of how 'stiff' the object is) in newtons per metre (N/m), x is the extension (or compression) in metres (m), and elastic potential energy (EPE) is in joules (J).

These different forms of energy demonstrate how energy can be transformed. As the ball hits the ground, some of the energy is transformed to sound energy – this means it loses some energy to bounce higher. Similarly, as the ball heats up, some energy is transformed to heat energy. Both of these transformations mean that the bounce of the ball is not 100% efficient, because energy has not only been used for bouncing.

Figure 2 When the tennis ball hits the ground, kinetic energy is transformed into elastic potential energy.

Figure 3 Kinetic energy is the energy of anything in motion. When you kick a football, the ball gains kinetic energy from the kick.

elastic potential energy the energy possessed by stretched or compressed objects

Check your learning 5.2

Recall and explain

1 **Distinguish** between elastic potential energy, kinetic energy and gravitational potential energy.

2 **Explain** how energy is transferred when a ball is bounced.

Apply and analyse

3 **Explain** how the kinetic energy of an object is affected if its mass decreases and the other variables remain constant.

4 **Explain** how the gravitational potential energy of an object is affected if its height increases and the other variables remain constant.

5 **Explain** how the elastic potential energy of an object is affected if its stiffness increases and the other variables remain constant.

Evaluate and create

6 In small groups, research another energy transformation. Then present your findings and **identify** the different types of energy that have been transformed.

Skill builder: Planning investigations

7 Students set up an experiment to investigate kinetic energy. They used a basketball and a ping pong ball. The students balanced the ping pong ball on top of the basketball in one hand, and then dropped them at the same time to see which would hit the ground first.

a Write out a method for this experiment that would help the students to observe the transformation of gravitational potential energy to kinetic energy. (THINK: What are all the steps needed to successfully complete the experiment? Is human error possible?)

b **Explain** why the students need to use one large and one small ball. (THINK: How is the gravitational potential energy transformed? Why would this impact results?)

5.3 Greater energy efficiency benefits society

In this topic, you will learn that:

- the greater efficiency that is achieved, the less energy is wasted and the less electricity costs within Australia
- electrical energy used in the home is measured in kilowatt-hours (kWh).

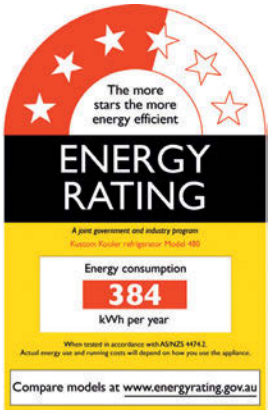

Figure 1 More stars mean an appliance is more energy efficient.

The ability to use energy efficiently is considered a benefit to society. How efficiently do you use your energy? How efficient are the devices you use in your home?

As a country, Australia is rich in fossil fuels. The majority of energy used in Australia is produced by these, and there is a large export market, where Australia sells these fossil fuels internationally. We also import resources like petrol for our cars. Fossil fuels are at risk of running out, because they take a significant amount of time to replenish themselves. For this reason, they are often referred to as non-renewable resources. However, they form as dead organisms decompose over millions of years, which means that they will eventually replenish.

All of these factors are relevant to Australia's use of electricity and how to use it more efficiently.

Energy efficiency in society

energy efficiency
a measure of how much input energy is transformed, rather than lost (via sound or heat)

Energy efficiency is a measure of how much input energy is transformed into the desired energy type, compared to the amount that might be lost as heat, sound or other unusable types. It is impossible to get 100% of the energy input in a device transformed into energy output, but scientists strive to design the best devices possible with the highest efficiency ratings.

Energy efficiency is calculated using the following formula:

$$\text{Energy efficiency} = \frac{\text{amount of usable final energy}}{\text{amount of initial energy}} \times 100$$

Although Australia has an accessible resource in fossil fuels, it is beginning to recognise the impact that continuous burning of fossil fuels has on the environment.

Pressure has been mounting for politicians to consider climate change when managing the use of these energy sources.

One approach is to display how efficient an appliance is with efficiency star ratings, and many appliances now come with these ratings. The more stars, the more energy efficient an appliance is. There are many benefits to purchasing an energy-efficient appliance.

- In the long term they can be cheaper. Although purchasing a 5-star appliance may cost $300 and a 2-star appliance may cost $200, over time the electricity bill for use of the more expensive appliance will be less than that of the cheaper appliance.
- Although getting solar power installed at home can be expensive, in the long run it is likely to reduce costs associated with electricity bills.
- Reducing Australia's dependency on fossil fuels reduces the need to burn fossil fuels, which reduces the amount of environmental damage and the impacts of climate change.

Kilowatt-hours

Electrical energy used in the home is measured in kilowatt-hours (kWh). The cost to a householder of each kWh varies around Australia and between different companies, but it is approximately 20 cents.

Scientists work together to increase the efficiency of the use of electricity

The world is striving to become more energy efficient. The Australian Government is gradually phasing out the use of inefficient incandescent light bulbs. This will deliver

considerable savings to the economy and to the environment. The move to more efficient lighting, such as compact fluorescent lamps (CFLs) and light emitting diodes (LEDs), was expected to save around 28 million tonnes of greenhouse gas emissions between 2008 and 2020. This is equivalent to taking more than 500 000 cars off the road. It is expected to result in savings of more than $50 per year for each household that changes all incandescent light globes to CFLs and LEDs. Has your household made the change yet?

All buildings, power stations and appliances are designed to reduce the loss of usable energy, but scientists, architects and engineers are always coming up with better ideas in their designs.

Figure 2 Newer street lamps use LED (light-emitting diode) lighting, which is more energy efficient.

Use of non-renewable resources

As mentioned in Chapter 4, coal is a non-renewable energy, which is used in Australia to generate electricity. Because coal is a cheap resource in Australia, and we are able to produce it ourselves, Australians have shown reluctance to switch to emerging renewable technologies, including solar power, hydropower and wind farms. Despite this reluctance, scientists are working on encouraging the use of these energy sources and finding more sustainable ways to use coal.

Going forward, society (especially younger generations) are seeking renewable energy sources and living more sustainably. When deciding to support resources, individuals need to determine if they are supporting convenience, financial outcomes or a sustainable future.

Check your learning 5.3

Recall and explain

1 **Define** the term 'kWh'.
2 **Explain** what the energy rating label is.
3 **Explain** why using a 4-star energy-efficient appliance is likely to cost less overall than a 2-star energy-efficient appliance.

Apply and analyse

4 a **Calculate** the electrical energy (in kWh) used by a 300.0 kW refrigerator in 24 hours.
b If each kWh is 20 cents, **calculate** the cost of using the described refrigerator for 24 hours.
5 **Assess** the use of coal as a source of energy to generate electricity.

Evaluate and create

6 **Outline** three ways that energy is wasted in your home. **Propose** a solution to minimise the waste of energy in your home.

Skill builder: Processing and analysing data and information

7 For three days in a row, record the reading on your family's electricity meter at exactly the same time each day (e.g. 6 pm).
a **Calculate** the number of kilowatt-hours your family used in the first 24-hour period (subtract the second reading from the first). Then **calculate** the number of kilowatt-hours your family used in the second 24-hour period. (THINK: What equation will help me calculate energy efficiency?)
b **Calculate** the approximate cost of each 24-hour period's electricity, assuming that each kWh costs 20 cents. (THINK: What information do I have? Where do I need to place this in an equation?)
c Write a list of all the electrical appliances your family used during this time (e.g. electric hot water, kettle, electric stove and/or oven, computers, TV, etc.). **Identify** the items that you think used the most energy during this time. (THINK: What items did your family use? Which items would use more energy? Can the appliance tell you this?)

*REVIEW

Multiple choice

1 The fact that energy cannot be created or destroyed but can be transformed or converted is explained by:
- **A** gravitational potential energy
- **B** kinetic energy
- **C** the law of conservation of energy
- **D** elastic potential energy.

2 The formula used to calculate gravitational potential energy is:
- **A** $\frac{1}{2} \times m \times v^2$
- **B** $\frac{1}{2} \times m \times g \times h$
- **C** $\frac{1}{2} \times k \times x^2$
- **D** $m \times g \times h$

3 Society may be reluctant to adopt sustainable energy sources because:
- **A** the financial cost seems too high
- **B** coal energy provides the best power
- **C** of the convenience of using renewable sources
- **D** of ignoring energy efficiency.

Recall and explain

4 **Define** the following terms in your own words.
- **a** Law of conservation of energy
- **b** Energy efficiency
- **c** Kinetic energy

5 **Explain** why energy is not 100% efficient, using an example.

6 **Recall** how energy is transferred.

7 **Outline** the energy transformations that occur when a ball is bounced.

8 **Identify** one economic reason Australia may not want to stop using fossil fuels and one economic reason that Australians may want to switch to more efficient energy sources.

9 Use an example of a toaster to **explain** how energy is transformed.

Apply and analyse

10 **Calculate** the efficiency of an incandescent light that uses 50 J of electrical energy in which only 10 J of the input energy is transformed to light energy.

11 The more stars an appliance is given, the more expensive it will be compared with similar appliances with fewer stars. If your family wants to buy a new dishwasher, would you advise them to buy a cheaper dishwasher or one with more stars? **Account** for your answer.

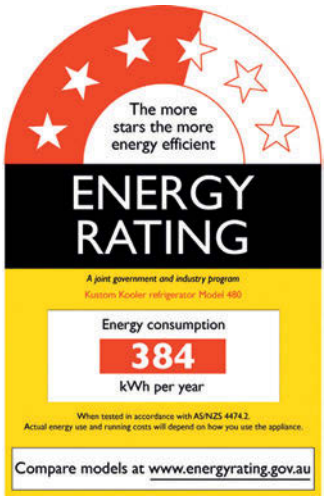

Figure 1 An energy rating label

12 **Explain**, using the law of conservation of energy, all energy transformations in a bouncing ball.

13 **Compare** the use of a 3-star energy-efficient appliance and the use of a 5-star energy-efficient appliance.

14 Figure 2 shows a pie chart with suggestions of what most Australian households use energy on. Based on this, **recommend** which energy sources would benefit the most from greater energy efficiency.

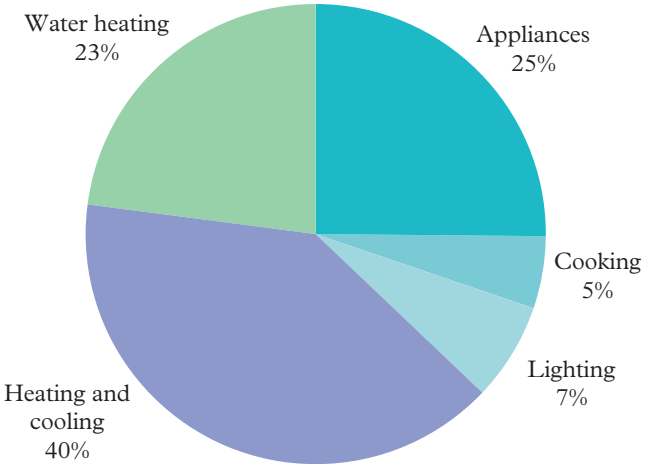

Figure 2 Share of total energy by end use – Australia – 2014

15 In 2019, 60% of electricity in Australia was generated from coal. However, coal consumption was 21% lower than its peak in 2008–2009. **Propose** what this suggests about society's preference in energy sources.

Evaluate and create

16 Design an investigation that will explore how much energy your year level uses each day at school. You will need to create a method and list of materials required. You will need to think about computers, heating, cooling, and the use of other electric items in your school. **Explain** why you have chosen the method and materials used.

Figure 3 How much energy does your year level use each day at school?

17 There have been many protests against the use of coal mines in Australia, with many fearing the environmental impacts. Despite this, coal continues to be a large export for Australia. **Investigate** if there are other resources Australia could export and any that Australia could also use to power the country. In your evaluation, be mindful that each resource may have its own issues with being used.

18 In NSW, transport is the biggest user of energy in the state – this includes cars, buses and trains, using approximately 45% of the state's energy. Using your knowledge of transport in your city, **propose** how this number could be reduced.

19 Write down all the ways you use energy during the day. Do you wear a smartwatch? Do you use a phone or a laptop? How do you get to school? Is it by car or public transport, or do you walk? How do you make breakfast? Is it in a microwave? Do you cook dinner using gas? Once you have written the list, **assess** how you could reduce the use of three energy sources during the day. Perhaps your school is close enough to walk to, or maybe you have an analogue alarm clock you could use instead of your phone.

20 When you make toast, electrical energy is transformed to heat energy to make the bread crispy. However, there are several other energy transformations that occur. **Identify** two other transformations, and consider how these could be reduced.

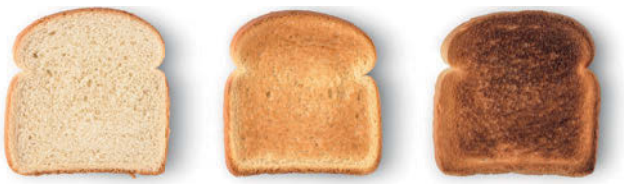

Figure 4 Bread to toast

Critical thinking

21 **Construct** a campaign poster that encourages Australians to adopt sustainable energy sources. In your poster **explain** the benefits and how energy is transformed.

22 **Investigate** how energy use has changed in Australia over the past 100 years. Note key changes that have increased energy consumption.

Go further

23 When a ball bounces off the floor, it has no potential or kinetic energy at the moment of impact. **Assess** where its energy has gone.

24 To investigate how sustainable you are, you can record your energy use for a week.

a **Identify** everything in your life that uses energy each week. You might want to think about:

- what you eat (e.g. what appliances are used in the kitchen?)
- how you study (e.g. do you use a laptop, tablet, notebook?)
- how you get to school (e.g. do you take public transport, drive or ride a bike?)
- what you do on the weekend (e.g. watch movies, play video games, use social media?)
- any other situation where you use energy.

b **Identify** how long everything you listed in part a needs to be:

- switched on or charged for (e.g. how many times a day do you charge your phone?)
- refueled or requires new batteries (e.g. if you get the bus to school, how many times a week does it need to get more petrol?)
- restored (e.g. do you have instant hot water at home?).

c Record your energy use in a table. Keep a tally of how much energy each device/appliance/situation uses.

d Present your weekly average use for everything you identified in part a in a graph. For example, if you charge your phone every day, this would be its own point on the graph.

e **Assess** how you could reduce your weekly energy use average. (Could you take notes by hand instead of using a computer? Could you walk to school instead of catching the bus?)

Research

25 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Renewable and non-renewable energy resources

Describe renewable and non-renewable resources of energy. Give some examples of renewable and non-renewable sources of energy. Explain the advantages and disadvantages of each resource. Assess the use of renewable and non-renewable energy resources.

»Global warming

What is global warming? What are greenhouse gases? What is carbon emission? What is carbon tax? How is the use of non-renewable energy resources related to global warming?

Figure 6 In September 2019, citizens held a rally to protest climate change.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Apply the law of conservation of energy to account for the total energy involved in energy transfers and transformations.	☐	☐	Go to pages 76-77
Describe how, in energy transfers and transformations, a variety of processes can occur so that usable energy is reduced and the system is not 100% efficient.	☐	☐	Go to pages 78-79
Discuss, using examples, how the values and needs of contemporary society can influence the focus of scientific research in the area of increasing efficiency of the use of electricity by individuals and society.	☐	☐	Go to pages 80-81
Discuss viewpoints and choices that need to be considered in making decisions about the use of non-renewable energy resources.	☐	☐	Go to pages 80-81

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.Figure 5 A tennis ball bouncing

THE UNIVERSE

Where did the universe come from?

Have you ever wondered ...

- How do astronomers see deep into space?
- What was the Big Bang?
- Where do stars come from?

6

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- outline some of the major features contained in the universe, including galaxies, stars, solar systems and nebulae
- describe, using examples, some technological developments that have advanced scientific understanding about the universe
- use appropriate scales to describe differences in sizes of and distances between structures making up the universe
- identify that all objects exert a force of gravity on all other objects in the universe
- use scientific evidence to outline how the Big Bang theory can be used to explain the origin of the universe and its age
- outline how scientific thinking about the origin of the universe is refined over time through a process of review by the scientific community

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

6.1 The universe is made of galaxies, solar systems, stars and nebulae

In this topic, you will learn that:

- Earth is part of the Milky Way
- galaxies are groups of stars held together by gravity
- solar systems are groups of planets held together by gravity.

universe
the collection of everything in existence; including solar systems, galaxies and stars

The **universe** is huge, and it is organised into groupings and structures by gravity. It is lit up and powered by the stars. Many of the stars are so far away from the Earth that their light takes thousands of years to reach us. This means we are actually looking back in time, because the light from a star tells us how that star looked thousands of years ago and not how it looks today. As well as stars, the universe has galaxies and solar systems.

Figure 1 Our solar system can be found on one of the arms of the Milky Way.

Galaxies

galaxy (galaxies)
a system of billions of stars, gas and dust that is held together by gravity

Milky Way
a barred spiral galaxy that contains our solar system

Groups of stars are held together by gravity. These groups of stars form **galaxies**. Our Sun is part of a spiral-shaped galaxy called the **Milky Way**. Galaxies are classified according to their shapes: elliptical, spiral or irregular (Figures 1 and 2).

In addition to stars, galaxies are also made of gas and dust that are also held together by gravity. Galaxies are sometimes considered to be the building blocks of the largest structures in the universe. These blocks group together to form clusters, which then form superclusters. The force of gravity connects all of these.

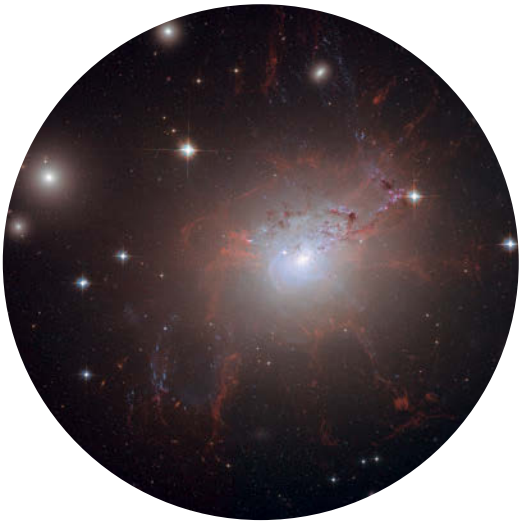

Figure 2 An elliptical galaxy

Solar systems

solar system
the eight planets, and their moons, that orbit the Sun, including gas or dust

Our **solar system** has the following elements:

- a central star that planets orbit
- objects that orbit the star, including comets, asteroids, moons, dwarf planets and dust.

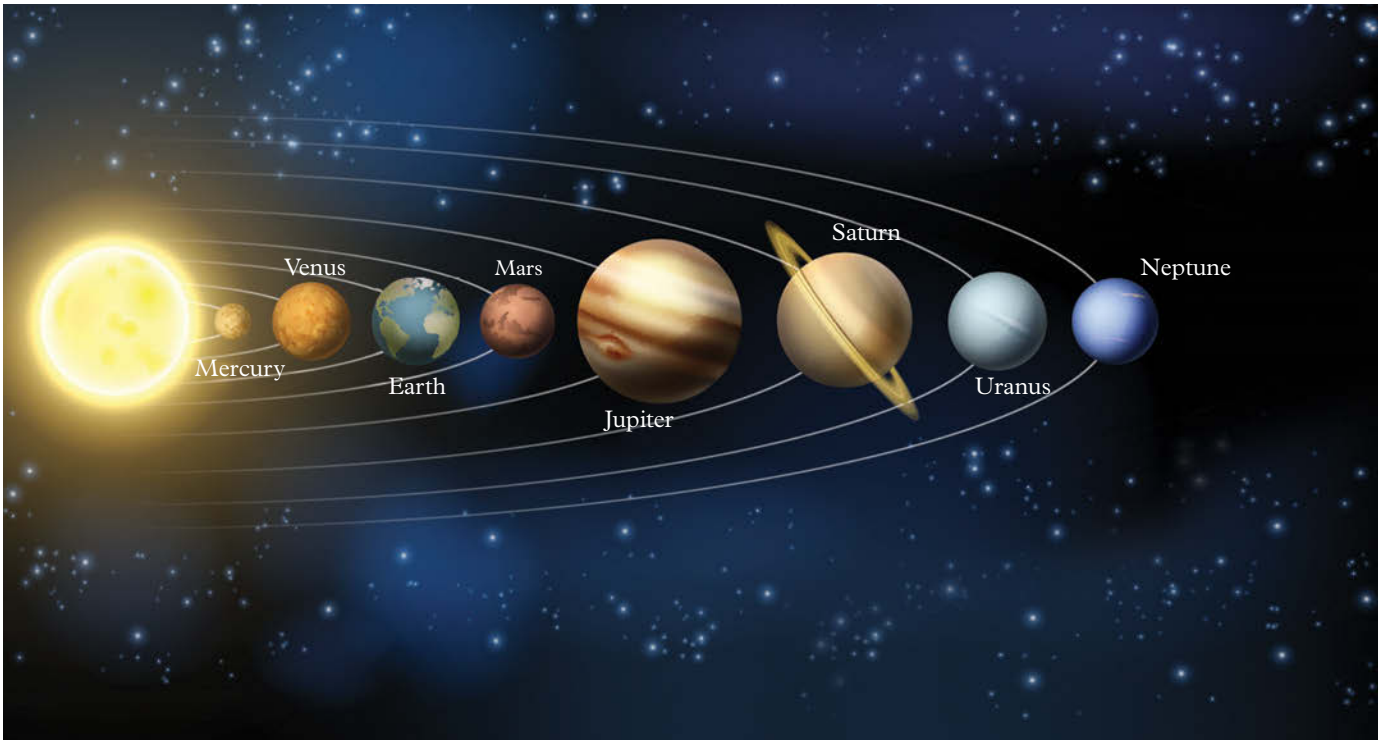

Figure 3 Our solar system

The central star in our solar system is the Sun, which is orbited by eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Dwarf planets and smaller bodies in our solar system also orbit the Sun. Our solar system was formed approximately 4.6 billion years ago.

Stars

A **star** is a giant ball of hot glowing gases that undergoes nuclear fusion. Stars can vary in size, mass, temperature and brightness.

Brighter stars are described as having a high apparent magnitude, and larger, hotter stars that are further away will have higher absolute magnitude. Most stars are made almost entirely of hydrogen and helium. These gases are constantly reacting at the core (centre) of the star and provide energy to the star through **nuclear fusion** (when atomic nuclei join). This energy is emitted as light (and other forms of electromagnetic radiation) and is what we see when we look at the stars at night. When we see groups or clusters of stars, these are constellations.

nuclear fusion
a high-energy reaction in which two lighter atomic nuclei fuse to form a heavier nucleus

star
an object in space that is made of hydrogen and helium, and which is luminous in the sky

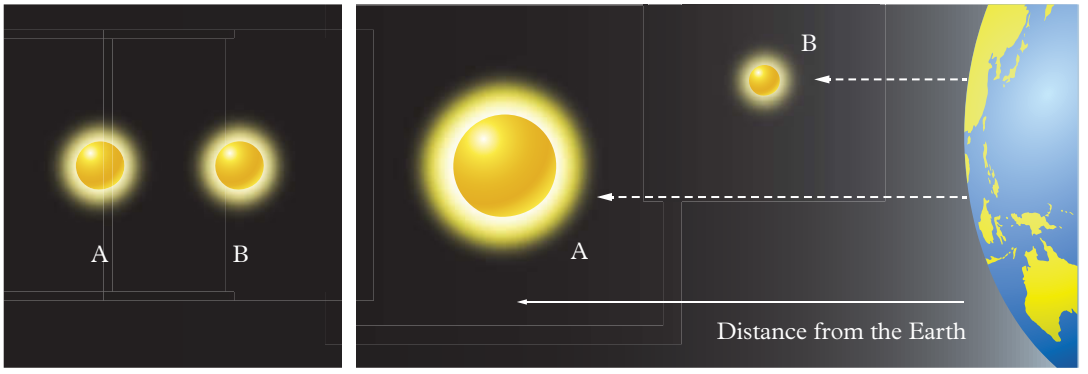

Figure 4 Although both stars A and B have the same apparent magnitude, A is more luminous and has a higher absolute magnitude than B.

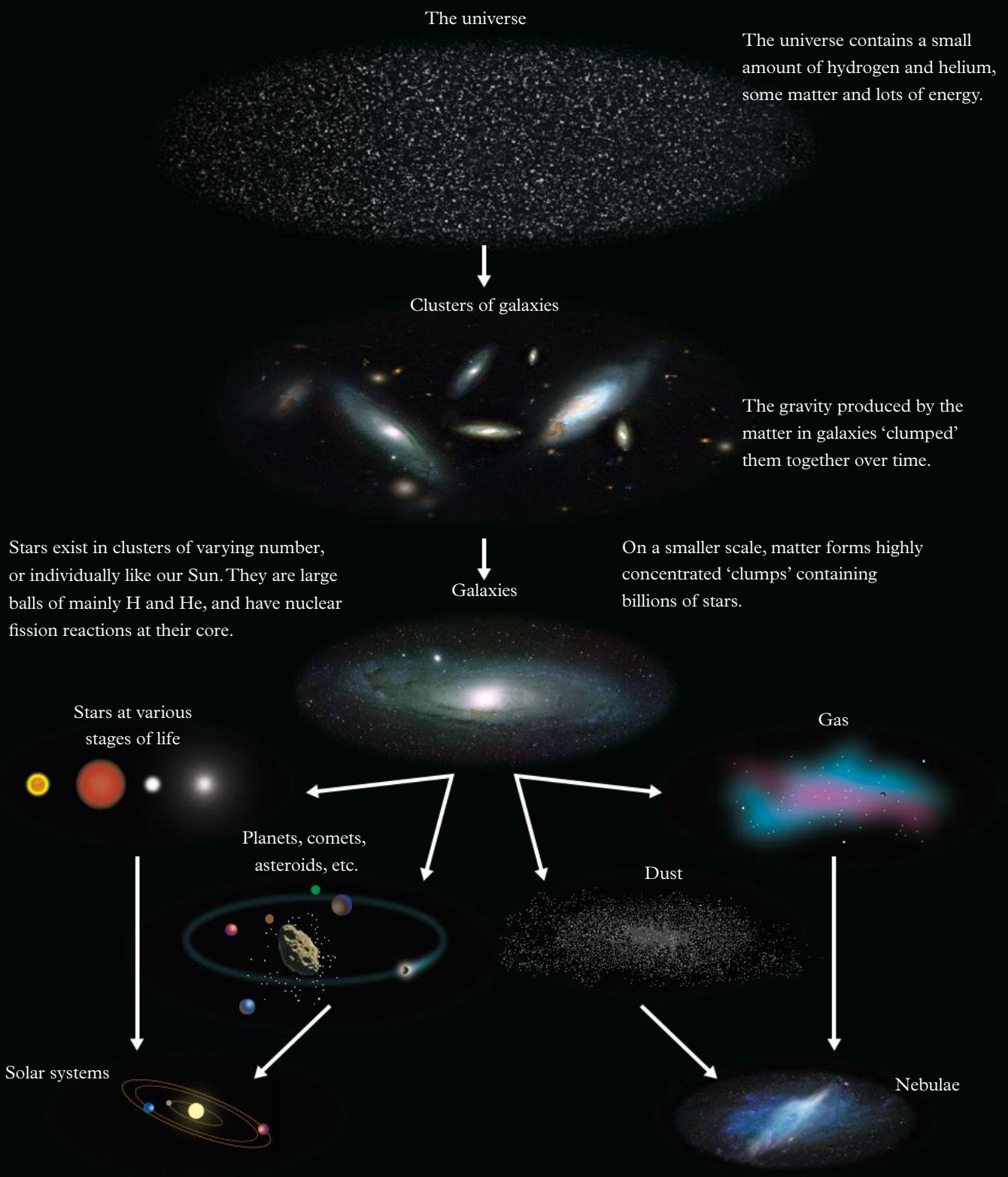

Figure 5 The hierarchical structure of the universe

What does a star's brightness mean?

The brightness of a star viewed from the Earth is measured on a scale called the **apparent magnitude scale** – a measure of how bright it 'appears' to be. The Sun is the brightest object in the sky and has an apparent magnitude of –27. In comparison, a full Moon has an apparent magnitude of –13. So, the more positive (and the less negative) the number, the dimmer the star.

A star may appear to be quite bright because it is close to the Earth though it may not actually be very bright (Figure 4). For example, the Sun is not a very bright star compared with other stars, but it is the closest star to the Earth.

The **absolute magnitude scale** measures a star's brightness as if all stars are the same distance from the Earth – its actual brightness or **luminosity**. Therefore, a star may have a higher absolute magnitude but appear less bright because it is a long way from the Earth.

What does a star's colour mean?

Another way of comparing stars is to analyse their colour. The colour of a star depends on its surface temperature. Blue stars are the hottest and red stars are the coolest.

An interesting method of displaying star data is on a graph called a **Hertzsprung–Russell diagram** (Figure 6). This shows a plot of the star's temperature on the *x*-axis and the star's absolute magnitude on the *y*-axis. When plotted this way, most stars, including our Sun, fall into a narrow diagonal band called the main sequence.

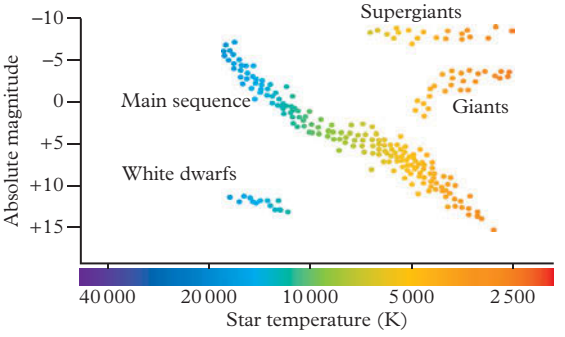

Figure 6 A Hertzsprung–Russell diagram

apparent magnitude scale
a scale for measuring the brightness of an object when viewed from the Earth

Hertzsprung–Russell diagram
graph displaying star data with spectral class or star temperature on the *x*-axis and absolute magnitude on the *y*-axis

absolute magnitude scale
a scale for measuring the brightness of objects from the same distance; used to compare the actual brightness of different stars

luminosity
the actual brightness of a star; see absolute magnitude scale

Check your learning 6.1

Recall and explain

1 **Outline** what each of the following are:
   - **a** a star
   - **b** a galaxy
   - **c** a solar system.

2 **Identify** the galaxy that Earth is found in.

Apply and analyse

3 **Contrast** a galaxy with a solar system.

4 **Calculate** the approximate difference in temperature between white dwarf stars and supergiants by interpreting the graph in Figure 6.

Evaluate and create

5 **Evaluate** this claim: 'Our solar system is the only solar system in our galaxy.' Hint: You might need to conduct some further research.

Skill builder: Processing and analysing data and information

6 Look at Figure 6 (the Hertzsprung–Russell diagram). **Interpret** this graph to **identify**:
   - **a** the coldest group of stars (THINK: Which axis represents temperature? Is another clue given to temperature in the graph?)
   - **b** which star has the largest absolute magnitude. (THINK: Which axis represents absolute magnitude?)

7 Using Figure 6, **calculate** the average difference in temperature from the giants to the white dwarfs. (THINK: What is the closest figure to their location on the graph?)

6.2 Stars begin their life cycle in nebulae

Figure 1 This image of Kn 61, a newly confirmed planetary nebula, was taken by Professor Travis Rector, University of Alaska, Anchorage, using the 8.1-metre Gemini Telescope. The nebula appears as a blue bubble, and a bright star and spiral galaxy can also be seen.

In this topic, you will learn that:

- stars are born in clouds of gas called nebulae
- stars exist in hydrostatic equilibrium which is the pull of gravity towards the centre and the push of energy from nuclear fusion
- stars have a life cycle: small stars eventually die and result in white dwarfs and black dwarfs, whereas larger stars explode in novas and supernovas.

In the constellation of Orion lies a group of stars known as the Saucepan. A misty patch in this constellation, just visible to the naked eye, is the M42 (or Great Orion Nebula). This region of gas and dust also has new stars just as they begin to emit light. It is a stellar nursery, with stars being born all the time. Our own Sun would have been born in a similar region. Throughout the universe, stars are at various stages of their lives. Young, medium age, old and dying stars can be found, as well as exploded stars.

Nebulae: The birth of a star

Across the universe are large clouds of hydrogen gas called **nebulae**, which act as star nurseries. Even though these hydrogen atoms are very small, they are attracted to each other by gravity. The more the hydrogen atoms gather together, the greater the attractive force. The hydrogen atoms in the centre of the cloud are under a great deal of pressure, causing the centre of the gas cloud to heat up. Eventually there is enough heat and pressure to fuse two hydrogen atoms together, forming helium. This nuclear fusion releases large amounts of energy in the form of heat and light. A star is born. You can see a nebula in Figure 1.

Adult stars

The release of energy from the nuclear fusion of hydrogen atoms forces the gas particles out, while the force of gravity pulls the atoms in. These two forces become balanced so that the star stabilises to a consistent size. This balance of forces is called a **hydrostatic equilibrium**. A main sequence star can maintain this balance between the forces for millions of years.

Older stars

Eventually the hydrogen available for nuclear fusion starts to decrease. When this occurs, the gravity force becomes stronger than the force pushing the hydrogen atoms out. The gas particles are pulled closer to the centre of the star, producing even greater pressure (and higher temperatures). Eventually the helium atoms start to fuse, forming carbon atoms. This form of nuclear fusion releases even more energy than hydrogen fusion. The star grows larger as the forces reach a new hydrostatic equilibrium. This cooling and expansion results in the formation of a **red giant** star (Figure 2). Our Sun will do this in about 5 billion years from now. Because of its size, the Sun will swallow up the inner planets of the solar system – Mercury, Venus, Mars and Earth.

Death of a star

Eventually the amount of helium available decreases as well. As the outer regions of lighter red giants fade away, the shell is called a **planetary nebula**, although it has nothing to do with planets (Figure 3). Only the core remains at the centre. Further nuclear reactions occur, increasing the rate of energy release and therefore the temperature. The core becomes white hot and the star is called a **white dwarf**. As this mass cools, the star gradually fades away to become a **black dwarf**.

nebula (nebulae)
a cloud of gas and dust in space; a star nursery

hydrostatic equilibrium
this refers to a condition where the forces become balanced resulting in some form of stability

red giant
a large, bright star with a cool surface that forms when a star like our Sun runs out of hydrogen fuel

planetary nebula
a glowing shell of gas formed when stars die

white dwarf
a small, hot star that forms when a star like our Sun runs completely out of fuel and slowly fades and cools

Heavier red giants seem to have a different fate. The nuclear fusion process continues through various elements until iron is formed. Eventually, the star runs out of energy for fusion reactions and collapses. This increases the pressure and temperature to extreme levels. The resulting explosion is the largest explosion in the universe – a **supernova**.

After the supernova, the remaining core is amazingly dense and electrons and protons collide to form neutrons, creating a **neutron star**. Neutron stars are only tens of kilometres in diameter and remarkably dense. A teaspoonful of neutron star material would have the same mass as 100 000 cars!

If a neutron star collapses further, its gravitational pull and density become so huge that not even light can escape. These are **black holes**. As matter falls towards a black hole, X-rays are emitted and this is how possible black holes are detected in space, although their existence is still to be determined absolutely.

black dwarf
a remnant formed when a white dwarf star cools and gradually fades away

supernova
an explosive death of a star

black hole
a region in space of infinite density where gravity is so large that nothing can escape from it, including light itself

neutron star
a small, highly dense star, made mostly of neutrons

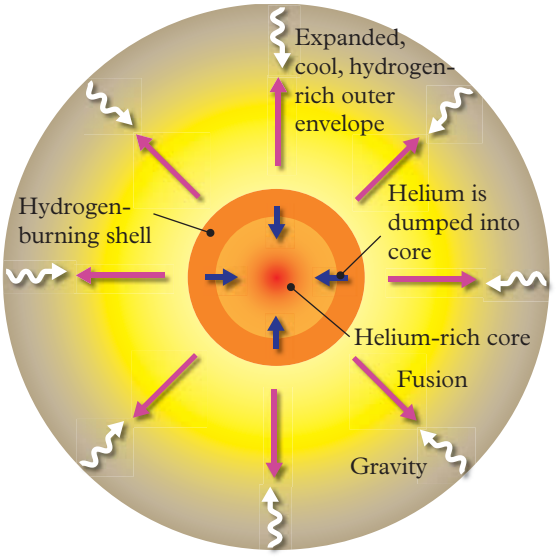

Figure 2 How a red giant star forms

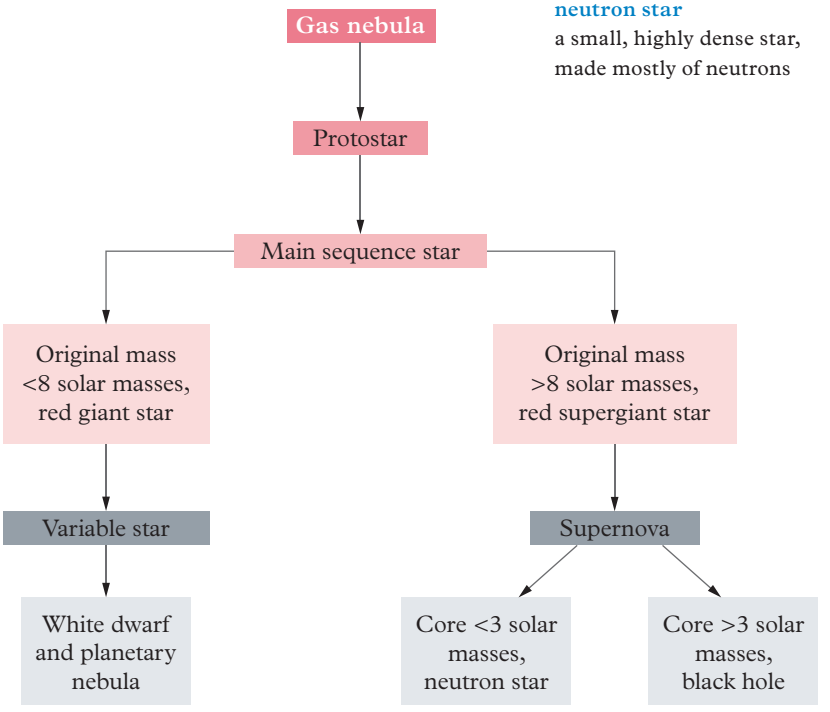

Figure 3 The life cycle of a star

Check your learning 6.2

Recall and explain

1 **Identify** what marks the birth of a star.
2 **Describe** a red giant star.
3 **Define** nebula.
4 **Clarify** what is left after a supernova.

Apply and analyse

5 **Compare** white dwarfs and black dwarfs. **Explain** why these are different to a red giant.

Evaluate and create

6 **Investigate** the life cycle of Rigel (one of the brightest stars in our night sky). Create a presentation to **explain** the life cycle for the general public. Be sure to include information on the following:

- where stars come from
- how stars grow
- how a star 'dies'
- the different types of stars.

You will need to **investigate** Rigel and record a reference list of any sources you use.

Skill builder: Communicating

7 Scientists communicate concepts visually to help understanding and clarify events.

a Using a flow chart, **outline** the life cycle of a star the size of our Sun. (THINK: How does a star this big form? What labels and arrows do I need to include in this flow chart?)

b Give your chart an appropriate label.
(THINK: Does this label concisely explain the information?)

6.3 Technology aids cosmological research

In this topic, you will learn that:

- telescopes enable scientists to look into the universe and see galaxies
- robots allow different planets to be explored safely.

People have always looked to the sky and stars and asked questions. They began recording the movements of the stars and sky centuries ago; however, it was not until recently that scientists have been able to describe and explain features and activities of the universe through the development of technologies.

Telescopes allow scientists to see further into space

telescope
an optical device that is used to make distant objects appear closer, through the use of specifically arranged lenses and light

Galileo Galilei changed human understanding of the universe when he turned his **telescope** to the night sky. Before he did this, scientists, philosophers and people made observations that were limited to what their eyes could see, which of course is what your eyes see when you look at the sky. With Galileo's telescope, people's eyes could gather more light to see fainter objects in the distance and see finer details in the sky.

With his telescope in 1610, Galileo was able to make the following discoveries.

- Jupiter had four bright moons orbiting it.
- Venus went through similar phases to Earth's Moon.

Until these observations, people believed that Earth was the centre of our solar system; these discoveries provided evidence that this was not the case. This was called the geocentric model. This idea was not broadly accepted at the time, with challenges made by the Roman Catholic Church.

From Galileo's first telescope, science has progressed to use further technology to search into space, trying to answer the question 'What is out there?'.

Modern telescopes see further

Modern telescopes use curved mirrors to gather light from the sky. The shape of the mirror concentrates different amounts of light, which allows astronomers to see different things. When you look into a telescope you see this light.

As science progressed from Galileo's original telescope, more sophisticated telescopes have been invented. For example, the twin Keck telescopes in Hawaii. These can see further into the universe and further back in time than previous telescopes. These twin telescopes are the third and fourth biggest in the world.

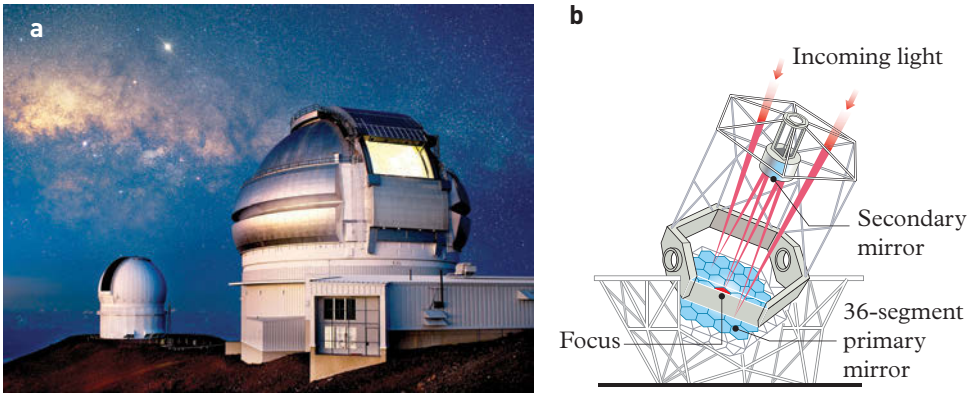

Figure 1 a The twin telescopes of the Keck observatories. **b** Each telescope uses 36 hexagonal mirrors each with a diameter of 1.8 m, which are controlled by computers to focus on astronomical objects. The telescopes can work together or independently.

Currently, the largest telescope in the world is thought to be the Large Binocular Telescope, located in Arizona, USA. In 2008, it discovered a galaxy that is over 7 billion light-years away from Earth.

The Square Kilometre Array (SKA) is a large multi-radio telescope project being built in South Africa and Western Australia. Eventually, the SKA will coordinate several large telescopes to be able to take large-scale photographs of the universe, allowing astronomers to see more galaxies. SKA will be used to test Einstein's theory of general relativity and map out galaxies to the observable universe, as well as searching for extraterrestrial life.

The Hubble Space Telescope was launched into low Earth orbit in 1990. It has a 2.4 m mirror, and it primarily observes ultraviolet, visible and near infrared regions of the electromagnetic spectrum. Because the Hubble Space Telescope orbits outside Earth's atmosphere, it is able to record more detailed images.

Charge-coupled devices

The invention of telescopes allowed humans to see further than they had before, but as often happens, the more people could see, the more they wanted to see.

This curiosity led to the invention of the charge-coupled device (CCD). The CCD is the chip that you find in a camera or phone that takes images.

CCDs are used to detect electromagnetic radiation and then convert this into digital information so that it can be processed. Mirrors collect the light and focus it onto the CCD chips – each chip collects millions of pixels of information over a period of time and sends this information to a computer.

Mars Science Laboratory

The further we have been able to see into the night sky, the further humans have wanted to travel into the skies. Within the last century, we have developed rockets, satellites and communication technology and begun to physically explore the universe.

In 1969, astronauts walked on the Moon for the first time. However, space travel places a lot of stress on the human body, and astronauts must undergo extensive training to prepare for this.

Advancing technology has created robotic space exploration. This exploration has focused on Mars in recent years, with *Curiosity* (a robotic rover) exploring Mars since 2012. *Curiosity* has advanced technology including laser spectrometers, microscopic imagers, a robotic arm to collect samples and AI (artificial intelligence) for autonomous navigation.

The Mars Science Laboratory is investigating whether Mars once had an environment that would support life, such as bacteria. This helps consider the question, is there other life in the solar system?

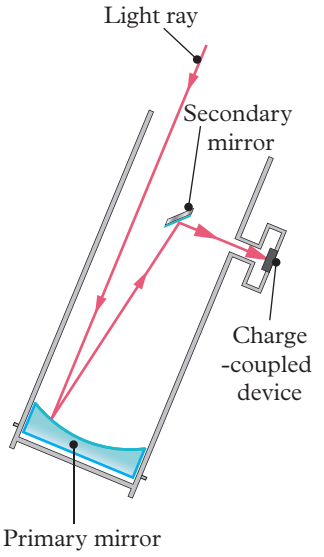

Figure 2 How a small telescope and a CCD are combined to take astronomical images.

Check your learning 6.3

Recall and explain

1 **Describe** the basic structure of a telescope.

2 **Recall** some of the major discoveries made using a telescope.

3 **Describe** technology other than the telescope that we have used to explore the solar system.

Apply and analyse

4 **Propose** why the 36 segments of the primary mirror in Keck telescopes are controlled by computer rather than by hand.

Evaluate and create

5 Using examples, **discuss** how advances in technology have led to advances in scientific knowledge and understanding of the universe.

Skill builder: Planning investigations

6 Prior to conducting a new investigation, it is important to conduct research into the existing information on this topic. **Investigate** two different types of telescopes in the atmosphere above the Earth.

a **Identify** the name, date of launch and purpose. (THINK: Read thoroughly to confirm your information is correct.)

b **Justify** why the source you have chosen to find this information through is valid and reliable. (THINK: Is it from a credible source? Are the authors scientists? When was it published?)

6.4 Specific measurements are used for the universe

In this topic, you will learn that:

- the Doppler effect is the apparent change in wavelength when the source of waves or the observer is moving
- red shift is the apparent decrease in frequency of light from galaxies moving away from the Earth
- light-years are a measure of distance that light travels in 1 year
- stellar parallax is a change in the apparent position of a star.

light-year
the distance that light travels in 1 year

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions

The universe that we can observe consists of all the stars, galaxies and other objects that we can see from the Earth – it is enormous. We can only see these objects because light, or another type of signal, from these objects has had time to reach the Earth and we can detect the signal.

Elements will absorb light energy in specific wavelengths, creating an absorption spectrum. When the same elements return to a stable state, they will release the same wavelengths of energy as an emission spectrum. These two spectra allow scientists to determine the elements that are present in different parts of the universe.

The Doppler effect describes that change in a frequency of a wave as an object moves towards or away from an observer.

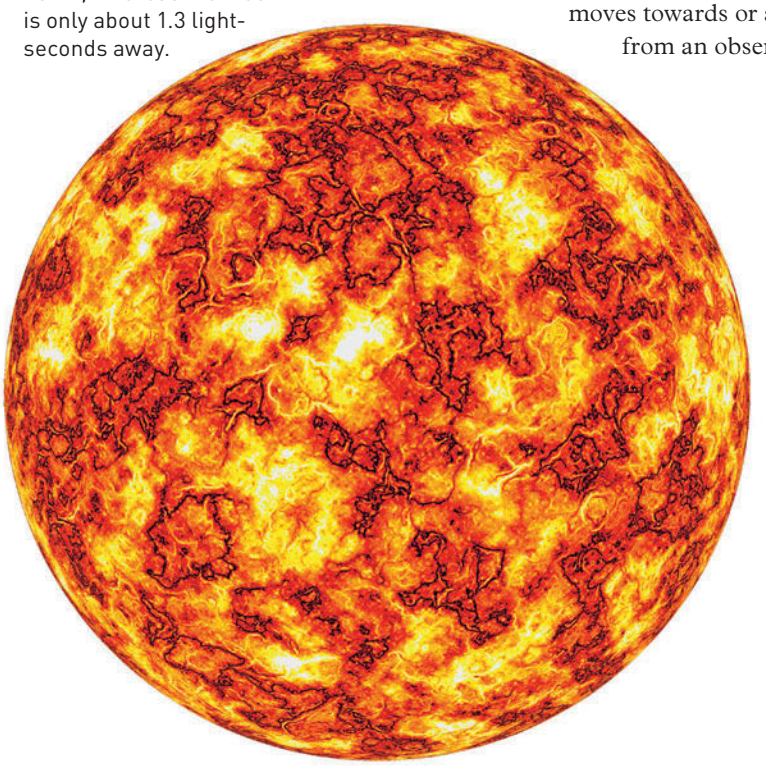

Figure 1 The Sun is approximately 500 light-seconds away from the Earth, whereas the Moon is only about 1.3 light-seconds away.

A red shift in the emission or absorption spectrum of a galaxy indicates that the galaxy is moving away from the observer.

Light-year

Light travels very fast – at 300000 km/s. The distance that light travels in 1 year is called a **light-year** (9500000000000 km). Light-years are used to measure the distance of stars from the Earth. The nearest star to the Earth is our Sun, which is only 500 light-seconds from the Earth. This means it takes 500 seconds (approximately 8 minutes) for the light from the Sun to reach the Earth. The next closest star to the Earth is Proxima Centauri, which is 4.2 light-years away. This means if Proxima Centauri was to explode, it would take 4.2 years for the light to reach the Earth and for you to see the explosion!

Stellar parallax

Every night, the stars and planets appear to move across the night sky. During the night, we can observe the 'movement' of our Moon through the sky as it rises and, much later, as it sets.

All stars 'move' in the sky; although, because they are so far away, their movement is much less noticeable than that of the Moon.

This effect, known as **stellar parallax**, is used by astronomers to calculate the distance to nearby stars (i.e. those stars closer than 100 light-years). Beyond this distance, spacecraft are needed to calculate the distance accurately. When a star is observed from two different positions (e.g. in January and then 6 months later in July), its position relative to other stars may appear to be different (Figure 2).

CHALLENGE
6.4a: Understanding parallax
Go to page **368**

INVESTIGATION
6.4a: Investigating emission spectra
Go to your **obook**

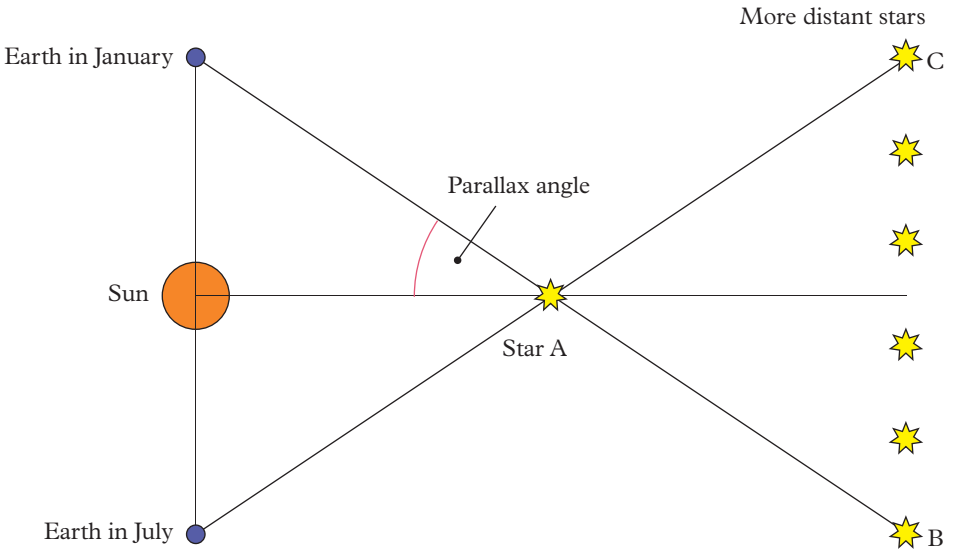

Figure 2 Measuring the distance to stars using stellar parallax. In January, star A (a close star) is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth's orbit, the distance to star A can be calculated.

Resource
STEM activity: Sit back and parallax

Measuring the movement of galaxies

As a star undergoes nuclear fusion, it releases energy in the form of light. The outer layers of gas surrounding the star contain elements that will absorb specific wavelengths of light energy. This causes dark lines in the spectrum of light that leaves the star. This is called the **absorption spectrum** of a star. The set of dark bands in the light spectrum is unique to the element contained in the star.

Alternatively, if there is a nebula or gas cloud near a star, the elements in the gas will also absorb some of the energy from the star and become excited. Eventually the elements will return to their stable state and emit (release) the unique bands of light energy they absorbed. This is called the **emission spectrum**.

Compare the emission spectrum and the absorption spectrum of helium in Figure 3. The absorption spectrum contains lines in exactly the same positions as in the emission spectrum.

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

absorption spectrum
a spectrum with lines missing from the pattern; the opposite of an emission spectrum because the element has absorbed its characteristic light wavelengths and removed them from the spectrum

Figure 3 a Absorption spectrum and **b** emission spectrum of helium

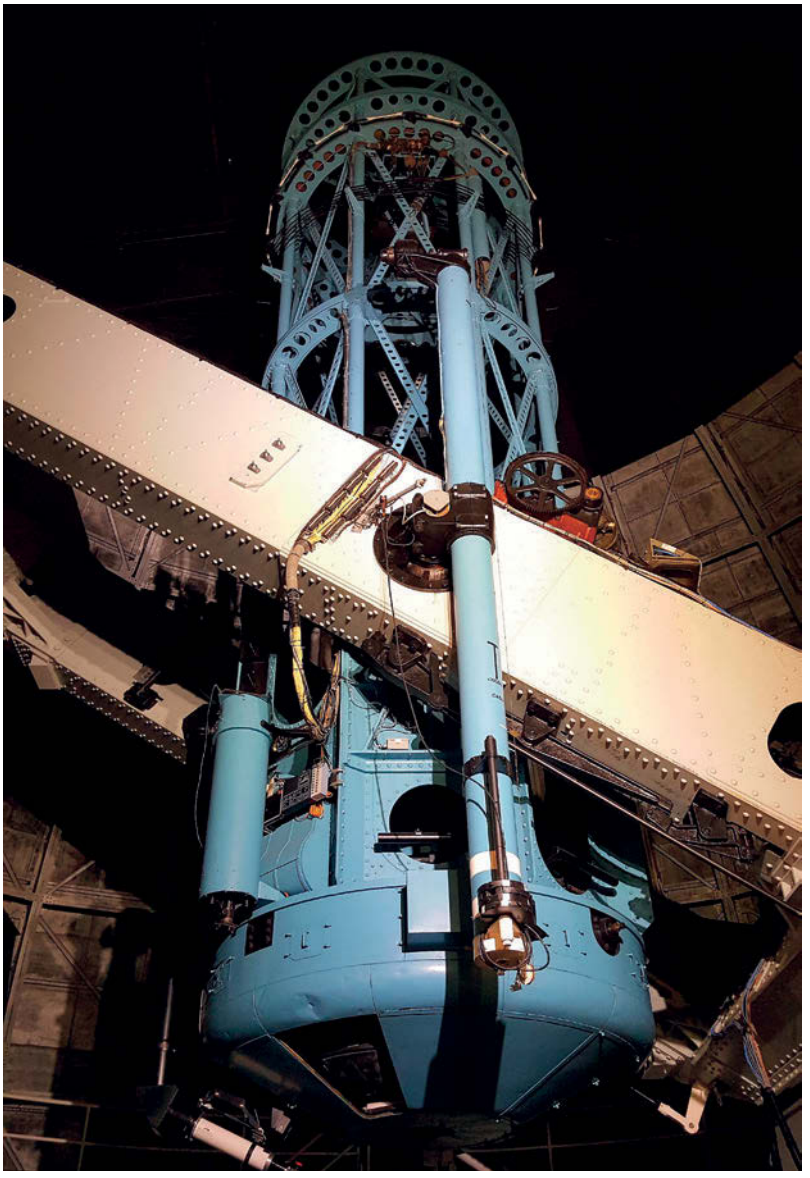

Figure 4 The Hooker telescope (which Edwin Hubble used) at the Mount Wilson Observatory

In the 1920s, using the most powerful telescope in the world at the time, Edwin Hubble examined the spectra of light absorbed and emitted by the galaxies.

Absorption spectra can also reveal another important aspect of a distant star – its velocity – which is what Hubble discovered.

Doppler effect

When a racing car races past you, the pitch of its sound appears to change. This can be modelled by making a 'yeee … owww' sound with your voice. The 'yeee' is the high pitch from the car's engine as it approaches you – its sound waves are being bunched up as the car speeds in your direction. This causes the lengths between the waves to be shorter, increasing the pitch (or frequency) of the sound. As the racing car passes you, the pitch you hear drops – that's the 'owww' part. The car is now speeding away from you and sending the sound waves back to you, lengthening their wavelength and lowering the pitch. The faster the car goes, the more pronounced the effect.

This is known as the **Doppler effect**, after its discoverer, Christian Doppler. The Doppler effect happens with ambulance and police car sirens, trains, fast noisy objects and light (Figure 5).

Red shift, blue shift

When Hubble looked at the absorption spectra of distant galaxies, he saw that the lines were shifted in the red direction of the spectrum. Red light has a long wavelength; blue light, at the other end of the visible spectrum, has a shorter wavelength. A shift in the red direction,

Doppler effect
the apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

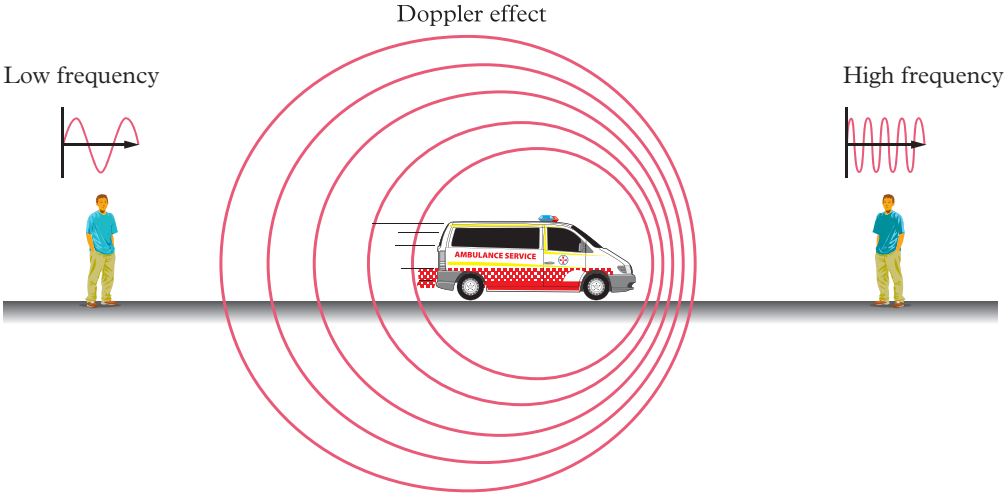

Figure 5 The Doppler effect

CHALLENGE
6.4b: Exploring the Doppler effect
Go to your obook

INVESTIGATION
6.4b: Calculating the distance to the Sun
Go to page 369

which is known as a **red shift**, indicates that the galaxy is moving away from the Earth. The greater the shift of the emission light bands towards the red spectrum, the faster the galaxy is moving. A shift in the blue direction (a **blue shift**) indicates that the star is moving towards the Earth. The greater the shift towards the blue spectrum, the faster the galaxy is moving.

Edwin Hubble's big discovery was that the more distant galaxies tended to have more red-shifted spectra and, hence, were travelling faster away from the Earth. This discovery became known as Hubble's law and provides compelling evidence for the Big Bang theory.

Hubble's law was followed up by a group of scientists including US-born Australian Brian Schmidt. Their research determined the expansion of the universe is accelerating. As a result, Brian Schmidt was awarded a Nobel Prize in 2011.

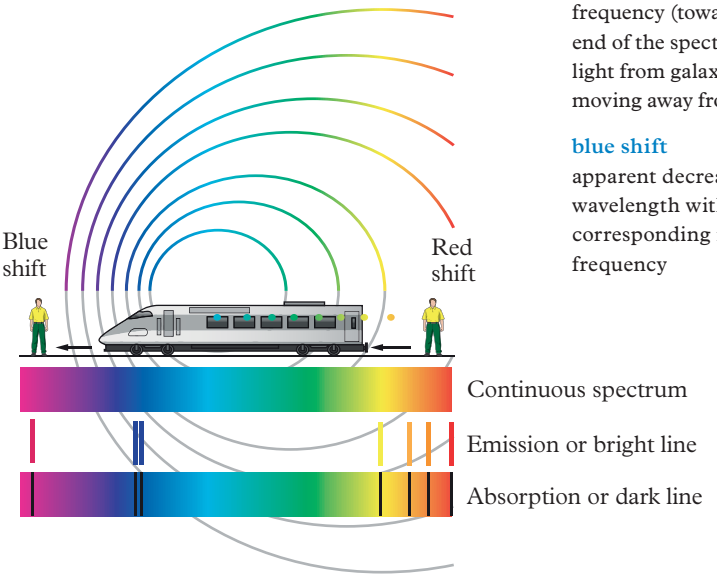

Figure 6 The red shift and blue shift

red shift
apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

blue shift
apparent decrease in wavelength with a corresponding increase in frequency

Check your learning 6.4

Recall and explain

1 **Clarify** what the term 'stellar parallax' means.
2 **Outline** how you would know you were looking at an absorption spectrum.
3 **Explain** what a light-year measures.

Apply and analyse

4 If a star that was 20 light-years away exploded right now, **calculate** when we would see it exploding.
5 **Calculate** the distance from Earth, in kilometres, of:
  a the Large Magellanic Cloud at 180 000 light-years
  b Beta Centauri at 525 light-years
  c the Andromeda galaxy at 2.5 million light-years.
6 **Compare** emission and absorption spectra.
7 **Summarise** how red-shifted light shows that a galaxy is moving away from us.
8 Figure 7 shows the spectra observed from three stars. Star A is at a fixed distance from the Earth, whereas stars B and C are moving.
  a **Deduce** what produces the dark lines on each spectrum.
  b **Extrapolate** which star, B or C, is moving towards the Earth. **Justify** your answer.

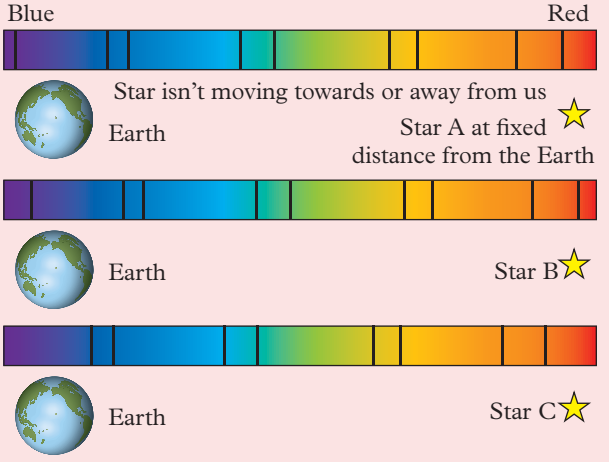

Figure 7 The spectra observed from three stars A, B and C

Evaluate and create

9 **Assess** why stars that are further away than 100 light-years can only be measured using space travel.

Skill builder: Conducting investigations

10 Scientists use scientific notation and specific measurement terms to record and report their findings.
  a 1 light-year is 9 500 000 000 000 km. Convert this to scientific notation.
  (THINK: What is scientific notation? How do I express this number using scientific notation?)
  b **Explain** why it is important for scientists to use a universal notation system.
  (THINK: Is it possible for numbers to drop off a report? Do scientists deal with extremely small and extremely large numbers? Science is shared among an international community).

6.5 Gravity is everywhere in the universe

In this topic, you will learn that:

- all objects exert a force of gravity on all other objects in the universe.

gravity
a force that attracts mass towards mass; for example, mass towards the centre of the Earth

Gravity is a force that holds you to the Earth; it is what keeps water in your cup, and it pulls balls back to the ground when you kick them. Gravity is the attraction of two objects and is everywhere in the universe.

Attraction between objects is gravity

All objects that have mass exert a force of gravity on other objects with mass. If two objects are placed in space, 10 cm apart, provided they each have mass, they will eventually pull towards each other and collide.

We don't notice the effects of gravity on a daily basis. This is because the day to day effects are small exertions of gravity. But it is possible to observe gravitational forces on Earth. Earth has a mass of 6×10^{24} kg, which is pulled by gravitational forces in space.

You may have heard that Earth's ocean currents are controlled by the Moon. The Moon's gravity pulls the oceans towards it as the Earth rotates on its axis each day.

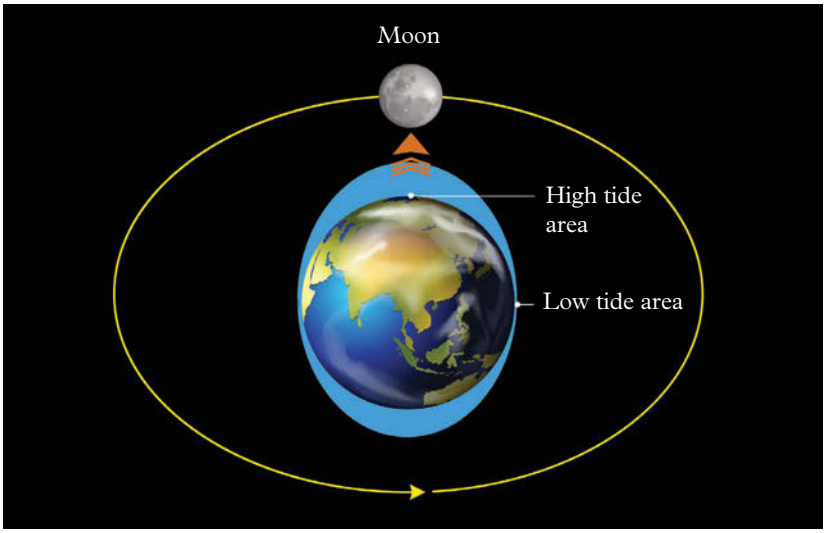

Figure 1 The Moon's gravity causes tidal changes on Earth.

In Figure 1 you can see that the bulge is created as gravity pulls the water on Earth's surface.

This is the same gravitational force that holds the Moon in orbit around Earth. If this force was not present, the Moon would veer away in a straight line, rather than orbiting Earth. Similarly, if this force did not exist, Earth would not orbit the Sun and would veer away. The Sun is held in orbit as it is the centre of the galaxy. Our galaxy, the Milky Way, feels the pull of gravity from other galaxies surrounding it.

Newton's universal law of gravitation

Isaac Newton is often drawn with an apple falling from a tree, and you may have wondered why. Newton famously realised that the force that made the apple fall to the ground was the same force that makes the Moon orbit the Earth.

Newton also realised that gravitational force decreased with distance – that is, the further apart two objects with mass are, the less they can exert a force on each other. Newton expressed this realisation in an equation. He stated that the force of attraction (F), in newtons, between any two objects with mass (m) acts with equal magnitude and in an opposite direction on each mass. This is the *universal law of gravitation*. It is expressed in the following formula:

$$F = G\frac{m_1 m_2}{d^2}$$

where G is the gravitational constant (6.67×10^{-11}), m_1 and m_2 are the masses of the two objects in kilograms, and d is the distance in metres between the centres of the two masses.

When the distance (d) between object 1 (m_1) and object 2 (m_2) is big, then d^2 will also be big. If d^2 is big, then the fraction in the equation will be a small number. This fraction is the force, which means that the force is also small. If the two objects are closer together, then the distance is small, which in turn makes the force large.

Gravity supports the Big Bang theory

After the universe had cooled to a certain point, gravity's attraction began the formation of the universe. Gravity is responsible for bringing the matter in the universe together, and as it has continued to age, gravity made larger structures and eventually planets.

- Approximately 1 billion years after the universe began, stars came into existence as a result of gravity pulling hydrogen and helium together. Once together, these groups became hotter until nuclear fusion occurred, giving rise to the stars.
- Not long after, gravity pulled stars and planets together, which formed the first galaxies, and gravity then pulled the galaxies together to create galaxy clusters.
- Approximately 5 billion years ago, the same gravitational force formed the Sun and planets. Not long after, approximately 4.6 billion years ago, gravity pulled particles together for the Sun, leaving the heavier particles left behind to form Earth.

In the beginning, there was only hydrogen, helium and a little bit of lithium in the universe. The remaining elements that make up Earth were created in the core of a star, which then spread through the galaxy. Gravity collected these elements until there were enough to form our solar system.

The history of Earth is intertwined with the history of the universe. You cannot talk about them separately, because the Earth was created alongside the universe. Understanding where life began helps scientists to understand where we came from and to investigate further whether we are alone in the universe.

Isaac Newton made discoveries that helped write the laws of our universe. From these laws, scientists are able to develop and test new theories.

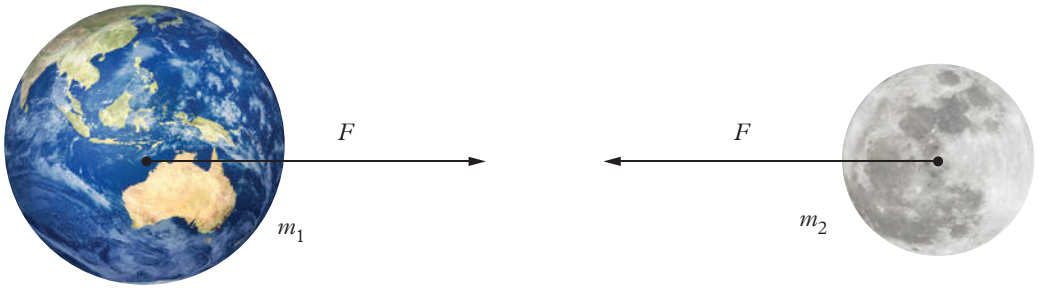

Figure 2 The gravitational force acting between objects is related to their mass and distance from each other. The greater the mass, the greater the gravitational force. On the other hand, the greater the distance between objects, the smaller the gravitational force. (This diagram is not to scale.)

Check your learning 6.5

Recall and explain

1 **Describe** what gravity is.

2 **Summarise** Newton's universal law of gravitation in your own words.

Apply and analyse

3 **Calculate** the force of attraction exerted by the Earth on the Moon using the following data.

Mass of the Earth = 5.97×10^{24} kg

Mass of the Moon = 7.36×10^{22} kg

Average distance between the moon and the Earth = 384 999 000 m

4 **Describe** how your answer for question 3 compares to the force of attraction exerted by the Moon on the Earth.

5 **Summarise** the information shown in Figure 1.

Skill builder: Questioning and predicting

6 a Write down 10 things you have observed about gravity on Earth.
(THINK: On a daily basis what do you notice about gravity? On a larger basis what do you know about gravity and the tides, or planes?)

b Select one observation from part a and **predict** what would happen if the force of attraction was lowered.
(THINK: How would it change on a daily basis? How would a change in the force of attraction impact this observation?)

6.6 The Big Bang theory is supported by evidence

In this topic, you will learn that:

- the Big Bang theory describes how the universe developed
- the universe is constantly changing and evolving.

singularity
a point at which a function takes an infinite value, for example, in space-time when matter is infinitely dense, such as the centre of a black hole

Big Bang theory
the theory that the universe began from a hot, dense state at some time in the past, from when it has continued to expand and will continue to do so into the future

cosmic microwave background radiation
form of electromagnetic radiation in the microwave spectrum left over from the formation of the universe; evidence of the Big Bang theory

The Big Bang is a theory that describes how the universe developed from a small dense singularity into the massively expanded space it is today. This theory is supported by large amounts of reproducible evidence.

How the universe began has been debated and studied. In ancient civilisations, people believed that the Earth was at the centre of the universe. Astronomers today theorise that the universe came into existence from a single dense hot point called a **singularity**. From this point, space expanded rapidly and silently – it wasn't really a bang at all. Over time, the universe cooled and matter (atoms) was formed.

Big Bang theory

The concept of the Big Bang was originally proposed in the 1920s, although it wasn't called this then. In 1929, the US astronomer Edwin Hubble discovered that the spectra of light from galaxies implied that they were moving away from the Earth. Hubble also found one of the most significant results in the history of the origin of the universe: that the further galaxies were from the Earth, the faster they were moving. The speeds were enormous. In fact, it is not the galaxies themselves that are moving away; rather, space is expanding and taking the galaxies with it (Figure 1).

But what is the universe expanding into? Based on Hubble's observations that the galaxies are racing away from each other, the obvious conclusion is that if you run things in reverse, everything must have come from the same spot. This idea led to the development of the **Big Bang theory**. As with all science, this theory is supported by many forms of evidence.

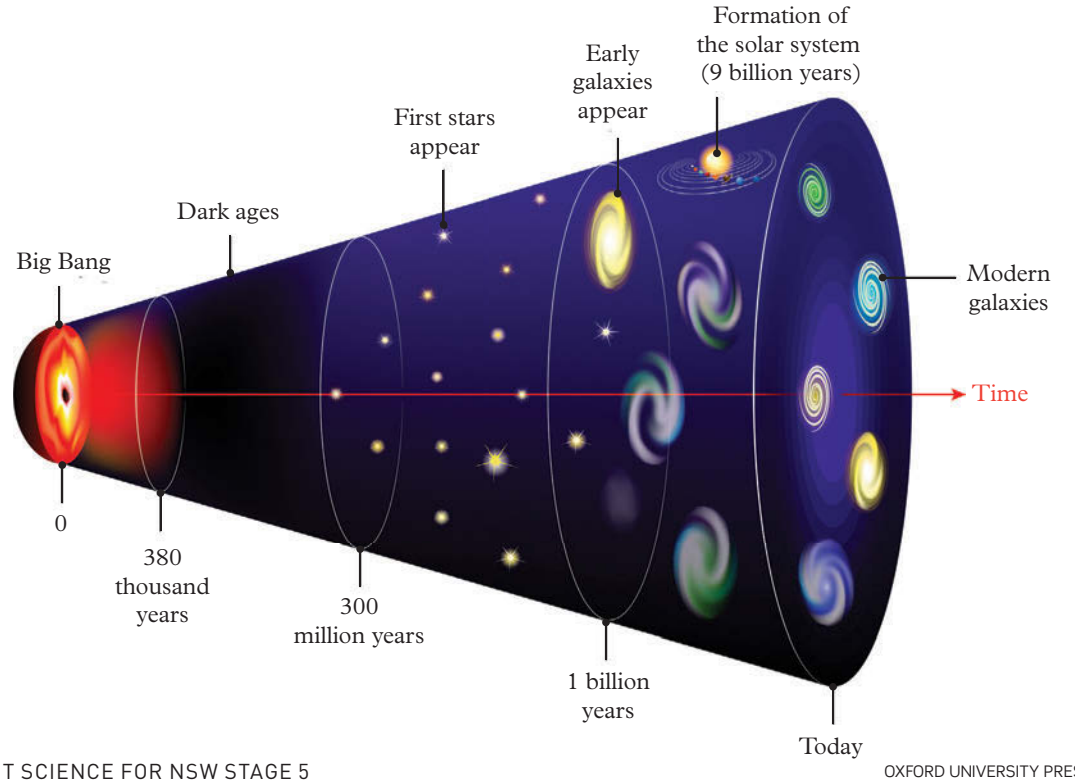

Figure 1 The evolution of the universe, according to the Big Bang theory. According to the Big Bang theory, the universe began from a rapid expansion from a hot dense state.

Microwave background

The concept of the Big Bang relied on the idea of the existence of some sort of radiation. It was hypothesised that the enormous amounts of heat released as part of the Big Bang would still exist in a much cooler form. In 1965, two US scientists, Arno Penzias and Robert Wilson (Figure 3), found evidence that the leftover energy existed as background radiation.

While testing a new, sensitive horn-shaped radio telescope antenna, Penzias and Wilson found a strong background noise that was interfering with transmission. They weren't trying to find it, they just happened to notice it. This background noise was a form of electromagnetic radiation known as **cosmic microwave background radiation** (Figure 2).

The existence of cosmic microwave background radiation was one of the greatest discoveries of all time – it was so important that Penzias and Wilson were awarded a Nobel Prize for their discovery.

Mixtures of elements

As shown by cosmic microwave background radiation, the universe has cooled since the Big Bang. As energy cannot be created or destroyed, the energy must have been converted into elementary matter. The simplest element that could have been made is hydrogen. The amount of hydrogen (and subsequent heavier elements) formed should be proportional to the amount of energy available. This would leave cool spots in the universe that are directly related to the mass of elements present. In 1992, the Cosmic Background Explorer (COBE) satellite detected these ripples in temperature fluctuations that are consistent with the formation of distant galaxies and old stars.

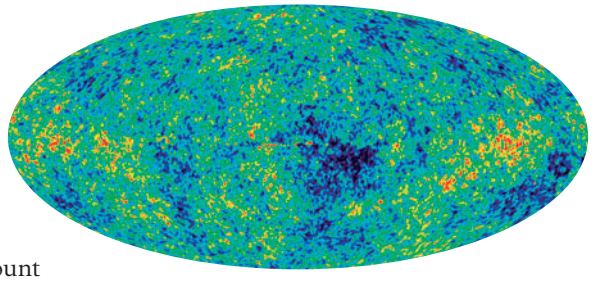

Figure 2 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky. These fluctuations correlate with the formation of nearby matter.

The universe is changing

When we examine distant galaxies, we are also looking back in time. The light from these galaxies takes many years to arrive on Earth. As a result, scientists can see old galaxies that developed millions of years before our own Milky Way. This has provided a timeline of galaxy formation that is consistent with the Big Bang.

All these observations have allowed astrophysicists to estimate that the universe is 13.7 billion years old.

Figure 3 Arno Penzias (left) and Robert Wilson (right) in front of their horn antenna with which they discovered cosmic microwave background radiation.

Check your learning 6.6

Recall and explain

1 **Explain** why the Big Bang is not actually a bang.

2 Write a paragraph to **describe** the Big Bang theory.

Apply and analyse

3 A theory is never final. Evidence is always needed to reinforce a theory. The Planck satellite was designed to examine cosmic microwave background radiation. **Assess** how evidence obtained from the Planck satellite will help support the Big Bang theory.

4 **Outline** what cosmic microwave background radiation is, and **explain** why its existence is important.

5 **Account** for why cosmic microwave background radiation has been called 'ancient whispers'.

Evaluate and create

6 **Assess** evidence that supports the Big Bang.

Skill builder: Communicating

7 Imagine that you have time travelled to 1650. Galileo has recently started looking at the night sky. You come from the future with knowledge of the Big Bang. Create a presentation to **explain** how this theory works to early scientists. Make sure you think about microwave background radiation, gravity and elements.
(THINK: What was early scientists' understanding of the Big Bang? What was their understanding of other scientific ideas such as helium and hydrogen?)

REVIEW

Multiple choice

1 **Identify** a possible shape of a galaxy.
- **A** Oblong
- **B** Elliptical
- **C** Regular
- **D** Cubic

2 Nebulae are clouds of:
- **A** helium
- **B** oxygen
- **C** lithium
- **D** hydrogen.

3 A light-year is:
- **A** the same as stellar parallax
- **B** the range of colours we see
- **C** the distances light travels in 1 year
- **D** the apparent change in wavelength when the source of the wave or the observer is moving.

Recall and explain

4 **Identify** the correct definition for each of the terms in Table 1.

Table 1 Scientific terms

Term	Definition
The Sun	Groups of stars that are close together in the sky
Galaxy	Theory of the creation of the universe in a huge explosion-like event
Constellation	Huge collection of stars held together by gravity
Universe	Used to locate and identify objects in the night sky
Big Bang	Our closest star

Figure 1 The Helix nebula in the Aquarius constellation

5 **Identify** what scientists Penzias and Wilson are famous for discovering.

6 **Classify** each of the following statements as true or false.
- **a** All stars are yellow and very hot.
- **b** All galaxies are the same shape and size.
- **c** The brightness of a star when viewed from the Earth is its absolute magnitude.
- **d** Bigger stars are usually hotter, brighter and burn for longer than smaller stars.

7 **Explain** why light-years are used instead of kilometres to measure distance in space.

8 **Summarise** why it is difficult to judge the distance of a star by measuring only its brightness.

9 **Recall** why the night sky enables us to look back in time.

10 **Classify** the following in order of largest to smallest: neutron star, the Sun, white dwarf, red giant.

11 **Distinguish** between a white dwarf and a red giant.

12 **Explain** how telescopes help scientists explore the night sky.

Figure 2 The Moon that we see is one of many moons in the universe.

13 Rewrite the following paragraph by selecting the correct word or phrase from the options given.
Most galaxies are moving *towards*/*away from* the Earth. The further away the galaxies are, the *faster*/*slower* they are moving. This is known as *Einstein's*/*Hubble's* law.

14 Write out Newton's universal law of gravitation equation and label each part. Make sure to **explain** what each component is.

Apply and analyse

15 Briefly **describe** the Doppler effect.

16 **Appreciate** the link between Hubble's observations and the Doppler effect.

Figure 3 The Hubble Space Telescope above Earth

17 **Account** for why you cannot see the stars (apart from the Sun) during the day.

18 Draw a diagram to show why different stars are visible from different places on the Earth's surface.

19 **Distinguish** between red shift and blue shift.

20 **Assess** why scientists use stellar parallax.

21 **Compare** the findings of *Curiosity* and the Hubble Space Telescope.

Figure 4 The *Curiosity* rover on Mars

Evaluate and create

22 If the Sun is 149 600 000 km from the Earth and light travels at 300 000 km/s, **calculate** how long it takes for light to reach us from the Sun. Express your answer in minutes.

23 How many kilometres from the Earth is each of these celestial objects?

- **a** Star Altair at 16.7 light-years
- **b** Coalsack Nebula at 600 light-years
- **c** Jewel Box star cluster at 7600 light-years

24 If the speed of light is 300 000 km/s, what distance does light travel in:

- **a** 1 second
- **b** 1 minute
- **c** 1 hour
- **d** 1 day.

25 **Evaluate** this statement: 'The Big Bang explains everything on Earth.' In your evaluation you should consider ethical and cultural beliefs.

26 **Investigate** a benefit of space research that people use in everyday life. **Summarise** how space exploration developed this.

27 **Investigate** Newton's universal law of gravitation. In your research **identify**:

- how he made his discovery
- how it was received by scientists at the time
- the implications for further science.

Then **discuss** how this law is still influencing science today and how it has helped refine thinking about the origin of the universe.

Critical thinking

28 Many cultures have legends about the origin of the constellations. **Investigate** Aboriginal and Torres Strait Islander, Polynesian or Ancient Greek legends. **Assess** how these legends still influence how we view and understand the constellations today.

29 Watch a movie set in space. **Summarise** its plot, and then **identify** the things in the movie that are scientifically correct and the things that are not.

Go further

30 Create a poster showing the fate of the Sun as it expands from its current size into a red giant and then as it contracts into a white dwarf. Label each stage and find photos from the internet to illustrate the process.

31 On 27 September 2007, the space probe Dawn was launched from Cape Canaveral at a cost of US $357 million, excluding the cost of the rocket. Dawn's journey includes exploration of the asteroid Vesta (2011) and the dwarf planet Ceres, between Mars and Jupiter (2015). Humans hunger for knowledge, but does this knowledge enhance our civilisation? **Discuss** if space exploration is vital to our survival.

Research

32 Choose one of the following topics for a research project. A few guiding questions have been provided, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Dark matter

Scientists think that there is extra matter in the universe that is invisible. This is called dark matter. What is the difference between ordinary matter and dark matter? What evidence do scientists have for the existence of dark matter? What is the composition of dark matter?

Scientists believe that the universe started from the Big Bang and that it will expand before gravitational forces pull it back in to start the entire process all over again. What effect does dark matter have on the future of our universe?

»Ion propulsion

The engines on some spacecraft use a unique, hyper-efficient system called ion propulsion. What is an ion? Can such an engine lift a spaceship from the Earth's surface? Why? What is the fuel used? How does this fuel produce thrust? Why are large solar collectors necessary? What is the thrust produced by the engines?

»Australian observatories

The Parkes Radio Telescope is a well-known Australian telescope. Find out a brief history of this telescope and what it is used for. The movie *The Dish* might be helpful in your research.

Figure 5 The Parkes Radio Telescope

»Exoplanets

Australian scientist Penny Sackett has led teams of scientists in searching for exoplanets similar to Earth. What is an exoplanet? How do astronomers search for them?

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Outline some of the major features contained in the universe, including galaxies, stars, solar systems and nebulae.	☐	☐	Go to pages 86-89
Describe, using examples, some technological developments that have advanced scientific understanding about the universe.	☐	☐	Go to pages 92-93
Use appropriate scales to describe differences in sizes of and distances between structures making up the universe.	☐	☐	Go to pages 94-97
Identify that all objects exert a force of gravity on all other objects in the universe.	☐	☐	Go to pages 98-99
Use scientific evidence to outline how the Big Bang theory can be used to explain the origin of the universe and its age.	☐	☐	Go to pages 100-101
Outline how scientific thinking about the origin of the universe is refined over time through a process of review by the scientific community.	☐	☐	Go to pages 94-101

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PLATE TECTONICS

How did Earth's continents form?

Have you ever wondered ...

- What causes a tsunami?
- How are mountains made?
- What makes a volcano erupt?

7

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- outline how the theory of plate tectonics changed ideas about the structure of the Earth and continental movement over geological time
- relate movements of the Earth's plates to mantle convection currents and gravitational forces
- outline how the theory of plate tectonics explains earthquakes, volcanic activity and formation of new landforms
- describe how some technological developments have increased scientific understanding of global patterns in geological activity, including in the Asia-Pacific region

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

7.1 The Earth's crust is moving

In this topic, you will learn that:

- continental drift is the theory of continental crust moving around the surface of the Earth
- sea-floor spread is the theory of oceanic crust splitting down the centre and spreading in opposite directions.

crust
lithosphere; the outer layer of the Earth

mantle
the layer of molten rock located beneath the Earth's crust

The Earth is made of layers. We live on the outer layer called the **crust**. Under the crust is the molten rock that makes up the **mantle**. Next, there is the **core**, which has two layers. The outer core is liquid iron and nickel, whereas the inner core is solid.

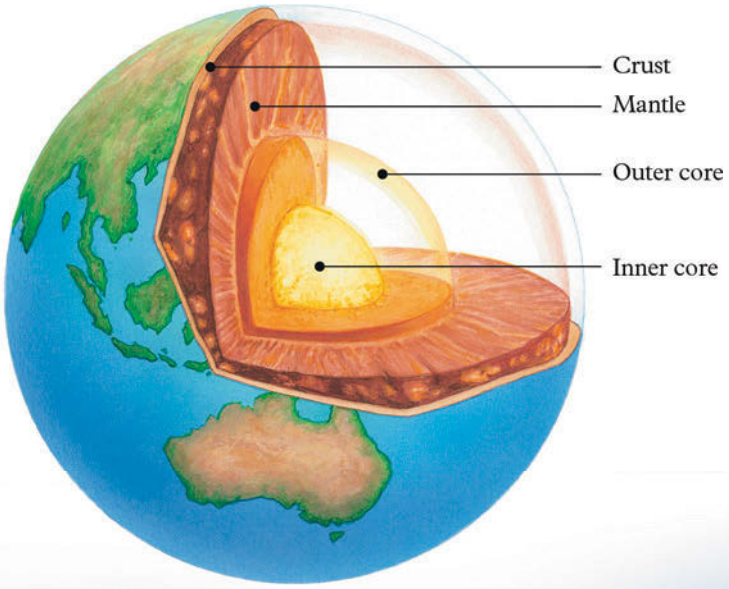

Figure 1 Layers of the Earth

core
the centre of the Earth

plate tectonics
the theory that the surface of the Earth is divided into a series of plates that are continually moving

Plate tectonics

The Earth's crust is broken up into seven large plates and many smaller plates called micro plates. The movement of these massive plates on the surface of the Earth is called **plate tectonics**. (The word 'tectonic' means 'building', so **tectonic plates** are the 'building blocks' of the Earth.)

Plate tectonics is a combination of two theories: continental drift and sea-floor spreading.

Continental drift is the idea that the continents are continuously moving and have significantly changed shape and position over millions of years. The theory of sea-floor spreading proposes that the middle of different oceans are cracking open and spreading apart very slowly.

There have been many theories that tried to describe why there are earthquakes, volcanoes, mountains and deep-sea trenches over the surface of the Earth. One of the first theories was that as the Earth cooled down after its original formation, it began to shrink and form 'wrinkles' on the crust's surface. Like all theories, this idea is testable and was refined as new evidence became available.

Figure 2 The Himalayan Mountains have been pushed up by pressure from beneath the Earth.

Continental drift

Before plate tectonics was fully understood, a German meteorologist, called Alfred Wegener, outlined the theory of **continental drift** in 1912. He observed that the coastline shapes of Africa and South America seemed to fit together like a jigsaw puzzle. Wegener proposed that the continents once all fitted together into a giant continent known as Pangaea.

Wegener proposed that Pangaea was a supercontinent that existed between 300–100 million years ago. When it started to break up, smaller pieces of crust slowly drifted away from each other to form the continents we see today. He backed up his claims with specific evidence such as the coastline fit between continents, similar fossils and rocks in widely separated continents, and the reconstruction of old climate zones.

Since the discovery of the supercontinent, Pangaea, other supercontinents have been identified. Rodinia is thought to have been the first supercontinent, formed 1.1 billion years ago. Gondwana (southern hemisphere) and Laurasia (northern hemisphere) were supercontinents that formed at the same time, roughly 550 million years ago.

Figure 3 The Pangaea supercontinent

The existence of these supercontinents is an interesting concept, but how did each one form? Wegener thought there must be movement, but he did not explain how each continent had moved over time.

Figure 4 Alfred Wegener pioneered the theory of continental drift in his book *The Origin of Continents and Oceans*.

continental drift
the continual movement of the continents over time

tectonic plate
a large layer of solid rock that covers part of the surface of Earth; movement of tectonic plates can cause earthquakes

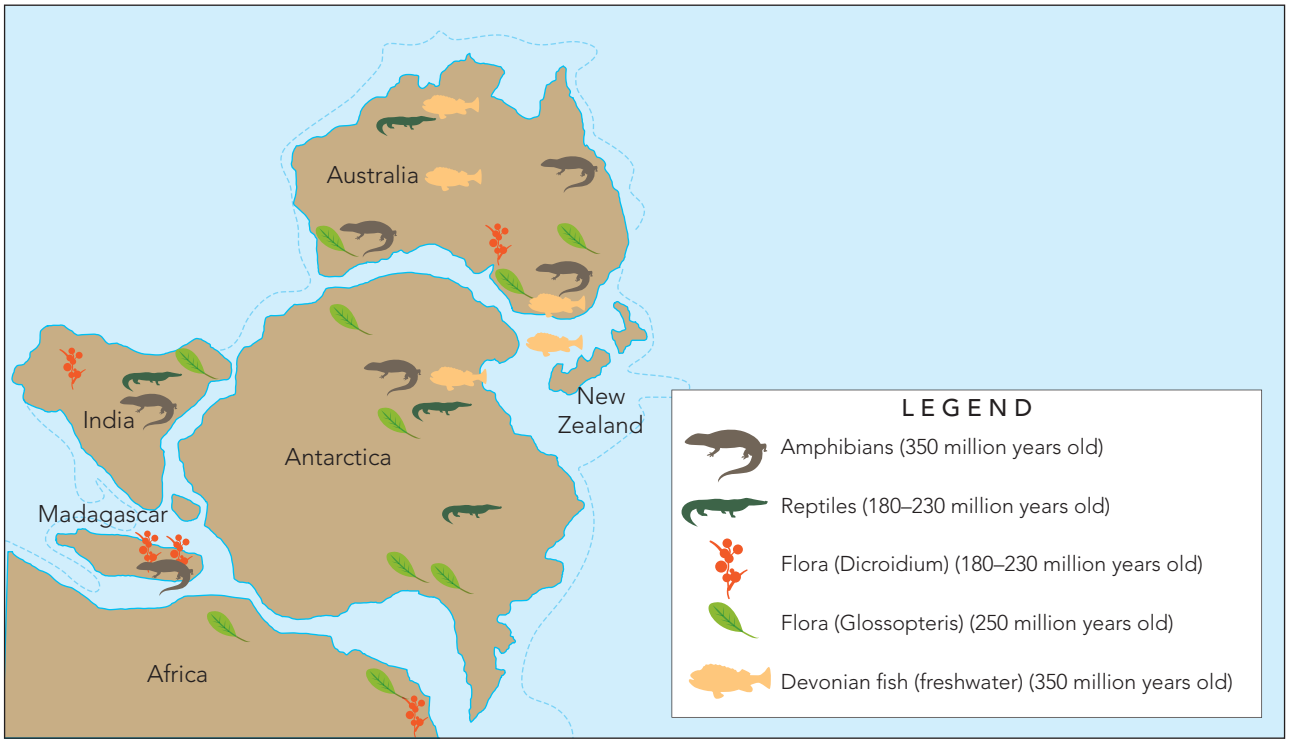

Figure 5 Various fossils, including the tree *Glossopteris* that could not walk, swim or fly, were found across India, Africa, Antarctica, Australia and New Zealand. How can these isolated occurrences be in so many different parts of the world?

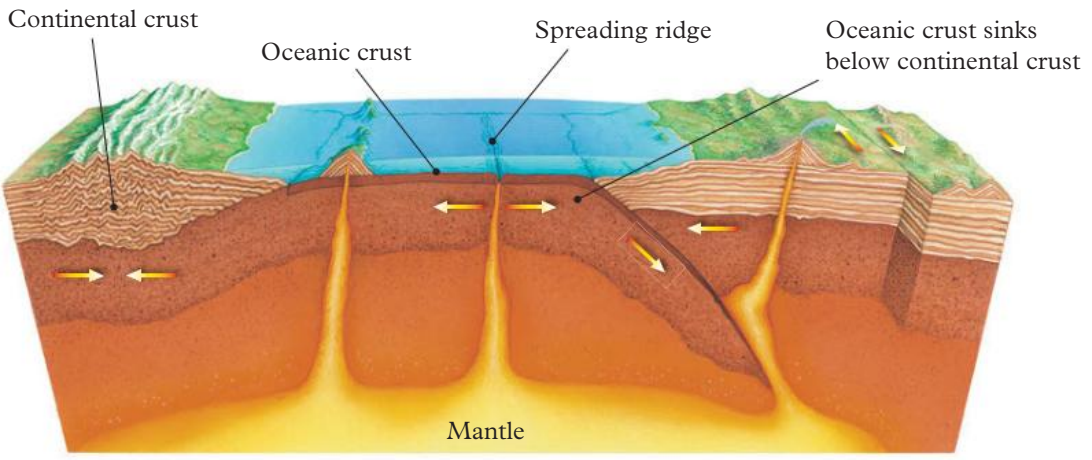

Figure 6 The oceanic crust separates until it eventually reaches a continental crust.

Tectonic plate movement

sea-floor spreading a theory that the middle of the ocean is spreading apart, forming new oceanic crust

Since Wegener's discovery of continental drift, scientists have refined theories of tectonic plate movements (Figure 9 further illustrates the tectonic plates on Earth). We now know that it is not just the continents themselves that are moving. The large moving areas include the crust under the ocean as well.

continental shelf underwater cliffs between the beach and the ocean

The movement of the plates explains the existence of landforms such as **continental shelves** (underwater cliffs between the beach and the ocean) and deep trenches in the ocean floor. It also explains how earthquakes and volcanoes are distributed, and the very young age of parts of the sea floor. Plate tectonics is a good example of how a scientific hypothesis can be suggested, discounted, modified and reborn.

Figure 7 Scientists research the ocean floor to learn about tectonic plate movement.

Sea-floor spreading

The idea of **sea-floor spreading** was proposed by US geologist Harry Hess. Hess's evidence came from the discovery of the Mid-Atlantic Ridge, a continuous mountain range in the middle of the Atlantic Ocean. His original hypothesis was that convection currents cause the crust to spread.

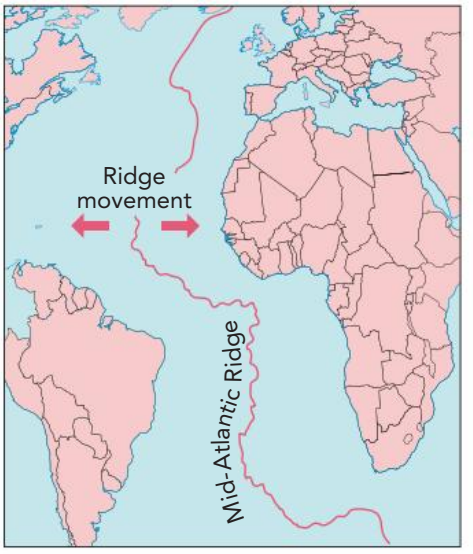

Figure 8 The Mid-Atlantic ridge provided evidence of sea-floor spreading.

If convection does occur within the Earth's mantle, then rising hot magma pushes up towards the crust, creating a ridge crest.

The immense pressure involved in making the oceanic crest means the crust splits (just like the crust of a new loaf of bread). It is pushed apart by more rising magma. As it is pushed away, tension between the surrounding rocks causes a rift zone and shallow earthquakes are formed as the tension is released. The oceanic crust then cools, becomes heavier and eventually sinks back into the mantle.

7.1b: MILO® convection currents
Go to your **obook**

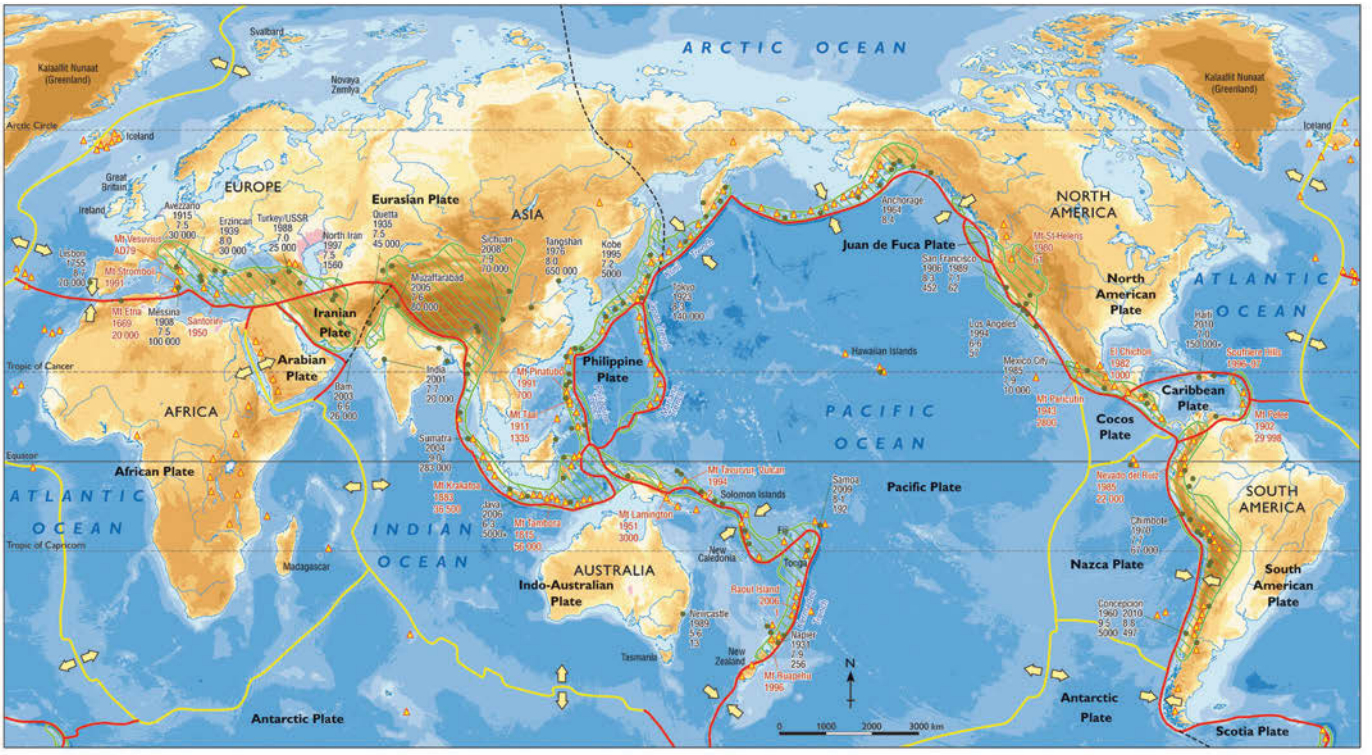

Figure 9 Tectonic plates on Earth

LEGEND

Tectonic plates
- Divergent boundary
- Convergent boundary
- Uncertain boundary
- Direction of movement
- Cocos Plate — Plate name

Volcanoes and earthquakes
- Volcano
- Mt Etna 1669 20 000 — Volcano name, eruption year, deaths
- Earthquake
- Kobe 1995 7.2 5000 — Earthquake location, year, magnitude, deaths
- Earthquake zone

Height of the land and depth of the sea (metres)
- Over 5000
- 4000 to 5000
- 2000 to 4000
- 1000 to 2000
- 500 to 1000
- 200 to 500
- 100 to 200
- 0 to 100
- Land below sea level
- 0 to –200
- –200 to –2000
- –2000 to –4000
- –4000 to –6000
- Over –6000

Check your learning 7.1

Recall and explain

1 **Examine** a world map. Apart from Africa and South America, **identify** other regions of the world that look as if they could fit closely together.

2 **Explain** the concept of continental drift.

3 As plates move away from each other at the mid-ocean ridges due to sea-floor spreading, **explain** what forms in their place.

4 **Recall** how the rift zone forms at the top of a mid-ocean ridge.

Apply and analyse

5 **Assess** why many scientists rejected Wegener's evidence in support of continental drift at the time.

6 **Analyse** the tectonic plate map in Figure 9. Where do you think the current spreading ridges are?

Skill builder: Problem solving

7 As a scientist, you must think critically about theories that are presented. Both Wegener and Hess provided a solution to explain the Earth's movement. Consider their theories.

a **Compare** their explanations. (THINK: What are the differences in their models?)

b **Evaluate** how they developed their theories using 'working scientifically' principles. (THINK: Did they conduct tests? Observe data and make predictions? Use problem solving techniques?)

7.2 Heat and gravity cause the Earth's plates to move

In this topic, you will learn that:

- tectonic plate movement is driven by convection currents in the mantle and gravity.

The Earth's surface has continued to slowly change – many rocks have worn down to form soil and sand, mountains and valleys have formed, and the land and oceans have changed shape. Some of this change is caused by weathering and erosion at the surface. Other changes are due to the movement of the molten rocks from deeper down, which in places push their way up to the surface and also move sections of the Earth's crust.

The mantle's convection currents

Video
Why do Earth's plates move?

Although the Earth can be described as a solid planet, the mantle is thought to be a mix of soft rock and solid material. The bottom of the mantle is partially solid, but the top part of the mantle is more like modelling clay. Temperatures in the upper mantle are about 1000°C and at the bottom of the mantle reach 3000°C.

In the mantle, **convection currents** move thermal energy (heat) in a circular motion. The thermal energy moves by convection in a circular motion up and down, just like water heating in a saucepan. It is these convection currents in the mantle that cause the tectonic plates to move.

convection currents the movement of energy from one place to another

The mantle closest to the Earth's core gains thermal energy. This means the molecules in the magma move faster. Because they move faster, they take up more space and become less dense. As a result, the heated magma near the core begins to slowly rise to the surface, leaving room for the cooler magma to take its place. The heated magma cools as it reaches the Earth's crust. As it cools, it is slowly pushed to one side as more heated magma arrives.

Ridge push

As heating and cooling causes soft rocks to move up and down in the mantle, these rocks put pressure on the overlying hard oceanic crust. The crust gets pushed in opposing directions and with enough force, the oceanic crust splits open, forming a mid-oceanic ridge. This process is known as ridge push and drives the movement of tectonic plates at the Earth's surface. New warm oceanic crust spews out of the ridge, like toothpaste out of a bottle, and the older cold crust moves away from the mid-oceanic ridge.

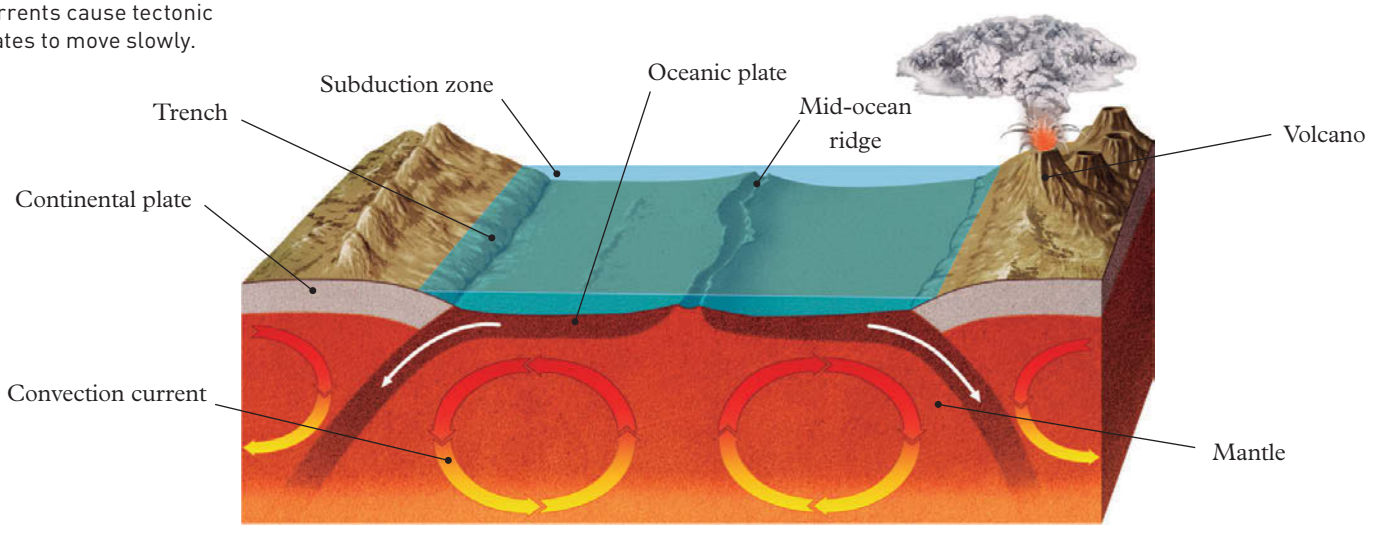

Figure 1 Convection currents cause tectonic plates to move slowly.

Gravitational forces

Mantle convection currents aren't the only reason tectonic plates move. As the oceanic crust spreads apart and creates new crust, it must also remove old crust.

Oceanic crust versus continental crust

The Earth's crust comes in two types: oceanic crust and **continental crust**. The crust is thickest under the continents and thinnest under the oceans.

As we have learnt, oceanic crust is formed at spreading ridges, where rocks from the mantle are pushed up to the surface. These rocks are dense, rich in iron and magnesium. Continental crust made predominantly of silicon and oxygen, though thicker than oceanic crust, is much lighter.

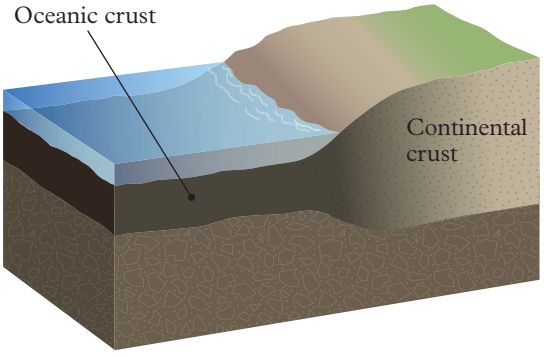

Figure 2 The oceanic crust is thinner beneath the ocean than it is beneath the continents.

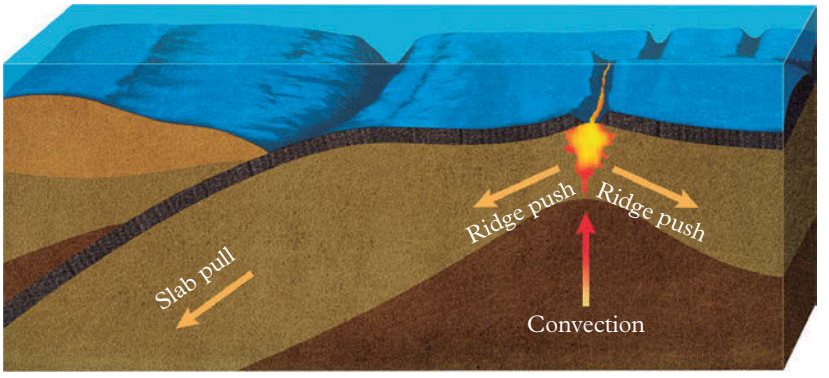

Figure 3 Ridge push and slab pull work together to move tectonic plates.

Subduction

As oceanic crust moves away from spreading ridges, it eventually hits continental crust. When this happens, the old oceanic crust will sink below the more buoyant continental crust. This is known as **subduction**. When the oceanic crust starts sinking into the mantle, the density of the crust increases, causing it to sink faster. This is called slab pull. The force of dragging the oceanic crust down into the mantle can be stronger if the subducting crust is very old and dense.

Slab pull and ridge push work together to move plates around the Earth.

continental crust
thick part of the Earth's crust which forms the basis of the large land masses

subduction
the movement of one tectonic plate under another tectonic plate

Check your learning 7.2

Recall and explain

1 **Identify** the layer of the Earth where tectonic plates are found.
2 **Recall** the two forces that work together to make plates move.
3 **Explain** subduction.

Apply and analyse

4 'The Earth's crust is the same thickness everywhere.' **Discuss** why you agree or disagree with this statement.
5 **Assess** why convection currents produced when you turn on a heater in a closed room are the same as the convection currents in the mantle.

Evaluate and create

6 What do you think would happen when two oceanic crusts collide? **Explain** your answer.

Skill builder: Communicating

7 Scientists present their findings in a logical progression. They present ideas in the order they were developed.
In this task, you must present the process of how heat and gravity change the Earth's crust. You need to present this as an explanation, including the steps involved in the process. You must present this as a diagram, and ensure that you accurately **explain** the information.
(THINK: Why is the process important? What is the key information for each stage in the process?)

7.3 Tectonic plates can have transform, convergent or divergent boundaries

In this topic, you will learn that:

- transform plate boundaries are when two plate boundaries slide alongside each other
- convergent plate boundaries are when two or more plates collide
- divergent plate boundaries are when two or more plates separate.

transform boundary
the boundary between two tectonic plates that are sliding past each other

fault
a fracture in rock where the tectonic plates have moved

Plate tectonics explains a wide range of features and events of the Earth. These features and events, once studied separately, can now be unified by a single concept: plate behaviour at plate boundaries. There are three general types of plate boundaries, based on the direction of plate movement. At transform boundaries, plates slide past one another; at convergent boundaries they come together; and at divergent boundaries they move apart.

Transform boundaries

One plate can slide past another along a single fault line (Figure 2). This is called a **transform boundary**. A **fault** is a fracture in rock where movement has occurred.

The two plates involved in a transform boundary can become jammed over a period of time until the pressure builds up and the plates slip.

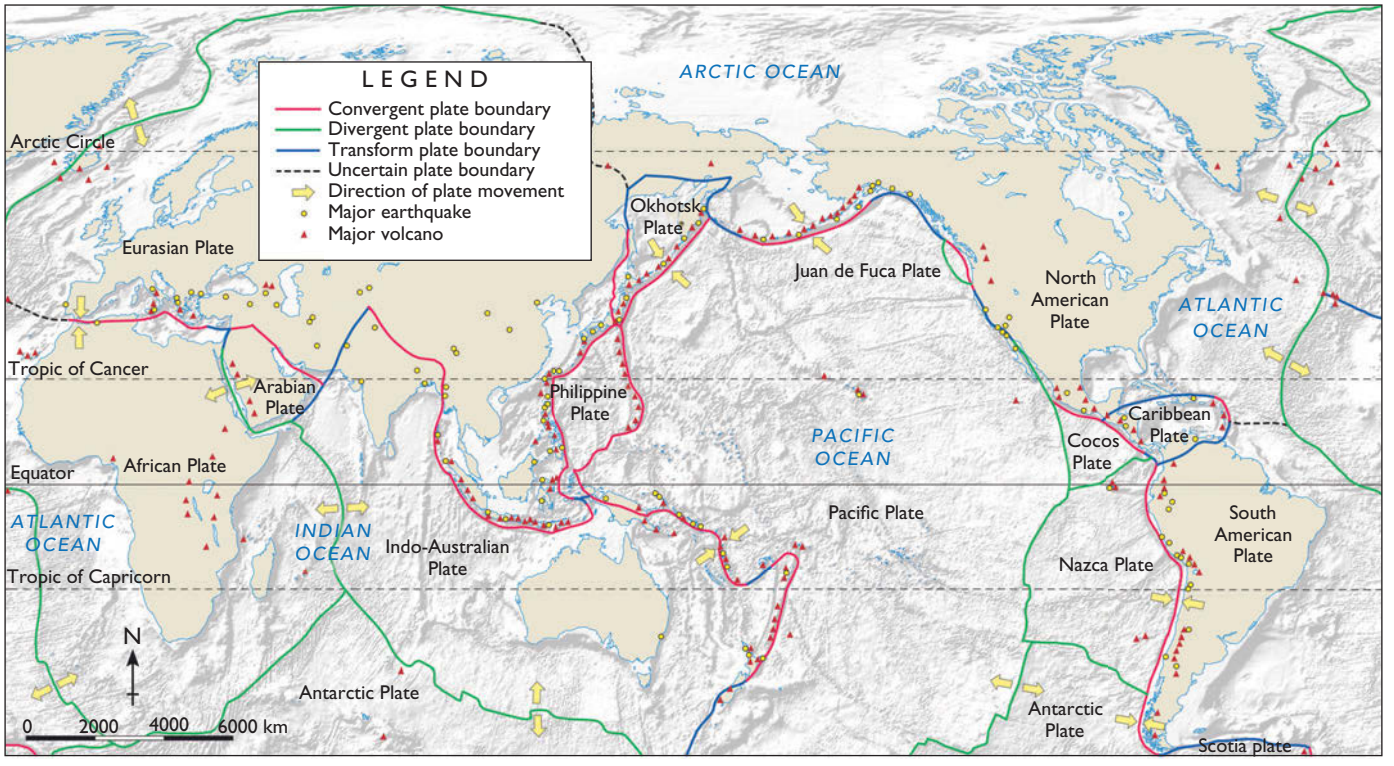

Figure 1 Volcanoes and earthquakes are located along the edge of the Earth's tectonic plates.

CHALLENGE

7.3: Chocolate plates
Go to page 371

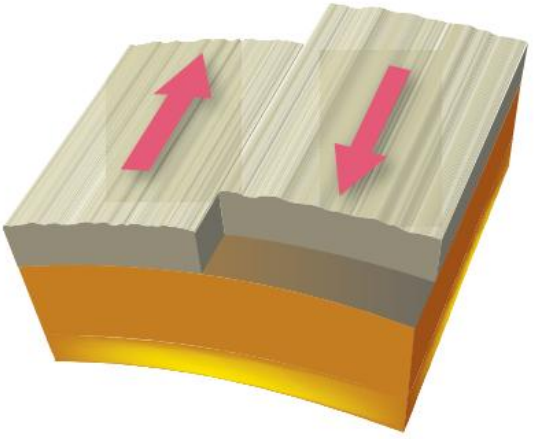

Figure 2 Transform boundary: one plate slides against another.

This slipping causes earthquakes such as the large earthquake that destroyed San Francisco in 1906, where the rock of the transform fault slipped by up to 5 metres.

Plate material in transform boundaries is not created or destroyed – the plates just slide against each other and **transform**. After an earthquake, you can often see the movement of the fault on human-made features such as railway lines (Figure 3).

Figure 3 Train lines can show evidence of plate movement after an earthquake.

Convergent boundaries

At convergent plate boundaries, two plates move towards each other (i.e. they are **converging**). There are generally three types of **convergent boundaries**, depending on the plates involved. Mountain ranges, volcanoes and trenches can all be formed by convergent boundaries.

Many of the world's major landforms are created by the collision of plates at convergent boundaries.

Figure 4 A satellite image of the Southern Alps, New Zealand. The Alpine Fault, a transform boundary, runs along the western edge of the snowline on the South Island and then out to sea.

converging
moving together

convergent boundary
the boundary between two tectonic plates that are moving together

transform
to change form; tectonic plates transform when they slide past each other

Figure 5 The San Andreas Fault in the USA.

divergent boundary
the boundary between two tectonic plates that are moving apart

diverging
moving apart

ocean trench
a deep ditch under the ocean along a tectonic plate boundary

rift valley
a deep valley that forms as a result of tectonic plates moving apart

mid-ocean ridge
a series of underwater mountains that form as a result of tectonic plates moving apart and allowing magma to rise to the surface

Ocean-to-continent collision

When oceanic crust collides with continental crust, the oceanic landform subducts into the mantle because it is denser. It creates a line of mountains along the crumpled edge and also volcanoes as the subducting slab melts in the mantle and molten rock rises through the crust. The Andes and volcanoes in South America are the result of an ocean-to-continent collision. An **ocean trench** may form at the line of plate contact as parts of the continental crust and oceanic crust get dragged down the subduction zone.

Continent-to-continent collision

When two continental plates collide, they have similar densities, so no subduction takes place. Instead, the edges of the two plates crumple and fold into high mountain ranges. This is how the Himalayas formed, when the Indian plate collided with the Eurasian plate about 50 million years ago.

Ocean-to-ocean collision

When two oceanic plates collide, the older, denser crust will subduct below the newer crust, creating a deep ocean trench. The subduction also creates a line of undersea volcanoes that may reach above the ocean surface as an island arc.

Divergent boundaries

Divergent boundaries or spreading plate boundaries form different features from those of convergent and transform boundaries. These spreading boundaries are **diverging** and can occur in the middle of the ocean or in the middle of land. The breaking up of the supercontinent Pangaea was probably due to divergent plate boundaries in the middle of the continental crust. Hot rising mantle rock from deep within the Earth might be the first step in a continent breaking apart. As the mantle rock rises, the continental crust is lifted and thins out. Cracks form and large slabs of rock sink into the Earth, forming a **rift valley** like those found in East Africa.

Making oceans

As the divergence process continues, the continental crust separates and a narrow sea or lake may form. The Red Sea between the Arabian and African plates is thought to be a divergent boundary at this stage of development. Eventually oceans are formed and a **mid-ocean ridge** is created.

Mid-ocean ridges are very wide – up to 4000 km. Sea-floor spreading occurs at a rate of only 5 cm per year, but none of the ocean floor is dated as older than 180 million years.

Figure 6 The Red Sea has formed as the African and Arabian plates have diverged.

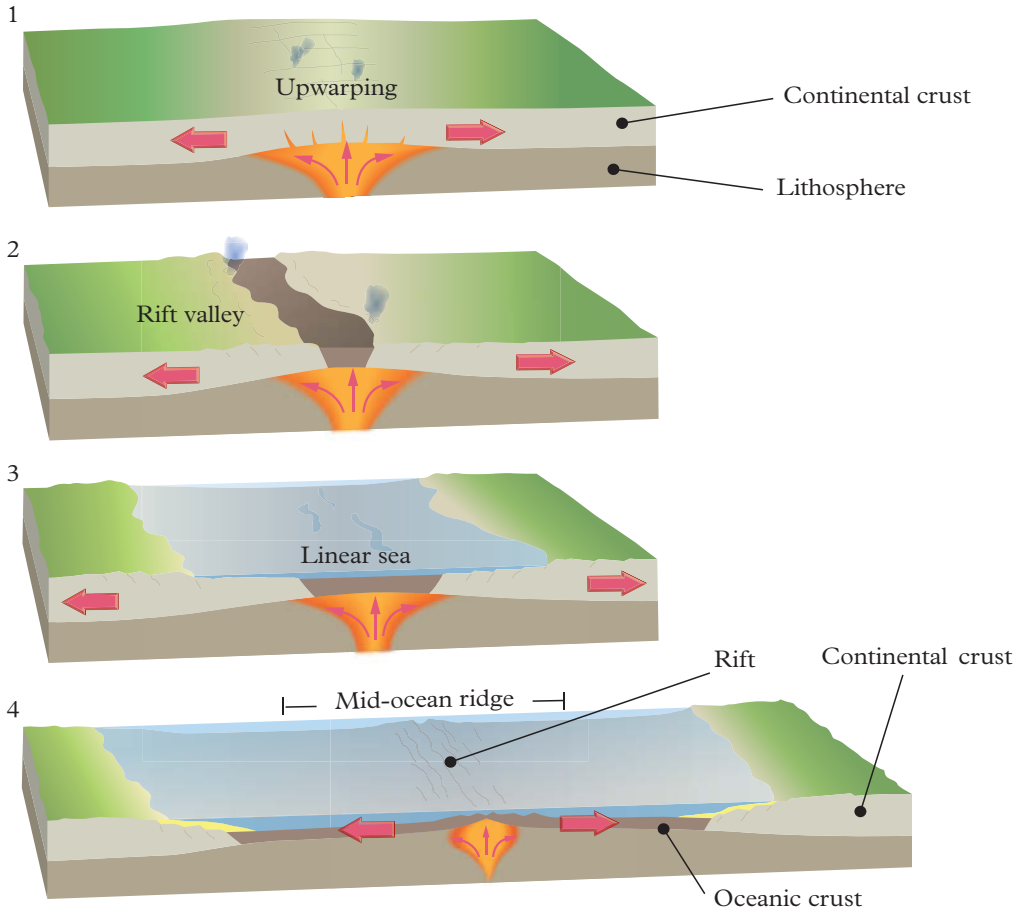

Figure 7 How divergent boundaries form oceans

Video
What happens when Earth's plates move?

Check your learning 7.3

Recall and explain

1 **Identify** the type of plate movement that happens at a transform boundary.
2 **Explain** what causes the continental crust to spread and break at a divergent boundary.
3 Use Figure 1 to **identify** where the major mid-ocean ridges are located.
4 Use Figure 1 to **identify** where the divergent plate boundaries are located.
5 **Explain** what determines which plate subducts at a convergent boundary.

Apply and analyse

6 **Assess** why divergent boundaries produce earthquakes and volcanic activity.
7 Transform boundaries are sometimes called strike-slip-fault zones. **Explain** why both names are appropriate.

Evaluate and create

8 According to Figure 1, in relation to the tectonic plates, **identify** where most volcanoes occur. **Discuss** if this is the same for earthquakes.

Skill builder: Questioning and predicting

9 Using your knowledge of tectonic plate boundaries, write a scientific question and a prediction for the following scenarios.
   a The 'Ring of Fire' is located in the Asia-Pacific region. Because of its location across tectonic plates, it experiences heightened geological activity. (THINK: Look at Figure 1; what geological features are present? Can you write a measurable question for this area?)
   b The Australian Alps run across the New South Wales and Victoria border. The alps formed after geological activity. (THINK: Look at Figure 1; what geological features are near this location? Is future geological activity likely?)

7.4 Tectonic plates can be constructive or destructive

In this topic, you will learn that:

- earthquakes can form from any plate boundary
- volcanoes form from convergent and divergent plate boundaries
- new landforms form from all plate boundaries.

tsunami
a series of large waves that result from an underwater earthquake

The boundaries between the tectonic plates create a lot of pressure as they try to move against each other. This pressure can be released suddenly in the form of a destructive earthquake, which in turn can form a tsunami. The crust of the Earth can also be very thin, and this allows the molten mantle to escape and become lava. This lava may eventually construct new islands.

Earthquakes causing tsunamis

Undersea earthquakes can move the sea floor and push up the water to form waves known as **tsunamis**. The earthquake in northern Japan in 2011 was a magnitude 9.0 on the Richter scale. The earthquake was centred 140 km off the coast and sent a 10-metre-high wall of water towards coastal towns and cities. The tsunami wave also travelled away from Japan, right across the Pacific Ocean, and was experienced as far away as North and South America, the Pacific Islands, and even in northern Australia as a small wave.

Japan is the most seismic country in the world because it lies near the boundaries of three tectonic plates: the Pacific, Eurasian and Philippine plates.

Volcanoes causing tsunamis

Volcanoes pose great dangers to those who live near them. Volcanic eruptions spew lava and ash onto the surrounding land. When this material is broken down by the action of wind and water, and mixed with organic material from plants and animals, it forms some of the richest soil in the world. So, in spite of the dangers, people continue to live near volcanoes because of the fertile soil they provide.

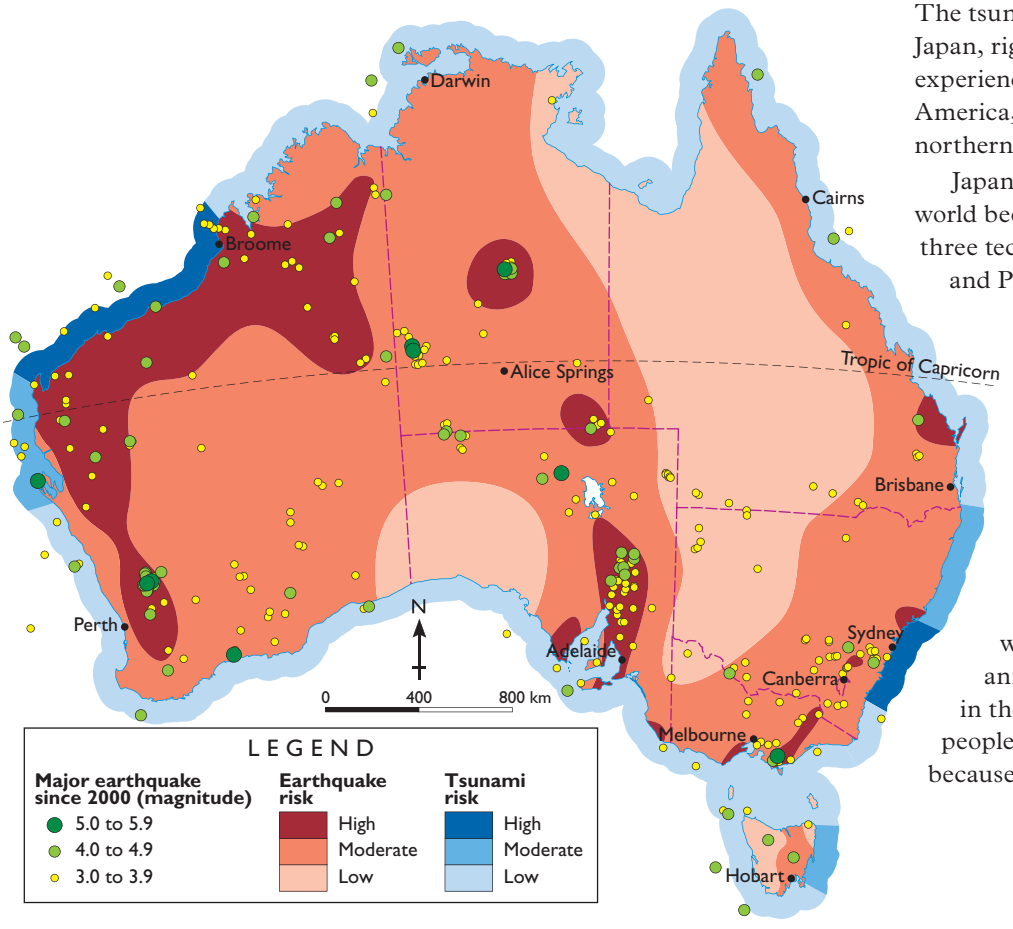

Figure 1 Australia: earthquake and tsunami risk

Hawaiian Islands

The Hawaiian Islands are in the centre of the Pacific Plate. Hawaii is not near a mid-ocean ridge, yet it has frequent volcanic activity. Most geologists believe this volcanic activity is caused by the movement of the plate over a 'hot spot' beneath the plate (see Figure 2). This is where a plume of hot magma comes up from the mantle through a thin area in the crust and creates a volcano. In the case of the Hawaiian Islands, the hot spot formed an undersea volcano. Over time, the volcano grew until it poked above the ocean surface and created an island. As the plates continue to move over the hot spot, more islands are built over millions of years and an island 'chain' is created.

The centre of a plate usually lacks earthquakes, volcanoes or folded mountain ranges because it is a long way from any plate boundary.

The theory of plate tectonics corresponds nicely with the distribution of earthquakes and volcanoes around the world.

Earthquakes in Australia

Australia is not located near a plate boundary and so our earthquake activity is minimal. However, there are still more than 300 magnitude 3.0 or greater earthquakes in Australia every year. Our plate, the Indo-Australian Plate, is moving towards the Eurasian, Philippine and Pacific plates. This creates stress within our plate and release of the stress creates earthquakes.

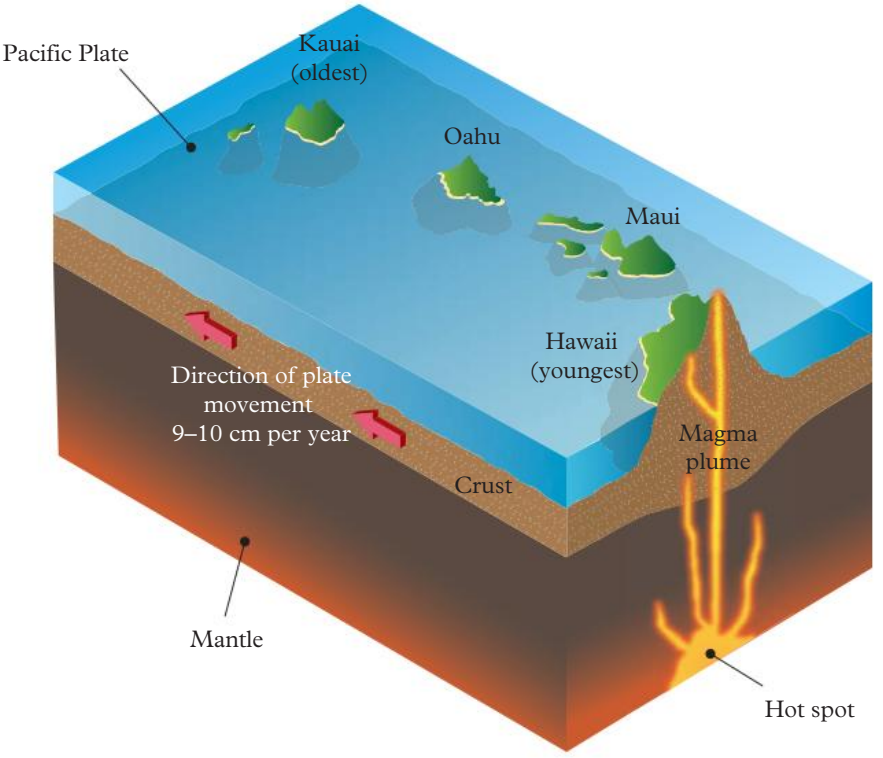

Figure 2 How the Hawaiian Islands were formed. (Only the largest islands are shown.)

Check your learning 7.4

Recall and explain

1 **Explain** what a tsunami is.
2 **Describe** how the movement of tectonic plates can be constructive.
3 **Explain** why Australia has few earthquakes when compared with the rest of the world.

Apply and analyse

4 **Compare** earthquakes and volcanoes.
5 **Contrast** the formation of volcanoes and mountains.

Skill builder: Conducting investigations

6 Many geological sites around the world hold cultural significance. Before conducting scientific fieldwork in these areas, this significance must be acknowledged.
   a Select and **describe** one geological area in New South Wales. (THINK: What are its features? How was it formed? What is its name?)
   b **Identify** one ethical consideration you need to check before conducting fieldwork. (THINK: What are the cultural or societal impacts of the fieldwork? Can you conduct the fieldwork elsewhere?)
   c **Identify** the next steps to take before proceeding. (THINK: Who do I need to contact? Does this need approval?)

7.5 Technology is used to understand global patterns of geological activity

In this topic, you will learn that:

- magnetometers, seismometers and seismic surveys are used to understand global patterns in geological activities.

seismometer
a device that responds to ground motions

Figure 1 A magnetometer is used to measure changes in the Earth's magnetic field.

Richter scale
a scale used to express the magnitude of an earthquake, based on recordings of a seismometer

magnetometer
an instrument that measures changes in the Earth's magnetic field

seismic surveys
a method for gaining information about the layers of the Earth where sound waves are sent into the Earth, and the time it takes for them to return is recorded

As technology has improved, scientists have been able to learn more about geological patterns and changes. Geology is the main study of the Earth and rocks. Geologists can specialise to become many professions including a seismologist (who studies earthquakes), a volcanologist (who studies volcanoes), or a geophysicist (who studies the physics of geology).

The development of new technology means that scientists can now try to predict global patterns in geological activity, including the continuous movement of tectonic plates. This understanding means that scientists can create warning systems so that people can be evacuated before the impact of an earthquake, tsunami or volcano.

The technology scientists can use includes (but is not limited to) magnetometers, seismometers and seismic surveys.

Magnetometers

A **magnetometer** measures changes in the Earth's magnetic field. A magnetometer can be used for the following:

- understanding changes in the Earth's crust
- learning about what causes an earthquake and then predicting when one is likely to occur; as stress near a fault line builds, the heat generated changes the magnetic field.

Often, magnetometers are placed around a fault line to monitor the fault. Cars, phone lines and mobile phone towers can affect the readings, so the position of magnetometers tends to be remote. Magnetometers are also portable, so large areas can be measured at once.

Seismometer

A **seismometer** measures movement in the ground. Seismologists use these frequently. Seismometers have a mass that is attached to a steady frame. This mass moves with any ground movement while the frame stays still. Originally, the mass was connected to an instrument that would mark a page – new technology means a computer records the mass's movements to produce a seismograph.

The size (amplitude) and frequency of the waves recorded on a seismograph can help predict the strength of an earthquake and the likelihood of a tsunami, and in combination with other scientific measures, it can help to predict the likelihood of a volcanic eruption. Seismographs can also locate the source and strength of an earthquake.

The **Richter scale** describes the intensity of an earthquake. It is used to state the power or magnitude of an earthquake. A number from the Richter scale is assigned to the intensity reading from a seismograph.

Seismic surveys

Seismic surveys are used to gain information about the layers of the Earth. Seismic surveys send sound waves into the Earth and measure the time it takes to reflect back to the surface. This measurement provides an idea of the structures and properties of the Earth's layers. The speed at which the wave reflects back provides insight about the density of the material, the type of rock, or any abnormalities in the layer.

Applications of technology

Natural disasters can be devastating for communities and countries. Certain parts of the world are more likely to experience earthquakes, tsunamis and volcanic eruptions because of their location on Earth's tectonic plates. The progression of technologies such as the magnetometer, the seismometer and seismic surveys means that people are better able to predict the likelihood of a geological event.

It is important to recognise that while these technologies can predict events, they cannot predict all events. Also, once an event is predicted, nothing can be done to stop an earthquake, tsunami or volcanic eruption.

Figure 2 A seismometer is a detecting device that measures motion of the ground caused by earthquakes or volcanoes.

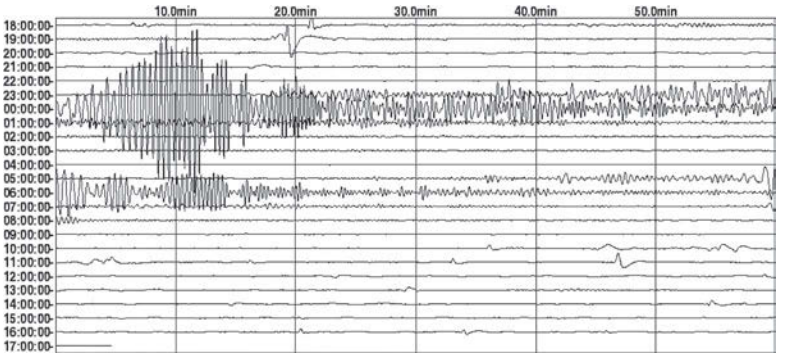

Figure 3 A seismograph usually appears as a series of waves; the higher the amplitude and frequency, the stronger the movement.

Warning systems mean that people are alerted earlier and can take measures for their safety. For example, in the event of a tsunami, warning systems mean that people can try to get to higher ground. These predictions also provide long-term recommendations, such as not building in certain areas.

The Asia-Pacific region, sometimes referred to by geologists as the 'Ring of Fire', experiences some of the highest frequencies of geological activity in the world. Disasters like the Fukushima earthquake in April 2011 display this. Different organisations investigate the likelihood of increased activity in areas like this and explore strategies for managing risk to humans.

Resource
STEM activity: Shake, Rattle and Record

Check your learning 7.5

Recall and explain

1 **Explain** what a magnetometer is.
2 **Describe** what a seismic survey measures.
3 **Recall** how the human impact of an earthquake or geological disaster can be minimised.

Apply and analyse

4 If a seismograph presented waves of high amplitude but low frequency, **explain** what this might imply about geological activity in the area.
5 **Propose** one industry that might use seismic surveys. **Explain** why these would help this industry.

Evaluate and create

6 **Evaluate** the prediction of earthquakes, tsunamis and volcanic eruptions. Provide evidence for why they can or cannot be predicted.

Skill builder: Planning investigations

7 During the early stages of the COVID-19 pandemic in 2020, researchers identified a change in the movement in the ground. Scientists have to ensure they use the correct equipment to measure scientific phenomena.

a **Identify** the equipment that scientists are most likely to use to measure movement in the ground. (THINK: What does a scientist measure when they record movement in the ground?)
b **Recall** why using the correct measurement device is important when conducting research. (THINK: What are the impacts of using the wrong device?)
c **Propose** what scientists would have recorded if they had used a magnetometer. (THINK: What does this device measure? Can it give information about the Earth's movement?)

REVIEW

Multiple choice

1 **Identify** which two of the following led to our understanding of plate tectonics.
- **A** Continental drift
- **B** Subduction
- **C** Sea-floor spreading
- **D** Magnetometers

2 **Identify** the type of plate collision where subduction is most likely to occur.
- **A** Continent to mantle
- **B** Continent to continent
- **C** Ocean to ocean
- **D** Ocean to continent

3 What type of natural disaster can be caused by an undersea earthquake?
- **A** A hurricane
- **B** A volcanic eruption
- **C** A tsunami
- **D** A bushfire

Recall and explain

4 **Identify** the correct definition for each of the terms in Table 1.

Table 1 Scientific terms

Term	Definition
Mantle	Centre part of the Earth
Crust	Layer of hot, semi-molten rock below the crust
Oceanic crust	Gradual movement of the continents across Earth's surface over time
Continental crust	Theory that states that large plates of the Earth's crust gradually move
Plate tectonics	Less dense crust containing continents
Tectonic plate	Hot liquid rock that comes up from the mantle
Continental drift	Thin, semi-rigid outer layer of the Earth
Convection current	Large area that may include continents and sea floor
Magma	Dense crust under the sea floor
Core	Movement in liquids or gases caused by rising hot material

5 **Define** and **describe** each of the following:
- **a** subduction
- **b** rift valley
- **c** transform fault
- **d** divergent boundary
- **e** convergent boundary
- **f** ocean trench
- **g** mid-ocean ridge
- **h** sea-floor spreading.

6 **Explain** what Pangaea was, and **describe** what happened to it.

7 **Recall** the evidence that Alfred Wegener used to support his theory of continental drift.

8 **Identify** what causes the force that moves the tectonic plates over the surface of the Earth.

9 **Explain** what causes major volcanic eruptions and earthquakes.

10 If Australia moves north to collide with Indonesia and Malaysia, **summarise** what geographical features could form and how our climate could change.

11 Most earthquakes occur at plate boundaries. **Explain** how an earthquake can occur in the middle of a plate.

12 **Describe** the process of subduction.

13 **Explain** how a scientist uses a magnetometer.

14 **Describe** two ways the movement of plate tectonics can be destructive.

15 **Recall** where most earthquakes occur and **propose** a reason why.

Apply and analyse

16 **Summarise** how volcanic activity shaped the Hawaiian Islands.

Figure 1 There is much evidence of volcanic activity on the Hawaiian Islands, such as **a** rocks that appear to flow into the sea formed from old lava flows, **b** mountains that rise out of the sea, **c** and **d** volcanic rock formations, **e** steam that rises from craters, and **f** lava flows from ancient veins.

17 **Explain** why a continental crust can't be subducted.

18 **Assess** how sea-floor spreading accounts for the young age of the sea floor.

19 The Himalayas formed when India collided with the Eurasian Plate. Mount Everest, the highest mountain on Earth, is 8848 metres high and continues to be uplifted at a rate of about 1 cm per year. **Deduce** how high Mount Everest might be in 1 million years if it continues its current rate of increase.

20 **Examine** Figure 2, which shows a topographic image of the Mid-Atlantic Ridge. **Explain** how this provides evidence for sea-floor spreading.

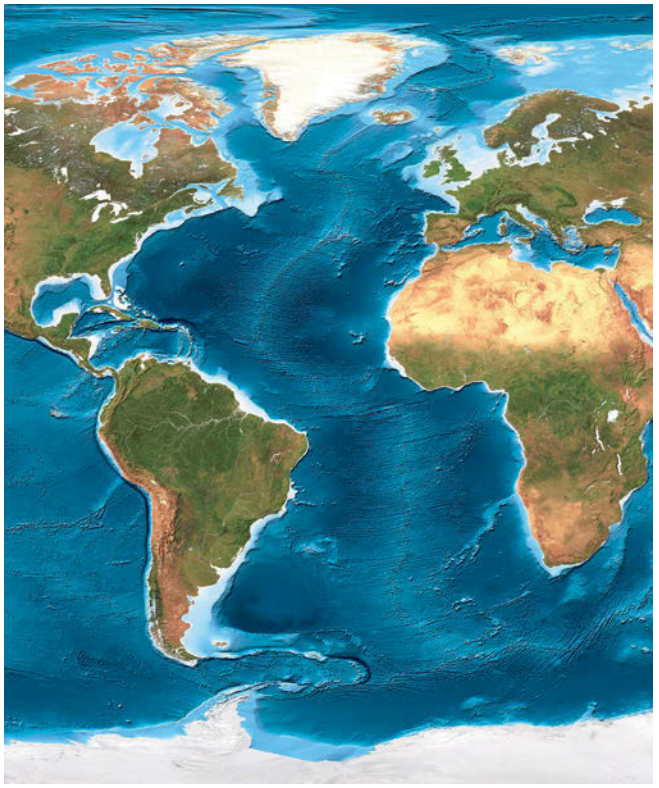

Figure 2 A topographic image of the Mid-Atlantic Ridge

21 If a part of the Pacific Plate is moving at a rate of 10 cm per year, **calculate** how far it would have moved in 100 years, 1000 years, and 1 million years.

22 **Explain** why modern GPS systems are useful for predicting future plate movements.

23 **Evaluate** the use of seismic surveys to assess Earth's movement over time.

Evaluate and create

24 Create a poster or multimedia presentation about a famous earthquake or volcanic eruption. List the facts about the event, as well as identifying what plate movement caused it, and **explain** the social, environmental and economic impacts, and the subsequent recovery process.

25 The Mariana Trench is located where the Pacific Plate is subducting under the Mariana Plate. Its average depth is 11 km below the surface of the water. Surprisingly, ocean explorers have found life at the bottom of the Mariana Trench. **Investigate** what lives so deep and how it survives.

26 Imagine you could travel into the future, to a time when your local environment is drastically different from how it is today. Base your imagination on the scenarios of plate movement described in this text. Create a travel brochure for a future tourist destination on this new Earth.

Critical thinking

27 If Australia was to move further north, eventually colliding with Indonesia, **evaluate** what geological features may form, and **propose** how this could impact the climate of New South Wales.

28 The movement of tectonic plates over time impacts the flora and fauna in a particular area. Look at Figure 5 on page 107. If the world was to form a supercontinent again, **propose** what may happen to some species on the planet. Then **assess** whether new species would be formed.

Go further

29 **Investigate** two geological natural disasters. For each, **identify** when and where it occurred, the tectonic plates it was near and the impact on surrounding areas.

30 Once there was one supercontinent called Pangaea. Initially it split in two: one part, Laurasia, moved north while the other part, Gondwana, moved south. Laurasia gave rise to Europe, Asia and North America. Gondwana gave rise to Africa, South America, Australia, India and Antarctica. Consider the climate changes each continent faced as it drifted to its current position and **explain** why, today, there are few links remaining between the plants and animals that originally inhabited the Gondwana subcontinents.

Research

31 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Subduction zones

The subduction of one plate under another is well understood by scientists today, but how this process begins is not. What do geologists mean by 'subduction'? What happens to the plates during subduction? What geological features are associated with subduction zones? How do new subduction zones form?

»The Earth's crust

The lithosphere and asthenosphere are different internal layers of the Earth. What is the lithosphere? What is the asthenosphere? How do the two 'spheres' interact? What other 'spheres' exist? How do they interact with the lithosphere and asthenosphere?

»Convection currents

Although the theory of convection currents in the Earth's mantle is the most widely accepted theory about what drives plate movement, there are several other theories. What other theories exist? Choose one and find out what evidence supports the theory. Who provides the theory? Why is it less accepted than the theory of convection currents?

»Magnetic striping

Magnetic striping was considered by some to be the final proof of plate tectonics. What is magnetic striping? Where does it exist? How is it linked to sea-floor spreading? What does it tell us about the age of rocks? What does it tell us about the Earth's history?

Figure 3 The New South Wales alpine range is old and thought to have formed from hot spots under the continent as it moved.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Outline how the theory of plate tectonics changed ideas about the structure of the Earth and continental movement over geological time.	☐	☐ Go to pages 106-109
Relate movements of the Earth's plates to mantle convection currents and gravitational forces.	☐	☐ Go to pages 110-111
Outline how the theory of plate tectonics explains earthquakes, volcanic activity and formation of new landforms.	☐	☐ Go to pages 112-117
Describe how some technological developments have increased scientific understanding of global patterns in geological activity, including in the Asia-Pacific region.	☐	☐ Go to pages 118-119

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GLOBAL SYSTEMS

How can we alter the course of climate change?

Have you ever wondered ...

- Why are certain species becoming extinct?
- What is the Kyoto Protocol and how does it affect Australians?
- Why do we get cyclones and flooding?

8

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- outline how global systems rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere, including the carbon cycle
- describe some impacts of natural events, including cyclones, volcanic eruptions or earthquakes, on the Earth's spheres
- evaluate scientific evidence of some current issues affecting society that are the result of human activity on global systems, e.g. the greenhouse effect, ozone layer depletion, effect of climate change on sea levels, long-term effects of waste management and loss of biodiversity
- discuss the reasons different groups in society may use or weight criteria differently to evaluate claims, explanations or predictions in making decisions about contemporary issues involving interactions of the Earth's spheres

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

8.1 Global systems rely on interactions between the Earth's spheres

In this topic, you will learn that:

- the Earth is made up of the atmosphere (air), biosphere (all life on our planet), lithosphere (solid and molten rocks of Earth) and hydrosphere (solid, liquid and gaseous water)
- the atmosphere, biosphere, lithosphere and hydrosphere interact to continue global systems.

Interactive
The Atmosphere

There are many different spheres that make up this planet and all interact as a dynamic system. The atmosphere (air) interacts with the biosphere (all life on our planet), hydrosphere (solid, liquid and gaseous water), and the solid and molten rocks of Earth called the lithosphere. This interaction influences the Earth's climates and ecosystems. A balance across the four spheres must be maintained to ensure the survival of all life on Earth.

The atmosphere

atmosphere
layer of gases that surrounds Earth and other planets

The **atmosphere** is a layer of gases that we commonly call air (Figure 1). The atmosphere is relatively thin compared with the size of the Earth: if the Earth were the size of a birthday balloon, the atmosphere would only be as thick as the rubber skin of the balloon.

The Earth is the only planet in our solar system that has an atmosphere that sustains life. It is vital to keeping us warm, controlling our weather, protecting us from the dangers of space, and carrying sounds.

The most important gas for humans and other animals is oxygen (O_2), but it only makes up 21% of the total atmospheric gases. Nitrogen (N_2) makes up the largest portion at 78% of the atmospheric gases. The remaining 1% of gases is made up of many gases such as carbon dioxide (CO_2), water (H_2O), ozone (O_3) and other greenhouse gases. Oxygen allows organisms to respire (breathe), ozone offers protection from the Sun's UV radiation, and carbon dioxide, water and other greenhouse gases trap heat to keep us warm.

Layers in the atmosphere

The atmosphere is more dense at ground level and thins out as you go higher above the Earth's surface. Approximately 99% of all the air in the atmosphere is found within the first 80 km from the Earth's surface. There is not really a top to the atmosphere – the air just thins out, with decreasing pressure, until you reach the relative emptiness of space. These changing conditions are identified as several atmospheric layers.

The biosphere

biosphere
the intersection between the atmosphere, hydrosphere and lithosphere, where all living things are found

The **biosphere** is made up of all the living things on the Earth, including plants, animals and single-celled life (bacteria). Within this sphere, there is an enormous degree of organisation and amazing biodiversity. There is also great interdependence between different parts of the living world.

From feeding relationships to more obscure dependencies, there is a fine balance between organisms that must be maintained. The Earth is the only planet in our solar system that is able to support such a complex biosphere. Although life could exist in all spheres on the Earth, each organism has specific requirements and so they are limited to specific environments on Earth.

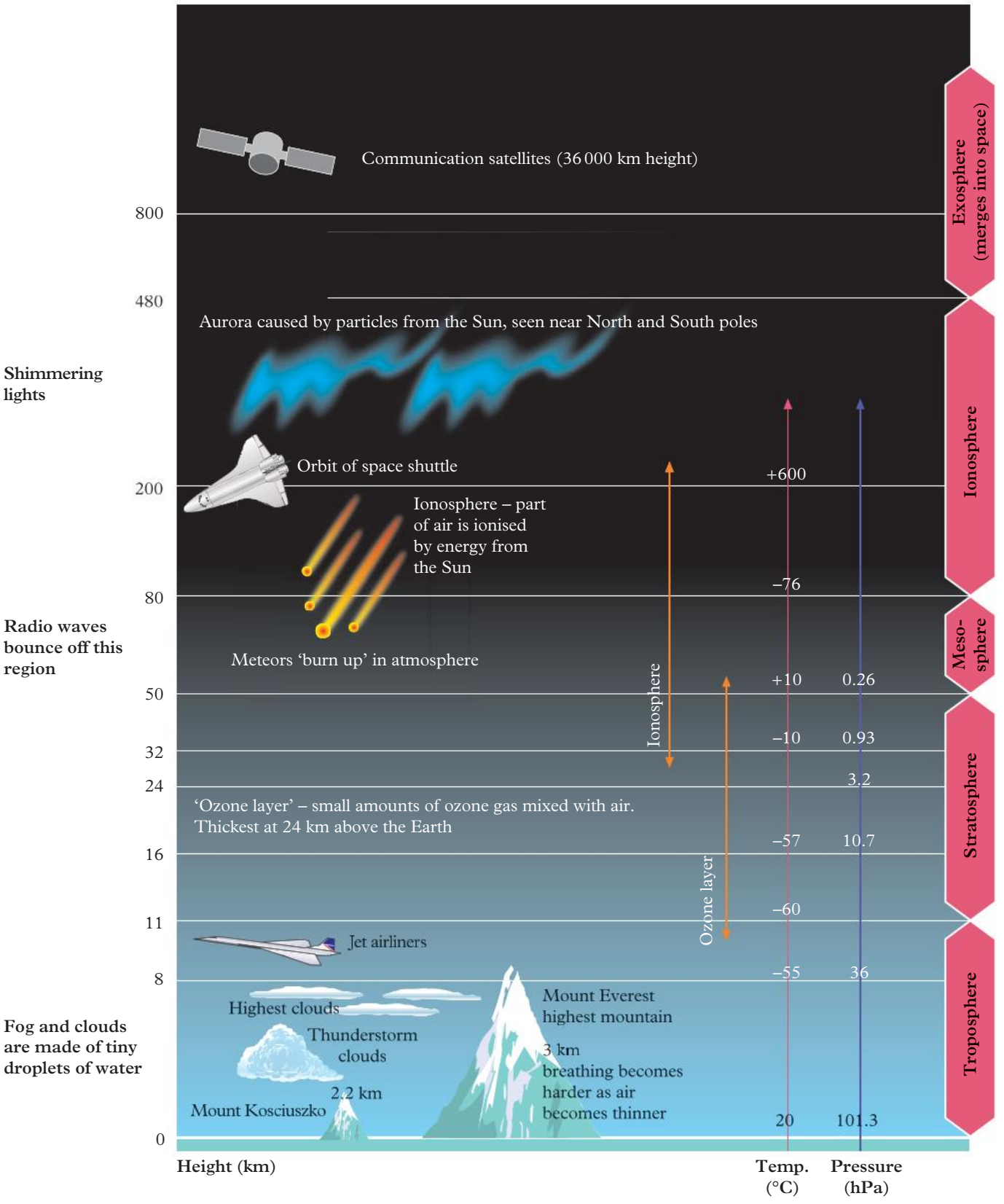

Figure 1 Each layer of the Earth's atmosphere has different characteristics.

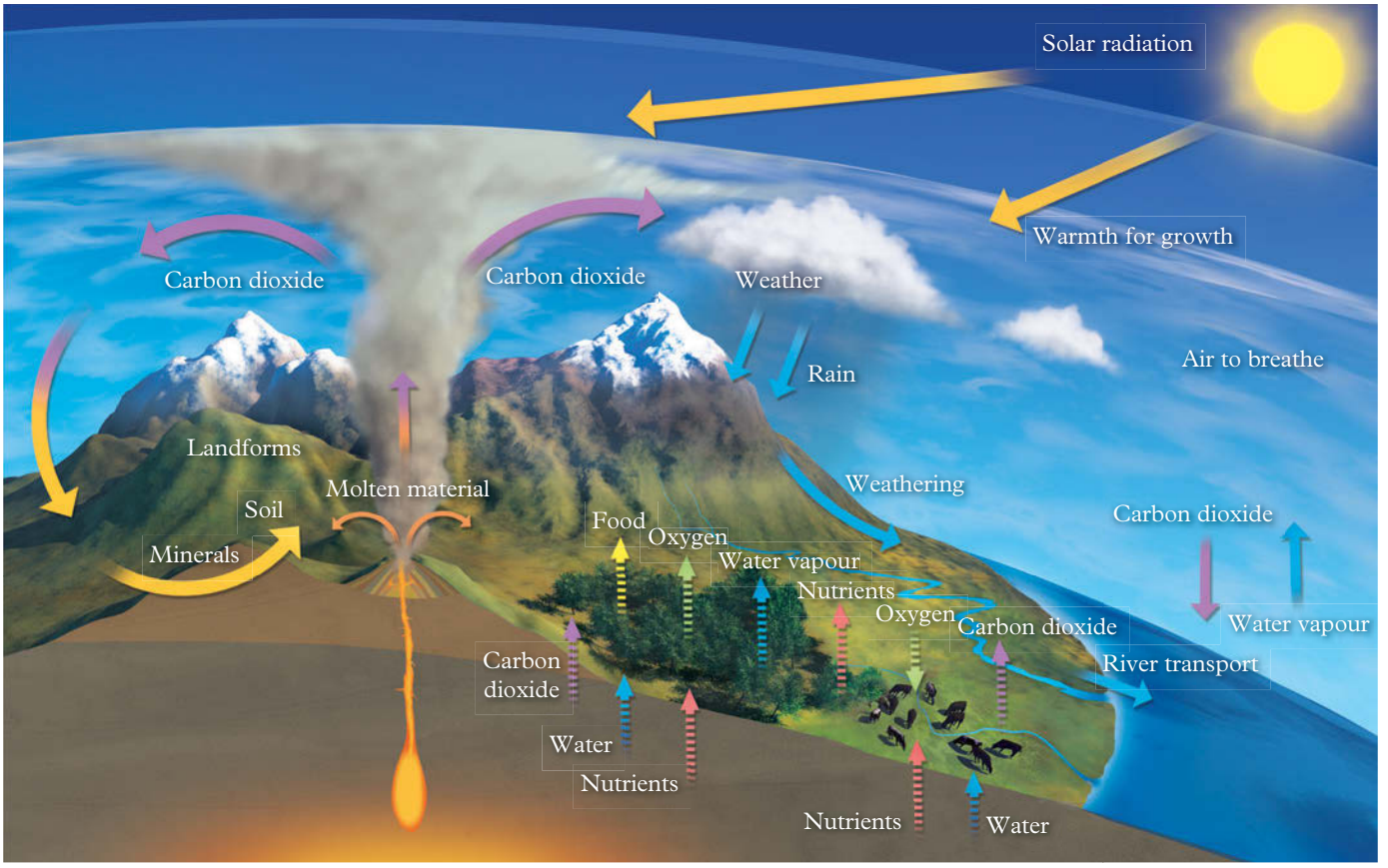

Figure 2 The inputs and outputs of the Earth's living and non-living systems

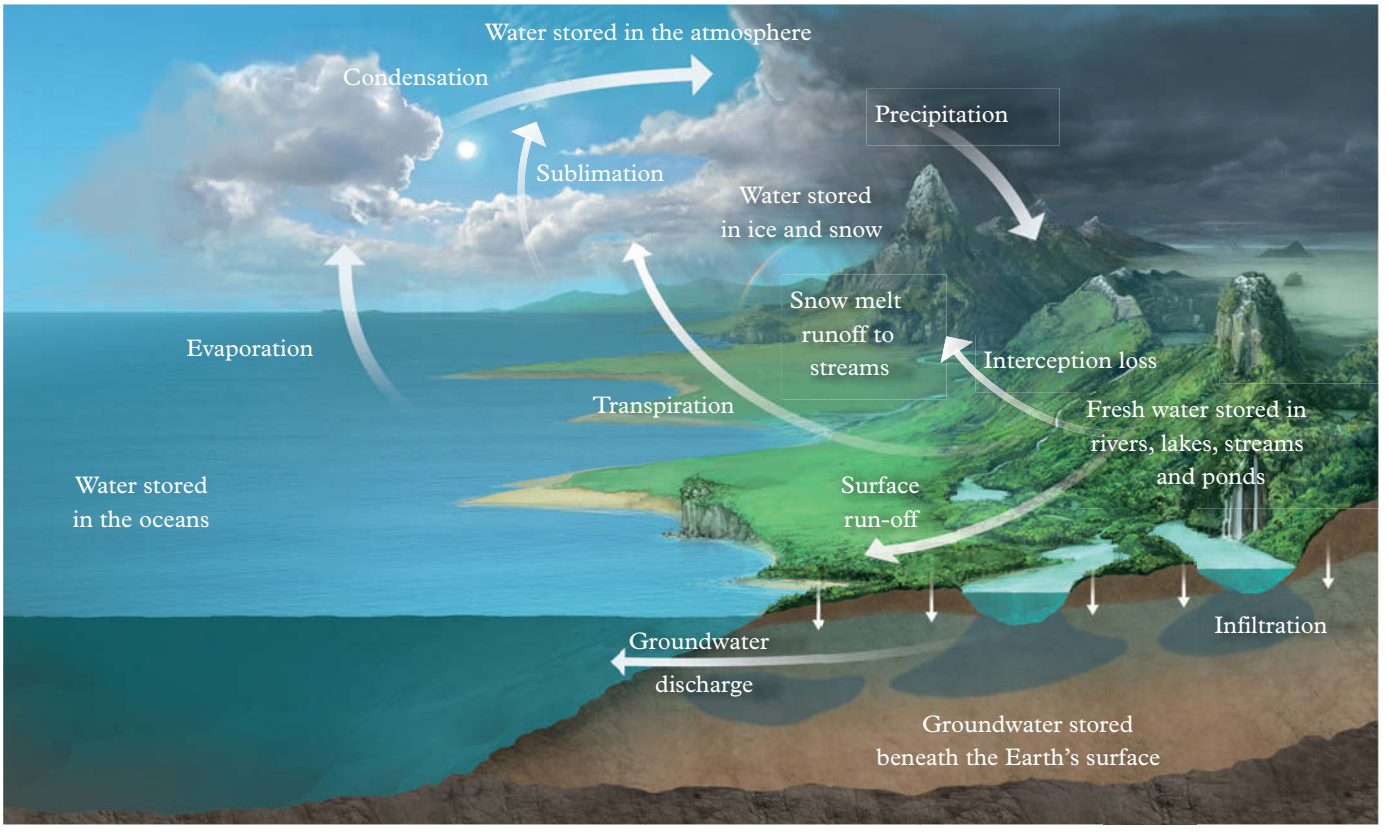

Figure 3 All the Earth's water makes up the hydrosphere.

Life can be found deep under the ocean, on the tops of the highest mountains, and in some rare cases single-celled life has been located living in space on the outside of the International Space Station. The wide range of conditions that exist in all these habitats accommodates a wide range of organisms – biodiversity (*bio* = life; *diversity* = variety).

The hydrosphere

The **hydrosphere** is made up of all the Earth's water. This includes oceans and lakes, frozen water in glaciers and ice sheets, groundwater in the soil and even the air droplets that concentrate in clouds (Figure 3). The hydrosphere covers approximately 70% of the Earth's surface, making the Earth the 'blue planet' when viewed from space. The huge amount of water, in all its various forms, is also home to many species of plants and animals. The hydrosphere interacts with and is influenced by each of the other spheres. For example, in the atmosphere you can find water in three different states: liquid (rain), vapour (clouds) and solid (snow and hail).

Hydrosphere influences climate

The part of the hydrosphere that is made up of frozen water is called the cryosphere. The cryosphere is very important in regulating the climate on the Earth, and it does this in a number of ways: it influences atmospheric and ocean circulation and currents, as well as the amount of moisture in the atmosphere, and it reflects rays from the Sun.

The lithosphere

The Earth is made up of many different layers. The outermost rocky layer of the Earth is the **lithosphere**, and it is made up of the upper mantle and the crust. Although the crust and upper mantle are only approximately 80 km thick, in terms of the scale of the size of the Earth, it is actually a very thin layer. The lithosphere is the slowest of Earth's system to change. Small changes can take thousands, even millions, of years. Towards the middle of the Earth, it gets hotter and, due to the heat, more molten (melted) and liquid. The outer core is liquid, but the inner core is a solid material of heavy metals. The inner core does not melt or boil because of the intense pressure it receives from the rest of the Earth pushing down on it.

lithosphere
outermost rocky layer of the Earth, consisting of the mantle and crust

hydrosphere
collection of all the Earth's water

The rocky crust of the Earth is made from magma (molten rock), which cools very slowly and at different times all over the surface of the Earth. The heat from the magma escapes into the air and water surrounding it. Tectonic plates float on the semi-liquid magma at the top of the mantle, moved around by heat driving convection currents. The tectonic plates move about 2–10 cm per year – a similar rate to the growth of your fingernails. To learn more about tectonic plates, refer to Chapter 7.

Interactive
Classifying components of the Earth

Check your learning 8.1

Recall and explain

1 **Identify** the layer of the atmosphere that we live in.
2 **Describe** what the lithosphere is made of.
3 **Describe** what makes up the biosphere.
4 **Explain** what happens to the amount of air as you go higher into the atmosphere.

Apply and analyse

5 **Compare** the hydrosphere and the atmosphere.
6 **Distinguish** between the biosphere and the lithosphere.

Evaluate and create

7 Draw a Venn diagram with four interlocking circles, one for each of the spheres studied. Label each sphere and include all features they share.

Skill builder: Questioning and predicting

8 Making observations enables scientists to make predictions. In this task, you must make and record observations about one of the Earth's spheres (atmosphere, biosphere, lithosphere and hydrosphere). Look outside for 10 minutes and make a list of observations about what is happening in nature.
   a **Describe** your observation. (THINK: What sphere is it occurring in? What is it affecting?)
   b **Explain** why this may be occurring. (THINK: What existing theories are there for this? Can I explain what I am seeing using one of these theories? Is there interaction between the spheres?)

8.2 The carbon cycle is a global cycle

In this topic, you will learn that:

- carbon is stored in carbon sinks, such as fossil fuels, limestone rocks, forests and the oceans
- humans can cause the carbon sinks to release carbon into the atmosphere as carbon dioxide.

Carbon (C) is a non-metal chemical element that is essential to all life on Earth. It cycles through all the Earth's spheres. Carbon trapped in the lithosphere cycles very slowly, whereas carbon in the biosphere, hydrosphere and atmosphere cycles much faster. Carbon can be stored for a long time in carbon sinks, such as fossil fuels, limestone rocks, forests and the oceans. Human activity can also cause the carbon sinks to release carbon into the atmosphere as carbon dioxide.

Cycling carbon

Video
The Carbon Cycle

Carbon is the fourth most abundant element on Earth and is the basic component of all living organisms. It is the basis of carbohydrates, proteins and lipids. Carbon can cycle through the land, oceans and atmosphere over both short and long periods of time.

- The geological carbon cycle is a long-term cycle that occurs over hundreds to millions of years and has resulted in the bulk of carbon being locked in carbonate rocks (carbon-based rocks) or in sediments as fossil fuels (oil, gas and coal). It can quickly change due to a bushfire or volcanic eruption pushing more carbon back into the atmosphere.
- The biological/physical carbon cycle is a short-term cycle that occurs over days, weeks, months and years, and it involves the cycling of carbon through photosynthesis and cellular respiration. Plants are excellent cyclers of carbon dioxide and can store it for long periods of time. When organisms die, some carbon is returned to the atmosphere via

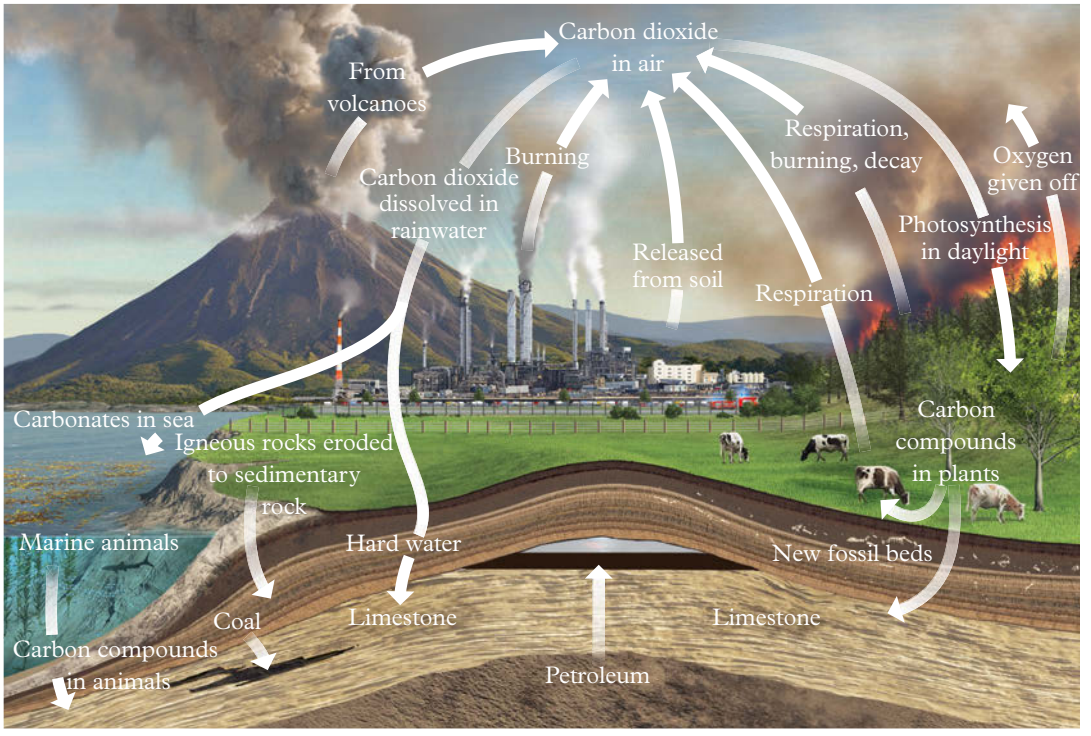

Figure 1 The complete carbon cycle showing the geological, biological and physical, and human factors.

decomposers who break down organic matter and some carbon remains as dead material to one day form fossil fuels.

Humans can tap into the geological carbon cycle by extracting fossil fuels such as oil, natural gas and coal to run their cars and produce energy. When we burn the fossil fuels, we release the carbon dioxide into the atmosphere quicker than the natural geological carbon cycle can balance out. Farming, deforestation (cutting down trees) and the industrial production of materials such as concrete are further ways humans are adding to the amount of carbon in the atmosphere. These processes can produce other carbon-based gases such as carbon monoxide (CO) and methane (CH_4).

Carbon sinks

A **carbon sink** is any feature of the environment that absorbs and/or stores carbon, keeping it from the atmosphere. This is an example of the biosphere, hydrosphere and lithosphere interacting to balance out the carbon in the atmosphere. There are many types of carbon sinks; some are short-term and others are long-term. Examples of different carbon sinks are included in Table 1.

carbon sink
any feature of the environment that absorbs and/or stores carbon

Figure 2 Bushfires are an important part of the carbon cycle, releasing carbon back into the atmosphere.

Table 1 Different types of carbon sinks and their storage times

Carbon sink	Storage time	Method	Spheres interacting
Forests	Long-term	Photosynthesis removes CO_2	Biosphere, atmosphere
Oceans	Long-term	CO_2 dissolves in water	Hydrosphere, atmosphere, biosphere
Carbonate rocks	Long-term	CO_2 is precipitated as carbonate rocks	Atmosphere, hydrosphere, lithosphere
Fossil fuels	Long-term	CO_2 is stored in dead organic matter underground	Atmosphere, biosphere, lithosphere
Organic matter in soil	Short-term	CO_2 is stored short-term and released during decomposition	Atmosphere, biosphere, lithosphere
Shells	Short-term	CO_2 is precipitated as carbonate shells	Biosphere, hydrosphere
Terrestrial organisms	Short-term	CO_2 is stored in organisms' breathing	Biosphere, atmosphere

Check your learning 8.2

Recall and explain

1 **Describe** what a carbon sink is. Provide two examples.
2 **Explain** how you are part of the carbon cycle.
3 **Explain** the difference between short-term and long-term carbon cycles.

Apply and analyse

4 **Distinguish** between the geological carbon cycle and the biological/physical carbon cycle.
5 **Identify** two ways human activity affects the carbon cycle.
6 **Compare** the speed at which carbon is released into the atmosphere through the biosphere and burning. **Explain** how this compares with carbon being released from the hydrosphere.
7 **Analyse** why bushfires are an important part of the carbon cycle.

Evaluate and create

8 Create a pie chart that represents how human activity diverts energy required for carbon fixation.

Skill builder: Processing and analysing data and information

9 Look at Table 1.
a **Identify** the spheres that are interacting in forests and shells. (THINK: Which columns and rows have this information?)
b **Construct** a graph that compares the short- and long-term stores. (THINK: Are there two obvious groups? Which data needs to go on the *x*-axis and *y*-axis?)

8.3 The water cycle produces rain and helps maintain seasons

In this topic, you will learn:

- the hydrosphere includes all the water on Earth
- the hydrosphere interacts with the lithosphere, atmosphere and biosphere
- the difference between weather and climate.

All of the Earth's water (including water in the air, water trapped in ice and water underground) continually cycles through the different parts of the hydrosphere. It evaporates into the air, lowering the air pressure and contributing to the formation of wind.

Water cycle

Water is an essential part of life and is important for many metabolic processes in your body. It is continuously moved through the atmosphere and biosphere in the process of the water cycle.

However, this does not mean that there is a never-ending supply of water. This is because the water cycle (Figure 1) is a *global* cycle. This means that water is not equally available in all ecosystems. For example, water that evaporates from the desert may later fall as rain on a forest thousands of kilometres away. For this reason, an ecosystem may have too little water (drought) or too much water (floods) for the organisms within it to survive. This is why it is important to monitor and analyse the patterns of rainfall across the globe to make predictions about weather elsewhere.

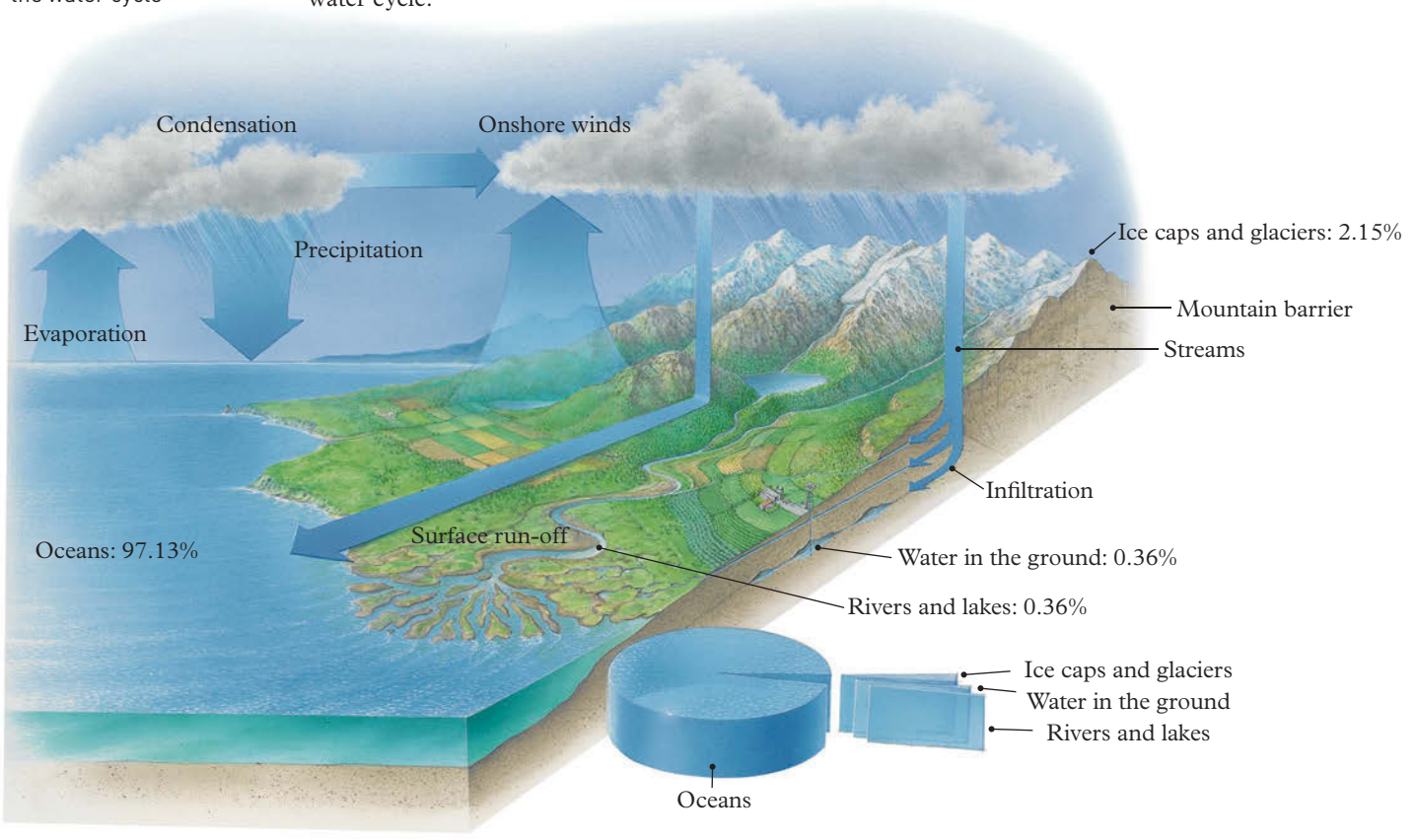

Figure 1 The distribution of water on the Earth and the water cycle

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8.3: Making a simple barometer
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INVESTIGATION
8.3: Making your own clouds
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Clouds and rain

Water vapour is the source of all clouds and precipitation and is therefore the most important gas in the atmosphere when it comes to understanding atmospheric processes. Water vapour is evaporated water – water as a gas. Water vapour that has evaporated from oceans and rivers rises until it reaches the cooler parts of the atmosphere. Cold air cannot hold as much moisture as warm air can, so the water vapour turns back into liquid water – condensation. These drops of water then form into clouds. The clouds may be carried onto land by winds and may be forced to rise when they reach a mountain barrier or another air mass. The colder air can no longer hold the condensed droplets and they fall as precipitation – rain, hail or snow. The precipitation eventually moves back to the world's lakes and oceans through rivers and streams and the process begins again.

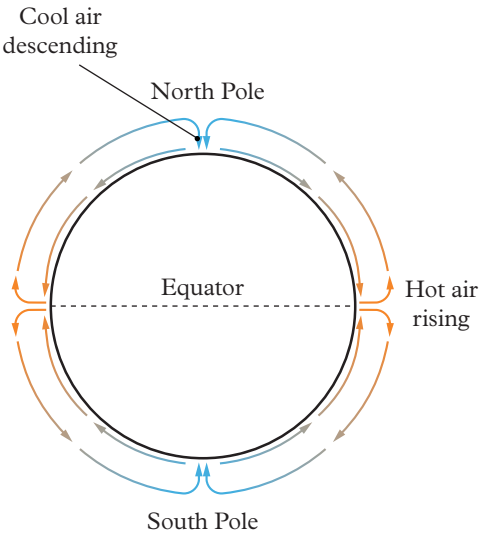

Figure 2 Movement of air at the Equator and at the poles can result in the circular movements of air called cyclones.

water vapour
a gaseous form of water

weather
a snapshot of what the air and conditions are like in any one place on the Earth at any one time

climate
weather conditions at a particular place over a long period of time based on the collection and analysis of large amounts of data

Weather and climate systems

Weather reports tell you what the weather will be like in terms of temperature, rain and other factors. Therefore, **weather** is a snapshot of day-to-day changes. **Climate** is more concerned with longer periods of time and involves the collection and analysis of large amounts of data. You can use weather predictions to decide what to wear each day, whereas climate predictions may help farmers plan what types of crops to grow, governments to decide whether to invest in certain technologies, or even households to decide whether they'll need to install an air conditioner.

Weather

Regions near the Equator are warmer than regions near the poles. Near the Equator, the Sun is directly overhead in the middle of the day. Because of this, the energy from the Sun is concentrated, so these regions are heated intensely. Near the poles, the Sun is lower in the sky, shadows are longer and energy from the Sun becomes more spread out. This is because the Earth's surface is curved, so the Sun's rays come in at an angle.

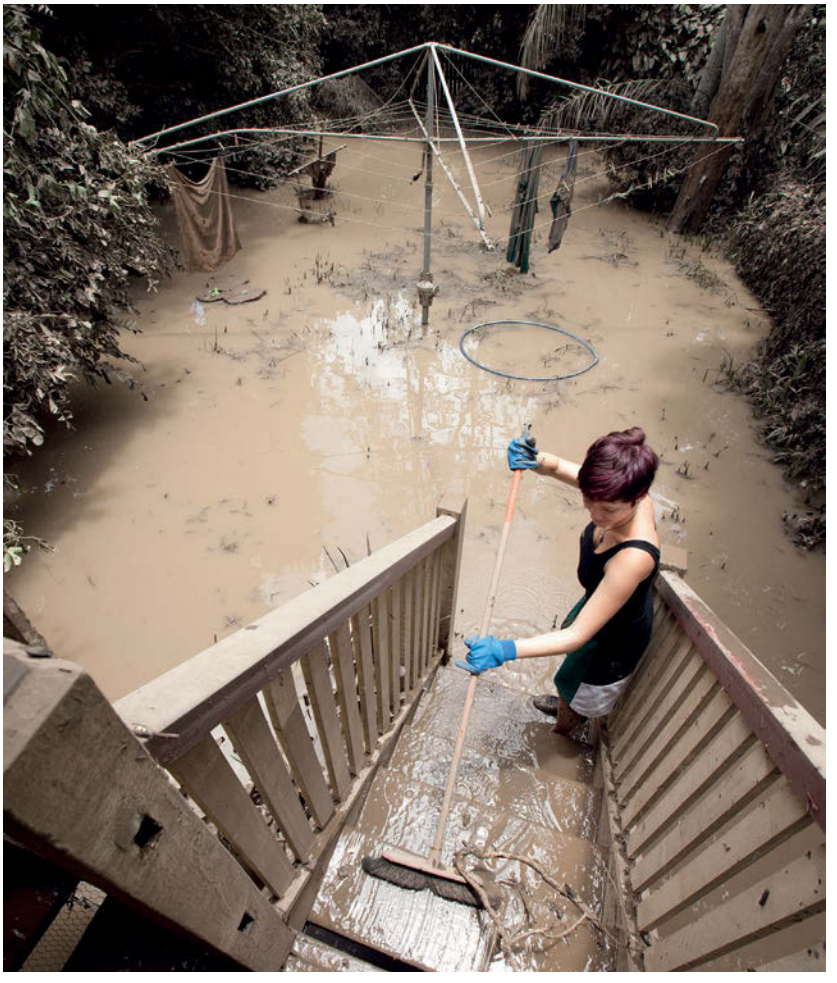

Figure 3 Flooding may follow torrential rain during a cyclone.

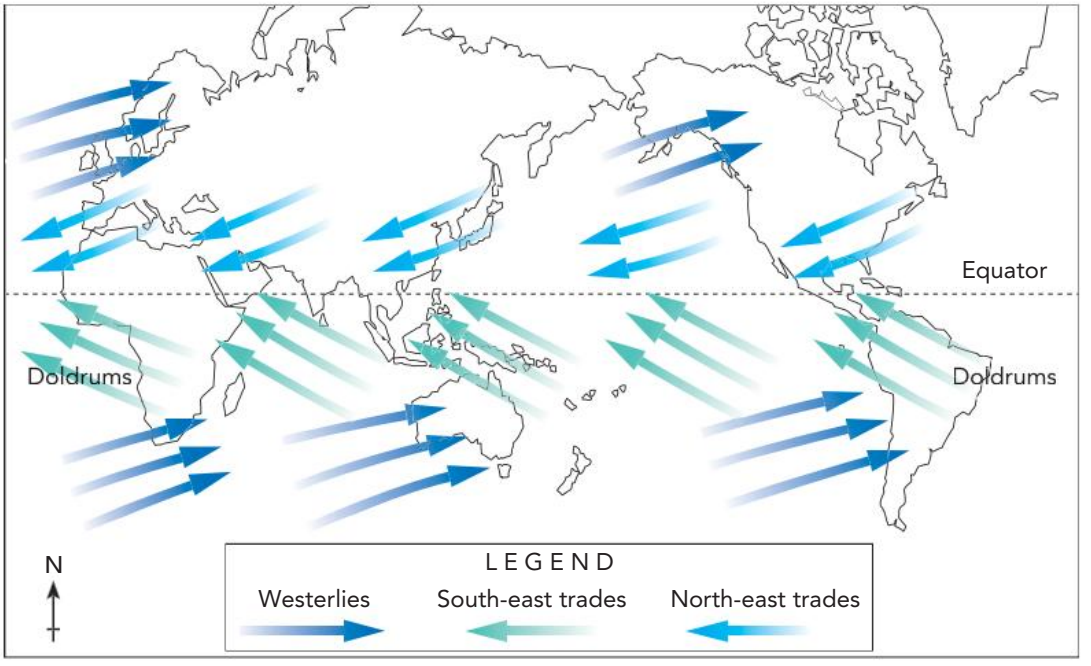

Figure 4 Wind patterns over the Earth. The Doldrums are areas of low pressure where winds tend to be very calm.

wind
the sideways movement of air as a result of lower density warm air rising through the atmosphere

Coriolis effect
the influence of the Earth's rotation on the direction of air or water movement

isobar
a line drawn on a weather map that joins places of equal air pressure

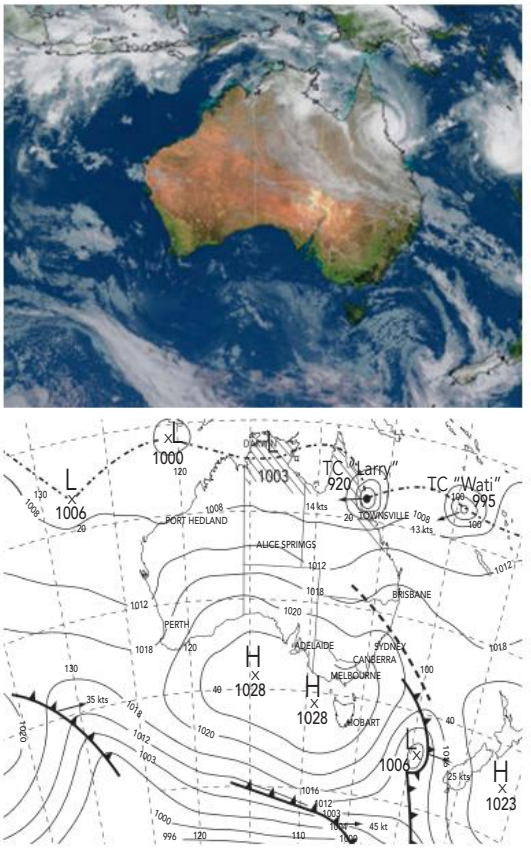

Figure 5 A **a** satellite image and **b** weather map showing tropical Cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006

As the air heats up, the particles in the air spread out and become less dense. As a result, the less dense, warmer air rises above the more dense, cold air. This means the warm air near the Equator rises into the atmosphere and colder air near the poles moves towards the Equator to fill the space left by the warm air (Figure 2). The movement of air is better known as **wind**. Wind is the result of sideways or horizontal movements of air due to pressure differences.

The **Coriolis effect** is the influence of Earth's rotation on the direction of air or water movement. The Coriolis effect can cause winds to deviate from the path you may expect them to take. The surface of the Earth can also interfere with the speed and direction of wind. Rough and mountainous terrain will slow wind and significantly change the wind's direction.

On a weather map, air pressure differences are shown as **isobars**; the closer the isobars, the greater the difference in pressure and the stronger the wind. Regions of high and low pressure are also shown on a weather map (Figure 5). Low-pressure areas are frequently associated with clouds and precipitation, whereas high-pressure systems bring clear blue skies.

Through the water cycle, the hydrosphere influences the atmosphere by altering winds. It also influences the biosphere by providing water for all animals and plants to survive.

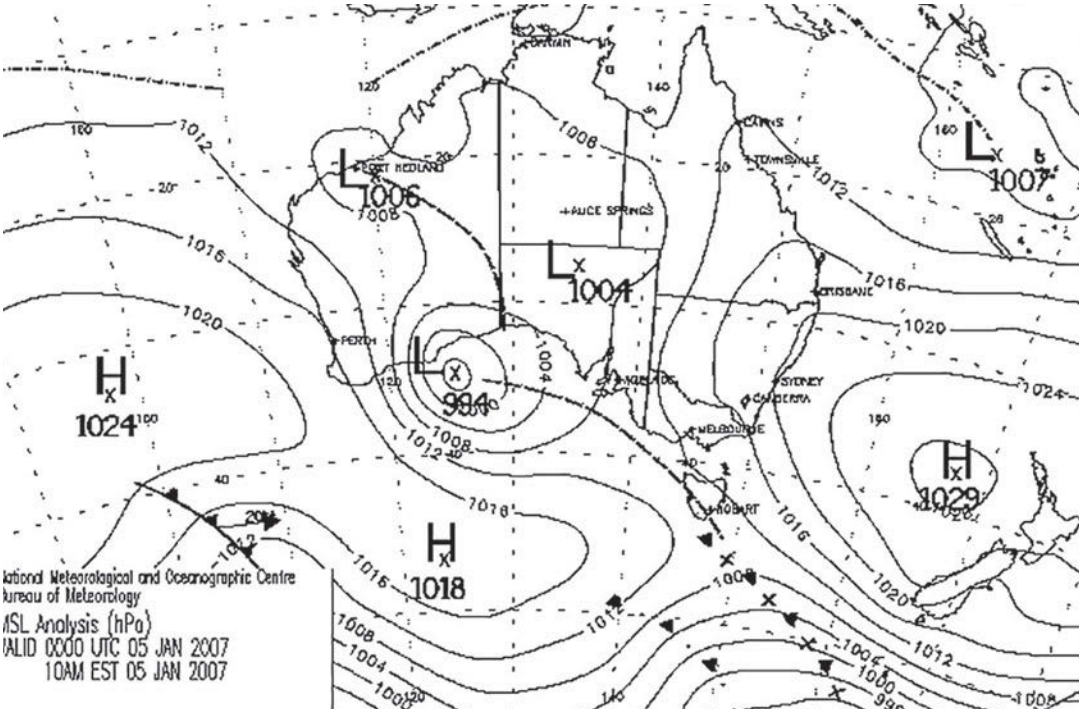

Figure 6 A weather map

Check your learning 8.3

Recall and explain

1 **Explain** the difference between weather and climate.

2 **Describe** what is meant by 'air pressure'.

3 **Explain** what happens to the pressure of the air when it gets heated.

4 **Explain** why it rains.

Apply and analyse

5 **Explain** how winds are related to rising air.

6 **Describe** the conditions that must occur for water vapour in clouds to fall as precipitation.

7 Write a list to **identify** as many weather terms shown in Figure 6 as you can.

Evaluate and create

8 Research a recent cyclone in Australia and **investigate** the weather patterns before, during and after in that area. Create a poster that communicates your findings.

Skill builder: Conducting investigations

9 The following equipment list is from an experiment that measures transpiration: soft leaves, zip-lock plastic bag, fan, retort stand, ice cubes, tape, marker pen, water, towels, beaker. In the given list, there are some incorrect and non-specific pieces of equipment.

a **Identify** which descriptions aren't clear.
(THINK: Based on this list, could I easily know exactly what I need? Are the amounts listed?)

b **Explain** how the list could be improved for each of the descriptions you identified in part a.
(THINK: Do I need a measurement? How many of each do I need?)

8.4 Global systems cycle the Earth's resources

In this topic, you will learn:

- the oxygen cycle is influenced by processes in the biosphere and atmosphere
- human activities impact the cycle of nitrogen in the atmosphere and lithosphere
- phosphorus is cycled through weathering and decay.

The cycling of all nutrients through the Earth's spheres is essential to sustaining life. Plants are able to absorb carbon dioxide from the atmosphere and produce more oxygen. Similar interactions between the various spheres enable a flow of matter, including phosphorus and nitrogen.

Cycling oxygen

Oxygen is the essential ingredient in cellular respiration, the process by which most organisms obtain energy for life. The Earth has a fixed supply of 'useful' oxygen even though it can be found everywhere. There are three reservoirs of oxygen:

- the atmosphere (0.49%)
- the Earth's crust or lithosphere (rocks) and the oceans (99.5%)
- living organisms – the biosphere (0.01%).

photolysis
the breakdown of a chemical substance by light, one example being the breakdown of water into oxygen and hydrogen

nitrogen-fixing bacteria
bacteria that convert nitrogen from the atmosphere into various nitrogen compounds

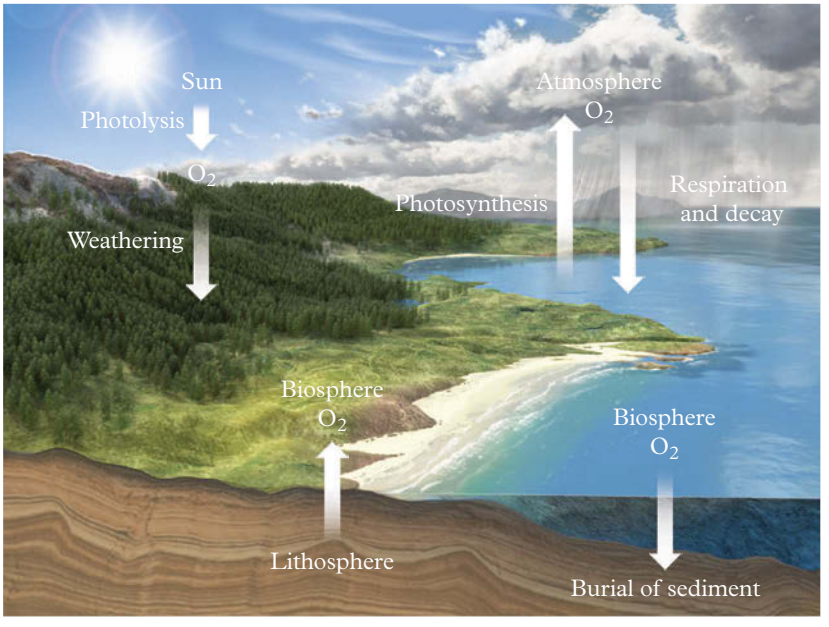

Figure 1 The oxygen cycle

In the atmosphere, oxygen exists as the molecules O_2 and O_3 (ozone) and in compounds such as water (H_2O) and carbon dioxide (CO_2). Oxygen can dissolve in the oceans, where it is available for uptake by marine organisms.

The oxygen cycle is influenced heavily by processes in the biosphere and atmosphere (Figure 1). In the biosphere, photosynthesis releases oxygen and cellular respiration absorbs oxygen. In the atmosphere, oxygen is formed through UV light converting water to oxygen and hydrogen in a process known as **photolysis**:

$$2H_2O + \text{energy} \rightarrow 2H_2 + O_2$$

Oxygen is removed from the atmosphere through the process of cellular respiration, the decay of organisms, and the weathering of exposed rocks.

Cycling nitrogen

Nitrogen is necessary for the synthesis of proteins and nucleic acids, which are vital building blocks for all organisms. Although nitrogen makes up 78% of the gases in the atmosphere (making it the most abundant gas), it is not in a form that can be used by living organisms. Bacteria play an important role in changing nitrogen into usable forms (nitrate, nitrite and ammonium ions) and returning it to the atmosphere.

Nitrogen-fixing bacteria are able to convert nitrogen (N_2) from the atmosphere into nitrate (NO_3^-) ions, nitrite (NO_2^-) ions and ammonium (NH_4^+) ions. Nitrogen-fixing bacteria live in root nodules of legumes – plants such as peas and beans. The nitrogen compounds produced by the bacteria are used

INVESTIGATION
8.4: Testing phosphorus
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by the plant to produce proteins. In return, the plant provides protection and other essential elements to the bacteria. **Denitrifying bacteria** are able to return nitrogen back into the atmosphere.

Many human activities affect the cycle of nitrogen in the atmosphere and lithosphere. These include fossil fuel emissions and run-off from fertilisers.

Cycling phosphorus

Phosphorus is an essential component of the energy molecule ATP (adenosine triphosphate), as well as the molecules DNA and RNA (with sugar–phosphate backbones) (see Figure 2, page 211). Without phosphorus, an organism cannot use available energy-containing molecules. The phosphorus cycle is the slowest of the biogeochemical cycles (Figure 2). Unlike photosynthesis and respiration, for example, weathering and decay are lengthy processes. Most of the phosphorus available to living organisms comes from sedimentary rocks and soils. Unlike in the other biogeochemical cycles, phosphorus does not have a gaseous phase. Farmers will often apply phosphate fertilisers to agricultural land or plant legumes between crops. In the phosphorus cycle:

- rain weathers rocks, releasing phosphate ions into the soil
- plants absorb phosphate ions via their roots
- phosphorus absorbed by organisms returns to the soil through urine, faeces and the decomposition of an organism's body
- phosphorus is locked in sediments and rocks for millions of years before being released by weathering and erosion, thus completing the cycle.

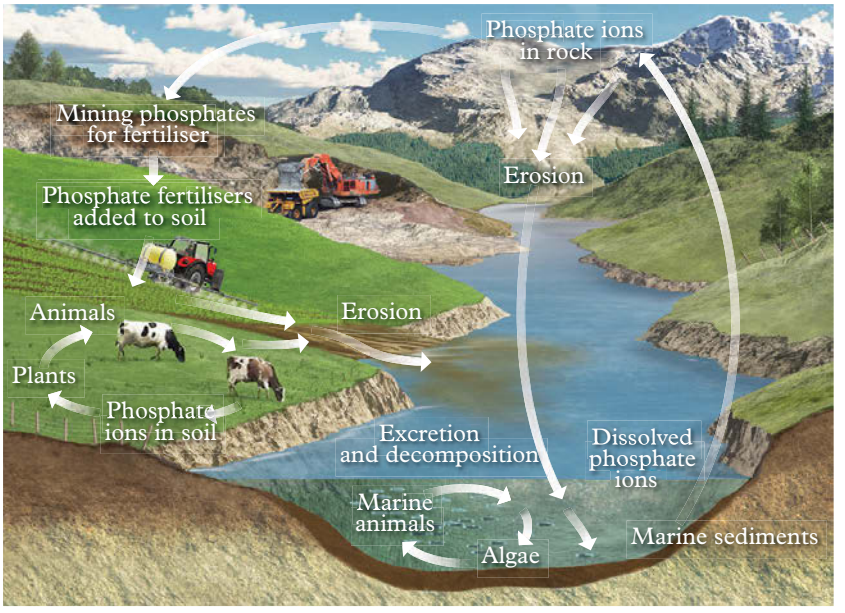


Figure 2 The phosphorus cycle

Run-off from agricultural land can lead to excessive levels of phosphorus in waterways. Because phosphorus encourages plant growth, excess levels lead to the increased growth of plankton and other aquatic plants. This results in an increase in oxygen consumption within this environment, suffocating fish and other aquatic animals, as well as blocking sunlight from bottom-dwelling organisms. This process is known as **eutrophication**.

denitrifying bacteria
bacteria that convert nitrates in soil to free atmospheric nitrogen

eutrophication
a process whereby excessive levels of phosphorus in waterways lead to the excess growth of algae and bacteria and an increased consumption of oxygen, suffocating fish and other aquatic animals

Check your learning 8.4

Recall and explain

1 **Recall** the three reservoirs of oxygen.
2 **Identify** three important molecules in your body that contain phosphorus.
3 **Explain** what nitrogen-fixing bacteria is.

Apply and analyse

4 **Explain** why plants struggle to grow in nitrogen-poor soils.

Evaluate and create

5 Draw a concept map that shows the contribution of micro-organisms to the cycling of nutrients in an ecosystem.

Skill builder: Communicating

6 Rewrite the following paragraph scientifically. (THINK: Is the language clear? Is it concise? Is the information supported by evidence? Is it descriptive or factual?)

Oxygen, the air that keeps us alive exists in the atmosphere. The atmosphere is a beautiful space above the Earth. Oxygen can dissolve into the oceans, ocean life can then absorb it for their survival. Oxygen cycles around the world, and is influenced from the smallest insect in the biosphere, to the biggest cloud in the atmosphere.

8.5 Natural events impact the Earth's spheres

In this topic, you will learn that:

- cyclones affect multiple systems because they cause storms, release lightning and result in destruction and erosion
- volcanoes impact the Earth's spheres because they release ash and gas into the atmosphere, and lava can flow into the biosphere
- earthquakes impact the lithosphere because they shift the earth, affecting the biosphere that relies on stability.

Figure 1 Christchurch, New Zealand, has experienced several devastating earthquakes. This photo is from 2011.

Natural events can have huge effects on the interaction between the Earth's spheres. Australia's location on tectonic plates is relatively stable and therefore most of Australia's volcanoes are now extinct; although there remain a few in Victoria that are considered dormant. It also means that the likelihood of earthquakes is reduced. Each year Australia experiences a cyclone season, particularly affecting Queensland and the Northern Territory. These cyclones can have disastrous consequences.

Cyclones

Cyclones are low-pressure storm cycles that form over warm tropical oceans. For a cyclone to form, the water temperature must be at least 25°C. During a low-pressure system, water evaporates from the ocean and forms clouds. These clouds then release heat energy into the air, which causes the pressure in the atmosphere to reduce further.

The lower pressure combined with the Earth's rotation cause the clouds to start to rapidly rotate towards the centre of the low-pressure zone. Once the winds reach 63 km/h, a storm cycle is considered a cyclone. The strongest winds can typically be found at the 'eye' or centre of a cyclone, but these winds can extend out from the storm for hundreds of kilometres.

Cyclones in the Southern Hemisphere spin clockwise, whereas in the Northern Hemisphere, they spin anti-clockwise and are called typhoons or hurricanes. The effects of cyclones on each of the Earth's spheres can be seen in Table 1.

Table 1 The impacts of cyclones on the Earth's spheres

Sphere	Cyclone impact
Biosphere	• Winds cause habitats to be polluted with debris from other habitats. • Animal habitats can be destroyed with trees being uprooted and food sources being depleted.
Lithosphere	• Heavy rains and damaging winds uproot trees and cause erosion. • Erosion of soil on beaches, agriculture and natural vegetation. • Rocks can be destroyed by strong winds.
Hydrosphere	• Creates an imbalance in water systems caused by flooding or tidal currents. • Increases in unnaturally large ocean waves can change water cycles.
Atmosphere	• Heat is redistributed from lower altitudes to higher altitudes. • Causes increased amounts of precipitation and moisture in the atmosphere. • The uprooting of trees may cause reduced oxygen in the atmosphere. • Lightning caused by storm cycles can increase charged particles in the atmosphere.

Volcanoes

Volcanic eruptions usually occur at convergent plate boundaries where one plate melts as it is subducted (forced down) into the mantle. They can also occur at hot spots on the Earth's mantle.

The impacts of a volcano on the Earth's spheres can be seen in Table 2.

Earthquakes

Earthquakes occur frequently over many parts of the Earth. Many of these earthquakes are small or occur away from city centres, and go unnoticed. Usually they occur at the edges of tectonic plates, but they can also occur in the centre of tectonic plates. Earthquakes can destroy cities, with the worst destruction close to the epicentre.

As layers of Earth are shifted, earthquakes disrupt the lithosphere. The impact of earthquakes on each of the spheres is shown in Table 3.

Table 2 The impacts of volcanic eruptions on the Earth's spheres

Sphere	Volcanic eruption impact
Biosphere	• Flowing lava, extreme heat and ash cloud can impact animal and plant populations. • After an eruption, volcanic soil is rich in nutrients and promotes new growth.
Lithosphere	• Burnt trees and plants from lava fertilise the soil. • Lava solidifies to create new rock formations.
Hydrosphere	• Water can become warmer and increase in acidity, potentially causing acid rain. • Depending on the location, glaciers and ice caps can melt, decreasing the salinity of the ocean. • Sulfuric acid combines with rain and becomes acid rain. • Underwater volcanoes can increase the carbon dioxide in the ocean. They also increase the hydrogen sulfide concentration, which gives rise to species that use this instead of sunlight.
Atmosphere	• Ash, carbon monoxide, hydrogen sulfide and water vapour are released, which contributes to the greenhouse effect and climate change. • Ash cloud impacts air traffic (e.g. birds and planes). • Water molecules are attracted to the ash cloud, which can increase clouds and rain. • Lightning storms are attracted to volcanic eruptions.

Table 3 The impacts of earthquakes on the Earth's spheres

Sphere	Earthquake impact
Biosphere	• Flora and fauna in surrounding areas can die or have their population reduced. • Animal behaviour can also change as a result of earthquakes.
Lithosphere	• The layers of the Earth are pulled apart or forced together. • Rock formations are destroyed or created. • Lakes and rivers can collapse. • Mountain ranges can be formed or have their height increased or decreased.
Hydrosphere	• Aquifers (permeable rock that contains or transmits groundwater) are disrupted. • Water forms (e.g. lakes and rivers) are changed. • Ocean currents can be impacted, and tsunamis can form from offshore earthquakes.
Atmosphere	• Increases in mountain heights can disrupt pressure flows in the atmosphere. • Earthquakes can increase the greenhouse effect as they release methane and warm the atmosphere's temperature.

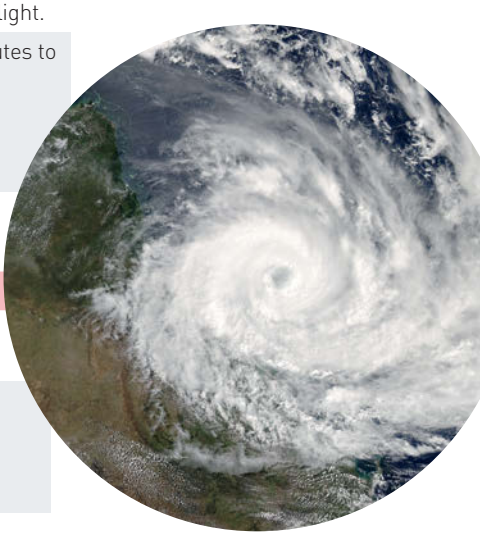


Figure 2 A satellite image of Cyclone Debbie nearing the north-east coast of Australia in 2017.

Check your learning 8.5

Recall and explain

1 **Explain** what a cyclone is.

2 **Recall** how earthquakes occur.

Apply and analyse

3 **Assess** whether the impact on the hydrosphere is greater during a volcanic eruption or a cyclone. **Justify** your answer.

4 **Recall** why cyclones weaken once they are on land.

Evaluate and create

5 **Investigate** one of the following sets of natural disasters:

- Cyclone Yasi (2011) and Cyclone Tracy (1974)
- Fukushima tsunami (2011) and Indian Ocean earthquake and tsunami (2004)

a **Identify** the following:

- similarities and differences
- major features of each
- human impact
- impact on each of the Earth's spheres.

b **Propose** why the impact of each event was different, despite being the same type of disaster. You might want to think about location, date and time of year.

Skill builder: Problem solving

6 Scientists seek to predict the behaviour of the Earth to provide early warning systems for the people who live in the surrounding areas.

a Based on your understanding of volcanic activity, **propose** why they are harder to predict than earthquakes. (THINK: What causes each of these phenomena?)

b Volcanic eruptions can be predicted by observing earthquake activity in the area. **Evaluate** this strategy by writing a pros and cons list. (THINK: Why would earthquakes occur at a similar time to volcanic eruptions? What are the positives and negatives?

8.6 Climate change is supported by evidence

In this topic, you will learn that:

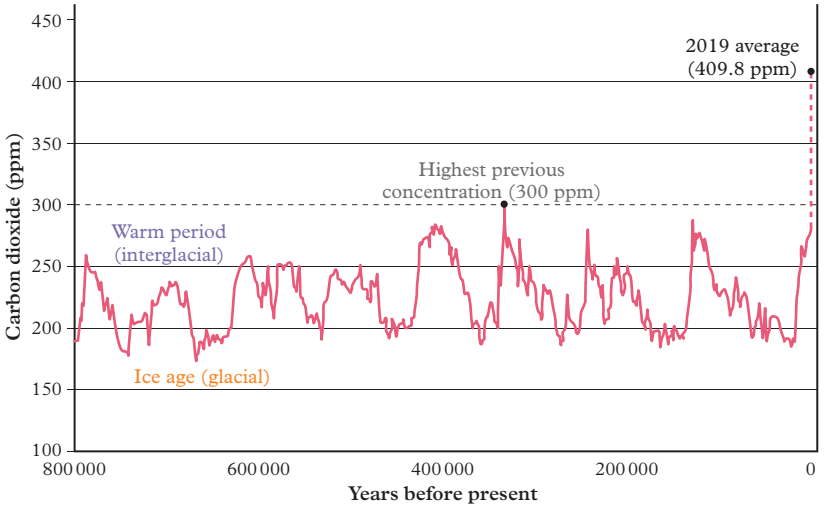
- the greenhouse effect is important for maintaining life on Earth
- permafrost contains the equivalent of about half of all fossil fuel emissions to date since the Industrial Revolution.

The Earth is surrounded by an atmosphere of greenhouse gases including carbon dioxide, methane and water vapour. These gases reflect radiation from the Sun and retain the warmth from the Earth, preventing extreme temperature changes. The average global temperature of the Earth has increased 0.8°C over the last 100 years. Evidence for enhanced climate change can be found in the melting of sea ice and permafrost and in increasing sea levels.

enhanced greenhouse effect
the additional effect that humans are having on the natural greenhouse effect due to the burning and release of fossil fuels

The greenhouse effect

The greenhouse effect is critical for maintaining life on the Earth. Solar energy passes through the atmosphere and warms the Earth's surface. Heat gradually leaves the Earth's surface and is radiated back into space. Some heat is trapped by the gases in the atmosphere.



Source: NOAA Climate.gov, data: NCEI

Figure 1 Carbon dioxide over 800 000 years

These gases act like a giant greenhouse of warm air, keeping the Earth warm. If heat were not trapped, the temperature would drop to –100°C each night and rise to 80°C in the day. The gases that contribute to the greenhouse effect include carbon dioxide, water vapour, methane, nitrous oxide and ozone. Since the Industrial Revolution of the 18th and 19th centuries, the level of greenhouse gases has been increasing, causing an **enhanced greenhouse effect**.

Increased levels of greenhouse gases

The concentration of carbon dioxide in the air has changed significantly (approximately 34%) since 1750. The bulk of that increase has happened since 1959. The concentration of methane in the atmosphere has also risen dramatically over the past century, more than doubling.

The main greenhouse gas is carbon dioxide. It is formed by the burning of fossil fuels, such as coal, petrol, oil and gas. We all use this energy for heating, lighting, transport, industry and communications.

Burning carbon-based fossil fuels releases energy (usually as heat) and produces carbon in the form of carbon dioxide and sometimes carbon monoxide or solid particulate carbon.

Forests consume carbon dioxide in the process of photosynthesis. Massive deforestation for farming and urban land has also led to an increase in carbon dioxide levels because these forests are no longer available to absorb excess carbon dioxide. This increase in production and decrease in absorption has resulted in an increase in the amount of carbon dioxide present in the atmosphere (Figure 1). Figure 2 shows which parts of the world emit the highest amounts of carbon dioxide.

INVESTIGATION
8.6a: What factors affect a greenhouse?
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INVESTIGATION
8.6b: Melting ice and its effect on sea levels
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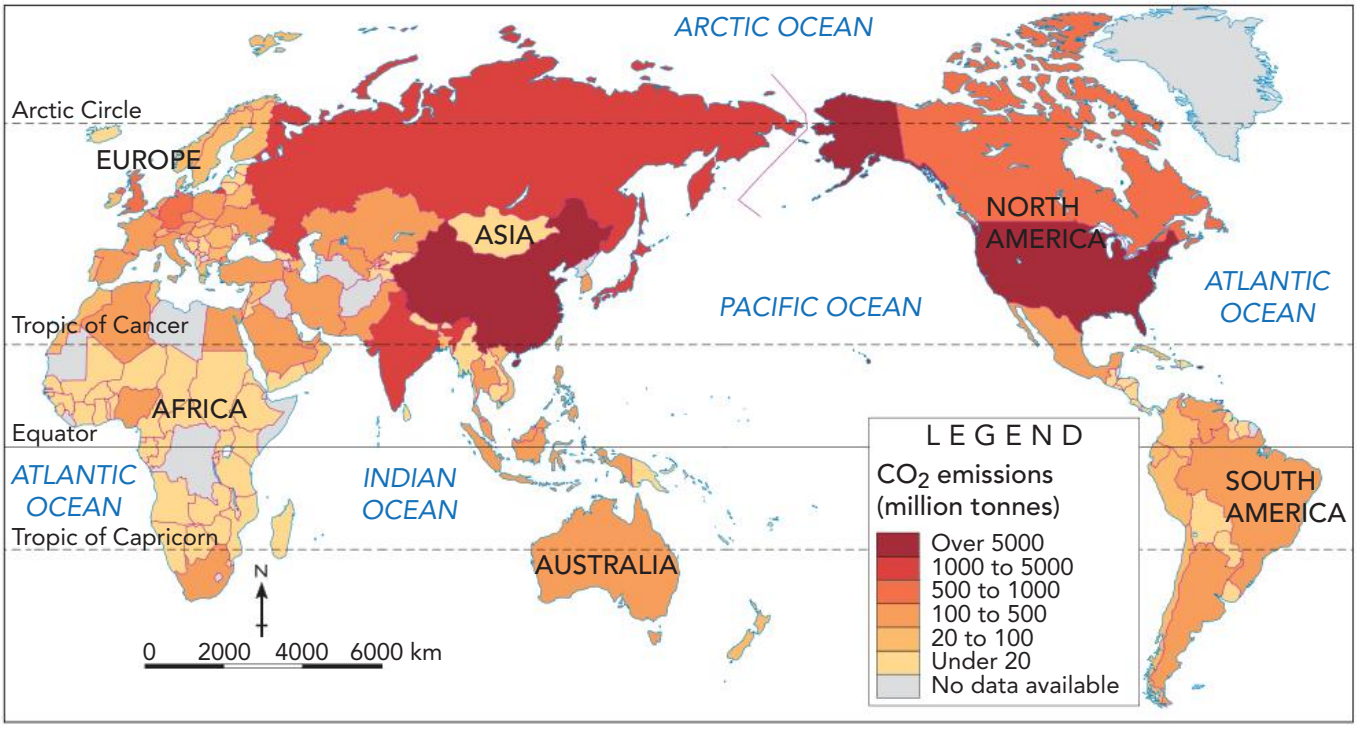

Figure 2 Global CO_2 emissions by area

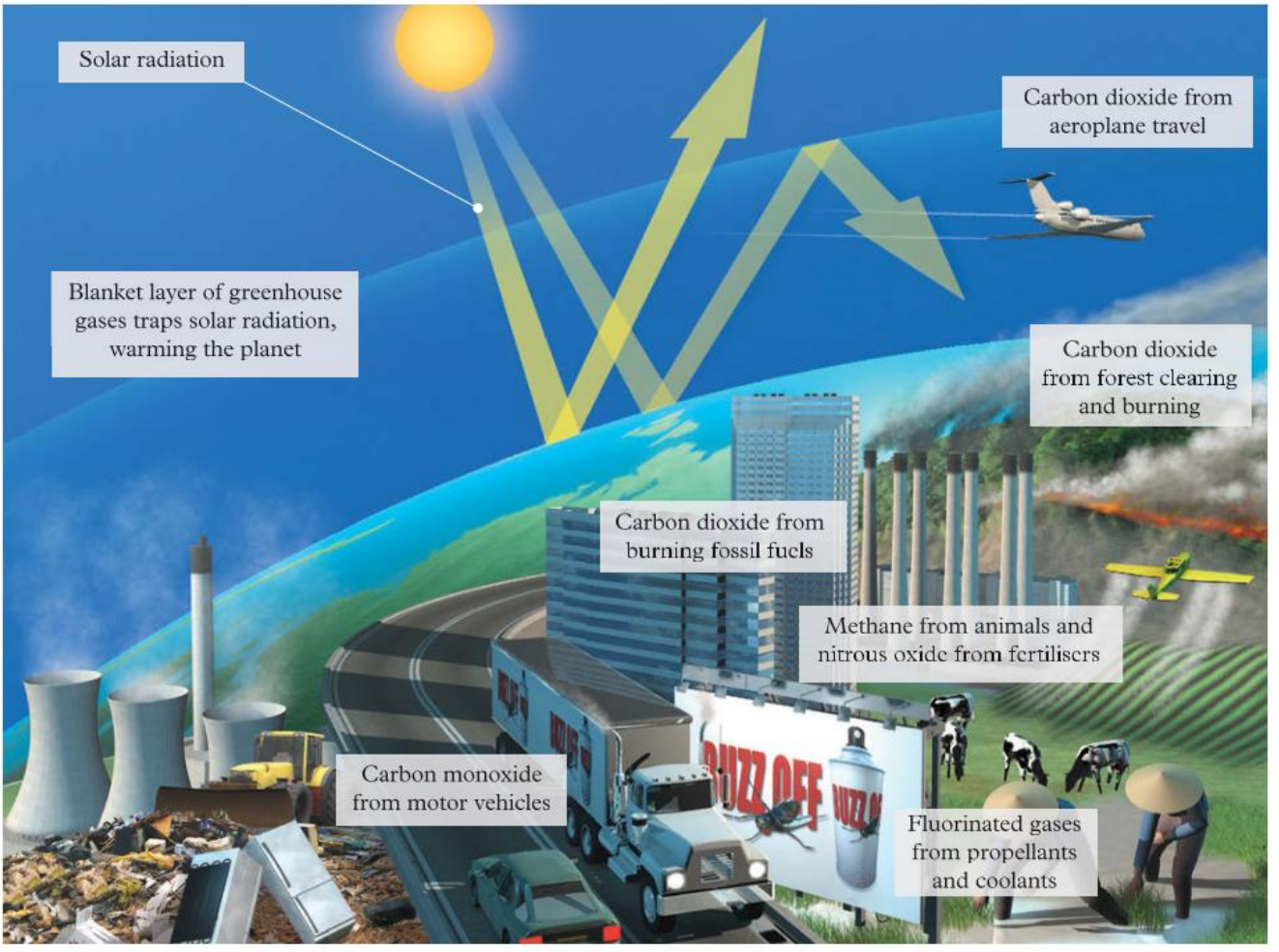

Figure 3 Human-induced climate change

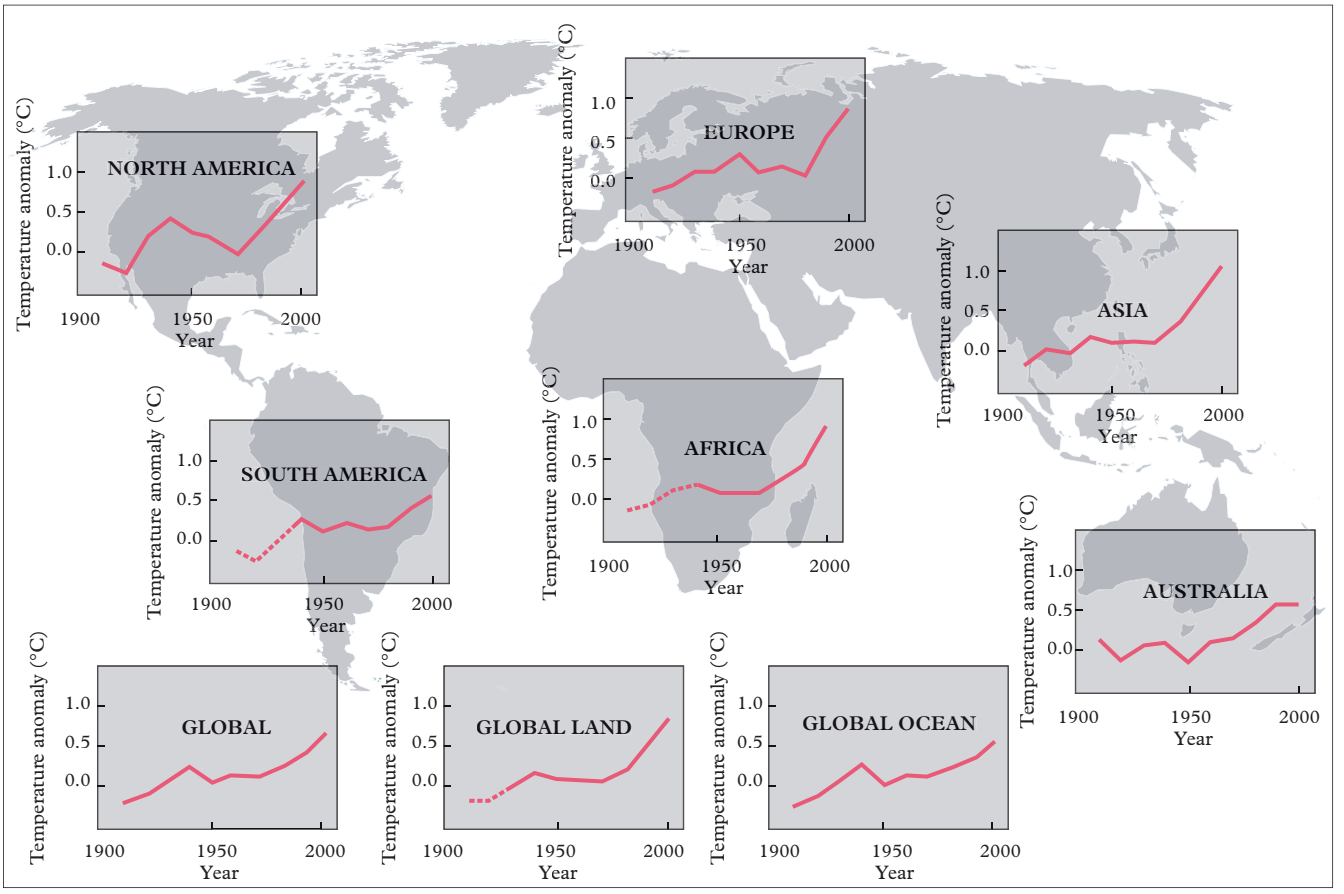

Figure 4 Global changes in temperature since 1900

Natural sources of methane in the Earth's atmosphere include the decay of organic materials in wetlands, termites, emissions from the oceans and the melting of methane hydrates, which are frozen forms of methane found in the ocean floor. Human activity also produces methane through energy production, increased emissions from livestock (e.g. cattle), landfill, biomass burning and waste treatment. The increase in these greenhouse gases has resulted in trapping more heat in the atmosphere. Figure 4 shows how global temperatures have changed since 1900.

Melting sea ice

The ocean is very important in the regulation of global temperatures. It is a carbon sink, absorbing carbon, but it also absorbs up to 90% of the solar radiation that hits the ocean. Warmer water in the ocean reduces the ocean's ability to absorb solar radiation. The warmer water also causes sea ice to melt.

Sea ice is vast, shiny and bright white – it acts as a big mirror that reflects the Sun's radiation back out to space, once again keeping the Earth cooler. When this ice melts, more heat is absorbed by the water, increasing its temperature. The warmer water heats the atmosphere above it, and so a cycle has begun that increases global temperature.

Melting permafrost

permafrost
ground that has been frozen since the last ice age; stores carbon

Permafrost is permanently frozen ground that stores carbon from plant material frozen during the last Ice Age. Scientists have been measuring the temperature of the permafrost in Siberia for over 150 years and they have noticed an upwards trend. This means the ice is getting close to melting temperature (0°C) (Figure 5). Scientists believe that as much as two-thirds of the Earth's permafrost could disappear by 2200.

If the Earth's permafrost does melt, it will release thousands of years' worth of carbon into the atmosphere. This would equate to roughly as much as half of all fossil fuel emissions to date from when the world became industrialised.

Rising sea levels

The gravitational pull of the Moon (and Sun), together with the rotation of the Earth, mean there is a high tide approximately every 11 hours. Over many centuries, average water levels have varied. An Ice Age traps water in glaciers and sea ice, exposing land bridges for animals to migrate. These changes are very slow, taking thousands of years to affect sea levels. Over the last 100 years, there has been a dramatic change in sea levels as a result of climate change melting ice at the polar ice caps (Figure 6).

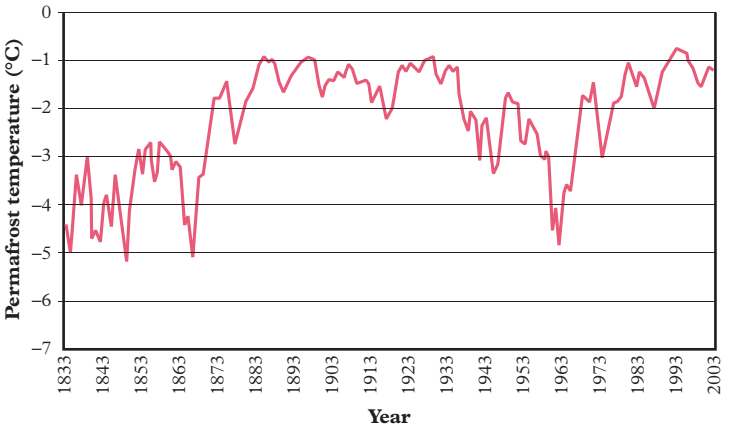

Figure 5 Historical measurements of Siberian permafrost temperatures at 5 metres depth suggest that the permafrost is becoming warmer.

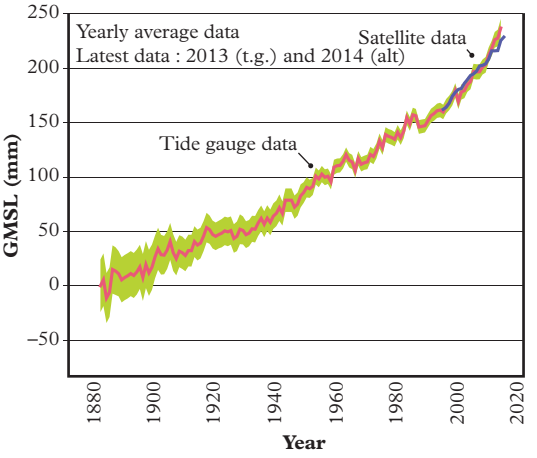

Figure 6 The CSIRO measured the Global Mean Sea Level (GMSL) from coastal tidal gauges and satellite data from 1880 to 2014. The overall trend indicates a consistent rise in sea levels.

Check your learning 8.6

Recall and explain

1 **Explain** why the greenhouse effect is actually good for life on Earth.

2 **Recall** what permafrost is and **explain** why it adds to emissions if it melts.

3 **Recall** how much the temperature on Earth has risen over the past century.

Apply and analyse

4 Climate change deniers suggest that the increase in sea levels is part of a normal cycle. **Compare** the timescale of previous global warming events to current climate changes.

Evaluate and create

5 **Examine** the data shown in this section. Use the data to support your opinion of the validity of the phrase 'global warming'.

Skill builder: Planning investigations

6 Information about climate change is shared in the scientific community and through media platforms.

- **a** Find two sets of data related to climate change; one from a magazine and one that is scientific. (THINK: Search for popular terminology in government websites.)
- **b** For each set of data, read the information surrounding it. **Assess** whether the language used increases or decreases the credibility of the data. (THINK: Is the data impacted by the information surrounding it? Does the data change based on where it was published if the original source is still used?)

8.7 Climate change has widespread effects

In this topic, you will learn that:

- climate change impacts Earth as a whole because of the interactions of Earth's global systems
- El Niño occurs when the Pacific Ocean waters are warmer than normal
- La Niña occurs when the Pacific Ocean is cooler than normal.

As you have learned throughout this chapter, the Earth's systems interact in a delicate balance. What may seem like small increases in global temperatures have lasting effects on the whole planet.

Figure 1 The aftermath of a cyclone: the number of severe cyclones is increasing.

Extreme weather events

The number of extreme weather events around the world is increasing. Scientists predict that storms will have greater maximum wind speeds and more sudden and extreme rainfall. More intense tropical cyclones will cause flooding, landslides and damage to buildings. Worldwide, the number of cyclones reaching category 4 or 5 has risen by 15% over the past 20 years. Cyclones intensify over warm ocean waters – another consequence of increasing global and ocean temperatures. We can also expect to see an increase in the loss of human lives as a result.

Health and disease

Higher temperatures in summer have increased heat-related deaths. A heat wave in Europe in 2003 was estimated to have killed between 22 000 and 35 000 people. Climate change is also thought to extend the zones for infectious diseases, such as dengue fever and malaria, which thrive in warm, moist conditions. In cities such as Beijing, China, stagnant weather conditions can trap both warm air and pollutants, leading to smog, which results in serious respiratory problems.

Loss of biodiversity

Over the past 30 years, climate change has changed the distribution of species, and resulted in extinctions. Many of the species at risk are Arctic and Antarctic animals, like polar bears and emperor penguins, which live on the ice.

Australian native plants and animals are well adapted to year-to-year climate fluctuations, such as floods and droughts, but often they can only survive within a narrow range of temperatures. This means that many species and ecosystems could be highly vulnerable to the rapid and sustained increase in long-term average temperatures of 1–2°C that are expected as a result of climate change.

Climate change modelling indicates that the extent of highland rainforest ecosystems of tropical north Queensland may decrease by up to 50% with a 1°C increase in temperature. These changes mean some species may become extinct. As all organisms in the biosphere are interlinked, the loss of one species will affect the survival of other organisms. Even a small decrease in a population may cause a decrease in the number of alleles in the gene pool, making the species more vulnerable to diseases in the future.

Deep ocean currents and climate control

Within the oceans are large deep ocean currents that act like conveyor belts to churn heat through various parts of the world and regulate temperature (Figure 2).

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water then cools and this colder water travels from the poles back to the warmer areas of the Earth. These large conveyer belts of water are driven by the differences in temperature and salinity.

CHALLENGE
8.7: Salt water density
Go to page **375**

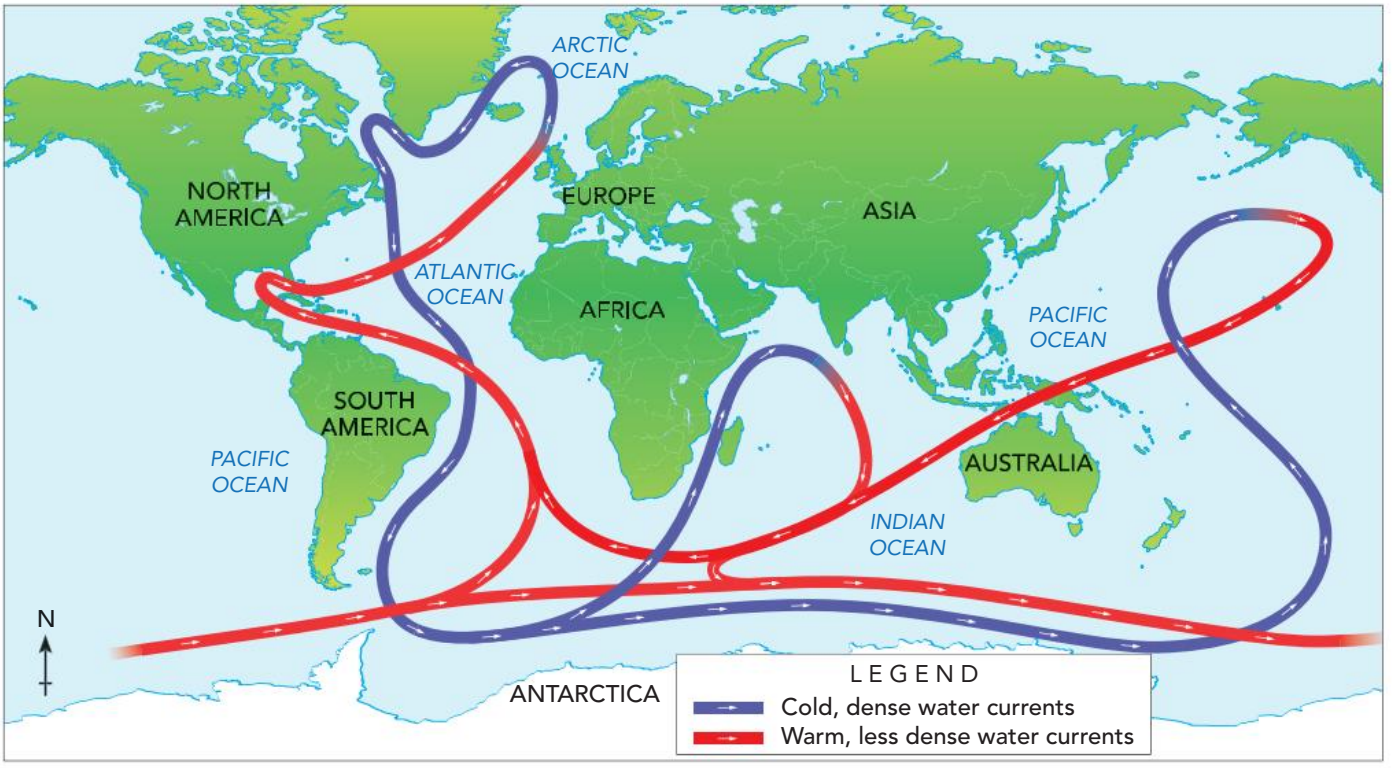

Figure 2 The path of the ocean 'conveyer belt', in which differences in temperature and salinity drive the movement of large currents of water.

Colder water is dense and heavy, and it moves towards the ocean floor; warmer water is less dense and moves towards the surface, completing the up-and-down conveyer belt-like movement. Less salty water is also less dense and rises to the surface, whereas salty water is denser and sinks. Heat from the Sun evaporates the top layer of the ocean. Therefore, the salt in the remaining water is more concentrated and sinks once again. This cycle of warm water and cold water is disrupted by the melting of the fresh water in ice caps. This in turn can affect the ocean conveyor belt that controls climate.

El Niño events occur when the waters of the Pacific Ocean are warmer than normal. This in turn causes more rain to fall in the Pacific Basin instead of in northern Australia. A La Niña event occurs when the Pacific Ocean is cooler than normal, causing increased rainfall and possible flooding in Australia.

Check your learning 8.7

Recall and explain

1 **Explain** why a change of only 1–2°C is sometimes enough to cause problems to species on Earth.

2 **Summarise** why a loss of biodiversity is a problem.

Apply and analyse

3 **Assess** how the temperature of the Pacific Ocean can affect Australia's climate.

Evaluate and create

4 Create a poster or webpage that brings awareness to how climate change is affecting the local ecosystem in the NSW coastal wetlands.

Skill builder: Questioning and predicting

5 The North Atlantic cod population has declined as a result of overfishing. The population no longer bounces back because of changing ocean currents and colder Arctic waters.

a **Identify** the variable that is changing in this situation. (THINK: What is impacting the decline of the North Atlantic cod?)

b **Construct** a hypothesis about this population, assuming climate change continues. (THINK: What do you expect to happen to the cod population with an increase in climate?)

8.8 Humans have an impact on climate change

In this topic, you will learn that:

- humans can reduce their carbon footprint and, with this, they can reduce the impact of climate change
- policies, including the Kyoto Protocol, set expectations for human behaviour in regard to climate change.

Kyoto Protocol
an international treaty which commits parties of the United Nations to reduce greenhouse gas emissions

carbon tax
a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme
the process of allocating a set limit of carbon credits to businesses that can then be traded

geosequestration
the capture and storage of carbon underground

The idea of the enhanced greenhouse effect or climate change (once referred to as global warming) was first raised by the scientific community in 1977. As a result, scientists around the world begin to coordinate their research in the World Climate Research Program. By 1983, the enhanced greenhouse effect was becoming a political issue. Currently, climate change is seen as a worldwide problem and this has influenced the focus of scientific research.

Kyoto Protocol

In 1997, an international treaty called the **Kyoto Protocol** was signed by many of the countries that are part of the United Nations. This document stated that global warming exists and that it is a result of carbon dioxide emissions resulting from human activity. The countries who signed the protocol agreed to start working to reduce carbon emissions by 5% of the 1990 emissions. Australia ratified the agreement in 2007. This required the Australian Government to limit its average annual greenhouse gas emissions during 2008–2012 to 108% of its emissions in 1990. In 2012, the protocol was amended to allow countries to commit to reducing carbon emissions until 2020.

Figure 1 The use of renewable energy, such as wind power, is one way to reduce carbon emissions.

Reducing carbon emissions

Many governments are encouraging industries in their countries to reduce carbon emissions. Some governments are charging a fee for each tonne of carbon a business emits. This is often called a **carbon tax**. Other governments have instigated a **carbon trading scheme** where each business is allowed to release a predetermined amount of carbon emissions. If a company needs to release more carbon dioxide or methane as part of their production process, then they must buy an allocation from another company. This also allows other industries to actively extract carbon dioxide from the atmosphere in order to sell 'carbon credits'. One carbon credit is often equivalent to 1 tonne of carbon dioxide.

Geosequestration

The capture and storage of carbon dioxide underground is called **geosequestration**. This process, often employed by oil companies, involves capturing carbon dioxide from power station chimneys, separating it and compressing it into a liquid. The liquid is then pumped into depleted oil or gas wells and sealed with a solid plug of thick clay.

Carbon farming

Plants remove carbon dioxide from the air as part of photosynthesis. This carbon dioxide is converted into sugars and proteins that are then used by the plant to grow. Therefore, the greenhouse gas becomes part of the plant's structure. The carbon is considered to be locked in the plant for as long as it lives. For some trees this can be hundreds of years. **Carbon farming** is the process of growing plants that are not harvested for firewood, building or any other purpose (Figure 2).

Figure 2 Carbon farming removes carbon from the atmosphere and locks it away for hundreds of years.

carbon farming
the process of growing plants that are not harvested for firewood, building or any other purpose

Reducing methane production

Methane, another greenhouse gas, is often produced as a result of grass fermenting in a cow's stomach. The increase in our population has meant more food (including meat) is needed. This has resulted in more cattle and therefore more methane being released into the atmosphere. Microbiologists at the University of Queensland are studying ways to modify the bacteria present in a cow's stomach so that they do not produce as much methane. Their model is the bacteria found in the foregut of kangaroos. This particular species of bacteria produces mainly acetic acid as a waste product. This acetic acid is then digested further by the kangaroo. It is hoped that the way these bacteria digest grasses can be mimicked by the bacteria in a cow, thereby reducing the emission of the greenhouse gas.

Small changes, big differences

There are many ways each person can contribute to slowing climate change. These include:

- using public transport or car pooling
- switching off electrical appliances at the wall when not in use
- using renewable energy such as solar panels
- buying local produce, which prevents fossil fuels being used to transport food over long distances
- reducing, reusing and recycling items to prevent them going into landfill and generating methane.

Small changes can make big differences.

Resource
STEM activity: City Planning

Check your learning 8.8

Recall and explain

1 **Explain** what the Kyoto Protocol is.
2 **Distinguish** between a carbon tax and a carbon trading scheme.

Apply and analyse

3 **Identify** two ways carbon dioxide can be removed from the atmosphere. **Explain** how these work.
4 **Discuss** how the values and needs of contemporary society have influenced research on climate change.

Evaluate and create

5 **Evaluate** the role of the government in climate change action. Consider the economic, societal and ethical implications of this.

Skill builder: Communicating

6 Imagine you are speaking with someone who thinks it is too hard to be environmentally sustainable and climate change is inevitable.
   a **Explain** why it is important to be sustainable. (THINK: What are the key facts that need to be communicated?)
   b **Evaluate** the impacts of individuals living in a sustainable manner. (THINK: What will change? Will there be bigger impacts?)

REVIEW

Multiple choice

1 Select the best definition for the lithosphere.
- **A** The outermost rocky layer of the Earth including the mantle and crust
- **B** The layer of gases that surrounds Earth and other planets
- **C** The intersection between the atmosphere, hydrosphere and biosphere
- **D** The collection of all the Earth's water

2 **Recall** the term that explains the impact of the Earth's rotation on the direction of air or water movement.
- **A** Permafrost
- **B** Carbon footprint
- **C** Solar energy
- **D** The Coriolis effect

3 Carbon emissions can be reduced by:
- **A** charging a carbon tax
- **B** using public transport
- **C** using solar energy
- **D** all of the above.

Recall and explain

4 **Identify** three different layers of the Earth.

5 **Identify** the layer of the Earth where the tectonic plates are found.

6 **Explain** what gases are found in our atmosphere and why they are important to life on Earth.

7 **Summarise** what a drought is, and **explain** which sphere it relates to.

8 Even though the Earth's inner core is hotter than its molten outer core, it is thought to be solid. **Explain** how this can be the case.

9 **Identify** the input from the solar system that has the greatest influence on our weather.

10 **Deduce** if salty water will sink to the bottom or rise to the top of the ocean.

11 Make a list of three ways that increasing industrialisation, particularly since the 19th century, has affected ecosystems.

12 **Describe** the most significant way in which humans have affected ecosystems.

13 **Identify** some of the predicted outcomes of climate change.

14 **Explain** how humans are shifting the distribution of energy in ecosystems.

15 **Describe** a volcanic eruption.

16 **Identify** the two most significant carbon-containing greenhouse gases.

Apply and analyse

17 The hydrosphere can have a huge effect on the other spheres. Australia is prone to devastating droughts where there is not enough water available for the needs of Australians.
- **a** **Explain** how drought could affect the biosphere.
- **b** **Describe** how this would affect the atmosphere.

18 **Distinguish** between water and water vapour. **Explain** if you could find both in the air.

19 **Explain** why it is warmer near the Equator than elsewhere on Earth.

20 The northern bettong is a very small, endangered nocturnal marsupial. It is an omnivore that eats small invertebrates, herbs, grasses and a species of fungus, which makes up approximately 45% of its diet. Northern bettongs were once widely distributed throughout Queensland. However, there are now only three populations left along the western edges of the wet tropics of north Queensland.

Investigate the northern bettong on the internet. **Identify** what human activities you think are contributing to the northern bettong being listed as endangered.

21 The glaciers on Mount Kilimanjaro in Tanzania are disappearing eight times faster than they were 20 years ago due to global warming. **Explain** how cloud cover can affect the atmospheric temperature and hence the melting of glaciers.

22 **Analyse** the effects of melting permafrost.

23 'Bushfires can have both a positive and negative impact on local ecosystems.' **Analyse** this statement.

24 **Assess** how cyclones impact multiple spheres of the Earth.

25 Phosphorus is a key component of your DNA. **Explain** what role the phosphorus cycle plays in that.

26 **Identify** two impacts cyclones have on the biosphere. **Explain** how these may impact the biosphere.

27 **Compare** the impact on the lithosphere of a cyclone and of an earthquake.

28 Climate scientists compare trends over many decades rather than data for one or two years. **Explain** why this is important.

29 **Discuss** why ocean currents are responsible, in part, for global temperature.

Evaluate and create

30 The biosphere includes parts of the lithosphere, the troposphere (the lowest part of the atmosphere) and the hydrosphere. Create a list of the parts of the biosphere you may find in each of these three spheres.

31 **Compare** water and air currents, and note their similarities and differences.

32 **Recall** what 'H' and 'L' represent on a weather map. **Explain** how they are formed, and **identify** the type of weather they are associated with.

33 The human population was fairly stable until about 1 CE. Then it started to grow, and its growth accelerated until it almost reached an exponential rate. In the past century, the human population has almost quadrupled. **Explain** what the likely effects of the population increase on world ecosystems are.

Critical thinking

34 **Construct** a chart or table that describes environmental carbon sinks and carbon producers.

35 Draw a mind-map showing the potential connections and dependencies between the four spheres of the Earth and their components. Challenge yourself to find as many links as possible.

Go further

36 Imagine you had to reduce your energy impact on the environment. Look at all the appliances and gadgets you use in your home. **Identify** which you could not bear to give up. Create an A4 page outlining why this one item is 'essential' to you and then make a list of appliances and gadgets that you could live without.

37 The Earth's climate and weather are the result of global interactions between systems and cycles. **Explain** how this supports the argument that logging in any country affects everyone else on the planet. **Identify** other human activities that fit into a similar category. **Discuss** your thoughts with the class.

38 Over 80% of the Earth's energy resources are non-renewable and declining. In the 20th century, most energy use was concentrated in a few nations, which make up only a small proportion of the Earth's population. The seven largest economies at the beginning of the 21st century (with 10% of the global population) used approximately 45% of the total primary energy supply. Yet approximately 2 billion people on the Earth do not have access to electricity. In a group, **discuss** this concept and form an opinion. **Identify** actions you could take to improve this situation.

39 **Explain** why an increase in the number of cases of malaria is expected as a result of enhanced climate change.

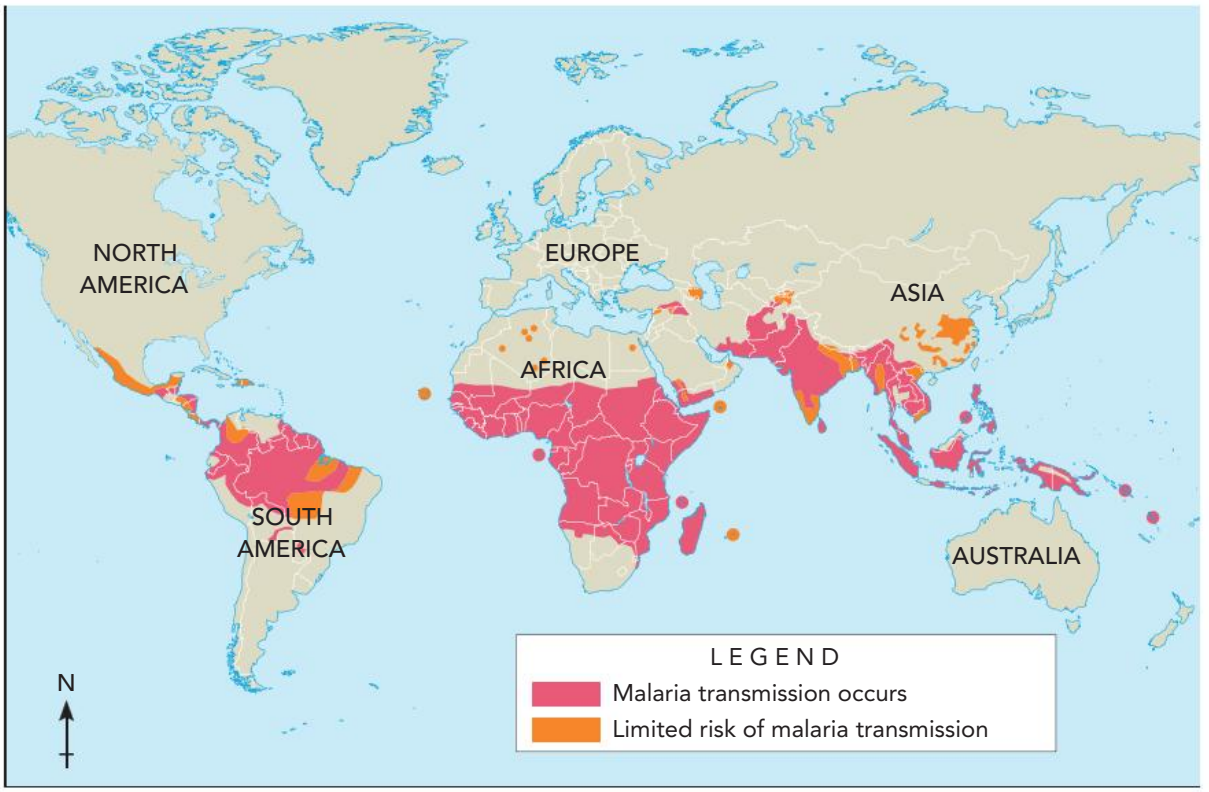

Figure 1 Countries or areas at risk of transmission of malaria, 2010

Research

40 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Peak oil

Our society runs on fossil fuels. Find out about the concept of peak oil and what implications it will have for our lives in the not-too-distant future.

»Responding to climate change

The Kyoto Protocol is an agreement between 181 countries that aims to stabilise greenhouse gas emissions in the atmosphere at a level that would prevent danger to the Earth's climate system. However, to date, the USA, the world's largest emitter of greenhouse gases, has not ratified the agreement. What does this mean for the effectiveness of the agreement? Which other countries are also not assisting and what might their motives be?

Figure 2 Coral bleaching along the Great Barrier Reef may be the result of rising sea temperatures, which block the photosynthetic reactions corals need to stay alive.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Outline how global systems rely on interactions involving the biosphere, lithosphere, hydrosphere and atmosphere, including the carbon cycle.	☐	☐ Go to pages 124-133
Describe some impacts of natural events, including cyclones, volcanic eruptions or earthquakes, on the Earth's spheres.	☐	☐ Go to pages 136-137
Evaluate scientific evidence of some current issues affecting society that are the result of human activity on global systems, e.g. the greenhouse effect, ozone layer depletion, effect of climate change on sea levels, long-term effects of waste management and loss of biodiversity.	☐	☐ Go to pages 138-143
Discuss the reasons different groups in society may use or weight criteria differently to evaluate claims, explanations or predictions in making decisions about contemporary issues involving interactions of the Earth's spheres.	☐	☐ Go to pages 144-145

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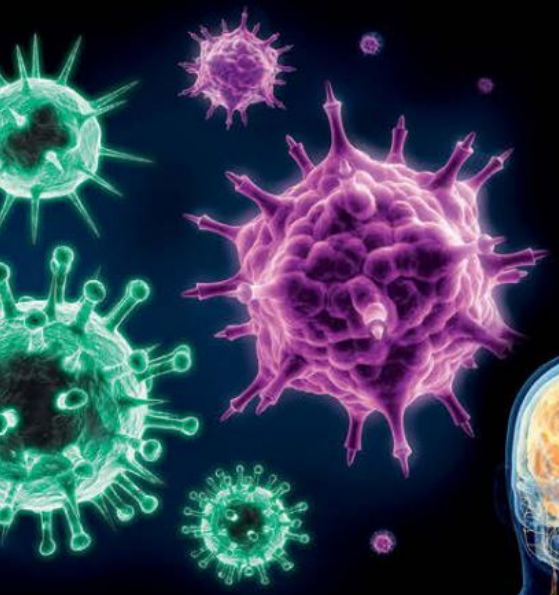
BODY SYSTEMS AND RESPONSES

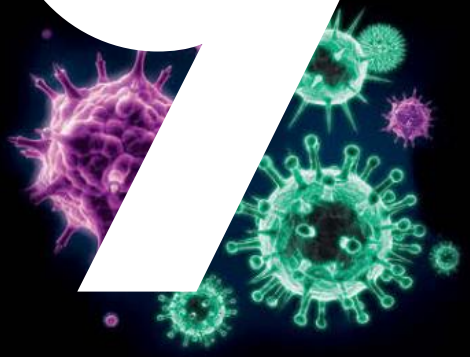
How does our body respond to the world we live in?



Have you ever wondered ...

- How many body systems there are?
- How do plants respond to their environment?
- How does your body fight off infectious diseases?

9



SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- describe some examples of how multicellular organisms respond to changes in their environment
- describe how the coordinated function of internal systems in multicellular organisms provides cells with requirements for life, including gases, nutrients and water, and removes cell wastes
- outline some responses of the human body to infectious and non-infectious diseases
- describe the role of, and interaction between, the coordination systems in maintaining humans as functioning organisms
- discuss, using examples, how the values and needs of contemporary society can influence the focus of scientific research, e.g. the occurrence of diseases affecting animals and plants, an epidemic or pandemic disease in humans or lifestyle related non-infectious diseases in humans

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

9.1 Plants detect changes in the environment to survive

Figure 1 The leaves on a deciduous plant change colour and fall off the plant during autumn.

hydrotropism
the growth or turning of plant roots towards or away from moisture

phototropism
the process where a plant's cells in the dark expand to bend the plant towards a light source; the growth or turning of a plant towards or away from light

deciduous
a type of plant that loses its leaves during the cooler months, to conserve energy when there is less sunlight; annual shedding of leaves

In this topic, you will learn that:

- plants respond to changes in the environment using hormones and receptors
- different types of plants produce different responses.

All organisms have the ability to respond to changes in the environment. If they don't respond, they are at risk of dying. Multicellular organisms have both internal and external receptors, which are able to detect changes in the environment (i.e. stimulus). This information is then passed on to other parts of the organism, which causes a response to occur.

Plants respond to changes in the environment

Plants need light for photosynthesis. Available light changes throughout the day depending on factors like cloud coverage, the time of day and the seasons. To maximise light exposure, plants engage in **phototropism**, in which cells of a plant that are in the dark (e.g. a shadow) elongate. This lengthening causes the plant to bend towards the light.

Plants also need water to survive. **Hydrotropism** is a process that results in a plant's roots growing towards water. The roots have specialised receptors that cause the roots to grow downwards. These receptors also detect changes in pressure in the soil. More pressure means more water, and so the roots of the plants grow towards these areas of increased pressure.

Deciduous plants lose their leaves

Plants that lose their leaves during the changing seasons are called **deciduous**. These plants typically lose their leaves in autumn, before the coldest months of winter.

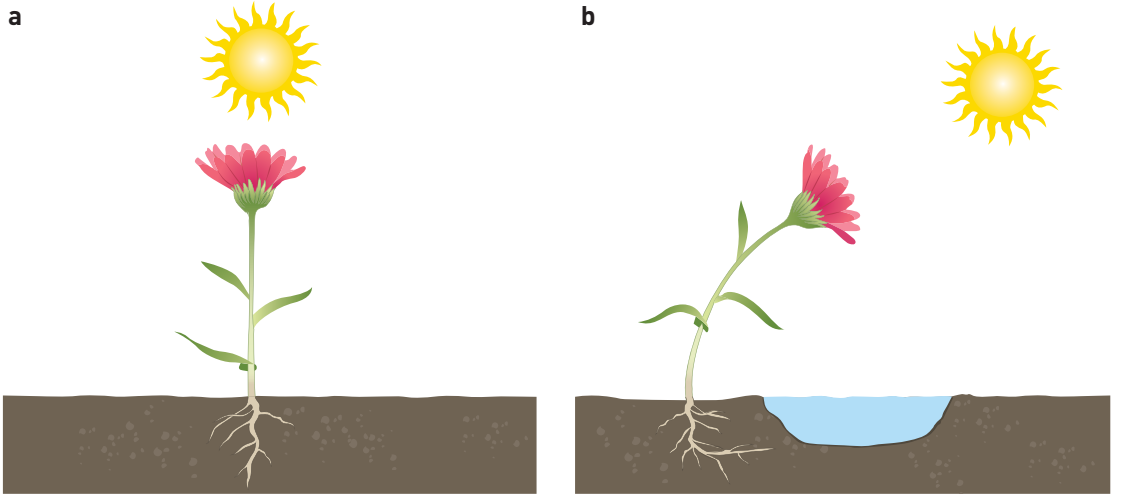


Figure 2 Phototropism is the movement of plants towards a light source, caused by cells in the dark expanding. Hydrotropism is the process by which a plant's roots grow towards water.

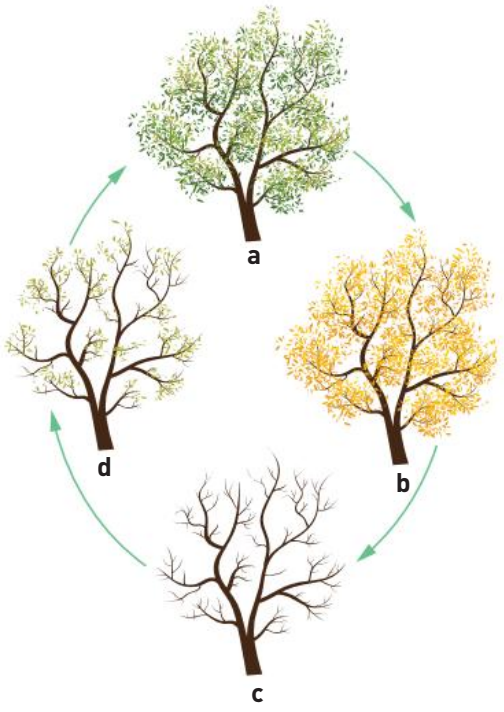


Figure 3 The life cycle of a deciduous tree: **a** summer, when the tree is full of leaves, **b** autumn, when a tree's leaves stop growing and begin to fall off, **c** winter, when a tree has no leaves left and **d** spring, where new leaves grow.

The shorter days during winter have fewer daylight hours, which means less light for photosynthesis. Plants detect the change in temperature and the reduced daylight length. This triggers a reduction in the amount of growth hormone being sent to the leaves.

Epicormic buds: A response to fire

Epicormic buds are growth points that lay dormant under the trunk of a tree until they are stimulated. Many Australian plants, including eucalypts, have epicormic buds. These epicormic buds are kept dormant by higher plant shoots that inhibit the release of growth hormones to the lower buds. When a bushfire burns the higher plant shoots, the inhibition of the growth hormones ceases, which stimulates rapid growth from the epicormic buds. The new leaves that come from the epicormic buds allow the tree to photosynthesise, which keeps the plants alive after a bushfire.

Figure 4 The new growth on this tree exists because of epicormic buds. These buds can grow after a bushfire.

Figure 5 Plants have inbuilt systems to increase their responses to the environment around them.

Check your learning 9.1

Recall and explain

1 **Describe** the process that causes plants to grow towards light.

2 **Identify** two things plants need to survive.

3 **Explain** how plants use epicormic buds to respond to bushfire.

Apply and analyse

4 Plant roots have been said to 'hear' running water and grow towards it. **Construct** an experiment to determine if this is possible.

In your answer, **identify** the following:

- independent variable
- dependent variable
- hypothesis
- method, including all materials required.

Evaluate and create

5 **Investigate** what plants are deciduous in Australia, and then **assess** whether deciduous plants can recover from a bushfire.

Skill builder: Questioning and predicting

6 Imagine you are a scientist investigating the different types of plants that grow around Australia. You have come up with the following prediction: 'If palm trees from Queensland are moved to Tasmania, they will see less annual growth than those that stay in Queensland.'

a **Identify** the controlled and measured variables. (THINK: What is being manipulated?)

b **Predict** what will happen to the trees as they grow in Tasmania. (THINK: What would colder weather do to the trees?)

9.2 Animals respond to changes in the environment

In this topic, you will learn that:

- animals use their senses (sight, hearing, smell, touch and taste) to respond to the environment
- animals receive information from the environment via receptors.

endotherm
an animal that regulates its own body temperature

Video
Multicellular organisms

Most animals use one of five senses to detect changes in their environment; these senses are sight, hearing, smell, touch and taste. The degree to which they use each of the senses depends on the environment in which they live and the adaptations they possess to survive those conditions. Each sense is associated with specialised receptors that will detect changes and bring about a response. Changes in the environment including temperature and the seasons also trigger responses in animals.

Animals respond to temperature differently

ectotherm
an animal that is unable to regulate its own body temperature

migrate
the movement of an animal from one region to another, typically in response to changing seasons

hibernation
an extended period of inactivity, typically in response to colder conditions

Ectotherms are animals that are unable to regulate their own body temperature; examples are amphibians, reptiles and invertebrates. If the external temperature increases, then their internal temperature increases, and if the external temperature decreases, then their internal temperature decreases.

For example, when a lizard's thermoreceptors detect a decrease in body temperature, they will seek out a warm rock to lie on. This will bring its body temperature back up. The lizard needs to leave the rock eventually so that it doesn't overheat.

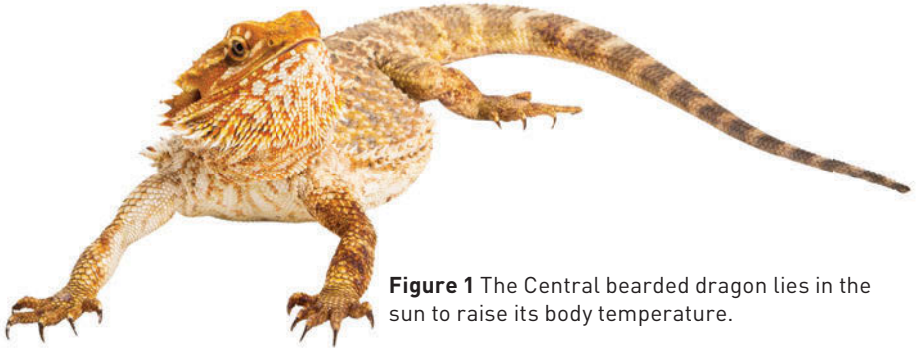


Figure 1 The Central bearded dragon lies in the sun to raise its body temperature.

Endotherms are animals that regulate their own body temperature; examples of endotherms are mammals and birds. An endotherm's internal body temperature remains constant throughout their life, regardless of the external temperature. For example, humans maintain a body temperature of approximately 37°C. When your body temperature starts to rise, your body produces sweat to release heat from your body. When your body temperature starts to drop, you may start shivering to generate heat.

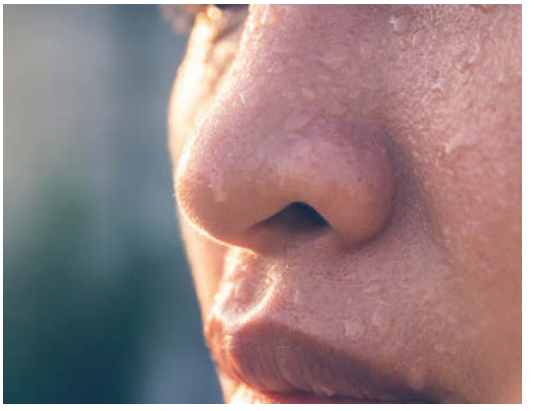


Figure 2 People sweat to cool themselves down when their internal body temperature starts to increase.

Animals move locations in response to their environment

Many animals **migrate** in response to changes in their environment. For example, birds often fly south during North America's winter. Notably, the great wildebeest migration in Africa occurs each year. The animals travel over 3000 km to find more readily available water and food.

Migration is only one solution to the changing seasons. **Hibernation** is an alternate

Figure 3 The great wildebeest migration occurs every year as thousands of wildebeest move to find more food and water.

solution, in which some animals will enter an extended period of inactivity for the winter. During hibernation, animals will have a slower heart rate, slower breathing and slower metabolic rate. These responses make the animal better equipped to survive winter, when food sources may be low.

Humans respond to changes in stimulus

Our bodies are constantly responding to internal and external changes. A **stimulus** is any information an organism receives that might cause it to respond. Responding to a stimulus can prevent major changes to the internal environment that could cause the organism to become ill or possibly die. The easiest stimuli to identify are those we detect with the major sense organs (the eyes, ears, tongue, nose and skin).

Responding to external change

Within our bodies, we regularly respond to changes without consciously acknowledging a stimulus and response. What tells you that you are thirsty or hungry? Your body is communicating with your brain to tell you to find water or food. A similar process occurs when you feel tired or have a headache. But what is the source of these stimuli?

Other examples of stimuli are less obvious. We are surrounded by bacteria, viruses and fungi. Although many of them are too small to see, our bodies are constantly monitoring their numbers and fighting off harmful micro-organisms.

Your body is an amazing combination of cells, tissues, organs and systems, all working together. Each plays a part in detecting stimuli and passing on the information to other parts of the body. The structures that receive stimuli are called **receptors**. There are different receptors for different purposes; for example, cells that detect light are called photoreceptors.

receptor
a structure that detects a stimulus or change in the normal functioning of the body

Sight

When light enters the eye, the photoreceptors convert the light into electrical signals. Two messages are sent: one message is to the iris (the coloured part of your eye) telling it to constrict and close the pupil, and the second message is to the brain via the optic nerve. The message sent along the optic nerve is interpreted by the brain, which then tells you what you are looking at.

stimulus
any information that the body receives that causes the body to respond

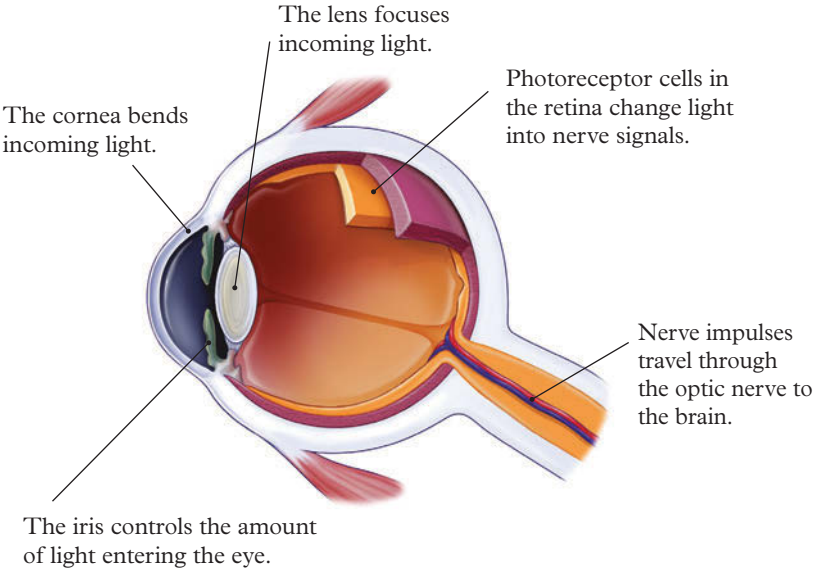


Figure 4 The human eye

Hearing

Strumming a guitar sets off a wave of vibrating particles in the air. These vibrations enter your ear and cause the eardrum to vibrate. These vibrations are transferred along the tiny bones of the middle ear and converted into nerve impulses. Your brain can then interpret these impulses, telling you what you are hearing.

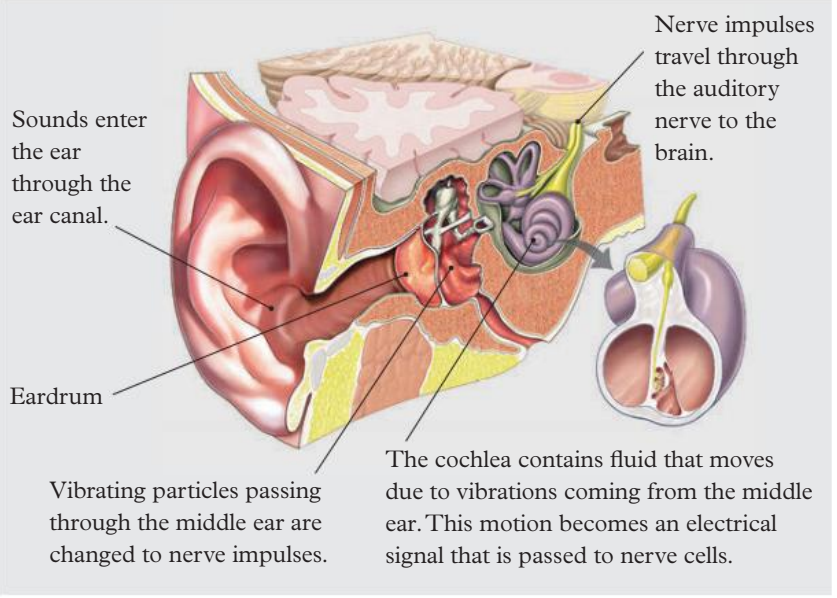


Figure 5 The human ear transfers vibrations to the middle ear. These then become nerve impulses.

Taste

Your tongue is covered in thousands of tiny taste buds (Figure 6). You can see these in a mirror. Taste buds contain special receptor cells that react to chemicals in foods. Taste buds can recognise basic kinds of taste such as sweet, salty, sour, bitter and a savoury taste called umami. When you eat or drink, the information from the taste receptor cells is sent to the brain through nerves. This tells you what flavours you are tasting.

Smell

Our perception of smell depends on chemical receptors that are found in each of our nostrils. These receptors, called chemoreceptors, detect chemicals in the air and then send messages to the brain, which interprets the message and tells us what we are smelling. Smell is closely linked to taste. If this seems strange, think about the last time you had a bad cold with a blocked nose. Did it affect your ability to taste? A lot of what people think is taste is actually smell.

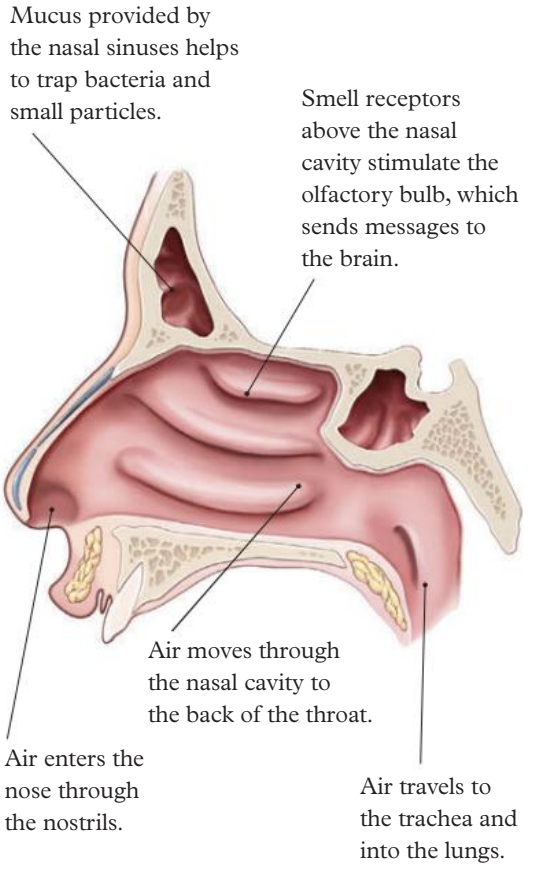


Figure 7 Chemoreceptors in human nostrils detect chemicals and send messages to the brain.

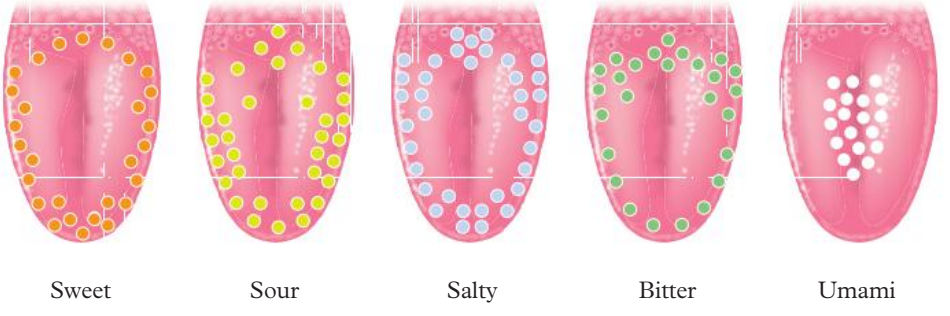


Figure 6 The human tongue has different regions dedicated to detecting different tastes.

Touch

While the other four senses are located in specific locations, touch is felt all over the body through the skin. The bottom layer of skin, called the dermis, contains many nerve endings that can detect temperature (thermoreceptors), pressure (mechanoreceptors) and pain (pain receptors). Information is collected by these receptors and sent to the brain for processing and reaction.

Some examples of how the skin responds to stimuli include:

- temperature changes, resulting in humans sweating to cool down or shivering to warm up
- changes in pressure, resulting in tickling sensations or pain.

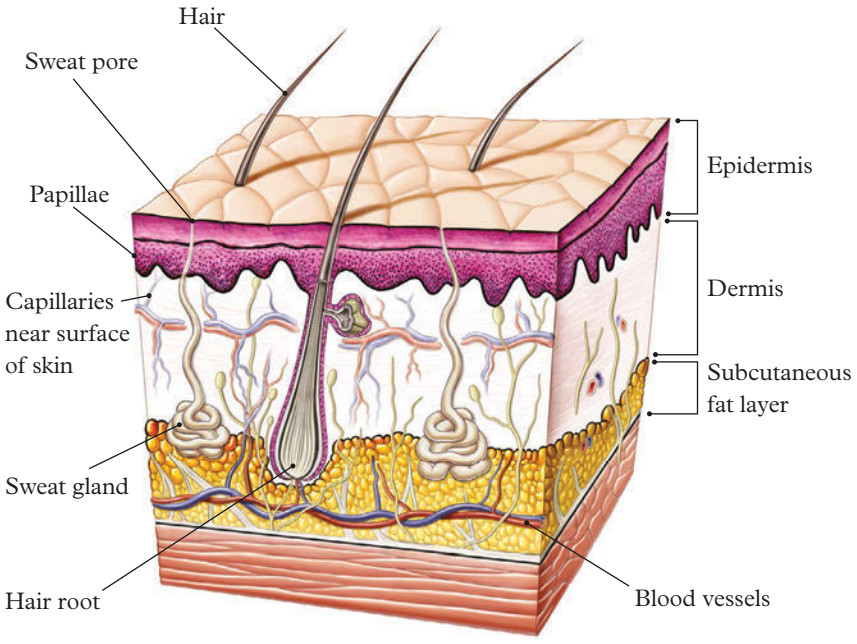


Figure 8 A cross-section of human skin

Check your learning 9.2

Recall and explain

1 **Define** the following terms.
   - a Stimulus
   - b Response
   - c Ectotherm
   - d Endotherm

2 **Explain** how an ectotherm regulates its body temperature.

3 **Identify** the five sense organs and **explain** their function.

Apply and analyse

4 **Compare** ectotherms and endotherms.

5 **Explain** why there are no reptiles found in Antarctica.

6 **Identify** a likely response to:
   - a walking on hot sand
   - b seeing something running straight towards you
   - c realising you've put salt on your cereal instead of sugar
   - d hearing a loud bang.

7 Imagine a situation where you are faced with a shortage of water. **Construct** a flow chart that outlines some of the possible responses within your body or in your behaviour.

Evaluate and create

8 **Discuss** how survival is possible without one or more of your sense organs.

Skill builder: Planning investigations

9 Jacob wants to know if the receptors sensitive to umami are distributed evenly on the tongue or concentrated in particular areas. He wants to give people the following foods to test his theory: sour hard sweets, gummy bears, sea salt crisps, grapefruit and mi goreng.
   - a **Identify** what experimental method Jacob could use to test his theory. (THINK: What is Jacob trying to test? How many repeats would he need to measure?)
   - b List any additional materials Jacob might need. (THINK: How could he make this experiment safe? How would the flavours be tasted?)
   - c Select two risks associated with Jacob's test. (THINK: Does Jacob need to use people in his experiment? Are there allergies?)
   - d **Explain** how the risks you identified in part c could be managed. (THINK: What would Jacob need to know about the participants? How could he avoid making people sick?)

Figure 9 Our tongue's receptors detect that a lemon is sour.

9.3 The nervous system controls the body

In this topic, you will learn that:

- the central nervous system is the control centre of the human body
- the peripheral nervous system carries information to and from the central nervous system to the rest of the body.

brain
the primary organ of the central nervous system consisting of soft nervous tissue and contained in the skull of vertebrates

central nervous system
the brain and spinal cord

spinal cord
the cylindrical bundle of nerve fibres and associated tissue which is enclosed in the vertebrae

Humans are constantly receiving stimuli from their environment through the peripheral nervous system. The neurons use electrical messages that are passed along to neurons in the brain and spinal cord that make up your central nervous system.

Central nervous system

The **central nervous system** is the control centre of the body. All incoming messages from your environment and your responses to them are processed through the central nervous system. The two main structures of the central nervous system are the brain and the spinal cord.

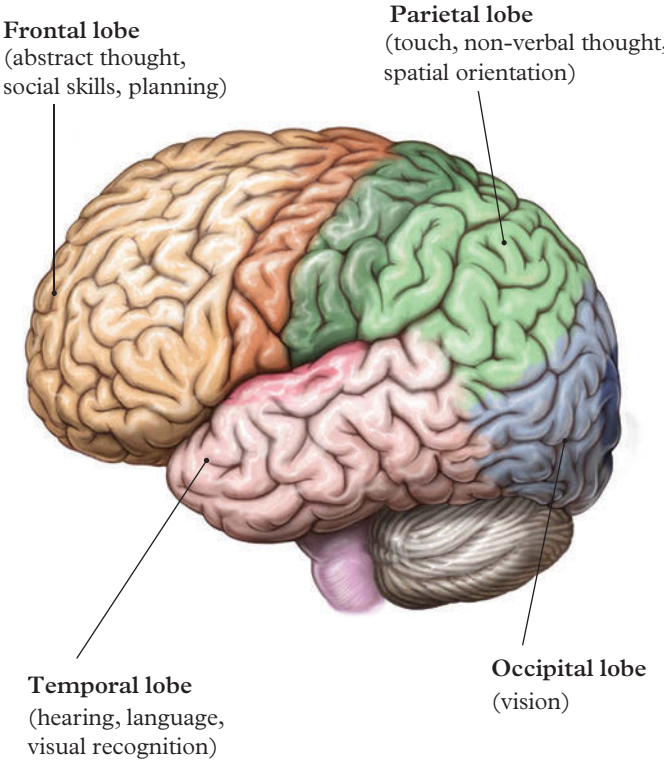


Figure 1 The lobes of the brain

The brain

The **brain** is the processing centre of the body and is mainly concerned with our survival. The brain is a soft, heavy organ that is surrounded by a tough skull. The brain gathers information about what is going on inside and outside the body. It then responds with appropriate reactions and behaviours. The brain is also home to your memories, personality and thought processes.

Lobes of the brain

The cerebrum or outer section of your brain is divided into four lobes or sections. These lobes have specific functions.

- The frontal lobe is located at the front of the brain. Its functions include emotions, reasoning, movement and problem solving.
- The parietal lobe manages the perception of senses, including taste, pain, pressure, temperature and touch.
- The temporal lobe is located in the region near your ears. It deals with the recognition of sounds and smells.
- The occipital lobe is at the very back of the brain. It is responsible for aspects of vision.

The spinal cord

The **spinal cord** has three major roles. It relays messages from the brain to different parts of the body causing them to respond. It sends messages from sensory neurons to the brain, and it is also responsible for reflex actions.

SKILLS LAB
9.3: Sheep brain dissection
Go to page **377**

Peripheral nervous system

The **peripheral nervous system** is a large system made up of all the nerves outside the central nervous system. The peripheral nervous system carries information to and from the central nervous system to the rest of the body, such as the limbs and organs.

The peripheral nervous system is divided into two parts.

- The **somatic nervous system** controls voluntary skeletal muscle movements, such as waving or reaching out to take something.
- The **autonomic nervous system** controls involuntary actions, which happen without our conscious control. This includes heartbeat, digestion, respiration, salivation and perspiration. The autonomic nervous system maintains your body's internal environment (a process called homeostasis).

The autonomic nervous system also has two parts: the sympathetic division and the parasympathetic division. These two divisions often have opposite effects. For example, the parasympathetic division slows down the heart rate, whereas the sympathetic division speeds up the heart rate. The systems work together to maintain a balance in the body.

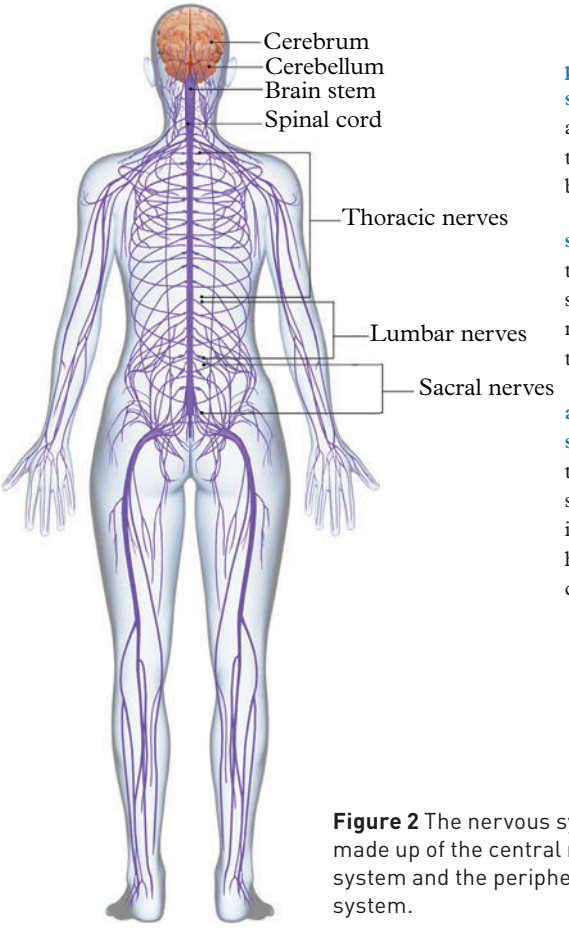


Figure 2 The nervous system is made up of the central nervous system and the peripheral nervous system.

peripheral nervous system
all the neurons (nerve cells) that function outside the brain and spinal cord

somatic nervous system
the part of the nervous system that controls the muscles that are attached to the skeletal system

autonomic nervous system
the part of the nervous system that controls involuntary actions such as heartbeat, breathing and digestion

Check your learning 9.3

Recall and explain

1 **Identify** the two key components of the central nervous system.

2 **Explain** the role of the peripheral nervous system.

Apply and analyse

3 **Compare** the occipital lobe with the frontal lobe.

4 **Distinguish** between the role of the somatic nervous system and the autonomic nervous system.

5 **Describe** the role of the cerebellum.

6 Draw a scientific diagram of the brain that shows the four lobes. For each of the lobes:

a **summarise** the functions carried out

b draw something to remind you of the functions carried out in that lobe.

Evaluate and create

7 **Propose** what someone with damage to their frontal lobe might have difficulty with.

Skill builder: Communicating

8 Create an information booklet explaining the difference between the central nervous system and the peripheral nervous system. This booklet should help students in your year level understand the differences between and the responsibilities of each system.

a **Identify** the key information. (THINK: Can you explain the components of each system simply? Why is this important?)

b **Synthesise** the information you found in part a and present this information for your target audience. (THINK: Who is your audience? Is it age appropriate?)

c **Construct** the information booklet. (THINK: What is the best way to present this information? Is the language I am using scientific (i.e. clear and concise)? Would including diagrams help?)

9.4 Neurons are the basic unit of the nervous system

In this topic, you will learn that:

- neurons are nerve cells that relay information throughout the body
- motor neurons take information to the brain from the body
- sensory neurons take information from the body to the brain
- interneurons relay information within the spinal cord.

Figure 1 Sensory neurons tell your body that your hand is cold when touching ice. Motor neurons tell your hand to let go of the ice.

synaptic terminal
a bulb at the end of the axon of a neuron which stores and releases neurotransmitter molecules to stimulate the following neuron

myelin sheath
a fatty layer that covers the axon of a nerve cell

dendrite
the part of a neuron (nerve cell) that receives the message and sends it to the cell body

sensory neuron
a nerve cell that carries a message from a receptor to the central nervous system

motor neuron
a nerve cell that carries a message from the central nervous system to a muscle cell

interneuron
a nerve cell that links sensory and motor neurons; also known as a connector neuron

Humans are constantly receiving stimuli from their environment through the peripheral nervous system. They relay this information via neurons that send electrochemical messages to neurons in the brain and spinal cord, which make up the central nervous system.

Nerves

The basic unit of the nervous system is a nerve cell or **neuron**. Scientists believe that we may have up to 100 billion neurons in our bodies, bundled together in fibres called nerves.

Neurons have many highly specialised features. Each neuron has a large **cell body (soma)** that connects to a long thin **axon**, which is also called a nerve fibre. The axon carries nerve impulses away from the cell body. The axons connecting your spinal cord to your foot can be 1 metre long. At the end of the axon is a small bulb called the **synaptic terminal**, also known as the axon terminal. Here, messages are passed to the next neuron. The axon is covered by a fatty layer called the **myelin sheath**, which helps to speed up a nerve impulse along an axon.

Dendrites are nerve endings that branch out of the cell body. These highly sensitive, thin branches receive information and form contacts with the axons of other neurons allowing nerve impulses to be transmitted.

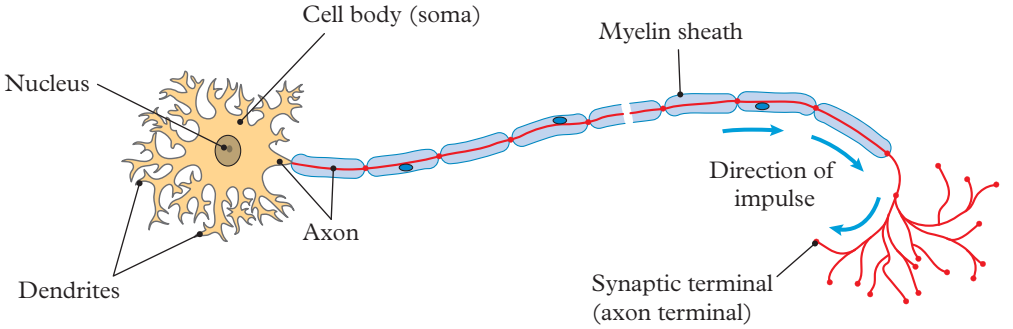


Figure 2 The basic structure of a neuron

Dendrites bring information to the cell, and axons take information away from the cell body. Information from one neuron flows to another neuron across a **synapse**. The synapse is a small gap separating neurons. When the message reaches the end of the neuron, chemicals called **neurotransmitters** are released from the synaptic terminal of an axon and travel across the gap to the dendrite of the next neuron. In this way, messages are passed around the body.

Types of neuron

There are three specialised types of neurons, all with different jobs.

- **Sensory neurons** (or afferent neurons) are sensitive to various stimuli, collecting information from either the body's internal environment or the outside world. Sensory neurons send the information they have collected to the central nervous system for processing.
- **Motor neurons** (or efferent neurons) carry messages from the central nervous system to muscle cells throughout the body, which then carry out the response.
- **Interneurons** link sensory and motor neurons, as well as other interneurons. Interneurons are the most common neuron in your body. They only make connections with other neurons.

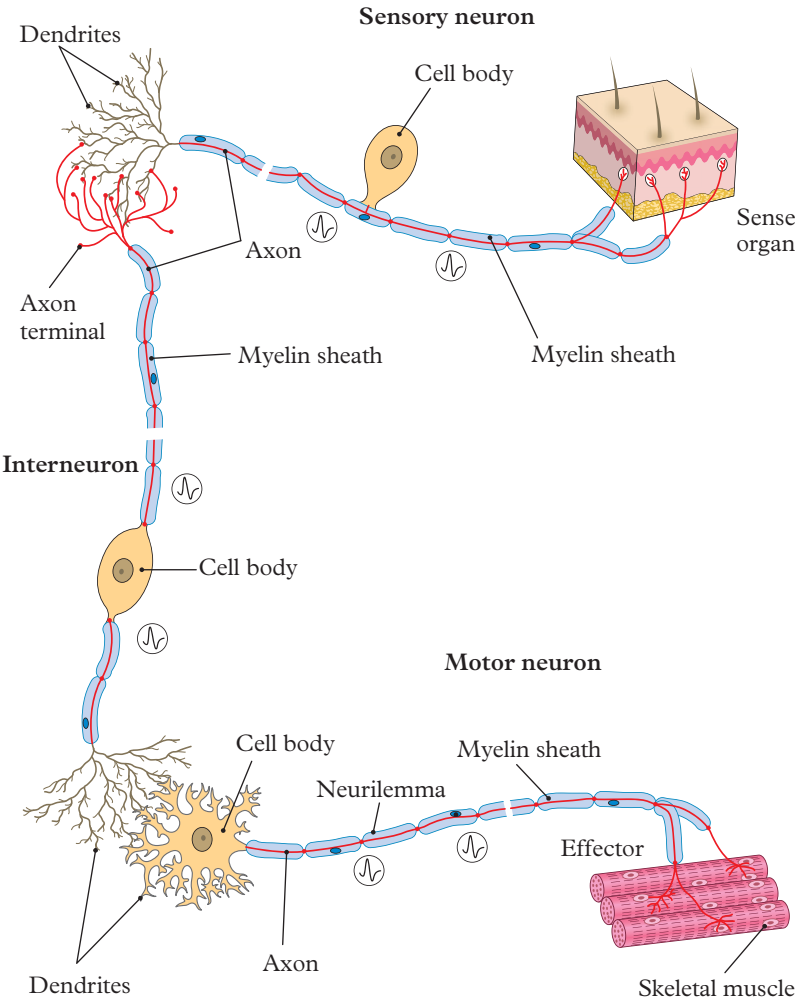


Figure 3 Sensory neurons receive information from sense organs (e.g. the eye); motor neurons take messages from the nervous system to the body (e.g. to your fingers to tell them to write); and interneurons link sensory neurons, motor neurons and other interneurons.

Check your learning 9.4

Recall and explain

1 **Define** the term 'neuron'.
2 **Explain** the role of the myelin sheath.
3 **Recall** what happens in the synapse.

Apply and analyse

4 **Compare** the roles of motor neurons, sensory neurons and interneurons.
5 **Propose** what may happen to someone if their interneurons weren't working.
6 Draw a diagram of a sensory neuron. Include the following in your diagram and **explain** each of their roles.
   - Axon
   - Cell body
   - Dendrites
   - a Myelin sheath
   - b Synapse

Evaluate and create

7 **Investigate** motor neuron disease using the internet. Find out about the following:
   - symptoms
   - cause
   - treatment.

Skill builder: Problem solving

8 Isadora's myelin sheath is deteriorating. **Identify** two problems associated with this. (THINK: What does myelin sheath do? How will this impact Isadora's life?)

9.5 The nervous system controls reflexes

In this topic, you will learn that:

- reflexes are involuntary actions that your body makes in response to particular stimulus.

To survive immediate danger, the body must be able to detect, process and respond to stimuli extremely quickly. Receptors in the nervous system detect stimuli and pass signals on to control centres. The control centres initiate a message to the effectors, which cause a response. Reflexes are special pathways that allow a response to occur rapidly without involving the brain for complex processing.

Stimulus response model

reflex
an involuntary movement in response to a stimulus

Stimuli can come in many different forms. It may be pressure or heat on the skin, a puff of air or strong light in your eye. These stimuli are detected by the receptors, and the message gets sent to the spinal cord and the brain via the sensory neurons. The spinal cord and brain form the control centre of the nervous system. The interneurons in this control centre pass the message on to other interneurons as your brain determines the most appropriate response to a stimulus. Once this is done, the motor neurons pass the message on to the muscles. In this case, the muscles are called the effectors because they are the cells that cause the body to respond. This simple pathway is called the stimulus response model.

Reflexes

If you ever accidentally touched something very hot, you will remember how quickly you snatched your hand away. In fact, it was so quick that you realise afterwards you didn't even have time to think about it: it was automatic.

A **reflex**, or reflex action, is an involuntary and nearly instantaneous movement in response to a stimulus.

During a reflex action, the sensory neuron carries the message from the receptor to the spinal cord. The interneuron then sends two messages at the same time: one to the brain and the other straight to the muscles via the motor neuron. This means the muscle is moving at the same time as the brain gets the message that the object was hot. This make reflexes even faster than usual responses.

Most reflexes help us in survival situations. Can you think of the advantages to these reflexes?

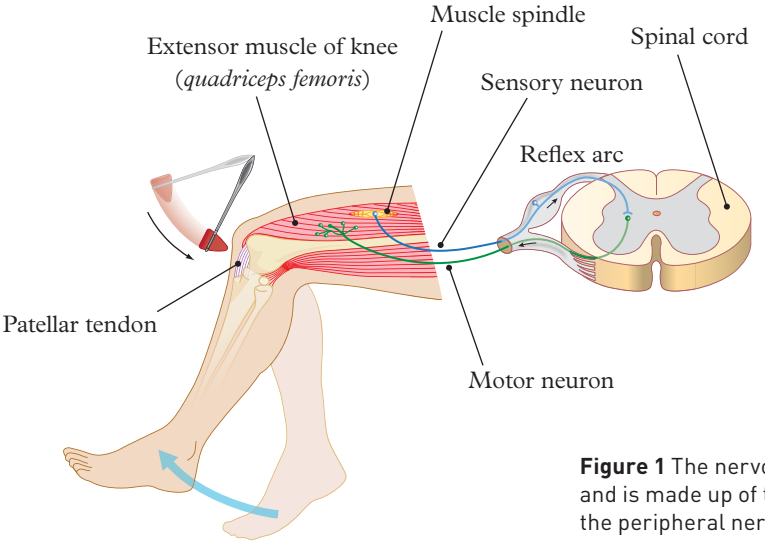


Figure 1 The nervous system controls reflexes and is made up of the central nervous system and the peripheral nervous system.

CHALLENGE
9.5a: How fast is the nervous system?
Go to page **378**

CHALLENGE
9.5b: Testing reflexes
Go to your **obook**

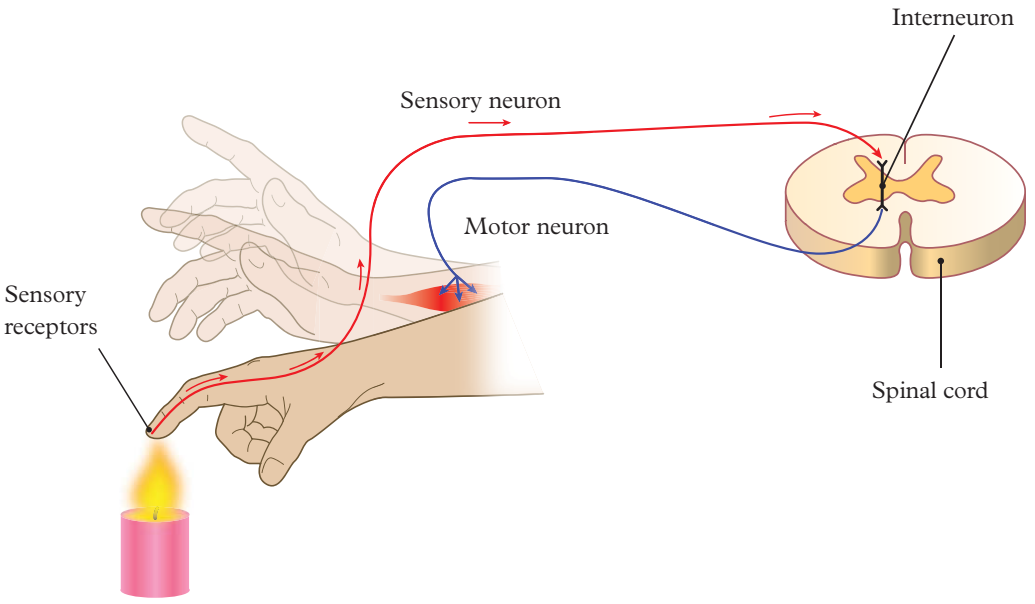


Figure 2 A reflex action ensures a rapid response to a potentially dangerous stimulus.

Resource
STEM Activity: Riderless bikes

Check your learning 9.5

Recall and explain

1 **Explain** what a reflex is.
2 **Describe** how a reflex works.

Apply and analyse

3 **Discuss** how reflexes help us survive.
4 **Construct** an experiment that measures the reaction time of your classmates. Make sure to include the:
- aim
- hypothesis
- materials you would need
- method you would use.

Evaluate and create

5 Imagine you are baking at home, and you reach to grab the tray from the oven without an oven mitt. **Assess** how a reflex stops you from burning your hand.
6 **Evaluate** this statement: 'People would get injured more frequently if their reflexes weren't working.' You will need to conduct some extra research before you can answer this question.

Skill builder: Processing and analysing data and information

7 Seth conducted a reflex test to measure the average time it takes someone to respond to catching a ball. He found that it took people the following amount of time (in seconds) to react:
0.04, 3, 2, 1, 0.9, 2, 4, 3, 2, 1.
a **Identify** any outliers in the data. (THINK: Is something unusual? Is there a result that seems different to the others?)
b **Identify** the median and mode. (THINK: What is the most common number? What is the middle number?)
c **Calculate** the mean. (THINK: What is the average reaction time?)

Figure 3 When you touch something sharp, like a cactus, a reflex response causes you to pull your hand away.

9.6 The endocrine system causes long-lasting effects

In this topic, you will learn that:

- the endocrine system is slower than the nervous system
- the endocrine system uses hormones to maintain control and regulate growth
- the chemical messengers act slower than nerve impulses sent by the nervous system, but their effects are longer lasting.

endocrine system
a collection of glands that make and release hormones

hormone
a chemical messenger that travels through blood vessels to target cells

target cell
a cell that has a receptor that matches a specific hormone

feedback mechanism
a feedback loop where the system responds to a particular stimulus; can be positive or negative

negative feedback mechanism
a regulatory loop in which the stimulus causes a response that acts in the opposite direction to whatever is being regulated

The **endocrine system** is a collection of glands that secrete (release) **hormones**. The hormones are secreted directly into the bloodstream and then travel around the body through the blood. Some cells in the body have receptors that match the hormone like a lock to a key. These cells are called **target cells**. Only a specific hormone can cause a change in the target cell.

The glands and organs of the endocrine system are spread throughout the body; this is shown in Table 1. Note that the endocrine system shares the hypothalamus with the nervous system.

Types of hormone

Hormones are classified into two types on the basis of their chemical structure: **peptide hormones** and **steroid hormones**. Most hormones are peptides. Peptide hormones are made from proteins and are produced by the anterior pituitary, parathyroid gland, placenta, thyroid gland and pancreas. Peptides travel through the bloodstream until they find and interact with specific receptors on the surface of their target cells. This causes the target cells to respond.

Steroid hormones include those hormones secreted by the adrenal glands and the ovaries (female) and testes (male). Steroid hormones are produced from cholesterol (a lipid) and are therefore classified as **lipid-derived hormones**. These can pass through the cell membrane and move directly into the target cells.

Hormones at work

Feedback mechanisms often control the effects of hormones on the body. Releasing a hormone into the body triggers a series of responses. A **negative feedback mechanism** regulates the rate of hormone production and

Table 1 Some structures and hormones of the endocrine system

Structure	Hormone	Target tissue	Main effects
Hypothalamus	Wide range of neurotransmitters	Pituitary gland	Links nervous system to endocrine system via pituitary gland to control many homeostatic functions such as body temperature, hunger, thirst and sleep patterns
Ovaries	Progesterone Oestrogen	Uterus Body cells	Thickens wall of uterus Development of female sexual characteristics; aspects of pregnancy and foetal development
Testes	Testosterone, progesterone and oestrogen	Male reproductive system, body cells	Development and control of male sexual characteristics; production of sperm
Pancreas	Insulin Glucagon	Liver, most cells Liver	Lowers blood glucose level Raises blood glucose level
Adrenal glands	Adrenalin Progesterone Oestrogen	Body cells Body cells Body cells	Increases body metabolism in 'fight or flight' response Important for calcium in bones Development of certain sexual characteristics
Pineal gland	Melatonin	Skin cells	Whitening of skin; involved in daily biological rhythms

secretion. When a stimulus is received that indicates there is too much of a hormone, this mechanism will produce less of the hormone. This also occurs in reverse: if there is not enough of a hormone being produced and secreted, the negative feedback mechanism will increase the amount.

Fight or flight?

Fight or flight (recently renamed as **fight, flight or freeze**) is a hormone and nervous-system response to dangerous, stressful or frightening situations. If you have experienced a scary situation, you may have noticed that your heart begins to race, you break out in a cold sweat, and everything around you slows down as your senses are bombarded with information. Most of the symptoms are triggered by the hormone adrenalin (also called epinephrine).

Adrenalin is constantly produced by the adrenal glands in small doses, and its usual function is to stimulate heart rate and enlarge blood vessels. When you are in danger, it takes on another role. It floods your system to cause an increase in strength and the rate of your heartbeat, raising your blood pressure and speeding up the conversion of glycogen into glucose, which provides energy to the muscles. Adrenalin provides your body with extra energy required if you need to fight or run away from a situation.

fight, flight or freeze
a stress response that helps an organism to react to perceived threats

Check your learning 9.6

Recall and explain

1 **Identify** the name of the system in your body responsible for producing hormones.
2 **Describe** the two different types of hormone.

Apply and analyse

3 **Compare** the roles of the thyroid glands and the pancreas in the endocrine system.
4 **Propose** why the endocrine system tends to be slower than the nervous system.

Evaluate and create

5 **Investigate** a disease associated with a hormone. Write a brief essay that introduces the disease, explains its cause and symptoms, and summarises research into the disease.

Skill builder: Questioning and predicting

6 A scientist claimed that because humans are highly evolved we don't experience stress that may put our lives at risk and we therefore no longer use the fight or flight response.
   a **Identify** the 'if' in this claim. (THINK: What would happen if we had evolved to no longer require this response?)
   b **Identify** the 'then' in this situation? (THINK: What do you expect to happen?)
   c **Construct** a scientific question that you can test for this claim. (THINK: Is this question testable?)

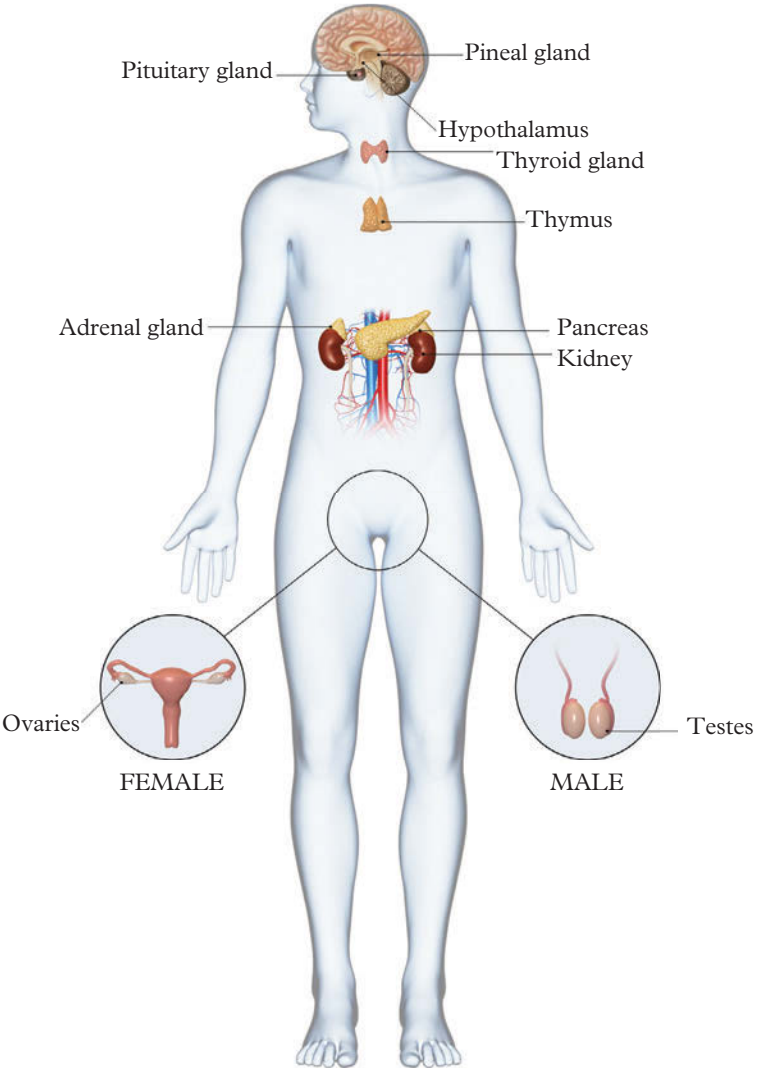


Figure 1 The human endocrine system

9.7 Homeostasis is the interaction of internal body systems

In this topic, you will learn that:

- internal body systems interact to maintain a constant internal environment within narrow limits
- the endocrine and nervous systems interact to maintain this balance by increasing or decreasing hormones throughout your body.

Figure 1 Your body must remain at 37°C. To achieve homeostasis your body might shiver if you are cold to try to warm itself up again.

Your body works to maintain constant levels of important nutrients, water and temperature in order to stay healthy. The process of regulating the internal conditions of the body is called homeostasis. This is achieved by negative feedback, whereby a response reduces the strength of the original stimulus, which in turn turns off the response.

Without extensive technology and equipment, humans have quite specific environmental requirements for survival. The human body needs access to nutrition, water, oxygen and the right temperature range to survive. If you're lost in a desert or in freezing temperatures, your body will try to maintain a temperature of about 37°C at all times to keep cells working efficiently. This 'business as usual' that is maintained by your body is called homeostasis.

The nervous and endocrine systems work together to control different parts of the body. They work in different ways and at different rates to detect change and produce immediate responses or slower changes.

Homeostasis

To maintain **homeostasis**, your body uses a mechanism a bit like a thermostat on a heater. When temperature receptors on your skin and in the hypothalamus of your brain detect cooling down (stimulus), then a message gets sent to a variety of effectors around your body. This may include muscles to make you shiver (to warm up) or blood vessels to redirect the warm blood flow to the important organs in your body (your heart, liver and brain).

If the temperature receptors detect that you are too hot (stimulus), then the effectors include your sweat glands and blood vessels. This causes your body to respond by increasing blood flow to your skin to lose heat by radiation, and releasing sweat for evaporative cooling. This is a negative feedback mechanism: the effectors respond by weakening the original stimulus. If you are too hot, then your body tries to cool you down. If you are too cold, then your body works to warm you up.

homeostasis
the process by which the body detects and responds to stimuli to ensure a stable internal state is maintained

Hormones at work

The rate of hormone production and secretion is regulated by the negative feedback mechanisms. If a stimulus tells the body that too much of a particular message has been sent, the body will produce a hormone to restore balance.

For example, if the body senses that it does not have enough glucose and therefore has low blood sugar, the body will secrete glucagon to raise blood sugar levels.

Blood glucose

As you eat, food gets broken down into smaller nutrients. All carbohydrates get broken down into simple sugars, including glucose. These glucose molecules travel through your blood and provide the energy for cellular respiration (i.e. the reaction of glucose with oxygen to produce carbon dioxide, water and ATP.

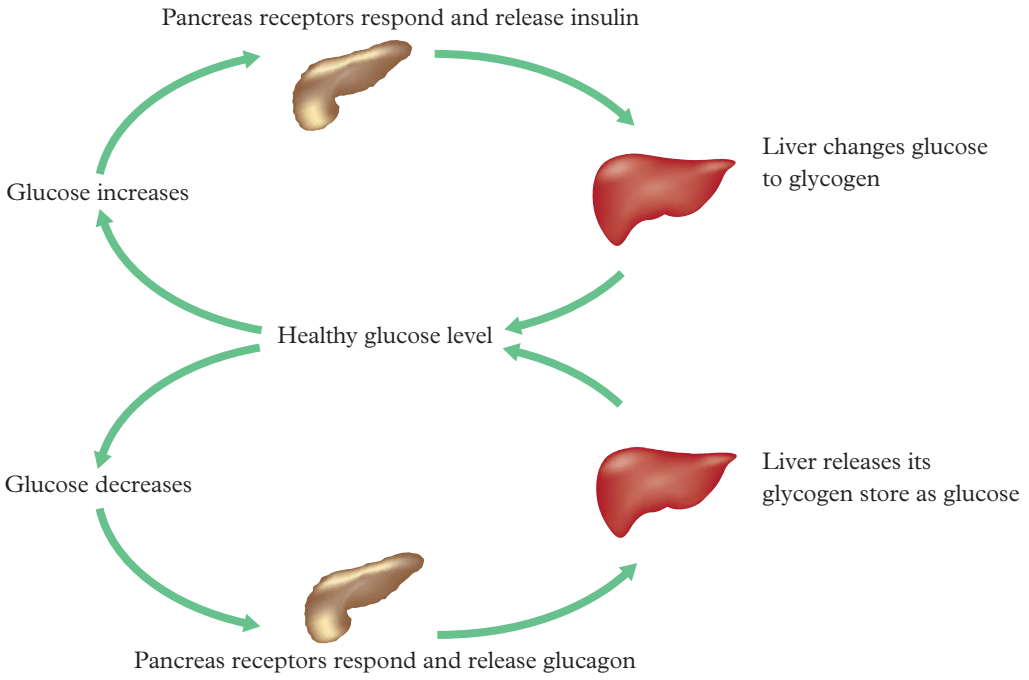


Figure 2 The pancreas and the liver work together to maintain healthy glucose levels.

Figure 3 People with diabetes need to check their insulin levels.

Too much glucose in the blood is not healthy because it causes water to be lost from cells through osmosis. Your body tries to control the amount of glucose in your blood. If the concentration of glucose in your blood is too high (stimulus), then receptors in the pancreas will detect it. They will then release the hormone insulin into the blood. Insulin will travel throughout the body to the insulin receptors on muscle and liver cells. These cells will then act as effectors and remove the glucose from the blood. This causes the blood glucose to decrease, removing the original stimulus. This is an example of negative feedback.

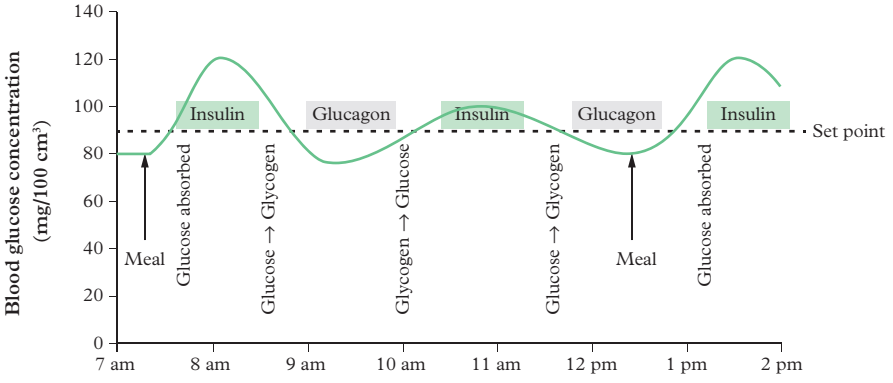


Figure 4 After eating, blood glucose levels increase. The body's response is to release insulin, which causes the muscle and liver effectors to remove the glucose and restore homeostasis.

If blood glucose levels are too low, then your body will use negative feedback to restore the levels to a homeostatic state. The low glucose levels are detected by receptors in the pancreas (stimulus). This time, the hormone glucagon is released into the blood. Receptors for glucagon are also found on the effector cells in the liver and muscle. Glucagon binding to the receptors causes the muscle and liver cells to release the stored glucose into the blood (response), increasing the amount of blood glucose once again.

Water regulation

Water is vital for human survival, but you may have noticed that when you drink a whole bottle of water, you might need to visit the bathroom within the next hour. Your body uses homeostasis to control the balance of water in your body. Water is required for a large number of functions and reactions in the body, and if there is too much or too little water in the body, its cells can be damaged.

The hypothalamus (a region in the brain) regulates water levels in the body. If you have been sweating on a hot day, your body is likely to have lost a lot of water. Receptors in the hypothalamus will notice changes in your levels of water and alert the pituitary gland. This will then release antidiuretic hormone (ADH) into your body, which reaches your kidneys to increase the re-absorption of water into the body during the production of urine. This is why your urine becomes darker if you are dehydrated. This is a negative feedback response. When you drink a lot of water, your pituitary gland receives a message to stop producing ADH.

Figure 6 Your hypothalamus regulates how much water you have in your body and causes reactions when you have too much or too little; this is what prompts you to drink.

Oxygen and homeostasis

Have you ever wondered why you become puffed when running a race? Oxygen and carbon dioxide in the blood are under strict homeostatic control. You need the oxygen for cellular respiration (i.e. the reaction between glucose and oxygen to produce water, carbon dioxide and energy) in a cell. Carbon dioxide is the waste product of this reaction.

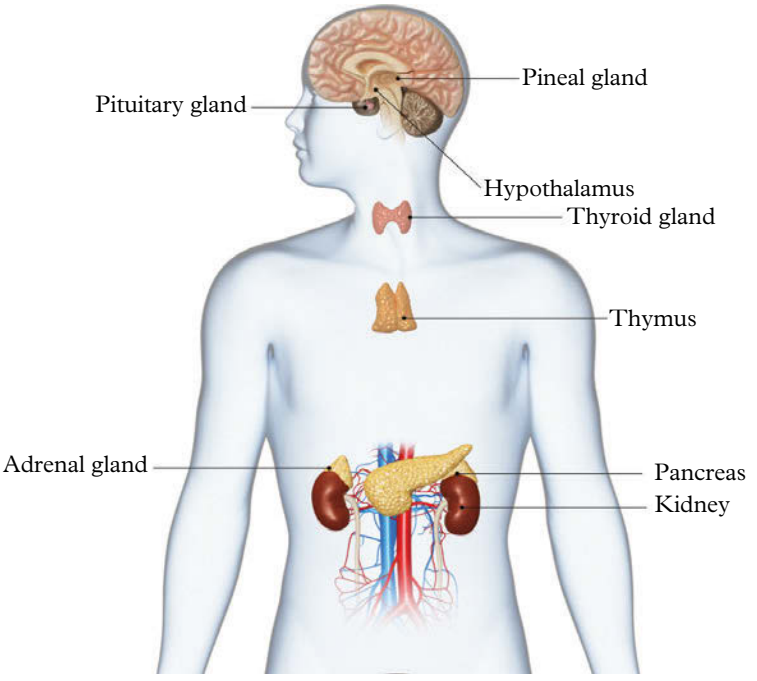


Figure 5 The pancreas is the endocrine organ responsible for th regulation of blood glucose levels.

When you sprint during a race, the muscles in your legs use a lot of glucose and oxygen, which produces a lot of carbon dioxide. This is released into the blood and is bad for the body. If you have too much carbon dioxide, a message is sent to make your heart beat faster and make your diaphragm move faster, which is why you might feel puffed after a race. These responses remove the carbon dioxide from your body.

Waste removal

The waste products of cells are removed by the respiratory system. The respiratory system and the circulatory system work together to ensure that carbon dioxide is removed from the lungs as we exhale. The kidneys, which are part of the excretory system, are responsible for removing wastes from the blood. The kidneys then ensure that this waste is removed from the body via urine.

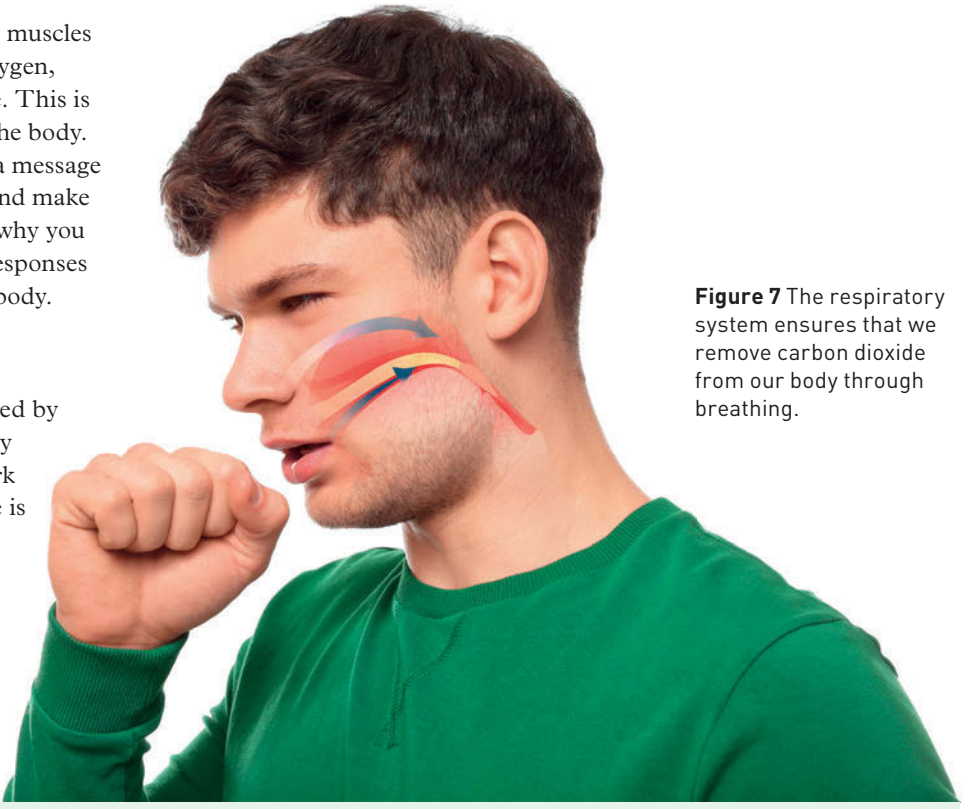


Figure 7 The respiratory system ensures that we remove carbon dioxide from our body through breathing.

Check your learning 9.7

Recall and explain

1 Using your own words, **define** homeostasis.

2 **Describe** how your body responds to excess carbon dioxide.

3 **Explain** what happens to your blood sugar levels when you eat.

4 **Recall** how your body responds to low blood sugar levels.

Apply and analyse

5 **Compare** the removal of waste from cells with the removal of waste from the kidneys.

6 If a negative feedback mechanism reduces the strength of the original stimulus, **assess** what a positive feedback mechanism might do. Include an example in your response.

Evaluate and create

7 In type I diabetes, cells in the pancreas are unable to produce insulin. **Propose** what effect this would have on blood glucose levels. **Investigate** how people with type I diabetes ensure that their blood glucose levels remain at the homeostatic level.

Skill builder: Planning investigations

8 To investigate homeostasis in humans, scientists may need to test body responses including temperature and heart rate.

- a **Identify** what equipment you would need to measure temperature in humans. (THINK: What is the best device to use?)
- b **Explain** whether taking someone's pulse with your fingers would be as successful as using a device, such as a smart watch. (THINK: What could go wrong measuring a pulse with fingers? Are the results from a device more accurate?)
- c **Recall** why it is important to use the appropriate device to measure a body response. (THINK: How might the wrong device impact your results?)

Figure 8 What is the best device to use to measure a body response?

9.8 Pathogens cause disease *

In this topic, you will learn that:

- infectious diseases are caused by pathogens
- pathogens include bacteria, fungi, protozoans, and non-living viruses and prions.

Our understanding of how infectious pathogens disrupt the normal functioning of our body and cause disease has developed over many centuries. It is now broadly accepted that pathogens cause disease; Table 1 shows the different types of pathogens.

One of the first people in Western medicine to question the accepted idea of supernatural causes of diseases was Hippocrates (460–377 BCE). He concluded that something in the air, soil, water and food causes diseases in humans and animals. His work was followed up by Claudius Galen (131–201 CE), who was a doctor to the gladiators and used animal dissections to explore anatomy.

Girolamo Francastor (1478–1553) was an Italian astronomer and doctor who was one of the first to suggest that disease could be transmitted from person to person via small invisible particles. He theorised that these particles could travel through the air, via contaminated clothing or by direct contact with the sick person. It took 200 years and the discovery of the microscope to confirm his theories and to develop the 'germ theory' used today.

germ theory
the current accepted theory that explains that pathogens cause infectious diseases

pathogen
an infectious-disease-causing agent

inoculation
the introduction of a pathogen, usually weakened, into a host

antibiotics
a medicine used in the treatment of bacterial infections

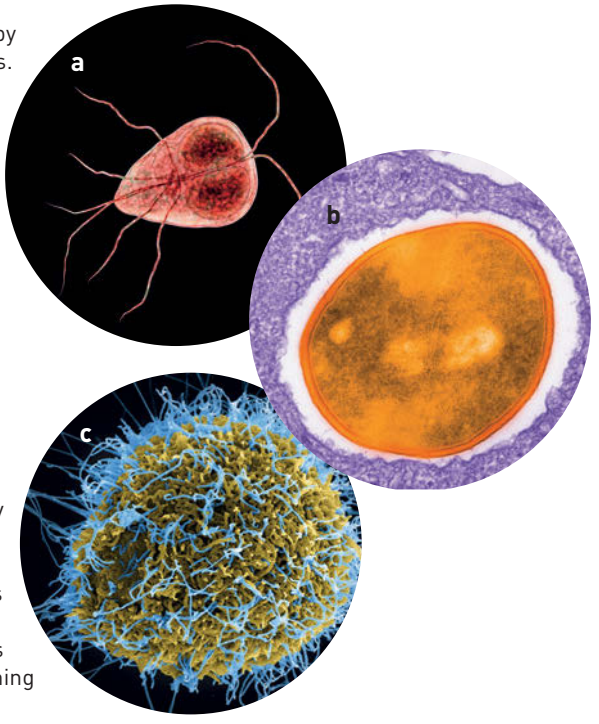


Figure 1 Most infections are caused by microscopic pathogens. **a** A protozoan is a single-celled organism that can live in other organisms and is responsible for parasitic infections. **b** Bacteria are very small cells that are able to reproduce by themselves. They can release toxins that affect the normal functioning of our body. **c** Viruses are unable to reproduce by themselves. Instead, they invade our cells and use the organelles to make new copies of themselves. This stops our cells from functioning properly.

Germ theory

Germ theory states that many diseases are caused by the presence and actions of specific **pathogens**. Germ theory was confirmed by Louis Pasteur and Robert Koch. Robert Koch went on to develop a set of rules known as Koch's postulates.

1. The microorganism or other pathogen must be present in all cases of the disease.
2. The pathogen can be isolated from the diseased host and grown in the laboratory.
3. The pathogen from a pure culture must cause the disease when **inoculated** into a healthy susceptible laboratory animal.
4. The pathogen must be re-isolated from the new host and shown to be the same as the originally inoculated pathogen.

Antibiotics

Before **antibiotics** were discovered, a single scratch from the thorn on a rose bush could become infected and kill you. In 1928, Alexander Fleming was trying to grow bacteria in his laboratory. When he returned from holidays, he discovered some Petri dishes he had left open on the bench were growing a mould similar to that found growing on bread. There were no bacteria growing near the mould. Fleming recognised that further investigation was necessary. He performed some experiments and discovered that the *Penicillium* mould was releasing a chemical that killed bacteria. Australian scientist Howard Florey was then instrumental in developing penicillin into a form that could be mass-produced. Both men were awarded the Nobel Prize in Physiology or Medicine for their work.

CHALLENGE
9.8: Investigating pathogens
Go to page **380**

INVESTIGATION
9.8: Investigating germ theory
Go to page **380**

Table 1 Different types of pathogens

Pathogen	Features	Example of disease
Bacterium	Unicellular organism Cell wall without nucleus or membrane bound organelles	Staphylococcus aureus
Fungus	Unicellular or multicellular organism Cell wall with nucleus No chloroplasts or chlorophyll	Tinea (a fungal infection that occurs between the toes)
Macroparasite	Multicellular organism Usually parasitic Absorbs nutrients across the cell membrane	Cysticercosis (an infection from eating contaminated uncooked meat, caused by tapeworm)
Prion	Not an organism Faulty protein molecule, which makes other proteins faulty through contact	Mad cow disease or Creutzfeldt-Jakob disease in humans
Protozoan	Unicellular or multicellular Cell wall with nucleus	Malaria
Virus	Contains genetic material surrounded by a protein	COVID-19

Video
Vaccines

Penicillin works by breaking down the cell walls of bacteria. Because human cells do not have a cell wall, they are unaffected. This means that penicillin will kill the bacteria in your body but not kill your own body cells. Viruses do not have cell walls. Instead, they have a protein coat that surrounds and protects them. This means penicillin does not affect viruses such as influenza or the common cold. Most viruses cannot be treated by any readily available medicines.

Check your learning 9.8

Recall and explain

1 **Identify** three living groups of pathogens.
2 **Explain** the difference between a virus and a bacterium.
3 **Summarise** germ theory.
4 **Identify** how Warren and Marshall used each of Koch's postulates to find the cause of stomach ulcers.
5 **Explain** how Louis Pasteur's discovery is still in use today.

Apply and analyse

6 A scientist hypothesises that a particular protozoan in Sydney water is responsible for an outbreak of a disease that causes an upset stomach and diarrhoea. **Outline** an experiment that could be performed to determine if the protozoan was in fact responsible for the disease.
7 A friend has been diagnosed with having a cold. His parents ask the doctor for some antibiotics to treat the infection. Determine what advice you think should be given and **justify** why.

Evaluate and create

8 **Investigate** a disease caused by either a virus, bacterium, fungus or protozoan. Provide details of the pathogen's discovery, and the symptoms, treatment and prevention of the disease.

Skill builder: Conducting investigations

9 Scientists that work with pathogens in the laboratory are at risk of being exposed to extremely dangerous illnesses. You may have seen people in a laboratory wearing full personal protective equipment (PPE). Those that work with pathogens typically have all their skin covered and sealed. This is one of the ways scientists manage risk.
   a **Explain** why wearing PPE in the laboratory is important when working with pathogens. (THINK: What are the risks of contracting a virus? What could happen if results were contaminated?)
   b **Identify** one other measure that can help keep scientists safe in the laboratory. (THINK: Should scientists work alone? What can go wrong if you are alone in the lab?)

9.9 The immune system protects our body

In this topic, you will learn that:

- the immune system has three lines of defence
- the immune system attacks any pathogen that does enter your body, to fight disease and keep you healthy.

immune system
a system of organs and structures that protect an organism against disease

phagocyte
an immune system cell that surrounds, absorbs and destroys pathogens

B cell
an immune system cell that produces antibodies in response to pathogens

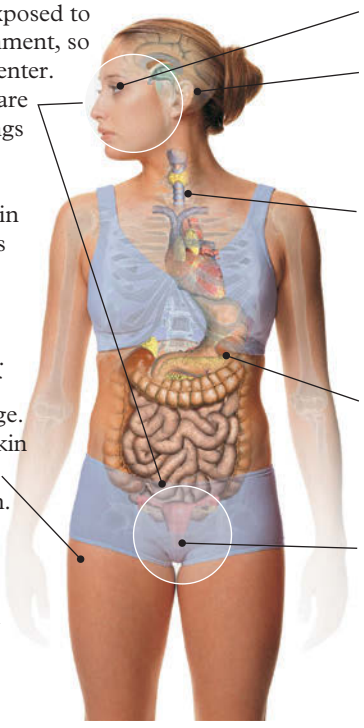
Our bodies have several ways of preventing us from catching diseases, as well as a series of responses in case we do become unwell. These responses are all part of the **immune system**. There are three lines of defence, and each line has a different mechanism for protecting and combating illness.

First line of defence

The first line of defence is to stop the pathogens from getting inside your body (Figure 1). It consists of the skin and mucous membranes.

The eyes, ears, nose, mouth and genitals are usually exposed to the air and/or environment, so pathogens can easily enter. Mucous membranes are the thin skin-like linings of these entry points. Chemical barriers are present here to assist in defence. Slimy mucus can capture and kill some of the bacteria.

Skin is a great barrier. It is thick, waterproof and difficult to damage. Helping protect the skin are the oils and sweat released from the skin. In dry conditions, bacteria are damaged and destroyed by the salt and antimicrobial chemicals in these secretions.



Tears wash pathogens out of the eyes.

Ear wax has a role in capturing pathogens trying to enter the body through the ears.

The small hair-like cilia and mucus that line the respiratory system catch and push possible pathogens back out of the body.

The stomach contains acid that kills most would-be pathogens.

Urine is slightly acidic, which makes it harder for bacteria to grow.

Figure 1 The first line of defence consists of a variety of structures and substances.

Second line of defence

Viruses, unlike bacteria, contain a protective coating that allows them to more easily slip through the first line of defence. If a pathogen gets inside your body, the body tries to remove it in one of two ways. First, a general 'seek and destroy' approach occurs regardless of the type of pathogen. This is called a general or **non-specific immune response**. The key parts of the non-specific immune response are:

- blood clotting, to stop additional infection through skin damage
- inflammation, to increase the amount of **white blood cells** reaching an infected area
- fever (some pathogens cannot survive at high temperatures, so heating up the body is one way to destroy them).

Second, white blood cells are produced by the body to destroy pathogens. Inflammation increases the amount of blood reaching an infected area so more white blood cells are able to attack the pathogen. The white blood cells may also release chemical messengers that increase the amount of fluid in the infected area, causing swelling. There are a few different types of white blood cells. Each type has its own role but they all work together. **Phagocytes** (Greek for 'cells that eat') deal with the non-specific immune response. They surround and absorb pathogens, destroying them in a process called phagocytosis.

Third line of defence

Any pathogens that are able to survive after the non-specific secondary response are targeted according to their type. This is called a specific immune response.

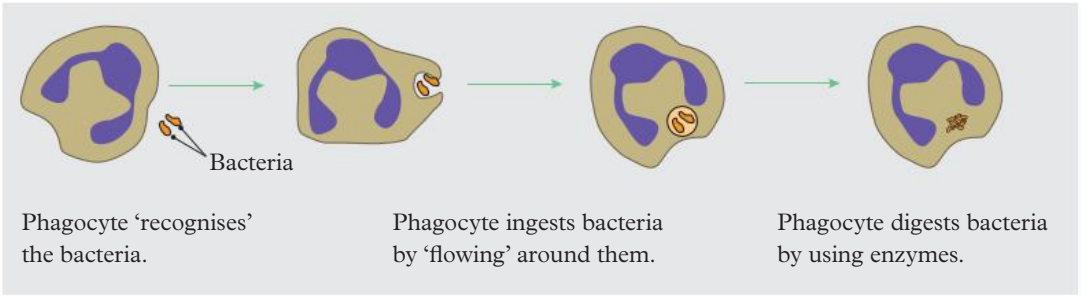


Figure 2 The process of phagocytosis

The specific immune response has two forms of attack. **B cells** (a type of white blood cell) produce special molecules called **antibodies**. These antibodies fit exactly onto a specific part of the pathogen. Each antibody will fit only one section of the pathogen. This will cause the pathogens to become locked together and stop them invading.

T cells (another type of white blood cell) then recognise the same specific pathogen and attack and kill it. B and T cells may take up to a week to recognise and destroy a pathogen. This is why recovering from an illness takes time.

Both the B and T cells will keep some memory cells alive, just in case the pathogen tries to invade again. This means the pathogen will be attacked and killed before it does damage a second time. Your body will be protected from re-infection in the future. You are now **immune**. This is called natural active immunity.

Unborn babies obtain some natural immunity by receiving antibodies across the placenta from the mother. Antibodies are also passed to babies through breast milk.

Another way to acquire immunity is through **vaccination** (or inoculation).

A vaccine can be:

- the dead pathogen
- a living but non-virulent (weakened) form of the pathogen
- parts of the broken-up pathogen.

Through vaccination, a person makes antibodies, which usually leads to immunity. Vaccinations are often given as a preventive measure. For instance, the influenza vaccine is recommended for people over 65 years of age because complications from influenza can be life-threatening in older people. Vaccination can also be given when there is an urgent need to provide immunity. For example, a tetanus vaccination may be given after a tetanus-prone injury, such as an open wound caused by a rusty or dirty object, because tetanus can be fatal.

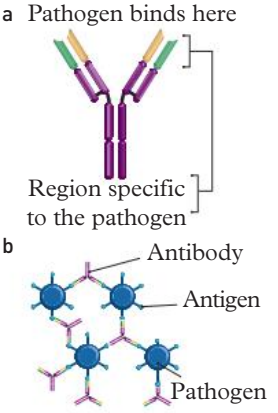


Figure 3 a Antibodies have regions that are specific to pathogens. **b** Antibodies cause pathogens to clump together.

antibody
a specific molecule produced by B cells that binds to a pathogen

T cell
an immune system cell that recognises and kills pathogens

immune
able to fight an infection as a result of prior exposure

vaccination
an injection of an inactive or artificial pathogen that results in the individual becoming immune to the disease

Check your learning 9.9

Recall and explain

1 **Identify** the parts of the body that make up the first line of defence.

2 **Describe** how the body responds if a pathogen gets past the first line of defence.

Apply and analyse

3 **Explain** the difference between a vaccination and a vaccine.

Evaluate and create

4 **Assess** which line of defence, if any, is most important. **Justify** your answer.

5 **Investigate** a disease that people are commonly vaccinated against. Write a list of details of what is in the vaccine and how effective it has been.

Skill builder: Communicating

6 You have been asked by a teacher at your school to explain the differences between the three lines of defence to year 7 science students. The teacher has encouraged you to use a diagram to explain this to the students, as they think the class will respond better to this.

a **Identify** what you need to include in a diagram for the three lines of defence. (THINK: What is the most important information?)

b **Construct** a scientific diagram/s to explain the three lines of defence to year 7 students. (THINK: What do scientific diagrams include? Where should you place labels?)

9.10 Humans respond to non-infectious diseases

In this topic, you will learn that:

- non-infectious diseases are not caused by pathogens
- non-infectious diseases are the result of environmental, genetic or nutritional factors.

Figure 1 A child with kwashiorkor disease, caused by a diet low in protein.

Unlike infectious diseases, non-infectious diseases are not caused by a pathogen. Instead, they are the result of genetic, environmental or nutritional factors. They can also be caused by a combination of these factors. They are not contagious: you cannot 'catch' a non-infectious disease from someone. However, some may be passed down from parent to child in the case of genetic disorders like Huntington's disease or cystic fibrosis.

Nutritional deficiency can cause disease

The nutrients you supply to your body can affect how well your individual cells do their job. The right balance of nutrients is very important. A deficiency in particular nutrients can cause diseases like rickets, scurvy and kwashiorkor.

Although other conditions such as type II diabetes, heart disease and obesity have nutritional links, patients can also have an underlying genetic predisposition to the disease.

To further complicate the situation, the environment in which someone finds themselves can influence the development of nutritional diseases. If there is little fresh fruit and vegetables available, you are more likely to develop some of these diseases.

Kwashiorkor

Protein is an important component of any diet because it is essential for cell growth and repair. If enough protein is not consumed, the body responds by slowing cell growth and repair. Kwashiorkor can develop, which leads to stunted growth, loss of muscle mass and fluid retention. If not treated, it is life-threatening.

Scurvy

Vitamin C plays an important role in the growth and repair of all body tissues. When people do not consume enough Vitamin C, for example by eating citrus fruits such as oranges, the body's ability to repair damaged tissue is inhibited. This can lead to scurvy, with symptoms such as weakness, spontaneous bleeding, ulceration of the gums and loss of teeth.

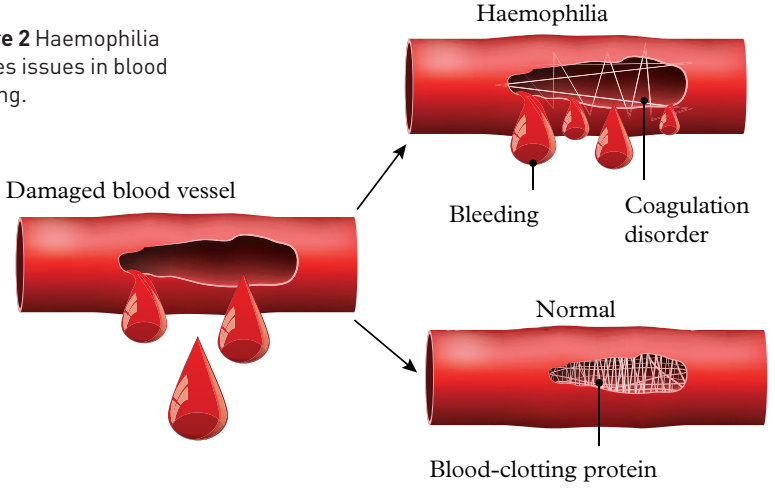


Figure 2 Haemophilia causes issues in blood clotting.

Genetic diseases and disorders

All genetic disorders are a result of a mutation in the DNA or chromosomes at some stage. If these mutations occur in the DNA of sperm and eggs, they can be passed on to future children. Examples of genetic diseases and disorders include haemophilia, cystic fibrosis, sickle-cell anaemia, muscular dystrophy, Down syndrome and fragile X syndrome.

Haemophilia

Haemophilia is an inherited disorder that prevents the affected person's blood from clotting. Typically, when we injure ourselves, our blood has a protein that assists in plugging the gap to stop the bleeding. If these proteins are not present, the body cannot prevent continous bleeding. If someone with haemophilia injures themselves, they are at serious risk. Modern science has isolated these proteins in blood cells and provides them to patients with haemophilia when needed.

Environmental and lifestyle diseases

As humans we are exposed to toxins, carcinogens and radiation on a daily basis. Some of these are harmless in small amounts, but with prolonged or extreme exposure, they can cause a non-infectious disease.

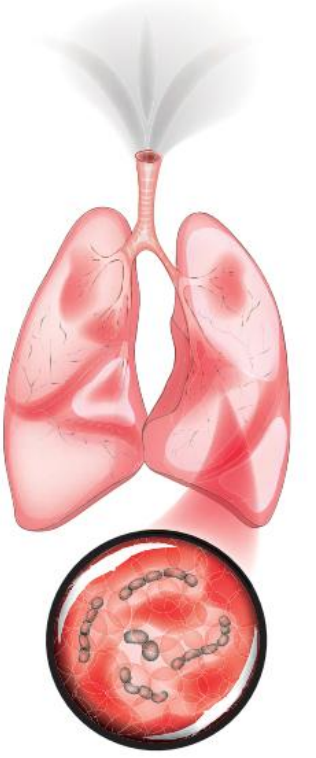
For example, excessive exposure to UV radiation can break chemical bonds within the DNA of your cells. DNA contains the instructions for every task and substance required for healthy functioning. Any change to these instructions can result in damage, which may be minor or major depending on where in the body the change occurs.

Asbestosis

Asbestosis is a lung disease caused by the inhalation of asbestos fibres. The fibres lodge in the lung tissue, and the body responds with inflammation and the creation of scar tissue to enclose the fibres. In the long term, this response can cause genetic change in the cells and result in lung cancer and mesothelioma (a cancer that forms in the thin layer lining the abdomen and organs such as the lungs and heart).

Emphysema

Emphysema is a progressive disease of the lungs. It causes shortness of breath due to inflation of the air sacs, which have been lined with tar from cigarette smoke. Smoking cigarettes can increase the likelihood of developing this disease. Cigarette smoke contains more than 70 known carcinogens, which are capable of causing emphysema, lung cancer and other health issues in the body.



Asbestos microfibre

Figure 3 Asbestosis affects the lungs.

Check your learning 9.10

Recall and explain

1 **Define** infectious disease, and provide an example.
2 **Identify** the three types of non-infectious disease.
3 **Propose** why our body needs a healthy diet.

Apply and analyse

4 **Compare** infectious diseases with non-infectious diseases.

Evaluate and create

5 Techniques for detecting genetic disorders are becoming more accurate and accessible. Write a brief essay to **discuss** the benefits and disadvantages of screening parents for common genetic disorders before having children.
6 **Investigate** a nutritional, genetic and environmental disease or disorder not covered in this section. **Construct** a presentation that provides details about the cause, symptoms and treatment of each. Your presentation should be no longer than 2 minutes and can involve a digital presentation, poster or any other elements you may need.

Skill builder: Communicating

7 Evaluating existing research contributes to developing new theories to test. The following three sources may provide information about scurvy symptoms.
- Your friend
- This book
- A medical journal, such as *The Lancet*

a Rate each resource out of ten for reliability. (THINK: Which is more credible? Is it likely to have been reviewed?)
b For each resource, **identify** one reason why it is credible and one reason why it may not be credible. (THINK: Where was the information published? Did it use the scientific method? Was the information reviewed? Is the author an expert in their field?)

9.11 Societies influence scientific research

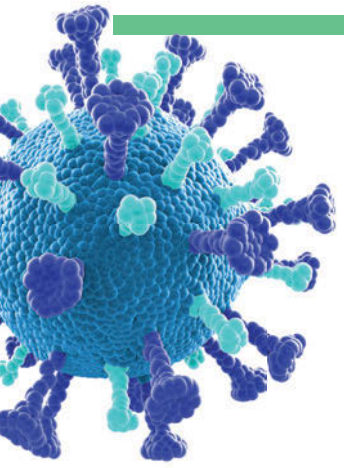
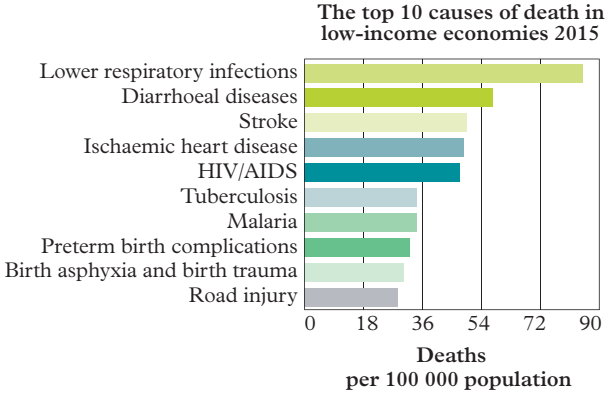


Figure 1 Society must be vigilant about outbreaks of dangerous viruses.

In this topic, you will learn that:

- the needs and demands of society influence scientific research
- Australia invests in research nationally and internationally.

History has shown that as scientific knowledge improves, better health and increased life expectancy follows. In developing countries, the majority of the top ten causes of death are the result of infectious disease. In contrast, for developed countries (including Australia) none of the top ten causes of death are due to infectious disease. Because of this, Australian society places more emphasis on supporting scientific research into non-infectious diseases such as obesity, heart disease and cancer.



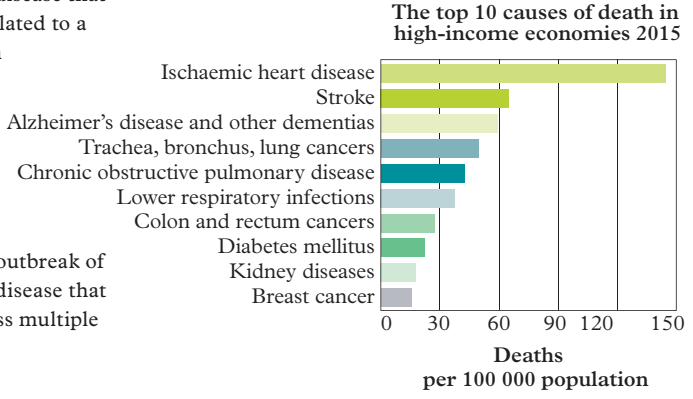


Figure 2 The top ten causes of death in low- and high-income economies in 2015

epidemic
a widespread outbreak of an infectious disease that is typically isolated to a specific region

pandemic
a widespread outbreak of an infectious disease that is spread across multiple global regions

Obesity

Obesity tends to result from the interplay between an individual's genetics, nutrition and environment. The World Health Organization (WHO) defines obesity as 'an excessive fat accumulation that presents a risk to health'.

Obesity requires a nutritional intake of calories greater than the amount being burnt off through your metabolism. Individuals can have a genetic predisposition to the disease, and home and work environments also influence dietary habits. The body's response to excess nutrients is to store these as fat.

Approximately 65% of adults and nearly 40% of all children in Australia are overweight or obese. These individuals have a greater risk of musculoskeletal disorders and a range of other diseases, including heart disease, type II diabetes and cancer. This places pressure on Australia's economy and health systems. The increased pressure causes Australian society to value research into obesity and ways to combat this disease.

Epidemics and pandemics

An **epidemic** refers to a disease outbreak that is actively spreading and affects a greater number of people in an area than would normally be expected. A **pandemic** relates to worldwide spread of a disease.

Epidemics and pandemics have occurred at various times throughout history. The Black Death (the Great Plague) in the 1300s killed as many as 200 million people. In 1918, the Spanish flu infected approximately 500 million people worldwide, and approximately 50 million people died. Different versions of influenza continue to cause health authorities concern every year. Since 2009, swine flu

Figure 3 Epidemics are an increased number of people with a disease in an area, whereas pandemics are the worldwide spread of the disease.

has caused up to 500 000 deaths around the world. This disease was transmitted between pigs and then from a pig to humans.

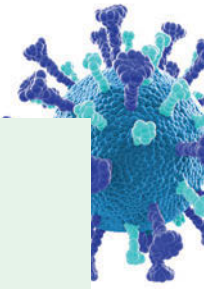
The rise of globalisation and ease of world travel dictates that contemporary society must be vigilant about outbreaks of dangerous strands of influenza.

In late 2019, COVID-19 emerged in China. This disease is caused by a new coronavirus similar to the SARS virus that caused an outbreak in 2003. In March 2020, COVID-19 was declared a pandemic by the World Health Organization.

HIV/AIDS

In the 1980s, the HIV/AIDS pandemic began. Without treatment, the human immunodeficiency virus (HIV) infection can progress to acquired immune deficiency syndrome (AIDS) within five years, eventually resulting in deaths. The current worldwide death toll stands at approximately 40 million people.

Around the world, there are many health campaigns to prevent the spread of the disease. Despite a relatively low infection rate in Australia, research was conducted to develop anti-viral drugs, which has resulted in very low HIV-to-AIDS progression rates in Australia.



Check your learning 9.11

Recall and explain

1 **Explain** the difference between an epidemic and a pandemic.

2 In your own words, **define** obesity.

Apply and analyse

3 **Examine** the graphs in Figure 2.

- a **Identify** the top cause of death in both developing and developed countries.
- b **Identify** the death rate of the top cause of death in both developing and developed countries.
- c **Interpret** if there is any overlap between the low- and high-income economies.

Evaluate and create

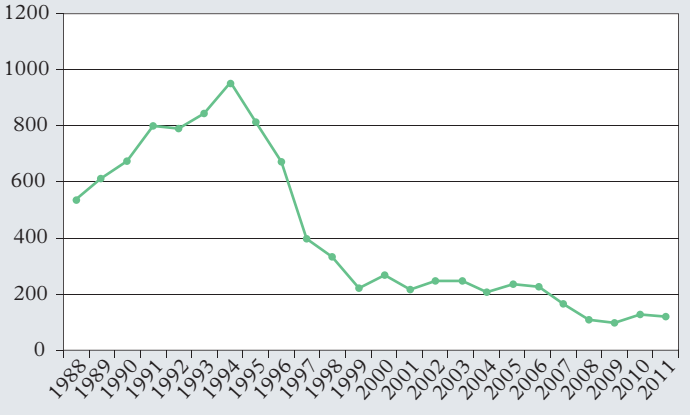
4 **Investigate** an example of how the values and needs of contemporary society have influenced the focus on scientific research in relation to the occurrence of diseases affecting animals and plants.

5 **Investigate** the global effort to produce a vaccine for COVID-19. **Discuss** why it is important for the world to act together to combat global diseases.

Skill builder: Processing and analysing data and information

6 Figure 4 shows the number of annual deaths from HIV/AIDS from 1988 to 2011 in Australia.

- a **Identify** what the *y*-axis and *x*-axis have information about.
  (THINK: What are the labels? What is happening in the graph?)
- b **Identify** what year had the most deaths.
  (THINK: What is the highest point on the graph?)
- c **Identify** how many deaths were in the year for part b.
  (THINK: What is the corresponding point on the graph?)
- d **Identify** the death rate in 2001.



Source: UNAIDS

Figure 4 Annual deaths from HIV/AIDS from 1988 to 2011 in Australia

REVIEW

Multiple choice

1 Which of the following explains what a neuron is?
- **A** A chemical released by organs of the body to create slow change
- **B** An electrical message released from the nervous system to create fast change
- **C** A cell that helps plants respond to sunlight
- **D** Part of the brain

2 Photoreceptors belong to sight, the way that chemoreceptors belong to _____
- **A** taste
- **B** touch
- **C** balance
- **D** hearing.

3 Select which of the following is not a pathogen.
- **A** Fungi
- **B** Bacteria
- **C** Adrenalin
- **D** Virus

Recall and explain

4 In your own words, **define** the following.
- **a** Stimulus
- **b** Homeostasis
- **c** Pathogen

5 **Describe** three ways the human body can receive a stimulus from the environment.

6 **Identify** two structures in humans that produce hormones, and **describe** their roles.

7 **Explain** why the nervous system and the endocrine system are both communication systems.

8 **Recall** how hormones are transported around the body.

9 **Describe** the features of the body's first line of defence.

10 Provide an example of an infectious disease.

11 **Explain** what an antibody is.

12 **Explain** how the specific immune system remembers pathogens for the next time you are infected by them.

13 **Recall** how epicormic buds allow survival of a plant after a bushfire.

14 **Describe** reasons why it might be important to have certain vaccinations before travelling overseas. Find two diseases you may need to be vaccinated against.

15 **Explain** what is meant by the phrase 'fight or flight' and how it relates to hormones.

16 The hypothalamus is an important structure within the brain that secretes hormones. It is responsible for maintaining a stable environment in your body. **Explain** how the hypothalamus is an example of the nervous and endocrine systems working together.

Apply and analyse

17 **Explain** what a feedback mechanism is and provide an example.

18 Complete the following sentence by inserting the missing words.
A person with diabetes has a problem with the hormone _____, which is secreted by the _____.

19 Transmission of pathogens can cause mass outbreaks of disease that affect large numbers of people. Most recently, COVID-19 has spread throughout the world. **Assess** the role of international travel in the spread of this disease.

20 People can suffer from multiple colds a year. **Propose** why this might be so.

21 **Examine** Table 1, which shows the leading cause of death in different age groups of Australians.
- **a** What is the second leading cause of death in people aged 15–24?
- **b** **Construct** a hypothesis about why lung cancer is the leading cause of death in people aged 65–74, whereas in people just younger and just older than this, coronary heart disease is the leading cause of death.

22 **Propose** a reason why recent pandemics typically don't kill as many people as the Black Death and the Spanish flu.

Evaluate and create

23 **Assess** why holding your nose might help you to swallow something that tastes awful.

24 In 2006, a woman in Canada fought off a polar bear with her bare hands when it attacked her son. **Propose** reasons for and against this reaction being attributed to the hormone adrenalin.

25 **Compare** viruses, bacteria and protozoa. **Explain** how they are similar and how they are different.

26 Write a creative story about what it would be like to live without one of your sense organs. You may want to conduct further research first.

27 Draw a cartoon strip with at least five squares, illustrating a person receiving a stimulus and then responding.

28 **Outline** what a vaccine may contain.

Table 1 Leading cause of death in different age groups, 2015–2017

Age group (years)	1st	2nd	3rd	4th	5th
Under 1	Perinatal and congenital conditions	Other ill-defined causes	SIDS (sudden infant death syndrome)	Accidental threats to breathing	Influenza and pneumonia
1–14	Land transport accidents	Perinatal and congenital conditions	Brain cancer	Accidental drowning and submersion	Leukaemia
15–24	Suicide	Land transport accidents	Accidental poisoning	Assault	Other ill-defined causes
25–44	Suicide	Accidental poisoning	Land transport accidents	Coronary heart disease	Breast cancer
45–64	Coronary heart disease	Lung cancer	Colorectal cancer	Suicide	Breast cancer
65–74	Lung cancer	Coronary heart disease	COPD (chronic obstructive pulmonary disease)	Colorectal cancer	Cerebrovascular disease
75–84	Coronary heart disease	Dementia and Alzheimer's disease	Cerebrovascular disease	Lung cancer	COPD
85 and over	Coronary heart disease	Dementia and Alzheimer's disease	Cerebrovascular disease	COPD	Heart failure

29 Prepare a visual presentation on the role of the different types of white blood cells in attacking pathogens.

30 The hygiene hypothesis suggests that childhood exposure to microbes and certain infections helps the immune system develop. As a result of potentially being too hygienic, developed countries continue to see a rise in autoimmune conditions such as asthma and anaphylaxis. **Investigate** these conditions, and **outline** the role of the body's own immune response in causing the symptoms.

31 **Describe** in your own words how the non-specific immune response works.

32 **Construct** a table that distinguishes between the different lines of defence.

33 **Explain** how the endocrine system assists your body to 'respond to the world'. **Discuss** why the endocrine system can't handle this big job on its own.

34 Most scientists and doctors believe that vaccinations for certain diseases should be compulsory, whereas small numbers of people believe it should be personal choice. In small groups, **discuss** different points of view and the consequences of these points of view.

Critical thinking

35 Haemophilia is carried on the X chromosome and is more likely to affect males. It is a genetic disorder.

a Research the following claim: 'People with haemophilia will have more complications from injuries than those who do not have haemophilia.'

b Find two sources to support your answer.

36 Animals enter hibernation to better survive changes in their external environment such as winter.

a **Investigate** how this helps the Eastern pygmy possum.

b **Propose** what might happen if the possum did not enter hibernation.

37 Louis Pasteur found that heat could kill microorganisms in milk. This discovery is still in use today. **Investigate** the use of heat in killing pathogens.

a **Identify** two reliable sources.

b **Summarise** one use of heat.

Go further

38 Human body cells are extremely sensitive to change, which is why our systems work very hard to maintain a relatively stable internal environment and why we move out of environments that are too hot or too cold. Plants are unable to get up and move to a new external environment. **Evaluate** whether plants would be more sensitive, less sensitive or have the same sensitivity to their internal environment than more mobile organisms. **Justify** your decision.

Research

39 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Stem cells for spinal injury

Nerve cells do not easily regenerate, so damage to the spinal cord is permanent. Scientists have been researching the use of stem cells in the treatment of spinal cord injury. What are stem cells? What type of stem cells are used in this research? What sorts of advances have been made in this field of research? What issues have affected such research?

»Type II diabetes

Type II diabetes is increasing in our society. Why is this? What is the cause of it? What complications can result from diabetes? What can you do to prevent diabetes?

»Artificial skin

Investigate the work of Australian scientists Dr Fiona Wood and Dr Marie Stoner on skin regeneration, including spray-on skin. Why is their area of research so important? How is it related to the treatment of the Bali bombing victims?

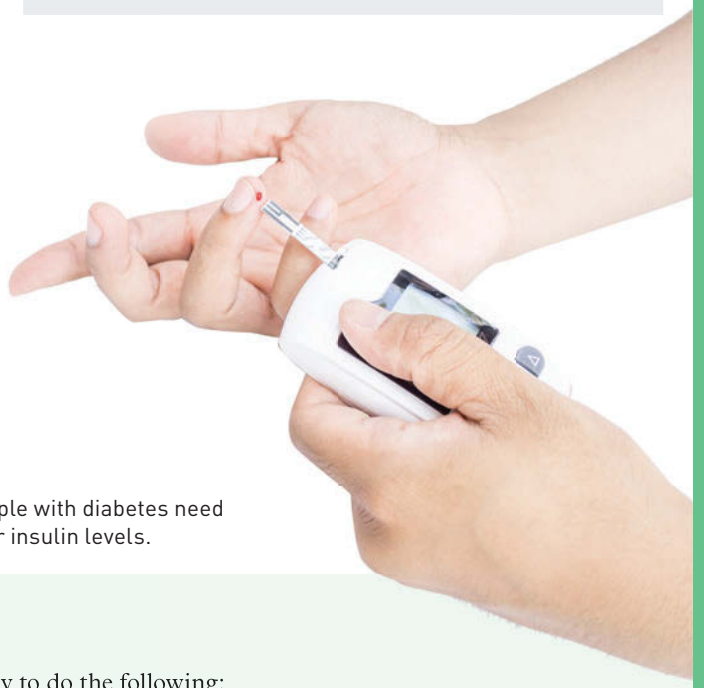


Figure 1 People with diabetes need to check their insulin levels.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Describe some examples of how multicellular organisms respond to changes in their environment.	☐	☐ Go to pages 150-155
Describe how the coordinated function of internal systems in multicellular organisms provides cells with requirements for life, including gases, nutrients and water, and removes cell wastes.	☐	☐ Go to pages 162-167
Outline some responses of the human body to infectious and non-infectious diseases.	☐	☐ Go to pages 168-173
Describe the role of, and interaction between, the coordination systems in maintaining humans as functioning organisms.	☐	☐ Go to pages 156-161
Discuss, using examples, how the values and needs of contemporary society can influence the focus of scientific research, e.g. the occurrence of diseases affecting animals and plants, an epidemic or pandemic disease in humans or lifestyle related non-infectious diseases in humans.	☐	☐ Go to pages 174-175

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

ECOSYSTEMS

How does science balance the needs of humans with the broader environment?

Have you ever wondered ...

- What happens in an unbalanced ecosystem?
- How can you reduce your impact on the environment?
- How did Aboriginal and Torres Strait Islander peoples live sustainably?

10

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- recall that ecosystems consist of communities of interdependent organisms and abiotic components of the environment
- outline using examples how matter is cycled through ecosystems such as nitrogen
- describe how energy flows through ecosystems, including input and output through food webs
- analyse how changes in some biotic and abiotic components of an ecosystem affect populations and/or communities
- assess ways that Aboriginal and Torres Strait Islander Peoples' cultural practices and knowledge of the environment contribute to the conservation and management of sustainable ecosystems
- evaluate some examples in ecosystems, of strategies used to balance conserving, protecting and maintaining the quality and sustainability of the environment with human activities and needs

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

10.1 All living things are dependent on each other and the environment

Figure 1 The flora and fauna of Mount Kosciuszko in New South Wales is an example of an ecosystem.

In this topic, you will learn that:

- an ecosystem is a community of living organisms and their non-living surroundings
- ecology is the study of the relationships of organisms with other organisms and their non-living environment.

An ecosystem is a community of living organisms (biotic) and their non-living surroundings (abiotic) and is the basic unit of ecology. Ecology is the study of the interrelationships of organisms with other organisms and their non-living environment.

The biosphere is a home for our ecosystems

The biosphere describes the living world. It is where all of the plants and animals live. The biosphere extends to any place that life exists. The biosphere can be thought of as the intersection between the atmosphere (gases), the hydrosphere (water) and the lithosphere (land). Because the biosphere is large and its relationships are so complex, we normally study smaller components of the biosphere, which are called ecosystems.

Ecosystems

Ecosystems vary in size. They can be as small as a puddle or as large as the Earth itself. Any group of **biotic** (living) and **abiotic** (non-living) things interacting with each other in a self-sustaining way is an ecosystem. Ecosystems are made up of habitats. A habitat is the place where a population of organisms lives. Habitats vary in size, depending on the amount of food, water and shelter they provide. A **population** is a group of living organisms that are the same species, living in the same place at the same time. When different populations interact with each other, they are called a **community**. For example, a population of humans can live in a town together. When all the plants in their gardens and their pets are included, then it becomes a community.

The habitat must supply all the needs of the organism, such as food, water, oxygen and minerals. These make up the non-living, abiotic conditions of the habitat. If the abiotic conditions are not appropriate for a population, then the individuals in that population will either migrate to find a habitat that can supply those needs or it will die out.

ecosystem
a number of communities together with the surrounding non-living factors

biotic
all the living organisms in an ecosystem

abiotic
all the non-living components of an ecosystem; for example, light, temperature and water

population
a group of the same species living in the same place at the same time

community
different populations living in the same place at the same time

Benefits of an ecosystem

Humans depend on ecosystems for survival. Ecosystems provide a number of benefits to ensure our continued existence.

Plants and animals work together to help maintain the balance of gases in the air

Plants and animals continuously cycle gases among themselves, the soil and the air. For example, during the day, plants take in carbon dioxide from the air and release oxygen into the air during a process called photosynthesis. Animals, including humans, use the oxygen in cellular respiration and release carbon dioxide into the air.

Insects, birds and bats help pollinate plants

Animals interact with plants in their search for food. Bees and other insects, as well as some birds and bats, transfer pollen from plant to plant. Pollination by animals is not only helpful for plants growing in the wild, it is also

CHALLENGE
10.1: Making a biosphere
Go to page **381**

INVESTIGATION
10.1: Purification of water
Go to your **obook**

important for crop plants grown commercially by humans. Over 70% of plant species worldwide, including fruits and vegetables, are pollinated by animals, insects or birds. Pollen may also be carried by wind or water.

Some organisms decompose organic matter

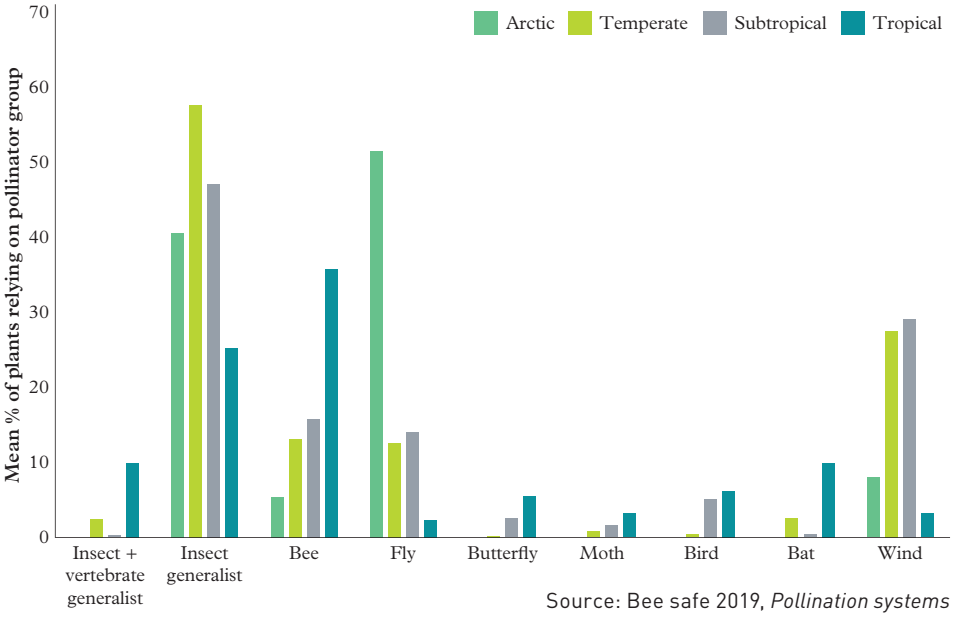
Some living organisms, called **decomposers**, get the food they need by breaking down the remains of other organisms. Decomposers not only prevent dead organisms from accumulating, but they also utilise the nutrients from the organism to grow and reproduce. These nutrients will then be passed on to other organisms when they are consumed by other organisms. The nutrients also pass through the decomposers as waste, which ends up in the soil in simpler forms that plants can absorb via their roots.

Wetlands and forests clean water

If you poured dirty water through a filter, you would expect cleaner water to come out. A similar situation happens in nature when water passes through a forest or wetland ecosystem. The tree canopy slows the flow of water, and by the time it reaches lower plants many of the pollutants and sediments have been filtered out.

Figure 2 Animal pollinators, such as birds, bees, bats and insects, visit flowers for food, such as nectar, and transfer pollen when they visit other flowers.

decomposers
organisms, such as bacteria and fungi, that feed on other dead organisms



Source: Bee safe 2019, *Pollination systems*

Figure 3 The mean percentage of plants relying on different pollinators in different ecosystems

Check your learning 10.1

Recall and explain

1 **Identify** the three systems that interact to form a biosphere.
2 **Recall** the scientific word for non-living components of an ecosystem. Give three examples of these components.
3 **Explain** the difference between a population and a community.

Apply and analyse

4 There are growing concerns about the falling number of bees worldwide. With over 70% of plant species worldwide, including fruits and vegetables, being pollinated by animals, **assess** the possible impacts for humans if bee numbers continue to drop. **Justify** your answer.

Evaluate and create

5 Imagine someone walked up to you and asked, 'Why is the environment so important?' Draft a reply to **evaluate** the key concepts covered in this section.

Skill builder: Processing and analysing data and information

6 **Interpret** Figure 3 to answer the questions that follow.
- a **Identify** the main type of pollinators in an arctic ecosystem. (THINK: What colour represents pollinators?)
- b **Identify** which group is responsible for the greatest total percentage of pollination. (THINK: What group has the highest pollination?)
- c **Identify** the percentage of plants in a tropical ecosystem that are pollinated by bees. (THINK: What axis of the graph represents this information? Look for the percentage figure.)

10.2 Organisms can have beneficial or detrimental relationships

In this topic, you will learn that:

- mutual relationships benefit both organisms
- commensal relationships benefit one organism and the other is not affected
- parasitic relationships are when one organism benefits and the other is harmed.

competition
a relationship between organisms using the same limited resources in an ecosystem

symbiosis
a close physical relationship that occurs over a long time between two members of different species

mutualism
a relationship between two organisms of different species in which both organisms benefit

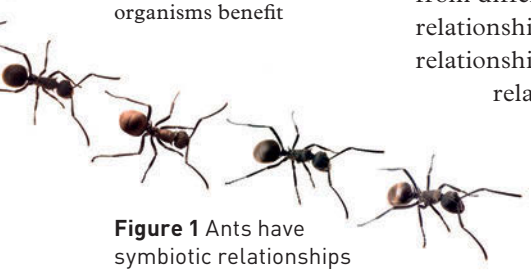


Figure 1 Ants have symbiotic relationships with other organisms as well as plants.

commensalism
a relationship between two organisms from different species, in which one organism benefits and the other organism is not affected

parasitism
a relationship in which one organism (parasite) benefits and the other organism (host) is harmed

All organisms interact with each other in a community. Individuals in a population may need to collaborate to gain access to resources that will ensure the species survival. This may cause competition for food or shelter. Although some organisms do not affect other organisms in an ecosystem, most organisms are part of a large network of living things. These relationships may be beneficial or detrimental. Relationships may be between organisms of the same or different species. Sometimes two organisms from different species form a close relationship with each other. This type of relationship is called symbiosis. Symbiotic relationships include mutualism, commensalism and parasitism. In mutualism both organisms benefit, in commensalism only one organism benefits, and in parasitism one organism benefits and the other is harmed.

Relationships within a species

There are three types of relationships between organisms of the same species.

1. *Collaboration* occurs when organisms cooperate with each other to ensure their survival. For example, ants leave a trail of scent when they look for food so that other ants from the same colony can find the food too.
2. *Mating* between members of the same species produces offspring, thus ensuring the survival of the species.
3. Intraspecific **competition** occurs when organisms of the same species compete for the use of the same limited resource. For example, seedlings from the same species compete with each other for light and space as they grow.

Relationships between different species

Symbiosis

Symbiosis is a close physical and long-term relationship between two organisms of different species. Mutualism, commensalism and parasitism are all examples of symbiosis.

Mutualism is a relationship between two organisms in which both organisms benefit.

Commensalism is a relationship in which one organism benefits and the other organism is not affected. For example, barnacles that attach themselves to whales. Commensalism is relatively rare in the natural world because it is unlikely that an organism will not be affected in some way by a relationship with another organism.

Parasitism is a relationship in which one organism (the parasite) lives in or on the body of another (the host). The parasite benefits but the host is harmed.

INVESTIGATION
10.2: What if more seeds were planted in a pot?
Go to page **382**

Figure 2 Mutualism A lichen is an alga and a fungus, although you cannot see the two organisms separately (except under a microscope). The alga produces energy for both organisms through photosynthesis, and the fungus provides support and other nutrients.

Figure 3 Mutualism The anemone fish (clown fish) hides within the tentacles of the sea anemone where it is camouflaged from its predators. The sea anemone is cleaned of algae by the fish.

Figure 4 Commensalism Sometimes herbivorous animals such as cattle and water buffalo flush insects out of the grass as they wander through. Birds such as cattle egrets feast on the insects.

Figure 5 Commensalism Certain plants rely on passing animals to disperse their seeds. The seeds have tiny hooks that attach to animal fur, and they will usually fall off a distance from their parent plant.

Figure 6 Parasitism Ticks attach to the skin of animals and slowly drink their blood. Bacteria from the digestive system of the tick can infect the animals.

Figure 7 Parasitism Hookworms attach themselves to the inner lining of the human intestine, feeding on nutrients as they pass by. If the host doesn't eat enough, the worm has been known to burrow out of the intestines and travel to other organs, where significant damage can be done.

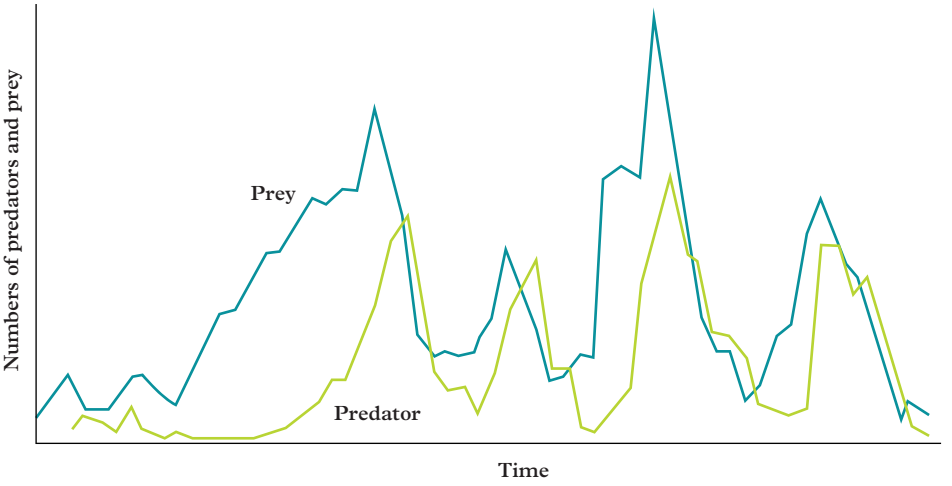


Figure 8 A predator–prey graph. The scales aren't shown, but the prey numbers tend to be greater than those of the predators. Notice that the increase and decrease in prey numbers usually comes before the increase and decrease in predator numbers.

Non-symbiotic relationships

Two non-symbiotic relationships are predator–prey relationships and interspecific competition.

In a predator–prey relationship, one organism (the predator) eats another (the prey). Therefore, one benefits and the other is harmed. It is not symbiotic because the relationship between the organisms is not long-term and it only happens when a predator has the opportunity to attack. Predators and their prey have a balanced relationship with each other. If all the prey are eaten, then the predator will starve. Figure 8 shows a predator–prey graph, which has a typical pattern.

Competition may also exist between members of different species that share a resource such as food. An example of this interspecific competition is shown in Figure 9.

Inhibition is a particular type of competition that occurs when one organism produces a chemical that directly inhibits or hinders the growth and development of another (Figures 10 and 11).

inhibition
competition that occurs when an organism stops the growth or development of another organism by producing a chemical; the slowing of a process

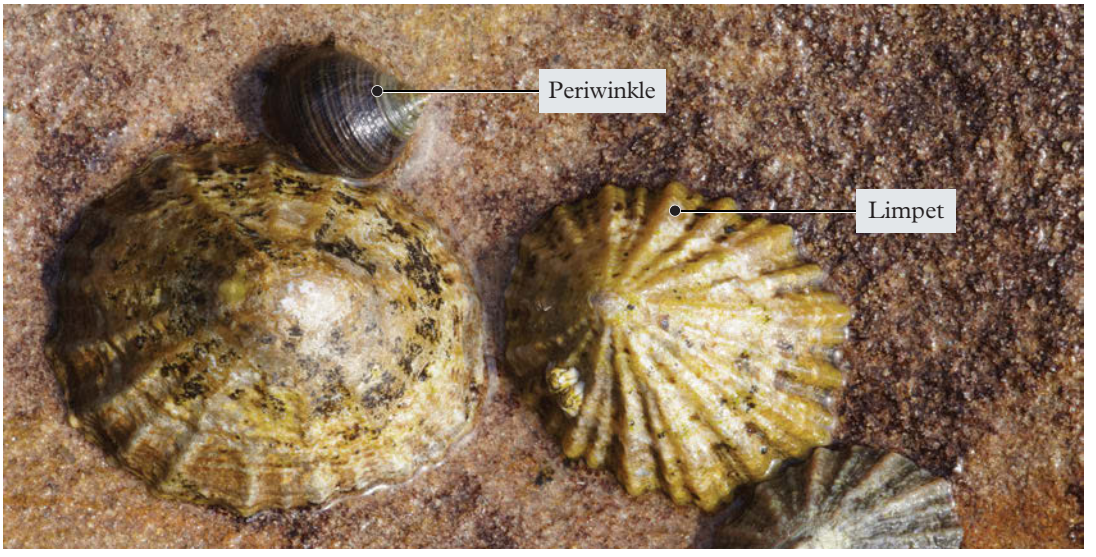


Figure 9 A black periwinkle (*Nerita*) competes for food with the limpet (*Cellana*) on a rock platform – both feed on algae growing on the rocks. The periwinkle moves faster but feeds less efficiently than the limpet, so both can survive because the periwinkles usually leave some algae behind for the limpets. However, when the periwinkles are removed, the limpet population increases.

Figure 10 *Penicillium* fungus mould (shown here growing on an orange) produces an antibiotic called penicillin that inhibits the growth of many species of bacteria.

Figure 11 The *Lantana* plant was introduced into Australia and has become a weed. It releases a chemical into the soil that inhibits the growth of native plant species.

Check your learning 10.2

Recall and explain

1 **Identify** one similarity and one difference between a predator–prey relationship and parasitism.

2 **Explain** how a large plant that produces a lot of shade prevents smaller plants from growing.

3 Study the predator–prey graph in Figure 8.
   - a **Propose** a reason for the 'lag' in the peaks for predatory numbers compared to the prey peaks.
   - b **Propose** a reason why the number of prey are always higher than the number of predators at the corresponding peaks.

Apply and analyse

4 Provide an example of the following relationships and **explain** how they work.
   - a Predator–prey
   - b Mutualism
   - c Commensalism
   - d Parasite–host

Evaluate and create

5 Some eucalyptus trees have mistletoe plants living on them. Mistletoe has very similar leaves to eucalyptus leaves. Mistletoe plants can make their own food, but their stems send suckers into the eucalypt to obtain water and minerals. If too much water and minerals are removed, the eucalypt can die. **Identify** the type of relationship this is, and **propose** a reason for this relationship.

6 Epiphytes are plants, such as ferns and some orchids, that grow high in the branches of other trees, especially rainforest trees. The epiphytes obtain sufficient light to make their own food, collect water from the moist air and obtain minerals from the decaying leaf litter that they catch at their leaf bases. The tree is not affected by these plants. **Identify** the type of relationship this is, and **explain** why the tree is not affected by these plants.

7 Ecosystems are said to be in a state of equilibrium or balance. **Identify** an example of how a change in the environment may lead to changes in the living community, and **identify** an example of how a change in the living community may lead to changes in the environment.

Skill builder: Planning investigations

8 You have been asked to investigate a mutual relationship in the environment surrounding your school. Your teacher has instructed you to decide whether you should collect first- or second-hand data.
   - a **Identify** a mutual relationship near your school. (THINK: What organisms benefit each other? Where do they live?)
   - b **Assess** whether it is more appropriate for you to collect first-hand data or secondary data to investigate this relationship. (THINK: Can you safely and accurately collect enough data? Is there existing research in this area?)

10.3 Population size depends on abiotic and biotic factors

In this topic, you will learn that:

- the population of a species is dependent on the availability of food and shelter, increases or decreases in predators, or a change in the environment such as a drought or bushfire.

All organisms live in a complex web of interrelationships – with each other and with their environment. An ecosystem needs to be able to maintain a balance so that all species exist at their optimum population size.

At its simplest, an increase in population due to reproduction and immigration must be balanced by the losses due to death and emigration (leaving).

Consider the food web for an ecosystem shown in Figure 1. If the number of frogs decreased in this ecosystem, the consequences could include:

- an increase in grasshopper numbers and thus a reduction in the availability of grass
- an initial increase in praying mantis numbers because of more grasshoppers
- a decrease in lizard numbers
- a diversion of birds towards a diet of praying mantises rather than frogs and lizards
- a consequent decrease in praying mantis numbers
- a further increase in grasshopper numbers and intensified reduction in the availability of grass. If this was severe enough, the ecosystem would be at risk because it depends on a good availability of grass.

The most likely outcome is that the bird population will decrease, resulting in lower population sizes for the other organisms. A positive effect is that it might enable the frog population to recover.

Ecosystem balance is a type of dynamic equilibrium. Changes may upset the equilibrium, but another equilibrium becomes established. This change sometimes does not have a big impact on the system, and the ecosystem doesn't differ greatly from the original; in other instances removing a key species can have dramatic impacts on the ecosystem. Changes in ecosystems occur naturally, but they may be intensified by external factors such as floods or bushfires. Reproduction, death, migration, natural events (e.g. seasonal changes), disasters (e.g. floods, droughts and earthquakes) and human intervention occur regularly.

quadrat
a randomly selected square plot used to estimate the number of organisms in an ecosystem

capture–recapture
a method of estimating the number of organisms in an ecosystem by capturing, marking and releasing organisms

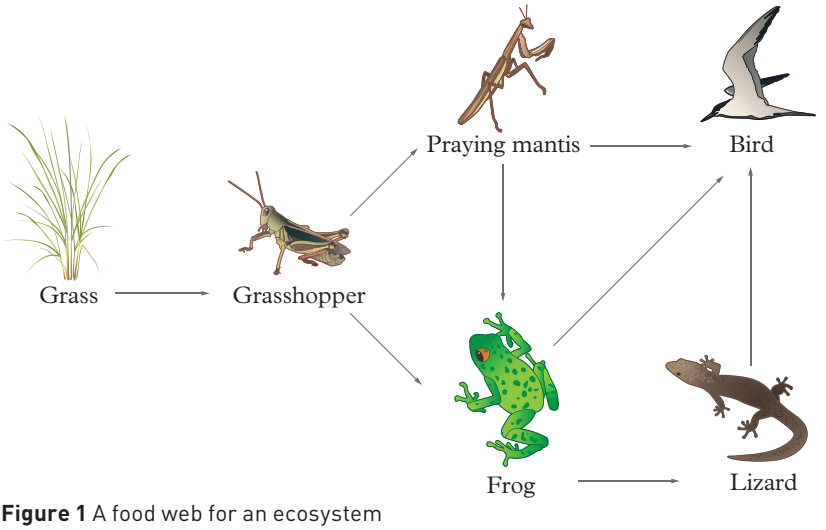


Figure 1 A food web for an ecosystem

Population dynamics

Population dynamics is the study of the changes in population numbers within ecosystems. Scientists can make predictions and take certain precautions to conserve species if they have an approximate idea of how many of each species are in a certain location. Regular sampling provides information about increases and decreases in population numbers, and causes can be identified.

Counting organisms

There are a number of ways to determine the size of a population. The 'simplest' way is to count all the organisms, but in practice this is rarely possible. Estimates are more easily achieved by counting from helicopters or using **quadrats** or **capture–recapture** methods. For human populations, a census is the usual method.

For plants and stationary animals, quadrats (i.e. randomly selected square plots) are marked in an ecosystem. The organisms in each plot are counted, an average is obtained, and then (knowing the total area of the ecosystem) the estimated number of organisms in the ecosystem is calculated. This method works well if a large number of quadrats are used and the organisms are evenly spread throughout the ecosystem.

For animals that are mobile, capture–recapture is a popular method. Animals are captured in traps and marked with tags, liquid paper or permanent marker on their tails. The number counted on the first capture is N_1. The animals are then released, and it is assumed that they disperse evenly throughout the population. Another capture (recapture) is made one or two days (or nights) later. The number of animals in this second capture that are marked are counted (M_2), as well as the total number caught in the second sample (N_2). An estimate of the population is then obtained using the following formula:

$$\text{Total number of animals} = \frac{N_1 \times N_2}{M_2}$$

Capture–recapture is a suitable technique for estimating the population size of small Australian mammals, such as the marsupial *Antechinus* or the common bush rat. Because most native Australian mammals are nocturnal, the traps may be set at night and checked the next morning.

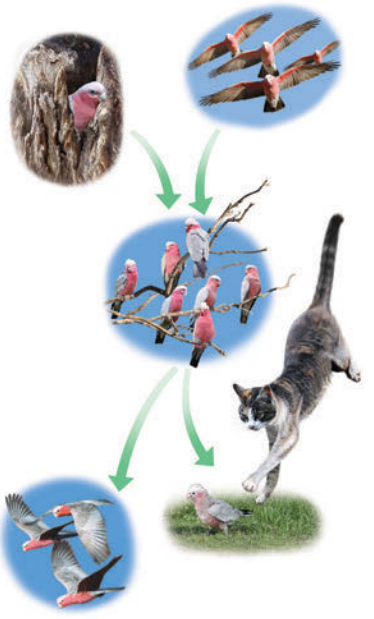


Figure 2 The size of a galah population in a particular area depends on the food available, the number of births and deaths and the presence of predators (in this case a cat).

Figure 3 Using a quadrat

Check your learning 10.3

Recall and explain

1. **Describe** suitable methods for estimating the population size of:
   - a plants and stationary animals
   - b other animals.
2. **Identify** the advantages and disadvantages of the methods you describe in question 1.
3. **Propose** why populations are usually estimated rather than just counted.
4. Using a specific example, **recall** how a bushfire might increase the size of a population.

Apply and analyse

5. Ecosystems are said to be in a state of equilibrium or balance. It appears that nothing is changing. **Assess** if there is change.

Evaluate and create

6. **Discuss** whether growth in population size is always desirable.
7. **Explain** how predator–prey relationships achieve a state of balance. **Explain** why this balance is essential for the:
   - a prey
   - b predator.

Skill builder: Conducting investigations

8. When research impacts an ecosystem, the environmental impacts on both animals and plants, as well as any cultural impacts on researching that particular area, must be considered.
   - a Think about where you live. **Identify** one animal species that could be investigated via capture–recapture. (THINK: Is this animal native to your area?)
   - b Highlight ethical issues of using this method on this animal. (THINK: Does this animal live elsewhere? Will any harm come to the animal? Do you need to think of cultural impacts?)

10.4 Matter is recycled in ecosystems

In this topic, you will learn that:

- matter cannot be created or destroyed (law of conservation of mass)
- matter cycles through an ecosystem via the water cycle, carbon cycle and nitrogen cycle.

Similar to energy, matter (such as atoms and molecules) flows through ecosystems. Plants absorb simple substances such as carbon dioxide, water and minerals, and convert them into sugars by photosynthesis. Animals eating the plants use the sugars and other compounds. When plants and animals die, the matter is rearranged by decomposers to obtain energy. In doing so, they break down the complex chemicals into simple compounds, which are reused by plants to grow, completing the cycle of matter.

nitrogen cycle
nitrogen moves through living and non-living things by changing forms

matter
physical substance made of atoms

Cycles of matter

Matter cannot be created or destroyed. This means matter must be recycled. The cycling of matter from the atmosphere or the Earth's crust and back again is called a biogeochemical cycle (*bio* means 'living'; *geo* means 'earth'). Decomposers are essential to the cycles of matter – they break down dead matter and convert it into simple substances that can be reused by plants, which are then consumed by animals.

Nitrogen cycle

Nitrogen is a gas that makes up approximately 70% of the Earth's atmosphere. It is a very stable element, and it is important for the production of DNA and proteins.

The **nitrogen cycle** is how the Earth processes and uses nitrogen. Nitrogen enters the Earth via rain or snow falling from the atmosphere. The nitrogen in the soil is then taken up by plants which helps them to grow. Plants are then eaten by animals, and the nitrogen in the plant is then accessible to the animals that consume them. When the animals and plants die, decomposers absorb the nitrogen and the cycle repeats.

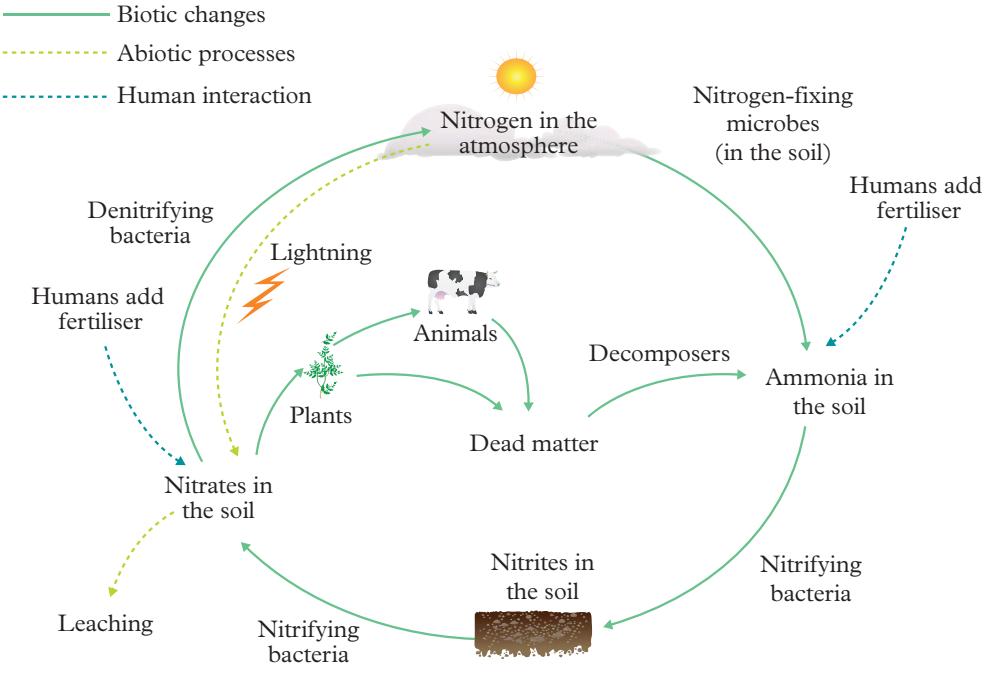


Figure 1 The nitrogen cycle

There are few living organisms that can use nitrogen as it is found in the atmosphere, but all living organisms need nitrogen delivered in a different way. Legumes, a type of plant, grow with nitrogen-fixing bacteria on their roots. Denitrifying bacteria return nitrogen to the atmosphere as nitrogen gas.

A lack of nitrogen in the soil can limit the growth of organisms. People use fertilisers to add nitrogen to the soil, which encourages plant growth.

Water cycle

The global water cycle is driven by heat from the Sun. Three major processes driven by solar heat – **precipitation** (rain, snow or sleet), **evaporation** and **transpiration** from plants – continuously move water between land, oceans and the atmosphere. On land, the amount of precipitation is greater than the amount of evaporation and/or transpiration, and the excess water feeds lakes, rivers and groundwater, all of which flow back into the sea.

Humans can alter the water cycle. For example, cutting down rainforests changes the amount of water vapour in the air (due to transpiration), which alters precipitation.

Water is not available equally in all ecosystems. Water that is evaporated from a desert may later fall as rain on a forest thousands of kilometres away.

Carbon–oxygen cycle

Carbon is found as carbon dioxide in the atmosphere and in compounds such as sugars, proteins and lipids (such as fats) in the bodies of living organisms. Globally, the return of carbon dioxide to the air by respiration is balanced by its removal in photosynthesis. Other ways of returning carbon dioxide to the air include the burning of fossil fuels, bushfires and the decomposition of dead matter. The natural balance of this cycle is disturbed by excess burning, which contributes to the enhanced greenhouse effect.

Atmospheric oxygen is required for cellular respiration and energy production. Carbon dioxide is released into the air during cellular respiration as well as through the decomposition process. Photosynthesis in plants removes carbon dioxide from the atmosphere and releases oxygen.

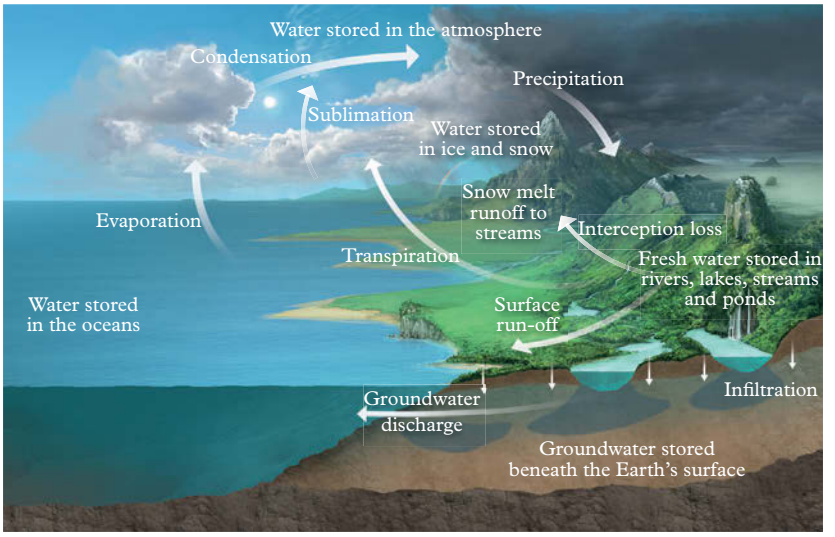


Figure 2 The water cycle

precipitation
the process in which water vapour in the upper atmosphere becomes liquid water in the form of rain, snow or sleet and falls to the ground

evaporation
the process of liquid water gaining thermal energy and changing into gas

transpiration
the process of water evaporating from plants

Check your learning 10.4

Recall and explain

1 **Explain** what matter is.
2 **Distinguish** between energy and matter.
3 **Describe** how nitrogen is cycled through the Earth and the Earth's atmosphere.

Apply and analyse

4 'You are eating the same atoms that were in dinosaur poo!' **Assess** how accurate this statement is. **Justify** your response with evidence.

Evaluate and create

5 **Evaluate** this statement: 'The nitrogen cycle is the most important system.'

Skill builder: Questioning and predicting

6 For each of the following predictions, write a hypothesis that can be measured scientifically. (THINK: What is being measured? What is being manipulated? What would the effects be?)

a If plants stop transpiring, then precipitation will still fall.
b If decomposers took too long to absorb nitrogen, then plants would grow more slowly.

10.5 Energy enters the ecosystem through photosynthesis

In this topic, you will learn that:

- ecosystems transfer energy from one part to another, for example, from plants to animals
- photosynthesis is the process of plants converting light energy into chemical energy.

photosynthesis
the process in plants in which glucose is produced from water and carbon dioxide

chlorophyll
a molecule (enzyme) found in chloroplasts that is used to speed up photosynthesis

stomata
small pores (openings) on a leaf surface used in the control of water and gas movement

All energy in an ecosystem comes from the Sun. Organisms undergo photosynthesis to convert this light energy. Animals cannot directly use energy from the Sun. Even in caves and other places where there is no light, the energy may be from dead plants and animals, which originally obtained their energy from the Sun. An exception is the chemosynthetic bacteria on the ocean floor and craters of volcanoes, which trap the energy from chemicals that convert one or more carbon-containing molecules (usually carbon dioxide or methane) and nutrients into organic matter without the use of sunlight.

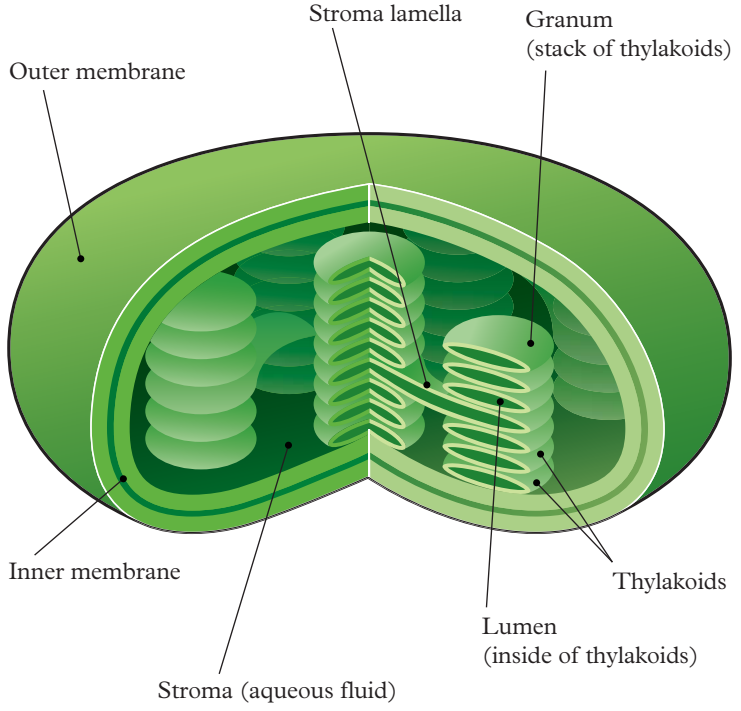


Figure 1 The structure of a chloroplast

Plants process light energy by photosynthesis

Living things need energy to grow and repair, to defend themselves, and to move around. The energy in an ecosystem usually originates from the Sun. Plants, some algae and bacteria are able to transform this light energy into chemical energy through a process called **photosynthesis**. In this process, water and carbon dioxide is converted into glucose (a sugar) and oxygen. The overall equation for photosynthesis is:

carbon dioxide + water → glucose + oxygen + water

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

Where does photosynthesis happen?

On average, a plant leaf has tens of thousands of cells. A single cell contains 40–50 chloroplasts, which contain the green pigment **chlorophyll**. Chlorophyll captures the Sun's light energy and traps it in the chemical bonds of glucose.

Because plants do not have lungs to breathe like we do, they must take in carbon dioxide through microscopic pores called **stomata** (singular 'stoma') in the leaves. The water needed for photosynthesis enters through the roots and travels to the leaves through xylem vessels.

INVESTIGATION **10.5a:** Inputs and outputs of photosynthesis
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INVESTIGATION **10.5b:** Effect of carbon dioxide on starch production
Go to your obook

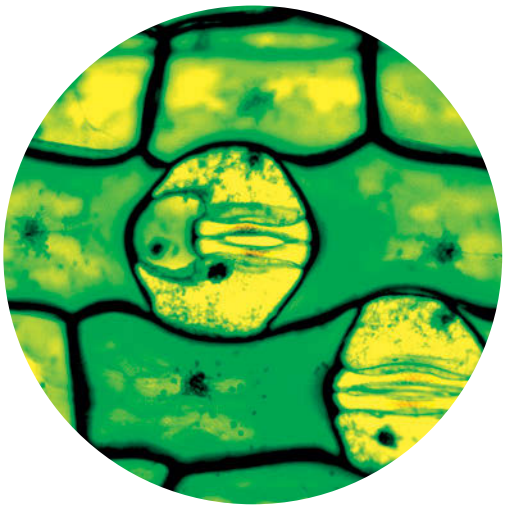

Figure 2 Guard cells open and close the stomata of a plant.

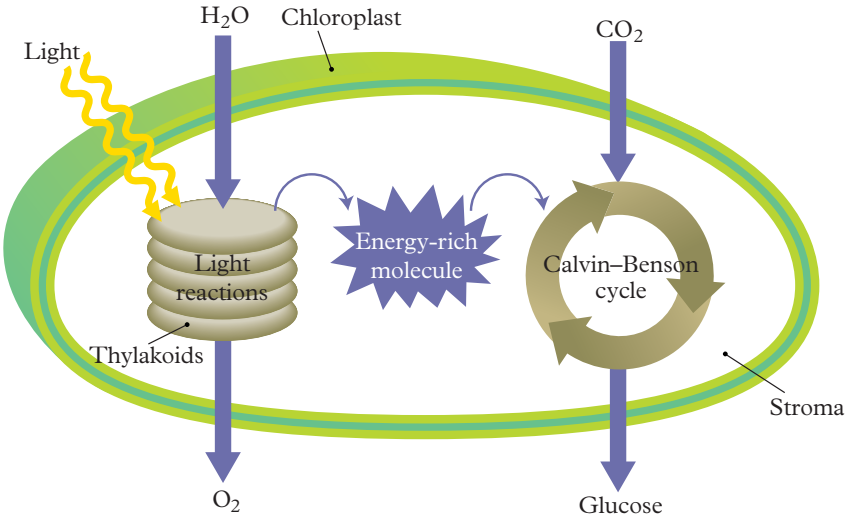

Figure 3 The light and dark reactions of photosynthesis occur inside chloroplasts.

A closer look at photosynthesis

Although the overall equation for photosynthesis is shown as one reaction, it is really two reactions.

1 The light reaction needs sunlight and takes place in the grana in chloroplasts. Sunlight causes charged particles (electrons) to become excited, and the bonds within water molecules are broken, releasing oxygen and forming energy-rich molecules.
2 The dark reaction does not require sunlight and takes place in the stroma of chloroplasts. The energy-rich molecules formed in the light reaction, together with carbon dioxide, are used to make carbohydrate molecules, such as glucose. This process is called the Calvin–Benson cycle or carbon fixation.

What happens to the glucose?

Plants are sugar factories, making millions of glucose molecules during daylight hours. Plants require a constant supply of glucose for energy to grow and repair damage. During daylight, more glucose is made than can be used directly by plants, so excess glucose is stored in the form of starch and other carbohydrates in the roots, stems or in the leaves. Starch is stored in underground storage organs, such as roots and tubers – potatoes, carrots and parsnips all store starch in this way.

Check your learning 10.5

Recall and explain

1 **Identify** where photosynthesis occurs.
2 **Recall** what is essential for photosynthesis.
3 **Identify** the raw materials needed for photosynthesis. **Explain** how they enter a plant.

Apply and analyse

4 **Explain** why it is fair to say that photosynthesis is the most important metabolic process on the Earth.
5 Draw a flow diagram showing the inputs and outputs of photosynthesis.
6 **Identify** some plant foods that we eat because they are stores of starch.

Skill builder: Communicating

7 Scientists communicate their findings through diagrams to explain processes.

a Draw a diagram that shows the process of photosynthesis. (THINK: What is important? Have I included every component?)

b Label this diagram and draw arrows to show the direction. (THINK: Have I linked the correct steps? Are the labels scientifically accurate?)

10.6 Energy flows through an ecosystem

In this topic, you will learn that:

- organisms convert energy that is locked in the bonds of sugar molecules via cellular respiration
- this is not efficient, and only 10% of the energy is passed to the next level in a food chain. Much of the energy is lost as heat and sound energy.

Living systems continuously take in energy from the Sun. When one organism eats another, it takes the energy that was stored in the cells and tissues. Of this energy, 90% is transformed into movement or stored again as the organism grows and repairs its own cells. Only 10% of the energy gets passed from one organism to the next in a food chain. Energy in an ecosystem flows in only one direction.

Energy for work

Many energy transformations keep a living organism alive and carry out metabolic processes (i.e. chemical reactions that keep cells working). We can describe these processes as the work of living organisms. Some of the types of 'work' performed by living organisms are shown in Table 1.

cellular respiration
see aerobic respiration

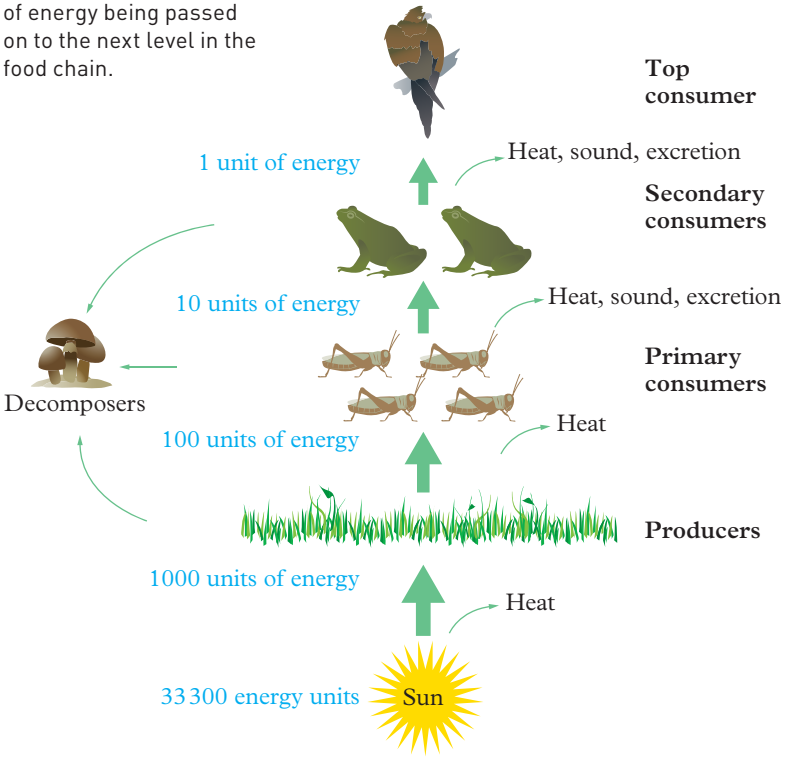

Figure 1 The movement of energy along a food chain can be represented by an energy pyramid. The size of each level represents the amount of energy being passed on to the next level in the food chain.

Cellular respiration

Whenever we burn a fuel (such as wood or oil), we release the energy that has been chemically stored in the molecules. This energy in the fuel molecules is organised, or ordered, because it is tied into the bonds in the molecule. Burning requires oxygen and is a rapid process which breaks the bonds of a molecule, releasing the energy as heat energy. Carbon dioxide and water are also produced.

Cellular respiration occurs in the mitochondria of plant cells. We can think of cellular respiration as similar to the burning example above. Glucose is the molecule that

Table 1 The 'work' of living organisms

Type of work	Examples
Building compounds	All organisms use energy to build and replicate molecules so they can manage metabolic processes, grow and pass information on to offspring.
Communication inside an organism	Energy is needed for communication within and between cells. Electrical and chemical energy are used when nerves transmit information throughout the body.
Physical movement	Energy is supplied for physical movement, such as movement of leg or arm muscles and involuntary movement such as contraction of the heart. In plants, energy is used for movement towards sunlight.
Transport	Energy is required to move nutrients and wastes throughout an organism's body. Electrical potential energy is needed to transport materials into and out of cells.

our body uses for fuel. Each cell uses oxygen to 'burn' glucose which converts the energy into other molecules including ATP (adenosine triphosphate). ATP is much more accessible for our bodies to use for energy. Fats and proteins can also be converted into ATP in cellular respiration.

When oxygen is used during cellular respiration, this is called **aerobic respiration**. In this process, carbon dioxide and water are by-products.

A closer look at cellular respiration

The energy stored in the chemical bonds of glucose ($C_6H_{12}O_6$) is transferred into ATP during cellular respiration. The general equation for cellular respiration is:

glucose + oxygen → carbon dioxide + water + energy

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36ATP$$

The breakdown of glucose to carbon dioxide and water requires two major steps.

1. Glycolysis occurs in the cytoplasm of the cell and produces 2 ATP molecules and pyruvate.
2. Aerobic respiration occurs in the mitochondria when oxygen is present. It produces 34 ATP molecules.

When we exercise, our muscle cells can run out of oxygen for aerobic respiration. When this happens our cells temporarily switch to producing energy anaerobically (without oxygen), and lactic acid is produced as a waste product. This does not produce as much energy as aerobic respiration, which is why our muscles feel weaker. In yeast cells, anaerobic respiration (known as fermentation) produces alcohol and carbon dioxide.

aerobic respiration chemical reaction that transfers energy to cells

Photosynthesis and respiration

Photosynthesis and respiration are effectively the opposite of each other. Photosynthesis traps energy from the Sun into chemical bonds, such as those of glucose. Respiration moves the energy out of glucose and into the bonds of ATP, which can then be used by cells. Many of the molecules in the two reactions are the same, but they are on different pathways. Glucose is a product of photosynthesis, whereas it is a reactant in respiration.

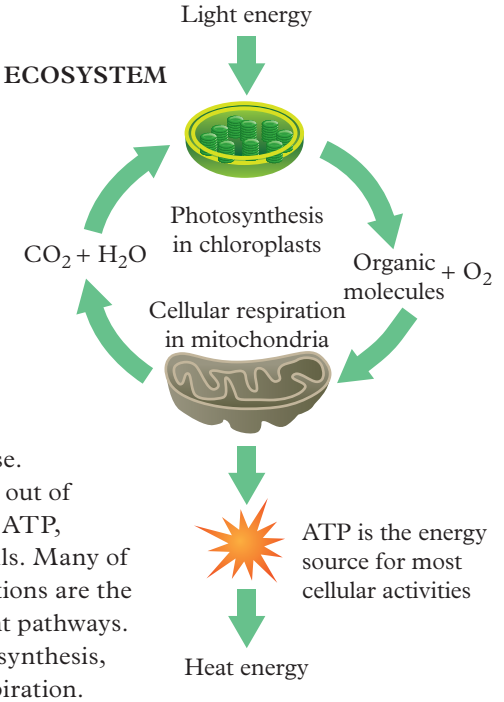

Figure 2 The relationship between photosynthesis and respiration.

Check your learning 10.6

Recall and explain

1. **Outline** the difference between energy and matter.
2. **Identify** the source of energy for cellular respiration.

Apply and analyse

3. **Explain** why cellular respiration occurs constantly in cells.
4. **Explain** why there are fewer top consumers than herbivores in an ecosystem.

Evaluate and create

5. Draw a concept map to **explain** how photosynthesis and respiration are connected. Use the following terms, plus any others you think are appropriate: glucose, energy, oxygen, carbon dioxide, water.

Skill builder: Problem solving

6. **Assess** the following statement: 'Photosynthesis and respiration are the opposite of one another, which means they are reversible.'
   - a Write a list of two things that support this statement. (THINK: Does this source suggest that they are the opposite of each other? Does it state that they are reversible?)
   - b Write a list of two things that do not support this statement. (THINK: Does this source state that they are not the same?)
   - c Draw a conclusion about this statement. (THINK: Have I considered the pros and cons of each argument?)

10.7 Natural events can disrupt an ecosystem

In this topic, you will learn that:

- population sizes are impacted by natural events
- natural disasters include drought, floods and bushfires – these events can disrupt a whole ecosystem.

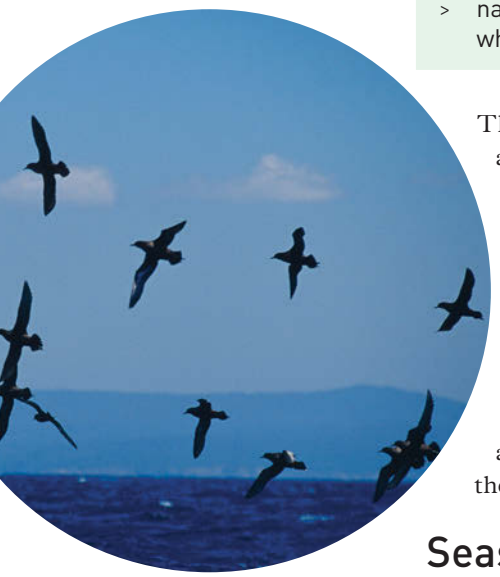

Figure 1 Short-tailed shearwaters leave their burrows on Montague Island on the southern coast of New South Wales and fly to feeding grounds in the Bering Sea during the northern summer. They return for breeding in late September.

The size of a population will increase and decrease as a result of many natural events. The limitation of resources, presence of predators, and migration and emigration of the organisms will all affect population numbers. Natural disasters such as drought, floods and bushfires will also cause changes throughout the whole ecosystem. Some plants and animals have adapted to cope with these events.

Seasonal change

When the weather becomes colder, many animals migrate to areas with warmer temperatures. As a result, their populations decrease in one environment and increase in another. During the breeding season (usually spring), numbers of animals will increase. Flowering plants will be pollinated and form seeds that spread throughout the environment and later germinate.

Figure 2 Flooding in northern New South Wales in 2017

Natural disasters

Australia has a widely fluctuating environment. Years of drought have been interspersed with torrential rains and flooding. When extreme natural change affects humans, we call these changes natural disasters.

Impacts of floods and droughts

Floods are an overflow of water onto dry land, which has an immediate effect on the growth of plants and the germination of seeds. This is particularly noticeable after a drought during which plants have managed to survive and seeds have remained dormant. Marine ecosystems do not benefit from floods on land. Run-off brings sediment, pesticides and fertilisers into the marine ecosystem, causing some algal species to dominate the environment.

Floods can be a hazard for some animal life. Small mammals often escape to higher ground. Snakes are flushed out of their cover, as witnessed in the 2011 Queensland floods, and became a potential danger to humans. Aquatic animals benefit enormously from floods. Fish can breed in water bodies such as lakes. Water birds then have an abundance of fish, insects and waterweeds as sources of food, and they can breed in great numbers.

Droughts pose an even greater challenge than floods. During droughts, animals migrate elsewhere and try to survive until conditions have improved. Some populations 'hang on' during drought, but other ecosystems are severely affected. For example, extremely dry topsoil was blown from central Australia to Melbourne and Sydney in recent years. This erosion removed essential nutrients for many plants, animals and agricultural ecosystems.

Impacts of bushfires on ecosystems

Bushfires destroy both plant and animal life. Many native Australian plants have adapted to be fire resistant and fire tolerant, and they may actually rely on fires to complete their life cycles. These adaptations include:

- thick bark that insulates and protects the growing and transporting tissue inside the trunk (stem)
- **epicormic buds** beneath the bark that can regenerate the branches when the fire has passed
- lignotubers within the roots that can grow into new shoots after fire.

Most *Eucalyptus* species have epicormic buds and lignotubers.

Animal populations in fire-prone areas are, in general, tolerant of fire. Some species can sense fire and escape to other areas or into underground burrows. The most vulnerable are small invertebrates and insects at the larval stage. The migration of animals will change the composition of the ecosystem in the fire area. Animals may not return to the area for a long time. The change in the vegetation and the soil conditions alters their food supply and sheltering options. The loss of shelter will increase the risk of predation in some cases.

lignotuber
a small growth in the root of a plant that allows regeneration after a fire

Figure 3 Native Australian trees have thick bark to protect them from fire.

Figure 4 Epicormic buds beneath bark can regenerate branches when fire has passed.

Figure 5 Lignotubers within roots grow into new shoots after fire.

Check your learning 10.7

Recall and explain

1 **Explain** how season change is different to a natural disaster.
2 **Describe** the impacts of flooding on an ecosystem.

Apply and analyse

3 **Compare** the impact of floods with the impact of drought on an ecosystem.
4 **Identify** long-term effects on plants after a drought, bushfire or flood.
5 **Propose** three reasons why natural events can disrupt an ecosystem.
6 **Identify** a natural disaster that occurred in Australia, and **describe** how this affected the ecosystem.

Evaluate and create

7 **Investigate** the impacts of the 2020 New South Wales floods on the relevant ecosystems.

Skill builder: Questioning and predicting

8 **Predict** how an animal might survive a:
a drought **b** flood **c** bushfire.
(THINK: What advantages and disadvantages does an animal present in each of these environments? How might an animal evolve if its species' populates an area where natural disasters are frequent?)

10.8 Human activity can disrupt an ecosystem

Figure 1 The Murray cod, and other native fish, have decreased numbers due to irrigation. Some fish are now declared rare or endangered.

biological control
releasing a living organism (a parasite or consumer) into an ecosystem in order to control a population

enhanced greenhouse effect
the additional effect that humans are having on the natural greenhouse effect due to the burning and release of fossil fuels

Figure 2 Phosphates in detergents and fertilisers on agricultural land wash into oceans, lakes, rivers and other water bodies. This leads to eutrophication – an increase in organisms that reduce oxygen levels in the water, harming other organisms.

In this topic, you will learn that:

- humans impact the ecosystems they live in – this impact can be positive or negative
- humans compete for resources with animals and plants, and they also introduce species and pollute ecosystems.

Humans can have significant short-term or long-term impact on the wellbeing and survival of other species. We compete with plants and animals for resources. We change the ecosystem by removing vegetation, increasing erosion of topsoil and enhancing global warming.

Competition for resources

In 2020, the world human population was approximately 7.8 billion, and it is predicted to rise to nearly 10 billion by 2050. This will cause a significant increase in demand for food, water and land, which means more pressure on Earth's natural resources. These resources are also needed by other species. For example, a large volume of water from the Murray–Darling Basin is used to irrigate agricultural land. This has seriously affected other species that depend on the river system such as the Murray cod and the river red gum forests that surround the Murray River, which are now placed under extreme stress during droughts.

Permanent removal of habitats by humans to use the land for building or agriculture, or to use the trees for wood, is very likely to result in significant changes to populations within ecosystems. Animals that previously lived in the habitat will migrate or die. Plant removal may reduce pollination of similar species in the area, as well as reduce nesting sites for many animals.

Pollution

Human activity has introduced many unwanted chemicals into ecosystems. Certain chemicals can cause sickness and/or death of certain species and, in some cases, can result in the collapse of entire food webs. Many industries now have much more restrictive rules about the chemicals they can release into the environment.

Fertiliser run-off is a common waterway pollutant. The excess nutrients can cause blue–green algal blooms. Once the bloom finishes, the algae die, which removes oxygen from the water which reduces nutrients and causes aquatic organisms to die.

Introduced species

Over Australia's history, many plants and animals that aren't native to Australia have been introduced. These plants and animals can disrupt ecosystems as they compete for resources with native species. For example, the introduction of rabbits during the late 1700s has impacted the natural environment.

Biological control was eventually used, in which there is the planned introduction of a different organism used to control the population. In the case of rabbits, a virus was introduced, which reduced the rabbit population and increased Australia's sheep herds.

Enhanced greenhouse effect

Increasing numbers of humans, increasing wealth and more sophisticated technology have resulted in the use of large amounts of fossil fuels for transport, industry, agriculture and electricity production. The burning of these fuels is contributing to increases in atmospheric temperatures and causing the Earth's climate to warm above normal levels. This is called the **enhanced greenhouse effect**.

CHALLENGE
10.8: Field trip
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The enhanced greenhouse effect has led to sea-level rise and, in some ecosystems, regular seasonal changes are becoming less predictable, and extreme weather events are occurring more often. Many organisms cannot adapt to these changes in their ecosystems and will likely die.

Ecological effects of climate change

Although many humans welcome the thought of warmer weather, small increases in average temperatures can have devastating effects on ecosystems (see Table 1). In mountainous areas, plants and animals that need cooler environments to survive are losing their habitats as the snowline retreats higher up the slopes. One such animal is the mountain pygmy possum, which needs a snow depth of at least one metre to provide enough insulation for hibernation. Less snow means the cycle of hibernation and breeding is disrupted.

Figure 3 The mountain pygmy possum is listed as an endangered species.

Table 1 Some of the main effects of climate change on ecosystems

Change	Effect
Changes in distribution and abundance of species – migration of species north or south, to higher levels or more suitable locations, due to increasing temperatures	Genetic changes as species adapt to new climatic conditions
Changes in the composition of ecosystems (e.g. due to species competition for resources or invasions of weeds and pests)	Increased weeds and other invasive species (i.e. pests)
Changes in metabolic processes (e.g. cellular respiration, photosynthesis, growth and tissue composition)	Changes in life-cycle events (e.g. breeding and migration)
Ocean acidification	Increased coral bleaching and destruction of and/or changes to coral reefs
Changes in river flows, sediment formation and nutrient cycles	Flow-on effects, such as eutrophication and algal blooms
Drying of ecosystems	Decrease in coastal mountain rainforests

Figure 4 Increased carbon dioxide levels in the atmosphere causes the ocean to become acidic. As a result, the polyps in the coral die, causing bleaching.

Check your learning 10.8

Recall and explain

1 **Identify** two ways in which humans compete with plants and animals for resources.
2 **Explain** what eutrophication means.
3 **Describe** the effects of climate change on two different ecosystems.
4 **Identify** two types of pollution.

Apply and analyse

5 **Compare** the impact of climate change and pollution on an ecosystem. Then **discuss** whether these two impacts can be thought of separately.

Evaluate and create

6 The human population was fairly stable until about 1 CE. In the past century, it has almost quadrupled. **Evaluate** the likely effects of this population increase on world ecosystems.

Skill builder: Processing and analysing data and information

7 On a global scale, the main energy sources are oil (≈35%), coal (≈23%), natural gas (≈21%), biomass and waste (≈10%), nuclear (≈6%) and hydro (≈2%). Wind, solar and geothermal power together account for only 2%.
a **Construct** a sector graph of the data. (THINK: What type of data am I presenting? Have I used appropriate labels?)
b Of all the sources, over 80% are based on fossil fuels. **Evaluate** what you think the focus of energy providers should be in the future. Should the people of Australia be involved in these decisions? **Explain** your answers. (THINK: Have you considered both sides of the decision?)

10.9 Aboriginal and Torres Strait Islander peoples manage the land

In this topic, you will learn that:

- Aboriginal and Torres Strait Islander peoples focus on reducing harm to the ecosystem and encouraging regeneration.

As the oldest continuous culture on Earth, Aboriginal and Torres Strait Islander peoples are custodians of the land. Aboriginal and Torres Strait Islander peoples ensure that there is a sustainable relationship between humans and the ecosystem they live in. They are involved in managing Australia's ecosystems based on traditional practices.

Agricultural practices

Many Australians are unfamiliar with the use of agriculture by Aboriginal and Torres Strait Islander peoples. Early European diaries provide evidence of First Nations peoples selecting certain seeds and conducting harvests at various points throughout the year. Alongside these crops, permanent housing and cemeteries existed, as well as structures used to store food, indicating that First Nations peoples were not a hunter–gatherer society.

Figure 1 Aboriginal rock carving of a kangaroo from Western Australia aged at 3000 years.

Many Europeans thought farming in the Australian desert would be impossible. But First Australians' knowledge of the land allowed them to farm the Indigenous grain belt. The Indigenous grain belt stretched across Western Australia, the Northern Territory, Queensland, South Australia, New South Wales and Victoria across the country of many Aboriginal nations. This meant that more of Australia's land could be used for agriculture, and it may have increased sustainability, as overharvesting one area was less likely.

This sustainable way of farming allowed plants to survive, and in turn, the people that relied on them as a food source. Indigenous nations also used food stores and would trade different food products with each other to ensure everyone had enough.

Aboriginal and Torres Strait Islander peoples also found multiple uses for the crops they harvested. According to Bruce Pascoe, many Aboriginal nations used the grass tree (*Xantheorrhoea*) for various purposes such as:

- a spear (made from the shaft)
- sticking things together (the resin acted as a glue)
- food (nectar from the flower)
- base for food (from the leaves)
- food source as the insects that lived on the plant could be consumed.

Indigenous peoples also practised aquaculture where specific nets would be used to catch different species at different waterways and rivers across Australia, notably at Berrawinna in New South Wales.

In contrast, early Europeans who arrived in Australia tried to cultivate Australia's natural land to suit European crops. European systems were based on individual land ownership, and their practices involved clearing native vegetation from the land, and planting crops and introducing domestic animals from Europe.

These systems did not recognise that Australia was a different climate and ecosystem to that seen in Europe, and soon enough they had introduced urban systems.

Figure 2 The grass tree *Xantheorrhoea* was grown as a crop.

As modern Australia attempts to move to a more sustainable way of managing the environment, Aboriginal and Torres Strait Islander peoples are being consulted and involved for their knowledge about how to utilise Australia.

For example, if Australia was to rely less on European crops and instead planted crops of yams, farmers may not need to use as much fertiliser and herbicides as the yam is native to Australia. Similarly, if Australians were to consider having herds of kangaroo and emu as food sources, rather than hooved European animals (e.g. cows) this may also have less impact on the natural Australian ecosystem.

First Nations peoples' methods can regenerate an ecosystem

Kakadu National Park, located in the Northern Territory, has a land area of approximately 20 000 km^2. It has a rich diversity of flora and fauna, with approximately 300 bird species and more than 1500 plant species! It is estimated that the Bininj (north of the park) and Mungguy (south of the park) peoples have continuously inhabited this land for at least 40 000 years. At the centre of their culture there is an emphasis on caring for the land and its wildlife being fundamental to their culture.

Figure 3 Brewarrina fish traps, one of Australia's oldest heritage sites, located on the Barwon River near the New South Wales town of Brewarrina

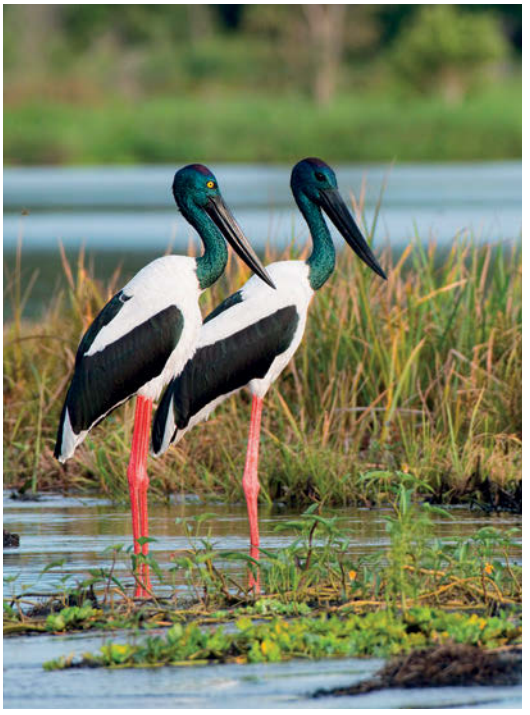


Figure 4 Jabirus live in the ecosystem at Kakadu.

Prior to the introduction of water buffalo by European settlers in the 19th century, mudja (*Hymenachne acutigluma*), a native grass, was not an issue for the Kakadu ecosystem. However, in the 1980s an eradication program began to remove the water buffalo from the ecosystem. As the water buffalo were removed, mudja grew quickly and interrupted the growth of other native plants, and also limited movement of Aboriginal and Torres Strait Islander peoples in the region. Originally, mudja was controlled through traditional fire management programs.

Today, local First Nations peoples work together with Kakadu National Park to conduct 'patch burning'. In this process, fires are lit early in the year when it is cool. These fires encourage new growth, and having burnt and unburnt land in a 'patchwork' makes it difficult for the fires to combine and for bushfire to spread. Patch fires also ensure that animals can escape to an unburnt area. Traditionally, patch fires were used to make travelling easier, help with hunting animals as they would run from the fire, protect food sources from bigger fires, signal to others and for spiritual and cultural purposes.

Using this traditional method has enabled the Kakadu National Park ecosystem to recover, and be a more sustainable method of land management.

Fire management

First Nations peoples are respectful of fire and work with it to ensure the continuing health of the plant and animal life. When the first Europeans arrived, they described the bush as being very open and being able to drive coaches through the trees. This was largely due to the First Nations peoples' ritual of regularly burning the bush. These regular small fires prevented build-up of dense scrub, which allowed new growth and encouraged herbivores, like kangaroos, to live in the bushland.

Overall, the Aboriginal approach to fire ensured that land was burnt at the right time of year for the region, in the right weather conditions, and that any neighbouring First Nations peoples were informed of the planned

Figure 5 Aboriginal and Torres Strait Islander peoples use fire to manage some landscapes.

burn. These burns ensured flora and fauna survived and were not impacted by the terrifying bushfires we are familiar with today.

Traditional methods ensured food sources could be replenished

Aboriginal and Torres Strait Islander peoples typically have a diverse diet to ensure no one thing is overeaten. For example, when hunting for bird eggs, some were always left to hatch. This ensures that there will always be more birds, and therefore eggs, in the future.

Ecosystems can be replenished for the future

Current land management methods can be improved by using knowledge of traditional methods. We've learnt, Aboriginal and Torres Strait Islander peoples cause minimal disruptions to the ecosystems that sustain them. Aboriginal and Torres Strait Islander peoples are dedicated to the continuance of the ecosystem and seek to help nature; this is in stark contrast to modern beliefs that the land is there for the use of humans.

The 2019–2020 bushfires that devastated much of Australia's east coast killed an estimated 1 billion native animals. Although some Australian plants require bushfires as part of their life cycle, some of these plants were unable to survive the intensity of the fires. By integrating Aboriginal and Torres Strait Islander peoples' traditional land practices with inherited European practices, Australia may have a sustainable future and in some instances see a resurgence in ecosystems that are currently being damaged and depleted.

Check your learning 10.9

Recall and explain

1 **Explain** how traditional burning techniques are used in Kakadu and the benefit that these practices bring to the environment.

2 The early Europeans abandoned the arid ecosystem around Uluru and Kata Tjuta because they couldn't survive. **Assess** why they may have struggled to find food there.

3 **Recall** the reason why mudja grass needed to be managed with fire.

Apply and analyse

4 **Discuss** Aboriginal and Torres Strait Islander peoples' land management in terms of:
   - **a** finding eggs and other sources of food
   - **b** using fire to aid the ecosystem.

5 **Discuss** how you think communities of Aboriginal and Torres Strait Islander peoples ranger teams contribute to sustainable ecosystems in Australia.

6 **Explain** why collaboration and communication are important to ecosystem management.

7 What special knowledge would Aboriginal and Torres Strait Islander peoples rangers bring by caring for cultural and heritage sites?

Evaluate and create

8 In a group of four, create a list of the biotic factors and another list of the abiotic factors important to the ecosystems in Kakadu National Park. One pair can create the 'biotic' list and the other pair can create the 'abiotic' list.

Skill builder: Problem solving

9 Australians are being warned about longer and more dangerous fire seasons becoming normal; however, the methods of Aboriginal and Torres Strait Islander peoples may help lower the severity of future fire seasons.

Consider the process of 'patch burning'. Use a cause and effect diagram to **assess** the use of patch burning in Australia to prevent future bushfires.

10.10 Human and ecosystem needs require balance

In this topic, you will learn that:

- while humans are part of the ecosystem they live in, they must be mindful to balance their needs and wants against what the ecosystem requires.

Different cultures and communities have different views on how to manage their local ecosystems. With human population growth, there is growing demand for food and resources. But at what cost? Providing for people is often at the expense of the environment. Awareness about the impact of humans on the environment is increasing and, with this, people are looking into sustainable practices that aim to protect and maintain the environment.

Resource
STEM activity: Spoiled by oil

Meeting societies' needs and wants

People in Australia expect a lifestyle that provides essential food, clothing and shelter, with many additional comforts. There has always been a balance between economical, social and environmental needs, where historically the environment has been seen as less important, resulting in damage to local and world ecosystems.

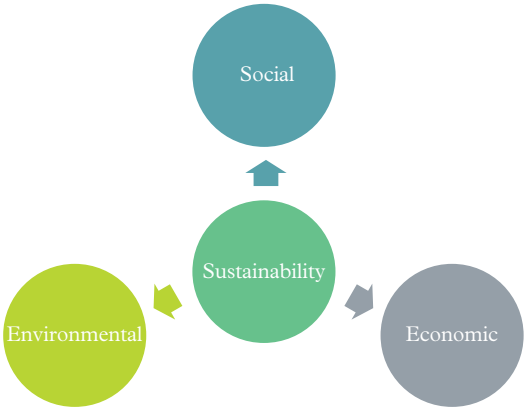


Figure 1 To achieve sustainability: economic, social and environmental factors must work together.

Nearly every aspect of your life is linked to mining, agriculture and fossil fuels. While in an ideal world we could ban these things easily, all technologies that we depend on (including phones and cars) rely on the resources these industries create. Can you think of anything that you would be willing to give up? These processes impact animal welfare and ecosystems worldwide.

If humans wish to maintain our current standard of living, we can either ignore our impact on the world or begin to invest in more sustainable practices. Environmental sustainability is about balancing the way we live with its impact on ecosystems. This will require individuals, communities, governments and countries working together.

Changes in agriculture may provide food for the future

To survive, we need water and food. Australia is fortunate to have a strong agricultural community and the ability to produce much of its own produce. However, Australia is also susceptible to major droughts, which has the risk of causing disastrously low water levels.

Since European settlement of Australia, little thought has been given to the environmental impact of agriculture. As our knowledge of this impact has increased, so has willingness to invest in agricultural practices that minimise impact, including:

- buffer zones of native plants between rivers and farmland to reduce soil erosion and chemical run-off
- crop rotation between cereal and legume crops to improve soil quality by returning nitrogen to the soil

- installation of drip irrigation to reduce water wastage
- planting previously cleared land with deep-rooted native vegetation.

As a country, some of the actions that can increase a sustainable environment are individual, some are done as a family or household, others as a community, and some are a national effort. Energy suppliers can make decisions about the installation of renewable power generation plants such as wind turbines. Individuals can make decisions about whether they support 'green' energy sources or install solar hot water.

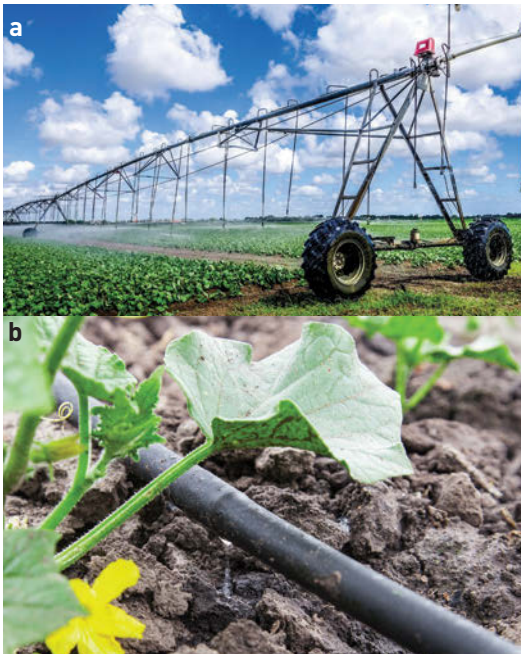


Figure 2 Scientists are developing ways to use water more efficiently: **a** traditional irrigation; **b** modern micro-irrigation system.

Figure 3 The number of Earths we need if the world's population lived like these countries.

Video
Ask a climate scientist

Check your learning 10.10

Recall and explain

1 **Define** sustainability.
2 **Identify** two approaches that agriculture can take to increase sustainability.
3 **Explain** why sustainable ecosystems are important.

Apply and analyse

4 **Identify** two positive and two negative outcomes of agriculture. Provide details about how the negative outcomes could be minimised.
5 **Examine** Figure 4 and answer the questions that follow.
   a Is the world population currently living within its means? **Justify** your response.
   b How many planet Earths would be required if all humans were to enjoy the standard of living of the average Australian?
   c As a class, **discuss** your answers to parts a and b. Set up a quick debate: Do you believe that everyone deserves the same standard of living? Is this possible?

Evaluate and create

6 Is it possible for humans to be truly sustainable? **Justify** your response.

Skill builder: Planning investigations

7 Design a method that would investigate the impact of rotating crops between cereals and legumes, to improve soil quality.
   a Select an appropriate method. (THINK: Is this the right way to measure this change?)
   b Determine the materials required. (THINK: Will these achieve the most accurate and reliable results?)

REVIEW

Multiple choice

1 A relationship between two organisms in which both benefit is:
- **A** mutualism
- **B** parasitism
- **C** abiotic
- **D** communalism.

2 Dr Jaxa wants to investigate the number of frogs in an ecosystem. **Identify** the best model.
- **A** Dr Jaxa would need to count each individual frog type in the whole ecosystem.
- **B** Dr Jaxa should use capture–recapture sampling.
- **C** Dr Jaxa should use quadrat sampling.
- **D** It is not possible.

3 The water cycle involves the processes of:
- **A** decomposition and precipitation
- **B** precipitation, evaporation and transpiration
- **C** aerobic respiration and transpiration
- **D** evaporation and photosynthesis.

Recall and explain

4 **Identify** three abiotic features of a terrestrial ecosystem and three abiotic features of an aquatic ecosystem.

5 **Identify** a way in which living things change the abiotic factors in their environment.

6 **Outline** two major biotic factors and two major abiotic factors that influence the size of the human population.

7 **Recall** what mutualism, parasitism and commensalism have in common, and what differentiates them.

8 **Describe** photosynthesis.

9 **Identify** the products of photosynthesis that are essential for cellular respiration.

10 **Explain** if competition can occur between members of the same species and between members of different species. Use examples in your answer.

11 If only 10% of the energy is transferred along a food chain, **explain** what happens to the rest of the energy.

12 **Explain** why the cycling of oxygen and carbon are so closely linked.

13 **Outline** how nitrogen cycles through ecosystems.

14 **Compare** and **contrast** the cycle of matter with the flow of energy through an ecosystem.

15 **Describe** what makes environmental conditions in Australian ecosystems so challenging for populations of living organisms.

16 **Describe** the adaptations to fire of many Australian plants.

17 Find some examples of how humans, especially since European settlement, have changed ecosystems because of introduced species.

18 **Identify** and **explain** the main process that results in energy being available to ecosystems.

19 **Identify** one land management practice of Aboriginal and Torres Strait Islander peoples, and **explain** how it contributes to sustainability.

20 List some examples of the benefits ecosystems provide and **explain** one of these benefits.

21 **Distinguish** between a flow of energy and a flow of matter in an ecosystem.

22 Write a word equation for cellular respiration.

Apply and analyse

23 Draw a concept map showing how photosynthesis and respiration are connected using the following terms (plus any others that you think are appropriate): glucose, energy, oxygen, carbon dioxide, ATP, water.

24 Observe your school ground or your home garden for one week. Keep a journal listing any examples of interrelationships between organisms.

25 **Outline** three changes you could make to your lifestyle to minimise your impact on the environment.

26 Are sustainability and modern life compatible? **Discuss**.

27 Imagine you are lost in the arid Australian outback. **Identify** the main abiotic factors that would make your survival difficult.

28 **Compare** the abiotic components of the Kakadu wetlands with the abiotic components of the ecosystems around Uluru.

29 **Outline** how food webs are linked to the flow of energy through ecosystems.

30 A bushfire burns most of the grass away in an ecosystem, but eucalyptus and wattle trees survive and quickly sprout new leaves. Use the food web in Figure 1 to answer the following questions.
- **a** **Predict** the initial change to the grasshopper population after the fire. How will this affect the kookaburra population?
- **b** **Evaluate** whether the loss of grass will affect the dingo population. **Explain** your decision.
- **c** **Identify** the type of competition experienced by kangaroos, wombats and grasshoppers.
- **d** **Evaluate** whether the loss of grass will affect the eucalyptus and wattle trees. **Explain** your decision.

31 Students on a field trip with a national park ranger set traps for a small nocturnal marsupial, *Antechinus stuartii*, in a heathland ecosystem. They captured 8 animals on the first night and marked white dots on their tails. Then they released the animals. On the second night, they captured 10 animals, of which 4 were marked.

a **Calculate** the estimation of the population size of *A. stuartii* in this ecosystem.

b **Explain** how the students could increase the reliability of this experiment.

Evaluate and create

32 **Explain** how a small seed is able to grow and form a huge log of wood that we can burn or use to make furniture.

33 **Analyse** the marine Antarctic food web in Figure 2 to answer the following questions.

a What is the relationship between orca whales and seals?

b What is the relationship between penguins and seals?

34 Choose a particular ecosystem and **construct** a poster that describes the relationships between its biotic and abiotic components.

35 **Construct** a brochure promoting sustainable living, listing 10 ways to reduce your impact on the environment and how they work.

36 Seed banks are an important way of preserving plant species at risk of decreasing populations or of extinction. **Investigate** the setting up and maintenance of seed banks. **Explain** how seed banks will contribute to sustainable ecosystems and to biodiversity.

37 Aboriginal and Torres Strait Islander peoples in Kakadu and around Uluru use burning to manage their ecosystems. **Analyse** the benefits and risks of using deliberately lit fires in ecosystem management.

38 Do you think modern technology has made it easier or harder to live sustainably? **Explain** your answer.

39 **Investigate** an introduced species to Australia and present information on the impact it has had on native Australian species.

Critical thinking

40 The green sea turtle lays its eggs in the warm sands of northern Australia. If the sand is at 29°C, half the turtles will be males and the other half will be female. Below 27°C, most of the turtles will be male. Above 31°C, most of the turtles will be female. **Assess** the effect enhanced climate change may have on the green sea turtle population.

41 Currawongs are birds that thrive in towns and cities because they can eat food scraps and any bird seeds left out by humans. They also hunt smaller birds and drive them out of an area. **Discuss** if it could be said that the impact of currawongs on the populations of small birds is a human impact.

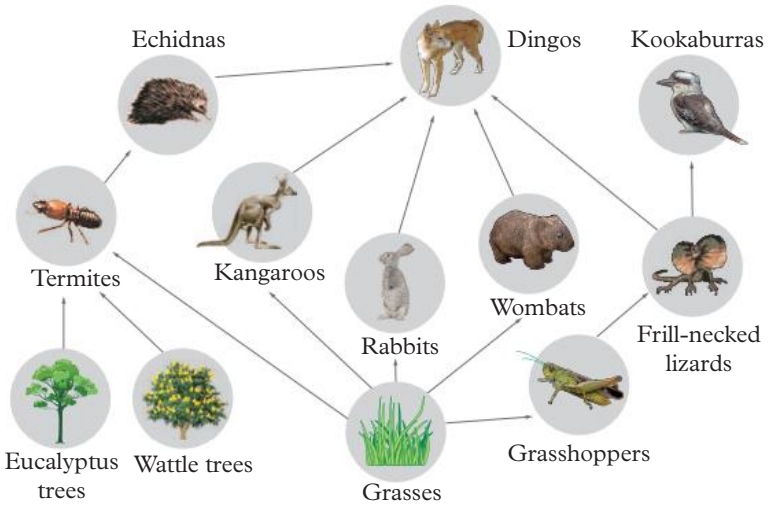


Figure 1 A food web

Go further

42 **Investigate** two ways pollution can be reduced in your local area. Then, **construct** an experimental design to measure whether people adopt these strategies.

43 **Propose** two ways your local ecosystem will be affected by the enhanced greenhouse effect.

44 **Construct** a presentation on the human impacts on one of the cycles. Include:

- information about the cycle
- human activities impacting the cycle
- the impact of these human activities
- details of initiatives to try and reduce the impact.

Note: You will need to investigate this beyond the information available in your book.

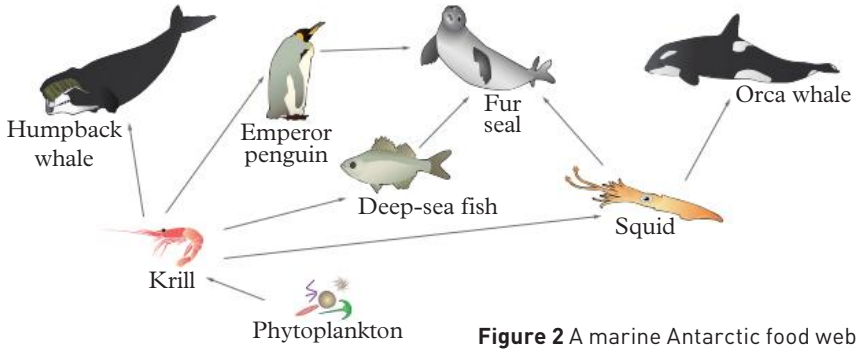


Figure 2 A marine Antarctic food web

Research

45 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Biological control

Australian native plants and animals have adapted to life on an isolated continent over millions of years. Since European settlement, native animals have had to compete with a range of introduced animals for food, habitat and shelter. Some native species have also faced new predators. Rapid changes in land usage, such as increased crop-growing areas, have also affected our soils and waterways. Research the meaning of the term 'biological control'. Find some more Australian examples of successful and not-so-successful examples of biological control.

»Frozen Ark Project

The Frozen Ark Project is a modern-day project named after the story of Noah's Ark. What is the Frozen Ark Project? What are its goals? How is it working towards achieving them?

»Ecological footprint

Scientists use modelling to calculate the area of land needed to produce all the resources you use and dispose of all your wastes. What lifestyle factors do they consider when constructing these models? What things can you do to reduce your carbon footprint?

»Wildlife crossings

A variety of strategies have been implemented around Australia to reduce wildlife road deaths and assist animals to cross roads safely. What are overpasses? What are underpasses? What types of animals would use each of these strategies? How effective are they at reducing road deaths? Have other strategies been implemented? Which is the most effective?

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Recall that ecosystems consist of communities of interdependent organisms and abiotic components of the environment.	☐	☐	Go to pages 180-181
Outline using examples how matter is cycled through ecosystems such as nitrogen.	☐	☐	Go to pages 190-193
Describe how energy flows through ecosystems, including input and output through food webs.	☐	☐	Go to pages 186-187
Analyse how changes in some biotic and abiotic components of an ecosystem affect populations and/or communities.	☐	☐	Go to pages 198-201
Assess ways that Aboriginal and Torres Strait Islander Peoples' cultural practices and knowledge of the environment contribute to the conservation and management of sustainable ecosystems.	☐	☐	Go to pages 198-201
Evaluate some examples in ecosystems, of strategies used to balance conserving, protecting and maintaining the quality and sustainability of the environment with human activities and needs.	☐	☐	Go to pages 196-197; 202-203

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

GENETICS AND BIOTECHNOLOGY

Where do your genetics come from?

11

Have you ever wondered ...

- Why is DNA important?
- What do scientists do to modify the food that we eat?
- How do vaccinations work?

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- relate the organs involved in human reproductive systems to their function
- identify that during reproduction the transmission of heritable characteristics from one generation to the next involves DNA and genes
- identify that genetic information is transferred as genes in the DNA of chromosomes
- outline how the Watson-Crick model of DNA explains:
  - the exact replication of DNA
  - changes in genes (mutation)
- describe, using examples, how developments in technology have advanced biological understanding, e.g. vaccines, biotechnology, stem-cell research and in-vitro fertilisation
- discuss some advantages and disadvantages of the use and applications of biotechnology, including social and ethical considerations

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

11.1 Human reproductive systems

In this topic, you will learn that:

- in human males, sexual reproduction begins in the testes, which make sperm
- in human females, sexual reproduction begins in the ovaries, which release an egg.

gamete
a sex cell containing half the number of chromosomes of other body cells

sperm
the male gamete of animals

ovum
the female gamete of animals and some plants

haploid
a nucleus that contains one complete set of chromosomes; usually found in a gamete

diploid
a nucleus that contains two complete sets of chromosomes

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

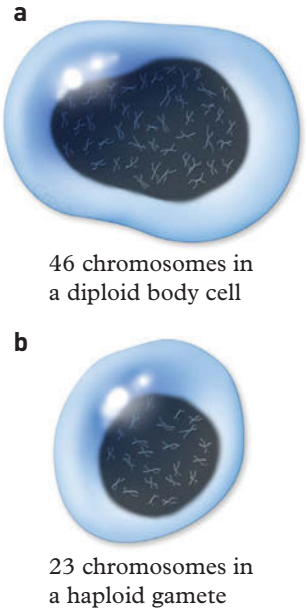


Figure 1 a A diploid body cell and **b** a haploid gamete

Reproduction is required to continue the human species. Humans reproduce via the male and female reproductive organs, which you have previously learnt about in Stage 4. A gamete is a sex cell (egg or sperm) that has half the genetic material of the parent cell. Gametes are haploid, which means they possess one copy of each chromosome instead of a pair. Meiosis is the process of cell division that produces haploid gametes. Two haploid gametes combine to produce the first diploid cell or a new organism. In females the production of gametes occurs in the ovaries, and in males the production of gametes occurs in the testes.

Half of your genetic material from your mother and half from your father

Half of the genetic material in each of your cells comes from your mother, and the other half comes from your father. Have you ever wondered how the genetic material in one of your parent's cells divided in half?

A **gamete** is a sex cell. In animals, the male gamete is **sperm** and the female gamete is an **ovum**. The male and female gametes of a species join to form the first cell of the offspring.

Gametes differ from all other body cells because they contain half the number of chromosomes of somatic cells – they are **haploid**. Most somatic cells in your body contain 46 chromosomes arranged in pairs (two sets of 23 chromosomes, or $2n$). They are **diploid**. Gametes (eggs and sperm) in humans have 23 chromosomes (n) (Figure 2). When the egg and sperm combine at fertilisation, a diploid somatic cell is produced – one set of 23 chromosomes comes from the mother and one set of 23 chromosomes comes from the father. In this way, all children are similar, but not identical, to their parents.

Meiosis is a special type of cell division in which the number of chromosomes is halved. Meiosis occurs only when gametes are being made. It is sometimes called reduction division and occurs in two stages, known as meiosis I and meiosis II (Figure 4).

Human gamete production

Human males produce sperm in their testes. Once the process has begun in the seminiferous tubules, sperm then divide once by mitosis to produce two diploid cells. One of these cells stays as a spermatagonium so that the cycle can be repeated, and the other becomes a spermatocyte, which then undergoes meiosis. Human males can therefore continue to produce new sperm for their whole lives.

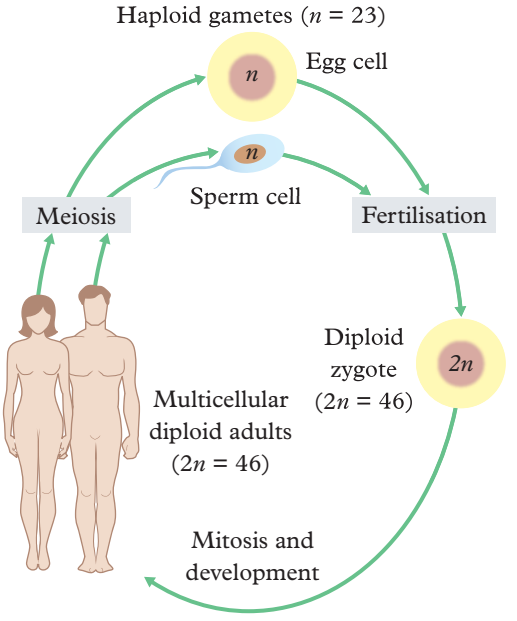


Figure 2 The human life cycle, involving mitosis and meiosis

In human females, ova are produced in the ovaries. At birth, human females have all their potential ova already. By the time a female reaches puberty, the number of ova has decreased from approximately 1–2 million to 300 000–400 000. This number will continue to reduce for the rest of their lives.

When a female is ovulating, an ovum is released from the ovaries. If a male sperm cell penetrates the protective layer around the ovum, meiosis will occur. Once this occurs, another round of meiosis occurs where a haploid ovum accepts the DNA from the sperm, and fertilisation is achieved. From this, a diploid zygote is formed.

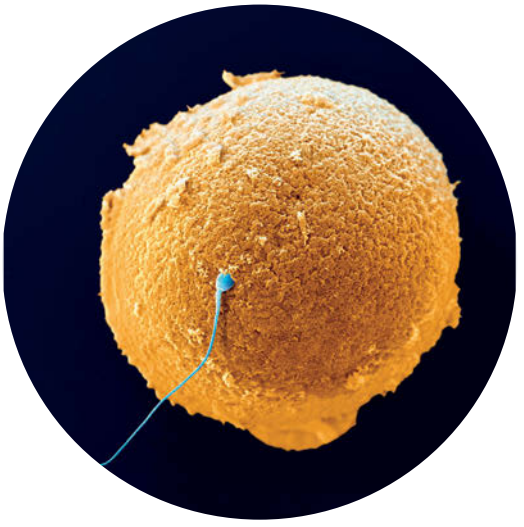


Figure 3 When a haploid sperm cell (*n*) fertilises a haploid egg cell (*n*), a diploid somatic cell (2*n*) is formed.

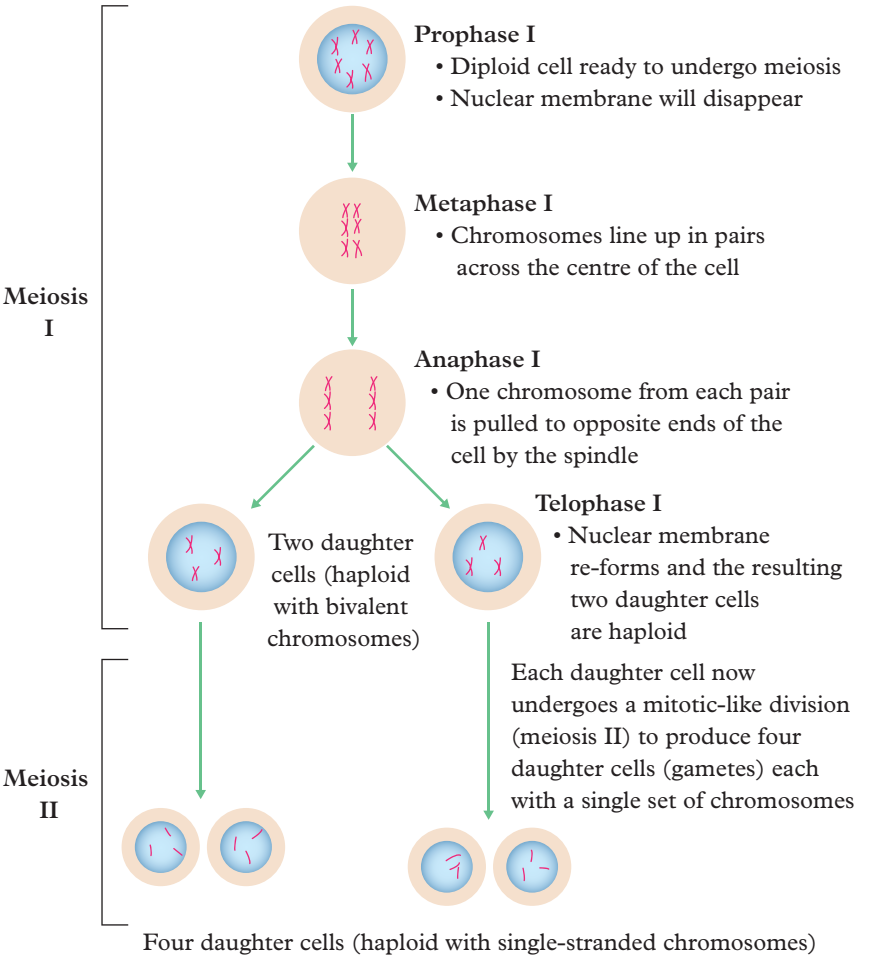


Figure 4 Meiosis consists of two rounds of each phase: prophase, metaphase, anaphase and telophase. If a gamete is fertilised, the chromosomes of the zygote will become bivalent again so that it can grow (by mitosis) into an embryo.

Check your learning 11.1

Recall and explain

1 **Define** the term 'gamete'.

2 **Compare** a haploid cell and a diploid cell. **Describe** each cell and provide an example of each.

3 **Construct** a diagram that shows the process of meiosis in reproduction.

Apply and analyse

4 We all started from a single cell, a zygote, which then grew into an embryo. **Identify** the type of cell division that is involved in the growth of a zygote into an embryo. **Explain** your answer.

5 **Discuss** whether the offspring of sexually reproducing organisms are identical to their parents.

6 **Recall** how gametes are produced in human males and females.

Evaluate and create

7 **Evaluate** why it is essential that the number of chromosomes is halved during meiosis.

Skill builder: Conducting investigations

8 When you conduct research, it is important to know what you are looking for.

a **Describe** what you need to see under a microscope to determine if mitosis or meiosis is taking place in a cell. (THINK: What would the cell look like?)

b **Explain** why your description in part a shows mitosis and meiosis. (THINK: What is it in the image that actually shows this is happening?)

11.2 DNA transmits heritable characteristics

deoxyribonucleic acid (DNA)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

nucleotide
the building block of DNA consisting of a deoxyribose sugar, phosphate and nitrogen base

adenine
a nucleotide of DNA or RNA; complementary to thymine in DNA and uracil in RNA

guanine
a nucleotide of DNA or RNA; complementary to cytosine

cytosine
a nucleotide of DNA or RNA; complementary to guanine

thymine
a nucleotide of DNA; complementary to adenine

In this topic, you will learn that:

- genes are made of DNA, which is the genetic material passed from parents to their children
- the DNA molecule consists of a double helix, a long molecule with the appearance of a twisted ladder.

Genes are made of a chemical called **deoxyribonucleic acid (DNA)**. DNA is the genetic material that is passed from one generation to another. It is found in the nucleus of almost every cell in your body (except red blood cells). The DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds. The double-helix shape of DNA is often compared to a twisted ladder.

DNA: The blueprint of life

DNA is like a blueprint needed to construct an organism. It contains a genetic code unique to the individual that can be passed to offspring, generation after generation, with little or no change.

Each cell within an organism contains DNA molecules with the same general structure.

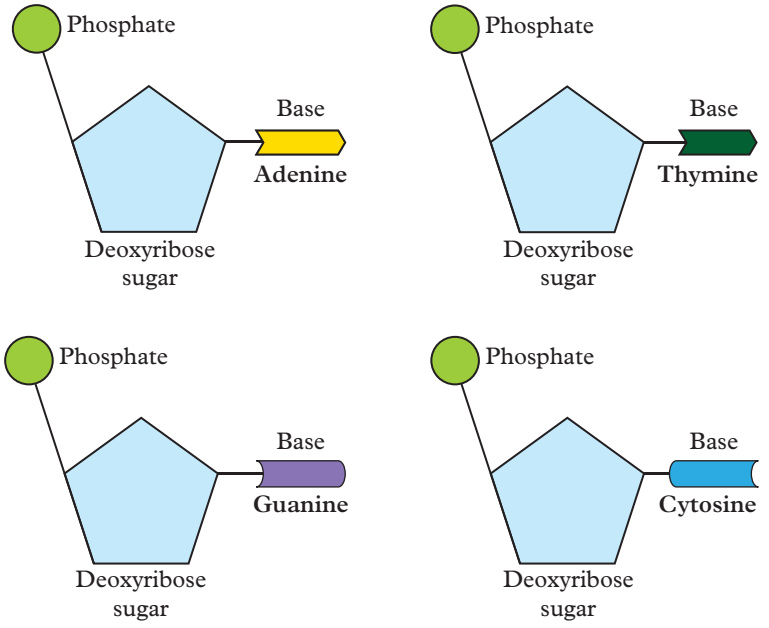


Figure 1 Nucleotides: the building blocks or subunits of DNA

Although DNA is common to every organism on the planet, each species has its own unique DNA sequences that define the species. However, individuals within a species have subtle variations in the structure of their DNA and therefore in the code that it carries. The more closely related the species are, the more similar the DNA. An understanding of the structure of DNA enables us to explain the similarities and differences that exist between and within species.

Structure of a nucleotide

Each DNA strand is like a necklace of beads. The individual 'beads' are called **nucleotides**. These are the subunits or building blocks of DNA (Figure 1).

A nucleotide is a complex molecule composed of three smaller molecules:

- a nitrogen base (sometimes just called a 'base')
- a sugar molecule (deoxyribose)
- a phosphate molecule.

In DNA there are four different types of nitrogen bases: **adenine** (A), **guanine** (G), **cytosine** (C) and **thymine** (T).

Structure of a polynucleotide chain

When nucleotides join together, they form a long polynucleotide chain called a nucleic acid. DNA is a nucleic acid. Nucleotides are joined together by their sugar and phosphate groups. The sugar of one nucleotide is joined to the phosphate of the next nucleotide. This forms a sugar–phosphate backbone like the sides of a ladder (Figure 2).

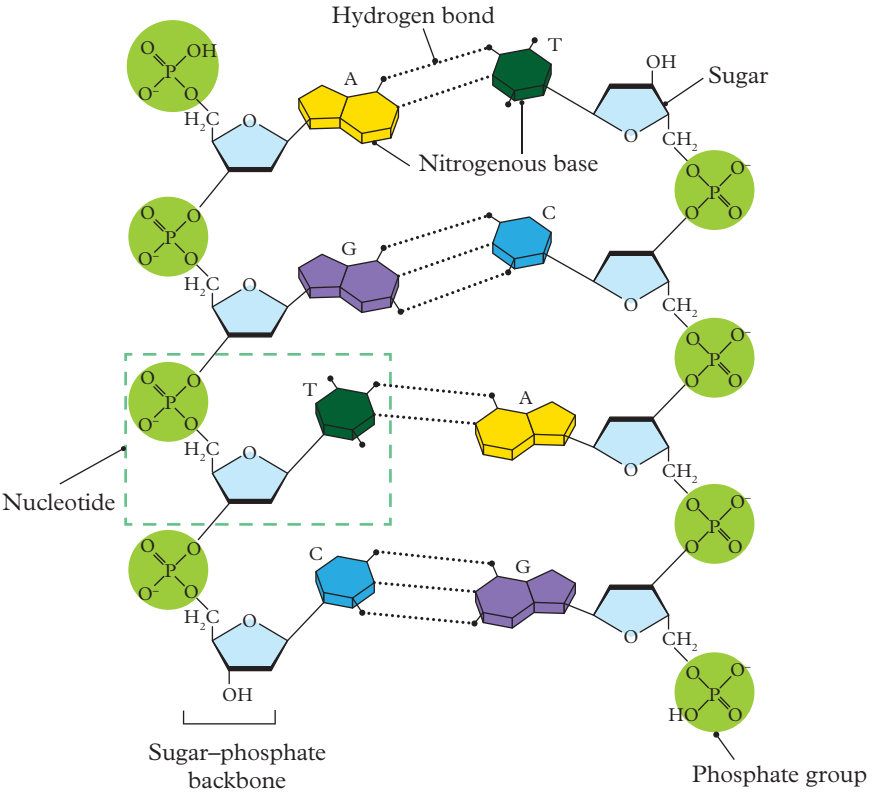


Figure 2 Nucleic acids like DNA are made of a chain of nucleotides joined together through a sugar–phosphate backbone.

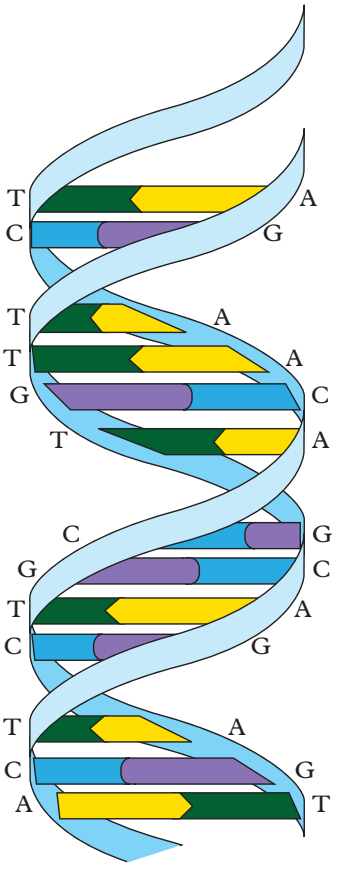


Figure 3 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules. The rungs are pairs of nitrogen bases.

Double helix

Two polynucleotide chains, or strands, are attached together across the 'rungs' by hydrogen bonds (relatively weak bonds) between the nitrogen bases. A large base (adenine or guanine) is always bonded to a small base (thymine or cytosine) because this gives the correct amount of space between the strands.

The four different types of nitrogen bases link in a specific way: adenine (A) always pairs with thymine (T), and cytosine (C) always pairs with guanine (G). These base pairs are called **complementary bases** or complementary base pairs. The two polynucleotides then wind into a double helix – the twisted ladder (Figure 3).

DNA molecules have two vital properties.

- DNA can make copies of itself: If two strands unwind, each strand can be used as a template to make a new DNA molecule.
- DNA can carry information: The order of bases along a strand is a code for making proteins.

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand. Adenine pairs with thymine, and cytosine pairs with guanine

Check your learning 11.2

Recall and explain

1 **Explain** what a nucleotide is.

2 **Recall** the four nitrogen bases of DNA.

3 **Describe** how nucleotides join together to form polynucleotides.

Apply and analyse

4 **Explain** what part of the DNA molecule varies.

5 **Summarise** how the order of the bases on one polynucleotide chain determines the order of the bases on the other chain.

Skill builder: Planning investigations

6 Jolene was trying to model the DNA double helix. Her materials include: coloured card, scissors, sticky tape and paper clips.

a **Propose** how Jolene could model DNA using these materials. (THINK: What does Jolene need to represent? How could she show the different bases?)

b Write a more specific materials list so that Jolene can demonstrate the elements of DNA. (THINK: What would benefit her list? Could it be more specific?)

11.3 Chromosomes carry genetic information as genes

In this topic, you will learn that:

- chromosomes are made up of DNA molecules wound around proteins
- segments of the chromosomes that code for specific traits (proteins) are called genes.

ribonucleic acid (RNA) a complementary copy of DNA that is able to carry the genetic message from the nucleus to the cytoplasm

Each cell in your body contains 46 chromosomes, except for red blood cells that are de-nucleated (0 chromosomes) and eggs and sperm, which have 23. These chromosomes are made up of DNA strands tightly wound around proteins. Along the DNA strand are sections called genes. When a protein needs to be made, DNA in the gene unwinds and a complementary copy is made. This complementary copy called **ribonucleic acid (RNA)** leaves the nucleus to make a protein in the cell's cytoplasm.

Video
Inheritance

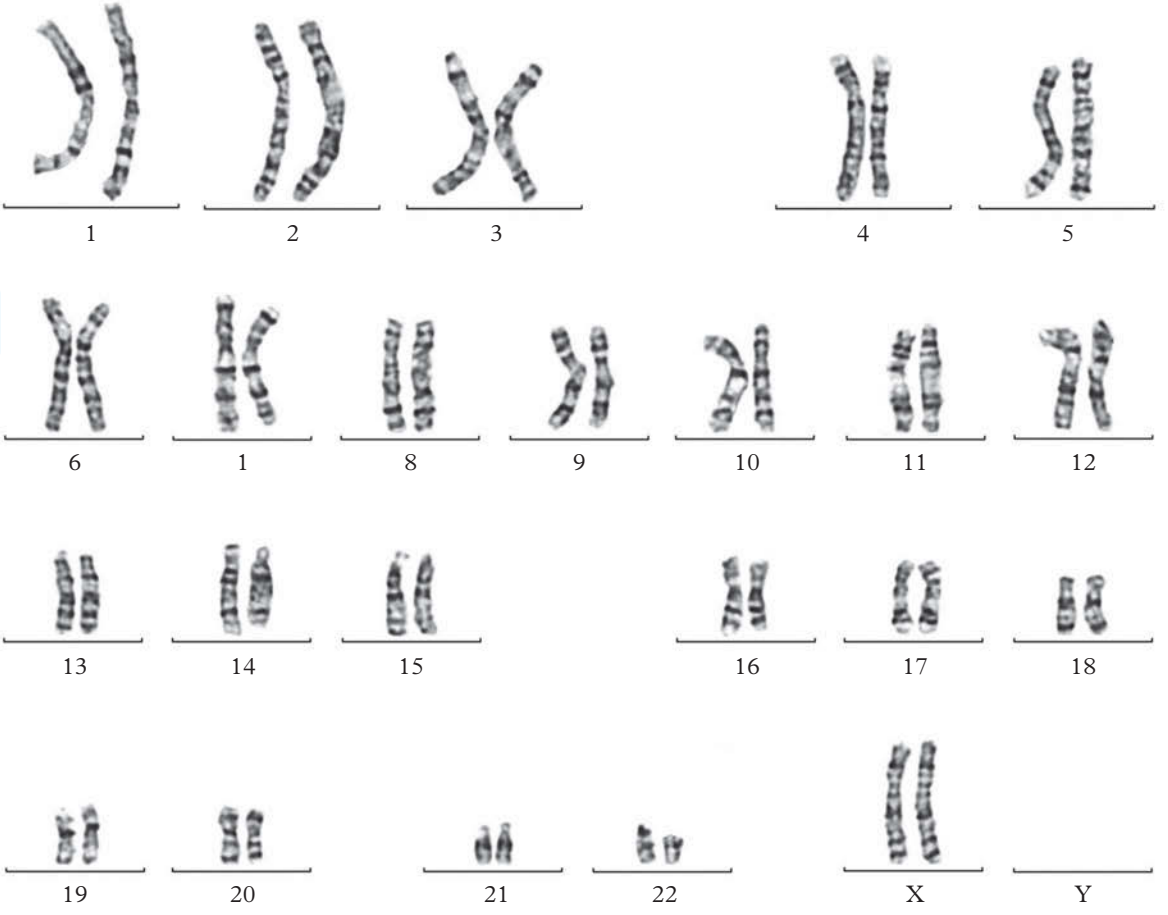


Figure 1 Pairs of chromosomes are often referred to by numbers according to their size – the largest pair is number 1. The last two chromosomes determine the sex of an individual. Human females have two X chromosomes, and human males have one X chromosome and one Y chromosome. This karyotype is from a female (XX).

DNA, chromosomes and genes

The chromosomes are located in the nucleus of a cell. There are 46 chromosomes in the nucleus of each human cell: 23 of them originated from the mother, and 23 from the father.

Along the length of each chromosome, in specific positions, are the genes seen as bands on the chromosomes within a karyotype.

Chromosomes can be organised into pairs according to length and banding patterns. Pairs of matching chromosomes are called homologous. A picture of all the homologous chromosomes in a cell, arranged from largest to smallest is called a **karyotype** (Figure 1).

The number of chromosomes does not indicate how complex an organism is. For example, a fern (plant) has 1200 chromosomes, or 600 pairs of chromosomes, compared with a kangaroo, which has 12 chromosomes and 6 pairs of chromosomes.

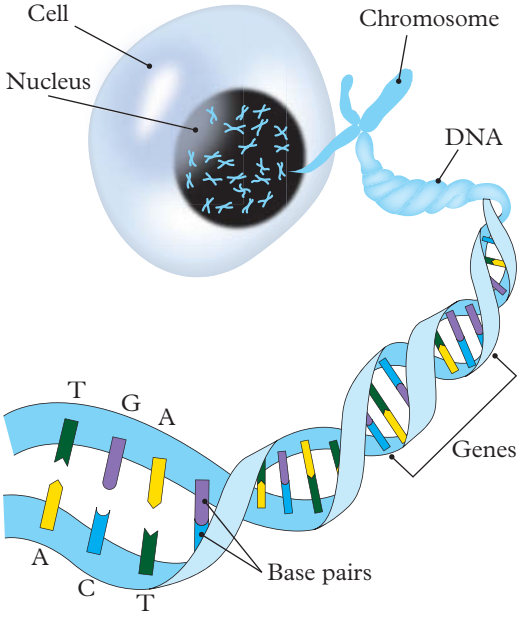


Figure 2 The relationship between DNA and chromosomes

DNA and chromosomes are related

DNA is found inside a cell's nucleus. By the time a cell is ready to divide, the DNA has copied itself and the chromosomes can clearly be seen under a microscope.

Chromosomes may be single or bivalent. The **bivalent chromosome** is the 'X' that you are familiar with. The two strands of a bivalent chromosome are identical to each other. Bivalent chromosomes are formed during DNA replication so that two identical copies are produced. Each strand of a bivalent chromosome is called a **chromatid**. The two chromatids are joined at the centromere (Figure 3).

bivalent chromosome
a chromosome that has duplicated, consisting of two sister chromatids joined at a centromere

chromatid
one half of a duplicated chromosome

karyotype
the arrangement of a complete set of chromosomes in pairs of decreasing size

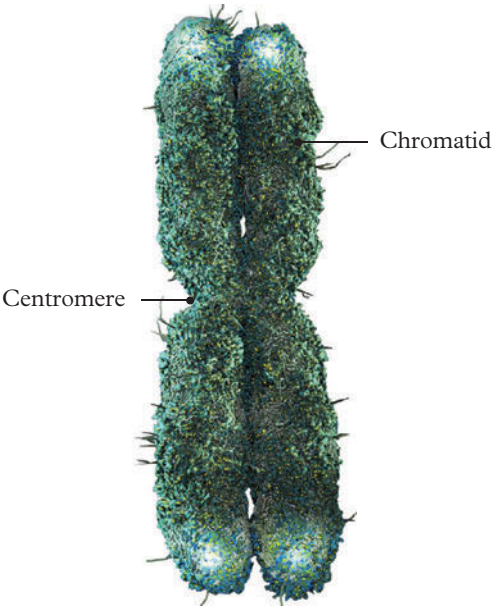


Figure 3 A bivalent chromosome is made up of two identical sister chromatids joined at the centromere.

If the DNA in a single chromosome were unwound, it would be 5 cm long. With 46 chromosomes in the average human cell, this means all the unravelled DNA in a single cell would be approximately 2 metres long! The chromosomes fit inside the cell because the DNA is tightly wound around small proteins called histones. These histones stack tightly together and only unwind when the instructions they carry are needed by the cell.

gene
a specific sequence of DNA that codes for a particular trait, usually a protein

genetic code
the sequence of nucleotides found in DNA that is inherited from parents

Genes are made of DNA

DNA in chromosomes consists of sections called **genes** (Figure 4). The order of nitrogen bases in each gene contains information for one characteristic or trait. For example, a gene may have information for making the pigment melanin, which determines skin colour. Another gene may have the information for making keratin for hair and nails. So a chromosome, which contains many genes, is like a recipe book with a lot of recipes.

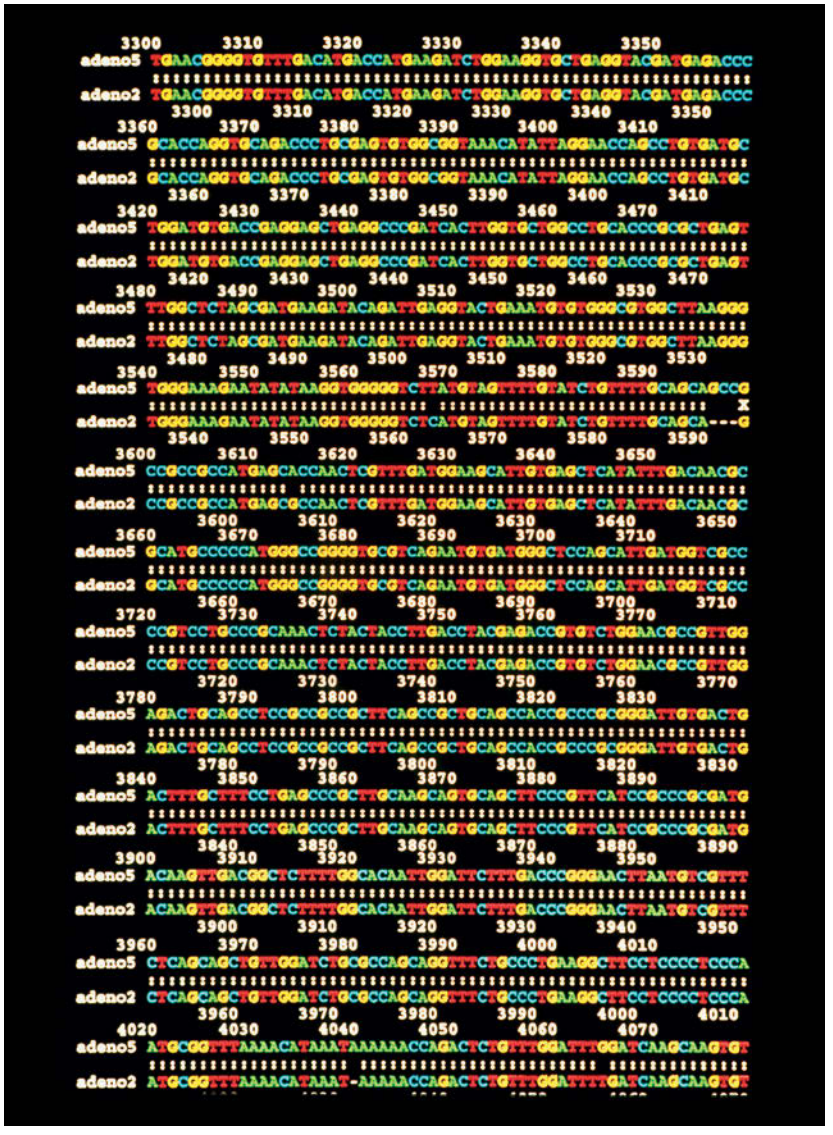


Figure 5 The sequence of bases on DNA is the coding system for life. The sequence of bases here comes from the DNA in adenovirus types 5 and 2. These viruses cause a range of illnesses including colds, sore throats and diarrhoea.

Genetic code

One major feature of DNA is its ability to replicate; the other is that it carries a genetic coding system for making proteins. The order of nitrogen bases on the DNA is referred to as the **genetic code** of an organism.

The genetic code specifies the structure of proteins (Figure 6). Some proteins (such as collagen) provide support for cells in the body. Other proteins are enzymes that help us digest food and speed up the chemical reactions of our metabolism.

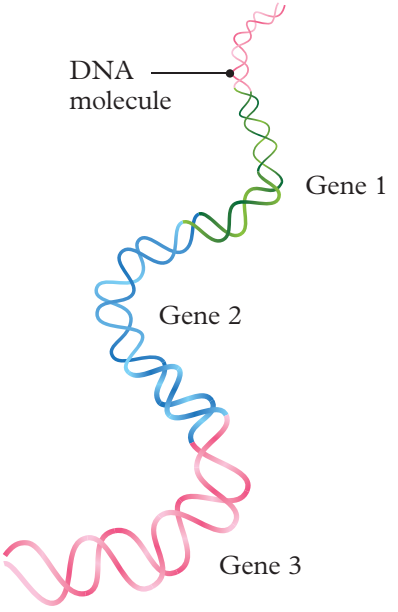


Figure 4 The relationship between DNA and genes

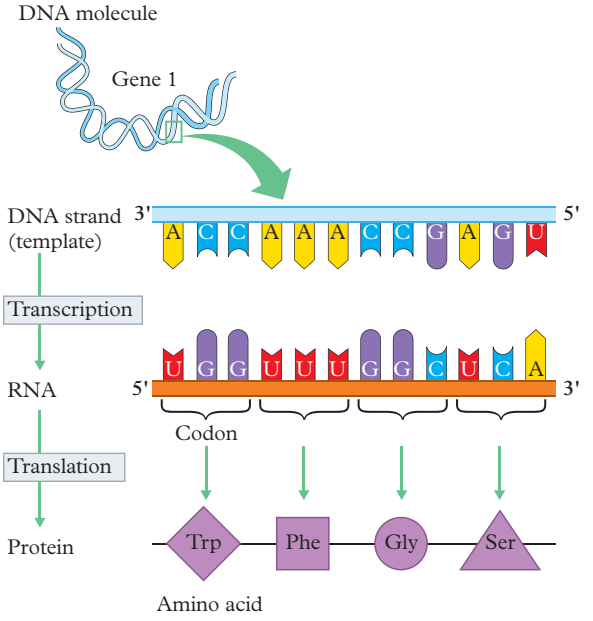


Figure 6 Protein synthesis

How genes make protein

To synthesise proteins, first the DNA double helix unwinds and one strand acts as a template to form a single-stranded complementary RNA molecule (Figure 7).

RNA

RNA contains a ribose sugar, unlike DNA that contains deoxyribose. The nitrogen bases in RNA are adenine, cytosine, guanine and uracil (U). RNA plays a key role in protein synthesis. RNA acts like a photocopy of the original DNA blueprint. This process of making an RNA copy from a DNA strand is called **transcription**.

Unlike DNA, RNA can leave the nucleus and attach to a ribosome in the cytoplasm. The RNA now 'tells' the ribosome the order in which to connect the amino acids that will make up a protein. The nitrogen bases on the RNA are read in groups of three, called **codons**. Each codon corresponds to a single amino acid. Eventually all the amino acids line up like beads on a necklace and form the finished protein. This process of forming a protein from RNA is called **translation**.

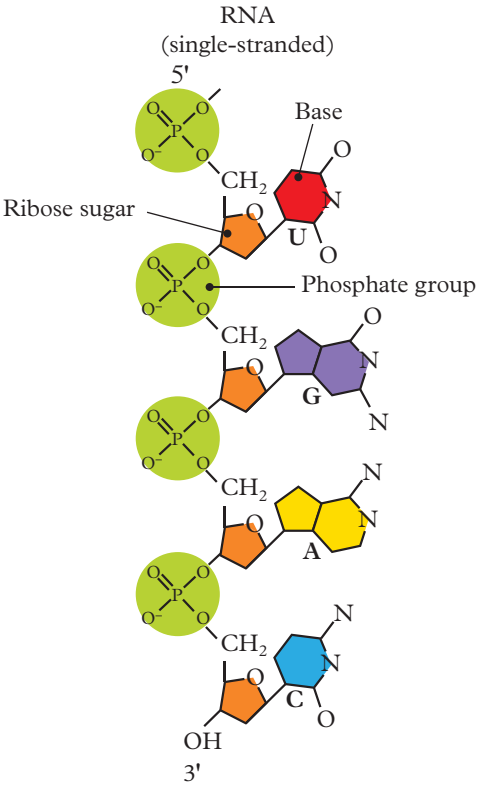


Figure 7 The structure of RNA

transcription
the formation of complementary RNA from DNA

codon
sequence of 3 nitrogen bases in RNA

translation
the formation of a protein from RNA; occurs on a ribosome

Check your learning 11.3

Recall and explain

1 **Distinguish** between a chromosome, DNA and gene.
2 **Recall** how many chromosomes are in each of your cells.
3 **Explain** what karyotyping is.
4 **Describe** how a protein is like a string of beads.

Apply and analyse

5 **Explain** the difference between transcription and translation.
6 **Determine** what the RNA sequence would be for the DNA sequence GTTAGCCAGT.

Evaluate and create

7 All organisms, past and present, contain the same building blocks of life: DNA. **Assess** the significance of this observation.

Skill builder: Communicating

8 Part of a base sequence on one polynucleotide strand on DNA reads ACTGGCATTCAG.
   a Write the base sequence. (THINK: What does each letter stand for? What is the pair to each letter?)
   b What is the base sequence of the corresponding sequence of RNA for which the first strand acts as a template? (THINK: What does each letter stand for? What is the pair to each letter? Has this changed?)

11.4 The Watson and Crick model explains DNA replication

Figure 1 Gregor Mendel's experiments with pea plants resulted in developments in the understanding of genetics.

In this topic, you will learn that:

- Watson and Crick's research developed the double helix model of DNA
- the model explains how DNA is replicated.

Scientists often collaborate with each other, or build on past research of others; this was the process of understanding genes and DNA. Gregor Mendel is now known as the 'father of genetics'. He made his discoveries by studying peas. James Watson and Francis Crick used other people's research to develop the double helix model of DNA. Another researcher, Rosalind Franklin, was mistaken for a laboratory assistant by a fellow researcher, and her research on DNA was shown to competing scientists without her permission.

principle of segregation
pairs of gene variants are separated into reproductive cells

principle of independent assortment
the inheritance of one set of factors from one parent is separate from the inheritance of other factors

Video
DNA

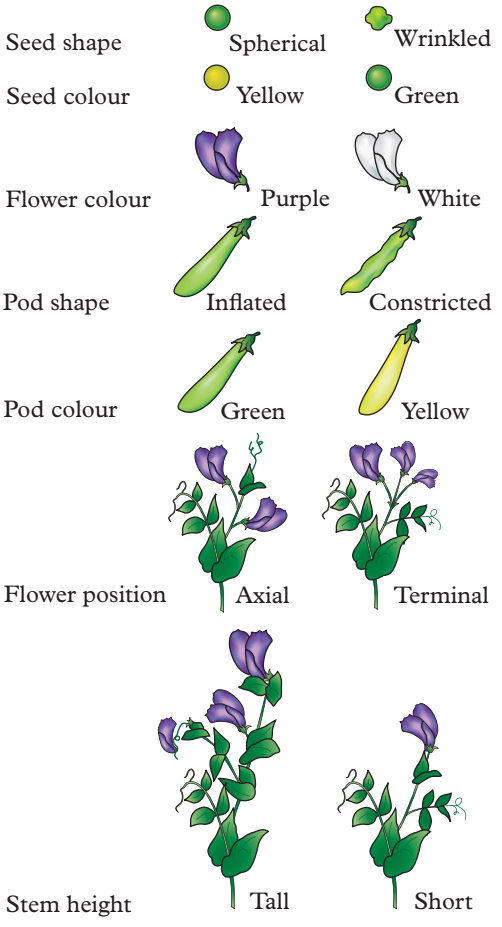


Figure 2 The seven traits, or characteristics, of pea plants studied by Mendel

Gregor Mendel

Gregor Mendel was an Austrian monk and scientist who experimented with peas. His experiments led him to conclude that 'factors' (now known to be genes) existed in pairs (one from each parent). From this research, he developed two important principles:

1. **Principle of segregation**, which stated that traits or characteristics of living things exist in pairs of factors. These factors must become separated or segregated before they can be passed on to offspring. Every organism inherits one set of factors from their mother and one set from their father.
2. **Principle of independent assortment**, which stated that inheritance of one factor occurs independently of the inheritance of other factors. So just because you inherit one factor (e.g. curly hair) from your mother, that does not mean you inherit all other factors from her (e.g. blonde hair, small nose). Factors are inherited independently of each other.

Watson and Crick's double helix discovery

The DNA of all living things (including plants and animals) have the same general structure.

Almost 70 years after Gregor Mendel's death, James Watson, a young chemist from the United States, went to the University of Cambridge in the United Kingdom. There he met Frances Crick, an English physicist.

Watson and Crick worked as a team to unravel the secret of the structure of DNA, which they identified as a double helix (two stranded spiral) in 1953. However, they performed no experiments themselves; their talent lay in interpreting the experimental results of others (secondary data). Many scientists contributed to Watson and Crick's research on DNA, including Linus Pauling, Erwin Chargaff and Rosalind Franklin.

One of the greatest achievements of Watson and Crick was their realisation that bases on one polynucleotide strand are bonded to bases on the other strand, with A always bonding with T, and G always bonding with C. The implications of the results of Erwin Chargaff's research, with DNA containing similar percentages of A and T, and C and G, were suddenly obvious. These base pairs are called complementary bases or complementary base pairs.

Two polynucleotide chains, or strands, are attracted to each other due to the chemical nature of the complementary bases. This is important for the easy 'unzipping' of the ladder during replication. A large base (adenine or guanine) is always bonded to a small base (thymine or cytosine) because this gives a consistent amount of space between the strands. RNA is a single-stranded polynucleotide with a similar sugar–phosphate backbone to that of DNA. However, RNA contains the sugar ribose and the four bases adenine, guanine, cytosine and uracil. RNA plays a key role in protein synthesis.

Rosalind Franklin

In 1951, Rosalind Franklin began work in John Randall's laboratory at King's College in London. When Franklin started work in Randall's laboratory, Maurice Wilkins (another scientist working on DNA) was away. When Randall gave Franklin responsibility for her part of the DNA project, no one had worked on it for months. When Wilkins returned, he misunderstood her role, treating her as though she were a technical assistant. Both scientists were actually peers. His assumption of her role was in line with the situation for women at the university at the time. Only males were allowed in the university dining rooms, and after hours Franklin's colleagues went to men-only pubs.

Figure 3 Rosalind Franklin, 1920–1958. Her contribution to solving the structure of DNA was not acknowledged at the time.

Between 1951 and 1953, Franklin came very close to solving the DNA structure. She was beaten to publication by Crick and Watson in part because of the friction between Wilkins and herself. At one point, Wilkins showed Watson one of Franklin's crystallographic images of DNA. When Watson saw the picture, the solution became clear to him, and the results were published in the journal *Nature* almost immediately. Franklin's work appeared as a supporting article in the same issue of the journal.

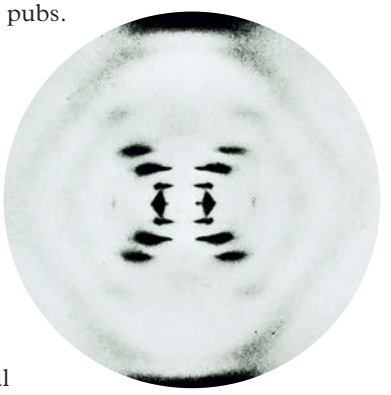


Figure 4 X-ray crystallography image of DNA taken by Rosalind Franklin

Check your learning 11.4

Recall and explain

1 **Recall** who is credited with discovering the three-dimensional structure of DNA.
2 **Explain** the process that Watson and Crick undertook.

Apply and analyse

3 **Explain** how the Watson–Crick model of DNA explains the exact replication of DNA.

Evaluate and create

4 **Investigate** the work of Linus Pauling or Erwin Chargaff, and **explain** their contribution to Watson and Crick's work.
5 Rosalind Franklin died from cancer at the age of 37. Watson and Crick received a Nobel Prize in 1962 for their work on the structure of DNA. The Nobel Prize cannot be awarded posthumously (after death). **Discuss** whether, if Franklin had been alive, she should have been awarded the Nobel Prize with Watson and Crick. **Justify** your response with arguments.

Skill builder: Processing and analysing data and information

6 Research Mendel's work. **Assess** the impact the work had on the science behind DNA and inheritance. (THINK: What aspects of his work are still supported today? What aspects have been refuted? Is there reliability in his original research?)

11.5 Mutations cause changes in genes

In this topic, you will learn that:

- mutagens cause permanent changes in the sequence of nucleotides that make up DNA, which are called genetic mutations
- the Watson–Crick model of DNA helps to explain how these mutations can lead to changes in genes.

mutagen
a chemical or physical agent that causes a change in DNA

genetic mutation
a permanent change in the sequence of nucleotides in DNA

Mutagens such as chemicals, UV light and substances in cigarette smoke can cause permanent changes in the sequence of nucleotides that make up DNA. These changes are called **genetic mutations**. There are a wide variety of different mutation types, including the substitution of one nucleotide for another or the deletion or addition of a nucleotide. These mutations can have varying consequences, ranging from advantageous to life threatening to no effect. Understanding the Watson–Crick model of DNA helps to explain how these mutations can lead to changes in genes.

Mutagens and mutations

A mutation is a heritable change in the structure or amount of genetic material (DNA). Therefore, a mutation is a permanent change in the DNA, and it may be in one gene or in a number of genes (part or all of a chromosome). 'Heritable' refers to the change being inherited.

If the change is in a single gene, then it is called a monogenic or gene mutation; if it affects most of a chromosome, it is called a chromosomal mutation.

Radiation	Chemicals	UV light
• Ionises biochemical compounds in cells, forming free radicals • The free radicals cause damage to DNA and proteins (e.g. breakages in chromosomes)	• Some chemicals insert into DNA instead of bases (i.e. they substitute for bases) • Other chemicals insert between bases, causing problems when the DNA replicates	• Causes thymine bases that are close together on a DNA polynucleotide chain to bind together, forming 'thymine dimers'. This causes problems during DNA replication

Figure 1 The effect of mutagens

Because DNA replication is a copying process involving huge numbers of base pairs, mistakes occasionally happen – these are natural mutations. The base sequence (order of nucleotide nitrogen bases) in DNA is critical – a tiny change in the sequence can change the order of amino acids in the protein encoded by the gene, which, in turn, may affect how the protein functions. Although the aim of genetic copying is to preserve that order, occasional errors can occur. On many occasions, these changes can be corrected by the cell or they do not cause a change in an important part of the protein that is produced by the gene.

It was a single mutation many thousands of years ago that prevented the production of brown pigment in eyes. As a result, blue eyes developed in humans. The mutation gave humans a new allele.

Natural mutations occur at a low rate. However, environmental factors called mutagens can increase the frequency of mutations. Mutagens include chemicals, radiation and ultraviolet (UV) light.

Types of mutations

There are two basic types of mutation:

- point or substitution mutations
- frameshift mutations.

A point mutation occurs when one base substitutes for another. As the genetic code is read in groups of three, this may or may not have an effect on the final protein. This is best shown using the sentence:

THE CAT ATE THE RAT AND RAN FAR

If there was a point mutation in this sentence, it might read:

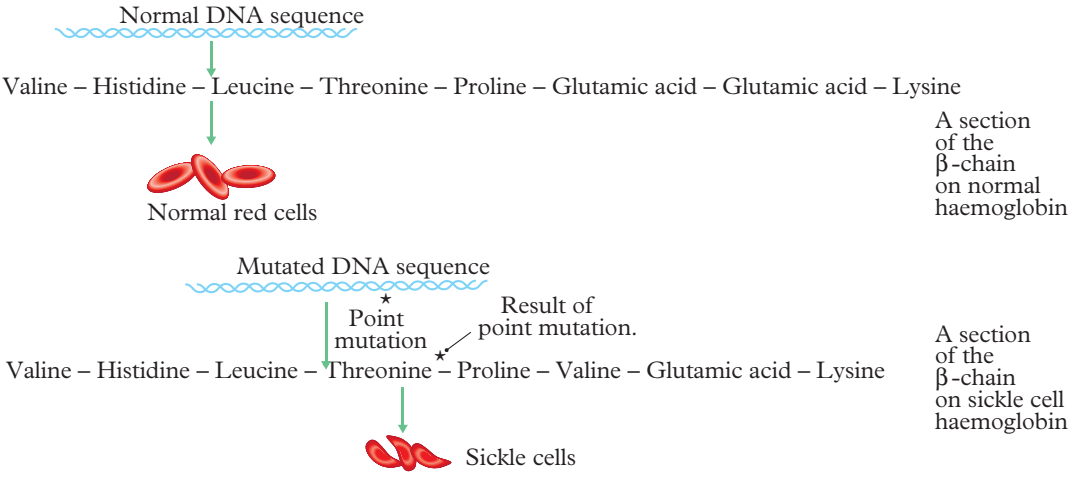


Figure 2 Haemoglobin and sickle cell anaemia – an example of the effects of a point mutation

THE CAR ATE THE RAT AND RAN FAR

In this case, the sixth letter, T, was substituted by R. In DNA it might be a G substituted for A. This small change will be passed on to the RNA but may not affect the order of amino acids in a protein.

Sickle cell anaemia is an example of a point substitution that does affect the final protein. The gene that codes for part of the haemoglobin molecule, which carries oxygen around the body, has substituted an adenine (A) for a thymine (T). So, the code in the DNA sequence reads CAC instead of CTC. As a result, the codon on the RNA reads GUG instead of GAG. This makes the matching amino acid valine rather than glutamic acid. This means a slightly deformed haemoglobin is produced, which doesn't carry oxygen as effectively (Figure 2).

However, a deletion or an addition can have a large impact on how the genetic code is read.

A deletion of the sixth letter (T) in the example sentence would result in the triplet code becoming:

THE CAA TET HER ATA NDR ANF AR

An addition of an extra R would result in the triplet code becoming:

THE CAR TAT ETH ERA TAN DRA NFA R

These are called frameshift mutations because the group-of-three reading frame has been shifted along the DNA strand.

Frameshift mutations have more damaging effects than point mutations because they change the entire reading frame of the DNA and RNA, producing quite a different protein. If the RNA sequence reads UAC after the mutation, then this is a 'stop codon' and the protein synthesis will stop at that location, resulting in a shorter molecule that is unable to perform its function.

Check your learning 11.5

Recall and explain

1 **Define** 'mutation'.
2 **Explain** what a mutagen is. Give some examples of mutagens and how they act to cause mutations.
3 **Recall** what a frameshift mutation is.
4 **Compare** a gene mutation and a chromosome mutation.

Apply and analyse

5 A normal RNA sequence is shown below, together with a mutated sequence

Normal sequence:
AUG ACG CAG AAU UGG GAU CCU ACG

Mutated sequence:
AUG ACA CAG AAU UGG GAU CCU ACG

Consult an RNA table and **describe** the outcome of the mutation on protein synthesis.

Evaluate and create

6 Can mutations ever be advantageous? **Justify** your answer.

Skill builder: Problem solving

7 a **Evaluate** whether a gene or a chromosome has the most control over the structure and function of an organism. (THINK: What is the role of a gene? What is the role of a chromosome? Which impacts functioning more?)

b **Explain** your reasoning for part a. (THINK: Can you justify your answer with evidence?)

11.6 Different versions of the same gene can be dominant or recessive

In this topic, you will learn that:

- alleles are different versions of a gene, which originated as a result of a mutation
- each person inherits one allele from each parent
- homozygous individuals have two identical alleles, whereas heterozygous individuals have two different alleles
- dominant traits appear with a single allele present, whereas recessive traits need two copies of the allele to be expressed.

allele
a version of a gene. Each person inherits one allele from each parent

homozygous
having two identical alleles for a particular trait

heterozygous
having two different alleles for a particular trait; a carrier for the recessive trait

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

recessive trait
a characteristic that results from the inheritance of two identical alleles

carrier
a person who is heterozygous and therefore has one recessive allele that is not expressed in their phenotype

genotype
the combination of alleles for a particular trait

Genes can have different versions (alleles) on the same location of a chromosome. Each allele is the result of a mutation. The unique combination of alleles for a gene inherited from parents is called the genotype of the organism. Only a single allele for a trait needs to be present for a dominant trait to appear in the phenotype. Recessive traits need two copies of the allele before it can be expressed in the phenotype. Phenotypes (the physical appearance of a trait) can be influenced by the environment.

Alleles

Have you ever wondered why some people look so much like their mother or father? Each cell in your body contains two sets of chromosomes – one from your mother and one from your father. If your mother has blue eyes, then you may inherit the gene for blue eyes from her. If your father has brown eyes, then you may inherit the gene for brown eyes from him. Both genes are for eye colour. Each version of the same gene (for eye colour) at the same position (or locus) of a chromosome is called an **allele**. All alleles originated at some point in time as a result of a mutation.

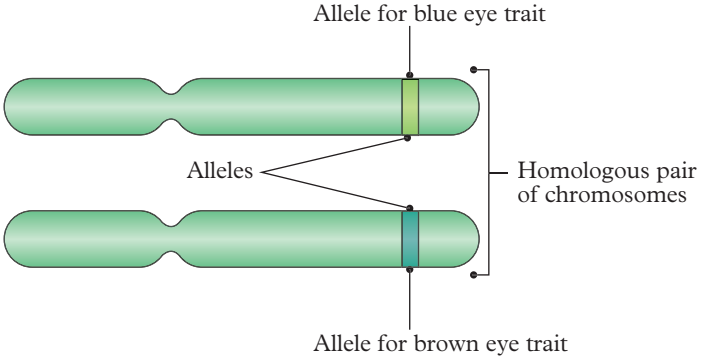


Figure 1 A pair of chromosomes

If a person has two identical alleles for a trait or characteristic, they are said to be **homozygous** for that trait. If a person has two different alleles for the same trait (e.g. a blue eye allele and a brown eye allele), they are **heterozygous** for the trait.

If someone is heterozygous for eye colour, then the colour of their eyes is determined by which allele is dominant. **Dominant traits** only need one copy of the allele to be visible in the appearance of the individual. Dominant traits are usually represented by capital letters. For example, brown eyes is a dominant trait and is often given the symbol 'B'.

Other traits are called **recessive traits**. These traits can only be seen if there are two copies of the allele present. The alleles for recessive traits are represented by lower-case letters. For example, blue eyes is a recessive trait and is given the symbol 'b'.

Therefore, a person with blue eyes must have two alleles for blue eyes (bb). In contrast, a person with brown eyes could be homozygous (BB) or heterozygous (Bb) for the trait. A brown-eyed individual who is heterozygous for the trait is sometimes called a **carrier** for the blue-eyed trait. They have the allele for blue eyes, but the trait cannot be seen in their appearance.

The combination of allelic symbols that a person has for a trait (e.g. BB, Bb or bb) is called their **genotype**.

Nature versus nurture

For over a century, scientists have puzzled over whether the genetic material you inherit (nature) or the environment in which you are raised (nurture) is more important in determining your characteristics. For example, genetically identical hydrangeas that produce pink flowers in alkaline soil and blue flowers in acidic soil suggest that nurture is more important. However, the growth of stems, flowers and leaves is a result of the genes in the plant.

Phenotype is the physical expression of a trait or characteristic that results from the genetic make-up of the organism and is influenced by the environment. An example is how tall you will grow. You inherit a series of genes from your parents that will determine your growth potential, but if you don't receive the appropriate nutrition when you are growing up, then this will affect your height later in life.

Monohybrid cross

Some traits, such as the ability to roll your tongue, are controlled by only one gene. This single gene has two alleles: one for rolling your tongue (the dominant trait, R) and one for non-tongue rolling (the recessive trait, r). We can examine how this single trait is passed on by using a **Punnett square** (Figure 2). In a Punnett square, the parents' genes are listed across the top and down the side. The remaining boxes are filled by combining the letters of each parent.

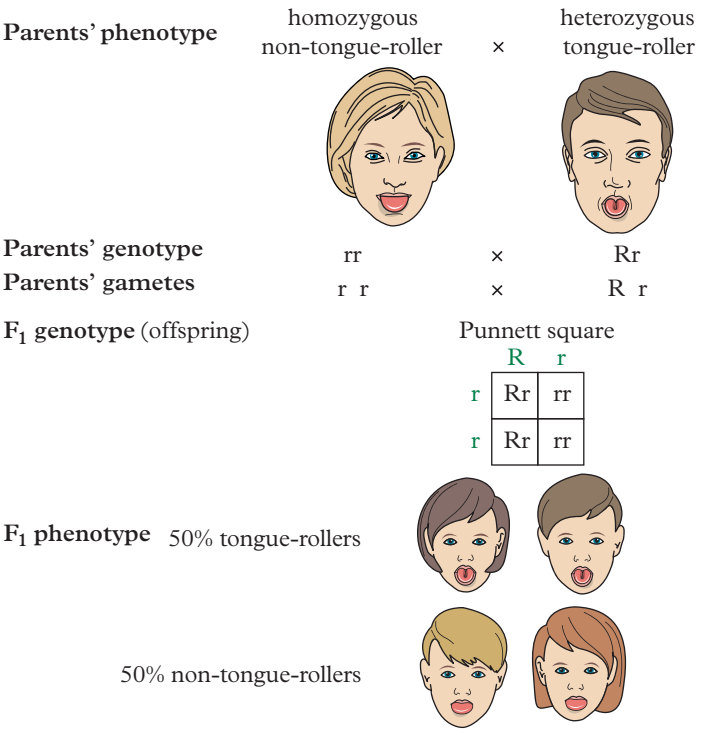


Figure 2 The ability to roll your tongue is inherited.

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

Punnett square
a diagram that is used to predict the outcome of breeding organisms

Check your learning 11.6

Recall and explain

1 Dimples (D) is dominant to no dimples (d). Write the genotypes for individuals who:
   - **a** are homozygous for dimples
   - **b** are heterozygous for dimples
   - **c** have no dimples.

2 **Explain** what a carrier is.

Apply and analyse

3 The trait for blue eyes is recessive to the trait for brown eyes. **Evaluate** the chances of two blue-eyed parents having a brown-eyed child. **Deduce** the chances of two brown-eyed parents having a blue-eyed child.

4 Wavy hair in humans is dominant to straight hair. A wavy-haired man and a straight-haired woman had two children. The first child had wavy hair, and the second child had straight hair. **Determine** the genotype of all four individuals and use suitable symbols to show your working.

Evaluate and create

5 A girl wants to check if her grey cat is heterozygous or homozygous for coat colour. Assuming breeding was ethical and time efficient, what cross should she carry out? **Describe** the results she would obtain if the cat is:
   - **a** homozygous
   - **b** heterozygous.

Skill builder: Processing and analysing data and information

6 If a right-handed man and a left-handed woman have children who are all left-handed, **assess** if this means that left-handedness is dominant. Provide evidence to support your view. (THINK: What tools can I use to investigate this? How can I present this information in a diagram?)

11.7 Genes on the sex chromosomes produce sex-linked traits

Figure 1 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.

autosome
a chromosome that does not determine the sex of an organism

sex chromosome
a chromosome that determines the sex of an organism

In this topic, you will learn that:

- sex chromosomes determine the sex of an organism
- human females have two X chromosomes, and males have an X and a Y chromosome.

Sex chromosomes contain genes that are inherited in a unique way. Fathers pass their X chromosome to all their daughters and their Y chromosome to their sons. Mothers will pass one X chromosome to each of their children. Autosomes are non-sex chromosomes.

Sex chromosomes

Humans have 22 pairs of chromosomes that are not sex chromosomes (called **autosomes**). The 23rd pair of chromosomes are the **sex chromosomes**. The genotype for the sex chromosomes in a female is XX and the genotype for a male is XY. These chromosomes contain the genes with information for sexual traits.

The X chromosome is larger than the Y chromosome (Figure 1). In addition to carrying genes for sexual characteristics, it contains information for non-sexual characteristics, such as blood clotting and red–green colour vision. Traits (and the genes that determine them) that are carried on a sex chromosome are said to be *sex linked*.

Males show deficiencies in these genes more commonly than females because they only have one X chromosome.

In general, when investigating the pattern of inheritance for a particular trait (characteristic), it is useful to consider each trait as one of the following four patterns (see also Table 1):

- autosomal dominant
- autosomal recessive
- X-linked dominant
- X-linked recessive.

Sex-linked conditions

Two conditions that are caused by defective sex-linked genes are red–green colour blindness and haemophilia.

Red–green colour blindness is an X-linked recessive trait. This means the red–green colour-blindness allele is found on the X chromosome and the trait only appears if no 'normal' alleles for this gene are present. The colour receptors in the retina of the eye are controlled by a gene on the X chromosome.

Table 1 The four patterns of inheritance

	Dominant	Recessive
Autosomal	• Males and females are affected equally over a large sample size. • Affected offspring have at least one affected parent (i.e. does not skip a generation).	• Males and females are affected equally over a large sample size. • Affected offspring may have unaffected parents (i.e. parents may be carriers).
X-linked	• Generally, more females than males are affected. • Affected offspring have at least one affected parent (i.e. does not skip a generation). • An affected father will pass the trait to all daughters but not to any sons. • An affected mother has a 50% chance of passing the trait to any son or daughter.	• Generally, more males than females are affected; females are carriers. • Affected offspring may have unaffected parents (men cannot be carriers, but women may be). • A carrier mother has a 50% chance of passing the trait on to each son. • Daughters of an affected father will all be at least carriers.

When the gene is defective, the colour receptors do not function properly and the person cannot distinguish red from green (Figure 2). Approximately 8% of males and less than 1% of females have red–green colour blindness. It is very rare for a female to have two defective genes but not so rare for them to be 'carriers' (heterozygous) of the defective gene.

Haemophilia is a disease that prevents the blood from clotting. This occurs when the X-linked gene that controls one of the clotting factors is defective. Even a small injury to a person with haemophilia can result in prolonged bleeding. Haemophilia can be treated by receiving clotting factors through an injection.

In the past there was no treatment for haemophilia. Queen Victoria, of the United Kingdom, appears to have had a spontaneous mutation in the gene on the X chromosome for making a blood clotting factor. She passed this defective gene on to some members of her family. When her male descendants inherited the X chromosome with the 'defective' allele, they often died prematurely.

Queen Victoria's granddaughter Alexandra was a carrier of the haemophilia gene. She married the last Tsar of Russia, Nicholas II, with whom she had four unaffected daughters and a son, Alexei, with haemophilia.

Communicating sex-linkage

When writing genotypes for sex-linked crosses, it is important to show the allele as being attached to either the X or the Y chromosome because the gender of the offspring is important in determining phenotype.

For example, in colour blindness, using X for normal and X^c for colour blindness, the genotype for a colour-blind female is X^cX^c, the genotype of a carrier female is XX^c, and the genotype for a colour-blind male is X^cY. Figure 3 shows how haemophilia can be communicated.

Key: H = normal allele and h = allele for haemophilia

Queen Victoria X^HX^h × X^HY Albert

↓

Carrier daughter X^HX^h × X^HY Her husband

↓

Alexandra X^HX^h (carrier granddaughter) × X^HY Nicholas II (last Tsar of Russia)

↓

Alexei X^hY (haemophiliac son)

Figure 3 Genotypes in the family tree of Queen Victoria leading to Alexei.

Figure 2 a A person with normal vision can see all the colours of these parrots. **b** A person with colour blindness would not be able to easily tell apart the red and green feathers.

Check your learning 11.7

Note: For the following questions, assume that the sex-linked gene is X-linked and recessive.

Recall and explain

1 **Distinguish** between autosomal chromosomes and sex chromosomes.

2 **Explain** whether the father or mother determines the gender of a baby. **Justify** your response.

Apply and analyse

3 A man and a woman, both of whom had normal sight, had three children, two boys and a girl. One of the boys had normal sight and the other was red–green colour blind. The girl had normal sight. **Identify** and write the genotypes for this family.

4 The girl from the family in question 3 later married a normal-sighted man and had a son who was colour blind. **Identify** and write the genotypes for this family.

Evaluate and create

5 Tortoiseshell cats have fur coats that are a combination of orange and black. The gene for hair colour is found on the X chromosome.

a **Explain** why all tortoiseshell cats are female. Use diagrams to **explain** your answer.

b **Deduce** what colour the offspring of a tortoiseshell cat and a black cat would be.

Skill builder: Problem solving

6 **Deduce** the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia. (THINK: How can I express this? Is there a scientific diagram I can use?)

11.8 Pedigrees show the inheritance of traits

In this topic, you will learn that:

- pedigrees are diagrams that show the pattern of inheritance for a trait
- in a pedigree, circles represent females, squares represent males, and shaded symbols are for those that express the trait
- generations are represented using Roman numerals.

pedigree
a diagram showing the inheritance pattern of a particular trait

Although each of your parents contributed to your genotype, the genotypes of other family members (e.g. grandparents, aunts and uncles) can all be important in explaining who you are. Inheritance of characteristics is often traced through families using family tree diagrams or **pedigrees**. There are specific symbols used in constructing pedigrees (see Figure 1).

- Males are represented by squares and females by circles.
- A relationship that produced offspring is shown by a horizontal line; a vertical line leads to the offspring.
- The characteristic being studied is shown by shading.
- Generation numbers are represented by Roman numerals, and individuals are represented by Arabic numerals and numbered from left to right.

Interactive
Pedigrees

When analysing a pedigree to determine whether a trait is dominant or recessive, the following rules apply.

- If neither parent has a characteristic and any of their children have it, then the characteristic is recessive (i.e. both parents are heterozygous and carry the allele for the recessive trait but it is not shown in their phenotype).
- If both parents have a characteristic and any of their children do not have it, then the characteristic is dominant (i.e. both parents are again heterozygous, they express the dominant allele in their phenotype but pass on the recessive allele to their children that do not show the trait).

Hence, for the pedigree in Figure 2, red hair is recessive because individual II2 and his partner do not have red hair but some of their children have it. They are both carrying the allele for red hair but are not expressing it. They both contribute their allele for red hair to some of their offspring.

In the pedigree shown in Figure 3, tongue rolling is dominant. This is because individual II1 and her partner can roll their tongues and some of their offspring can and some cannot. The parents are both heterozygous for tongue rolling.

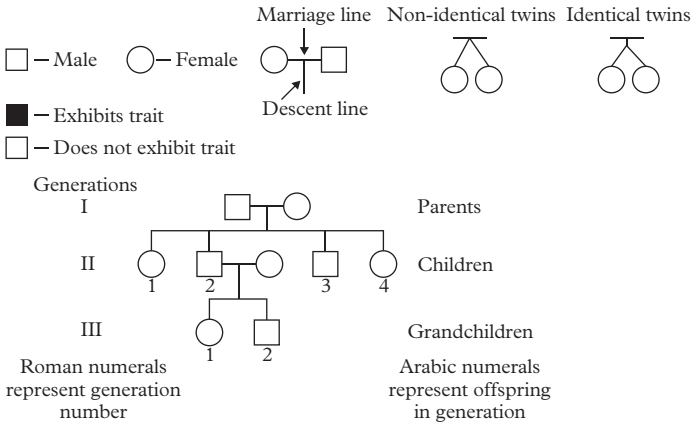


Figure 1 Some symbols used in family tree diagrams

Analysing pedigrees

There are a series of questions you should ask when determining the inheritance pattern from a pedigree.

1. Are more males or females affected by the trait? If YES, go to 2. If NO, go to 3.
2. Do all daughters of affected males have the trait? YES – Sex-linked dominant. NO, go to 4.
3. Do all affected children have an affected parent? YES – Autosomal dominant. NO, go to 5.
4. Has a carrier mother passed it on to half and/or some of her sons? YES – Sex-linked recessive.
5. Do affected children have unaffected parents? YES – Autosomal recessive.

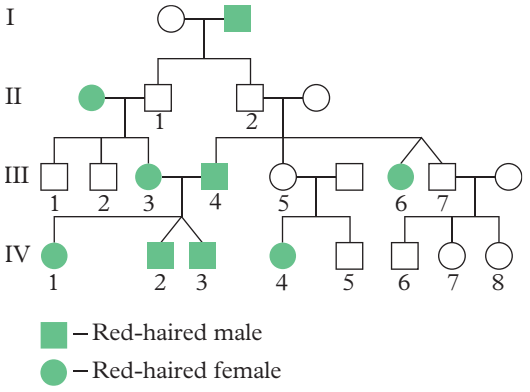


Figure 2 A pedigree for red hair

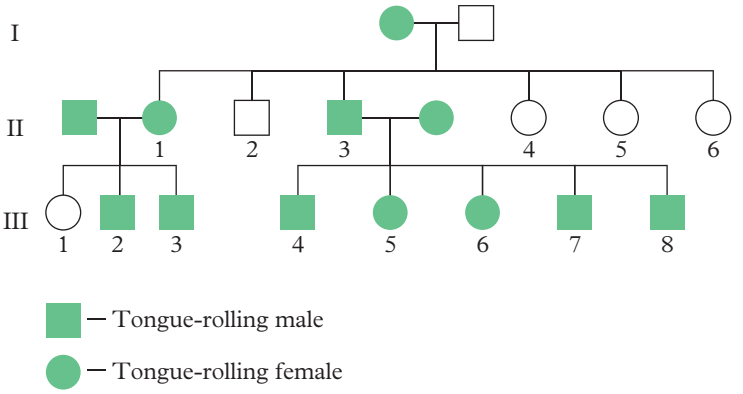


Figure 3 A pedigree for tongue rolling

Check your learning 11.8

Recall and explain

1 **Explain** the purpose of a pedigree.

2 **Recall** what shapes represent a male and a female in a pedigree.

Apply and analyse

3 A particular X-linked disease causes weakening of the muscles and loss of coordination. This often leads to death in childhood. A pedigree for this disease is shown in Figure 4.

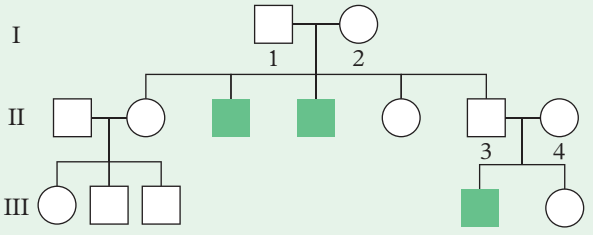


Figure 4 A pedigree for a particular X-linked disease

- **a** Use this pedigree and suitable symbols to show the genotype of individuals 1–3. **Explain** what the genotype of individual 4 must be.
- **b** **Explain** what a carrier is. **Identify** one carrier shown in Figure 4.

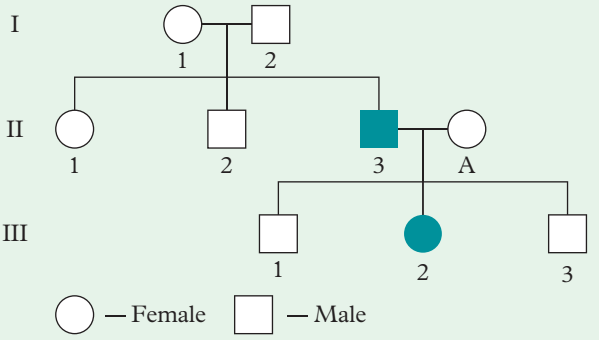


Figure 5 A family pedigree

4 Look at Figure 5.

- **a** In this family pedigree, is the characteristic indicated by shading dominant or recessive? **Explain** your answer.
- **b** If R represents the allele for the dominant trait and r represents the allele for the recessive trait, write the genotypes for I1, I2 and person A.
- **c** If A and her partner had another child, **calculate** the chance of the child having the characteristic indicated by shading. Show your working.

Evaluate and create

5 Create a pedigree of yours or a friend's immediate family for a trait of your choosing.

Skill builder: Communicating

6 Some people have ear lobes that hang free and some people don't. Natalie has attached ear lobes, but both Natalie's parents and her brother, Daniel, have free-hanging ear lobes (Figure 6).

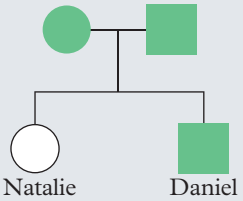


Figure 6 Pedigree for hanging or attached ear lobes

- **a** Is the characteristic of free-hanging ear lobes a dominant or recessive trait? **Explain** your choice. (THINK: What makes something dominant or recessive? Can you tell from the pedigree?)
- **b** Use suitable symbols to represent the alleles for the ear lobe gene, then write the genotypes of:
  - **i** Natalie
  - **ii** Natalie's parents.

  (THINK: How can this be best represented?)
- **c** **Identify** the possible genotypes for Daniel. (THINK: How can you express this?)

11.9 Genetic engineering changes an organism

In this topic, you will learn that:

- genetic engineering is the process of changing the genetic code of an organism
- a transgenic organism is an organism with DNA from a different species inserted into its genome
- gene therapy involves inserting a healthy version of a gene into an individual with a defective gene.

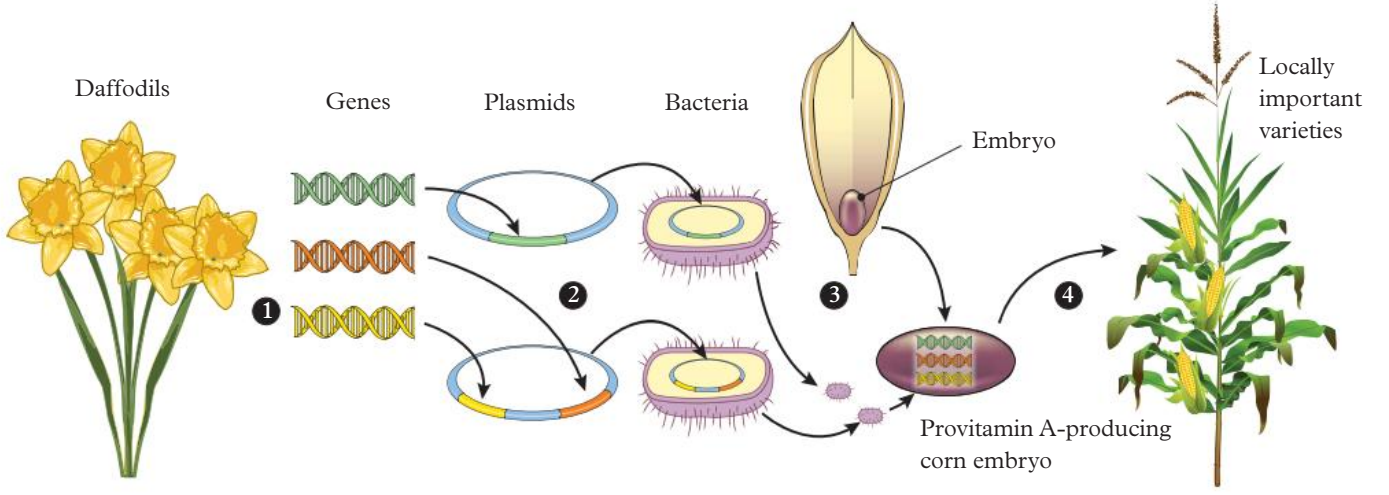
Resource
STEM activity: Dragon breeding

The ability to insert genes from one organism into another relies on the universal nature of DNA. This means that the DNA in every organism is made out of nucleotides with the same four nitrogen bases (A, T, C and G). As our understanding of DNA structure and its importance has increased, technologies involving the control and manipulation of genomes have been developed.

A genetically modified organism is an organism that has had its DNA changed in some way.

Video
Genetic engineering

A transgenic organism is an organism with DNA from a different species inserted into its genome. Genetic engineering is the process of changing the genetic code of an organism. Gene cloning uses this process to produce multiple copies of a particular gene. This can be done to mass produce proteins such as insulin. Gene therapy involves the insertion of a healthy version of a gene into the chromosomes of an individual with a defective gene. Current Australian laws prevent any changes to the germ-line cells of an individual.



1. The gene that produces vitamin A is isolated from a daffodil.
2. This gene is added into a plasmid, which is a small loop of DNA that acts as a vector transporting the gene into a bacterial cell.
3. The bacterial cells containing the plasmid are added to the embryonic corn plant.
4. The transgenic corn plant grows. The introduced genes produce high levels of vitamin A.

Figure 1 Scientists can grow transgenic corn that produces high levels of vitamin A.

Genetically modified organisms

One of the most controversial developments in modern food production is the proliferation of genetically modified organisms (or GMOs). Genetically modified (GM) plants have been modified in the laboratory to enhance certain desired traits, such as increased resistance to herbicides or improved nutritional content. Traditionally, the enhancement of desired traits has been achieved through selectively breeding or mating two organisms that have the trait. Genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy. For example, geneticists can isolate a gene for drought tolerance from one plant species and insert that gene into a different species. The new GM plant will display a tolerance to drought. Not only can genes from one plant be transferred into another plant, but genes from non-plant organisms can also be used. Transgenic organisms are those that contain a foreign gene inserted from another organism, usually a different species.

Agriculture has been significantly affected by the introduction of transgenic animals and genetically modified crops and foods (GM foods), including plants that are resistant to herbicides and pesticides. There are also 'pharm' plants and animals that produce pharmaceutical proteins required by humans.

Crops that have been engineered to resist disease mean that farmers use lower amounts of pesticides and herbicides when growing these crops. This reduces both the production costs and also the amount of pesticides and herbicides released into the environment.

Examples of plants that have been genetically engineered in this way include those shown in Figures 2–4. Figure 1 shows the process of introducing a gene from a daffodil into corn.

GMO issues

GM crops may pose a threat to biodiversity in certain circumstances because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. The significant increase in GM plants has only occurred in the past decade or so.

Figure 2 Transgenic variety of cotton that is pest resistant. Genes (specifically one that codes for a protein toxic to many serious insect pests) from the bacterium *Bacillus thuringiensis* have been introduced into the chromosomes of this plant. The protein is called Bt (*Bacillus thuringiensis)* toxin and the plants are Bt plants. The toxin only becomes active in the alkaline environment of the insect gut, whereas in vertebrate animals it is destroyed by the acid in the stomach.

Figure 3 Transgenic papaya plants in Hawaii are resistant to the ring spot virus. Genetically engineering papaya has saved the industry. The technology has also been exported to other countries where ring spot virus is damaging papaya plants.

Figure 4 Golden rice has had genes inserted from daffodils. These genes control the production of a chemical that is converted into vitamin A, making this rice much richer in vitamin A than non-transgenic rice. Without adequate amounts of vitamin A, people's eyesight can be severely impaired, even leading to blindness.

The organic food movement is completely against the principle of GM foods, and public debate into the benefits and dangers of such foods is likely to continue well into the future. Some people believe that GM foods pose health risks, although there is no clear evidence for or against this.

A criticism of GM foods is the potential for accidental gene transfer to other species. GM plants may also contaminate non-GM plants of the same species; for example, when wind blows the pollen from one farm to another nearby. Another problem is that increased pesticide and herbicide resistance may develop in insects and other pests. The GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.

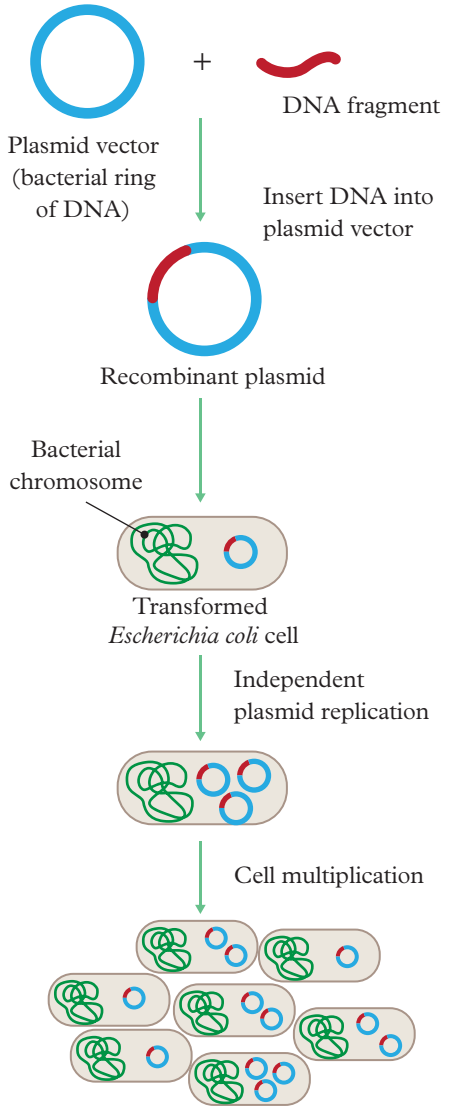


Figure 5 Gene cloning

vector
an agent (often a bacteria or virus) used to deliver a trans-gene

Genetic engineering in medicine

Gene cloning

Another application of genetic engineering is gene cloning: to insert a gene, for example a human gene, into bacteria so that the bacteria now produce a human protein that can be purified and used to treat a human disease (Figure 5). This method avoids the rejection issues faced by using similar products from animals, such as pigs or sheep. An example is the production of human insulin by bacteria. Insulin is injected by people with diabetes to help control their blood sugar levels.

Gene therapy

Gene therapy involves the insertion of a healthy gene into the chromosomes of an individual with a defective gene. Gene therapy that involves the body cells (somatic cells) can be therapeutic only. This means that the new gene cannot be passed on to the next generation. At present, gene therapy targeting germ-line cells (cells destined to become gametes) is not legal in Australia.

Gene therapy has been quite successful in the treatment of cystic fibrosis (CF). Patients with CF have a deficiency in a gene that controls the production of a protein that regulates the movement of ions across cell membranes.

A major symptom of CF is the accumulation of a thick mucus that can damage lung tissue. This reduces lifespan significantly.

Medical scientists have been able to clone the healthy gene in bacteria. The purified gene is then attached to a carrier molecule called a **vector**. The vector, in this case a harmless virus, is added via a spray through the nose of patients. The virus enters many of the lung cells and inserts into the DNA in the nucleus. When the lung cells divide, the new cells contain the healthy gene.

Apart from the success with CF and the great potential of gene therapy, there has been limited progress since the first clinical trials in 1990. Several people died as a consequence of the technique. The ethics of treating patients with a technique that involves significant risks to life have to be considered carefully.

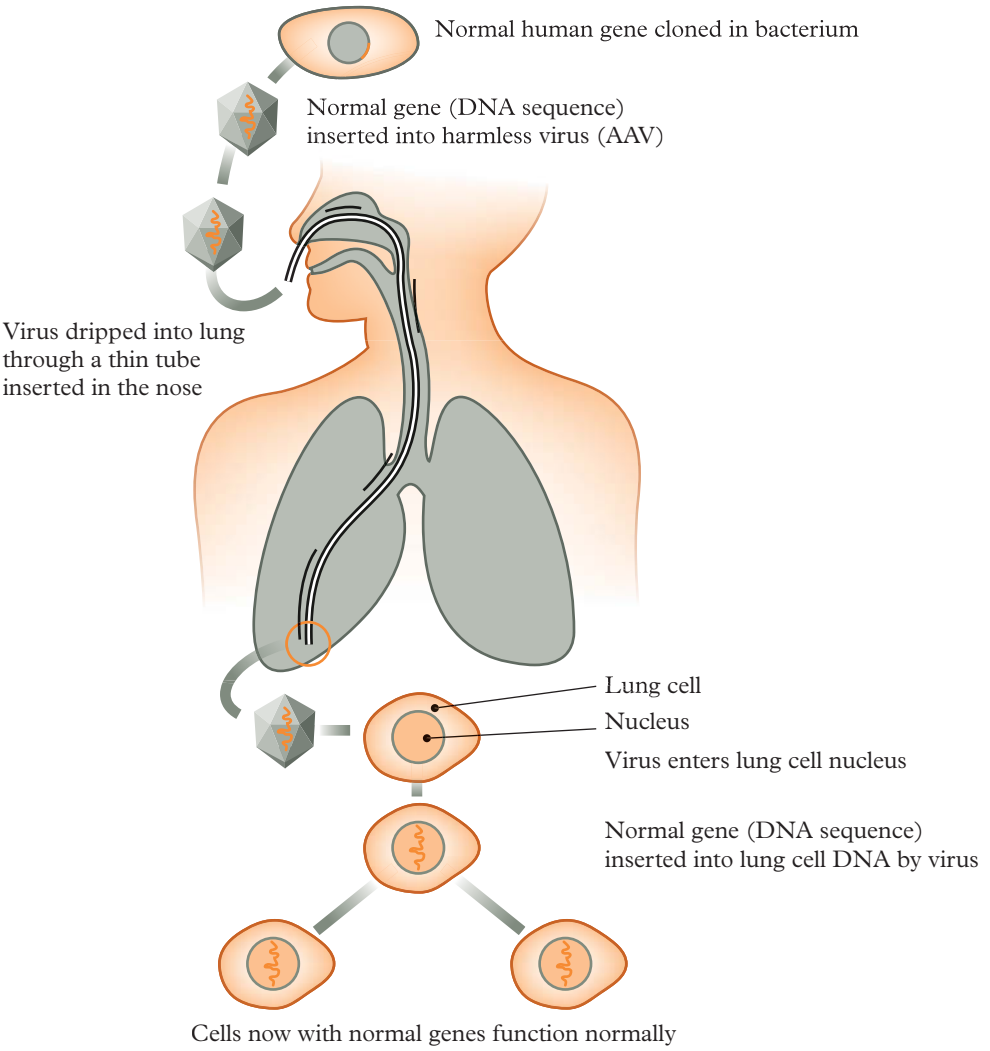


Figure 6 Gene therapy

Check your learning 11.9

Recall and explain

1 **Define** transgenic species.
2 **Summarise** a method that is used to insert 'new' genes.
3 **Identify** two reasons for genetically engineering plants.
4 **Identify** the aim of gene cloning.
5 **Describe** the process used to produce human insulin by gene cloning.
6 **Explain** why scientists choose bacteria to clone human genes.
7 **Recall** an example of a successful gene therapy treatment for a disease.

Apply and analyse

8 **Identify** an example of an organism that has been genetically engineered for use in agriculture. **Explain** how this has been useful.
9 **Discuss** whether you think foods derived from GMOs should be labelled.

Evaluate and create

10 **Assess** the factors that would influence your decision to purchase or not to purchase food derived from GMOs.
11 **Evaluate** the use of GMOs in agriculture versus their use in treating genetic diseases in humans. **Explain** if the function affects your opinion.

Skill builder: Planning investigations

12 Your school is investigating the use of genetically modified strawberries. **Assess** whether it would be better to use secondary or primary data in this investigation. (THINK: Which would contribute more to the area of science? Do you have access to the necessary equipment and materials to conduct an investigation?)

11.10 Biotechnologies use living organisms

In this topic, you will learn that:

- biotechnology is a technology that involves the use of living organisms mainly in the fields of agriculture, food science and medicine
- gene probes are used to identify inherited diseases and risks
- stem-cell research studies the properties of stem cells
- in-vitro fertilisation is the process where an egg is fertilised outside the body and then inserted in the uterus.

Figure 1 A blood sample is collected from a newborn infant to screen for phenylketonuria – a disease that affects the way the body breaks down proteins.

genetic screening
the testing of a cross section of individuals to determine whether they have a particular trait or disease

gene probe
short sections of nucleotides known to be complementary to the genetic sequence of interest

genetic testing
the testing of an individual to determine whether they have a particular trait or disease

Biotechnologies are often controversial because they can challenge people's cultural, religious, ethical and moral viewpoints. When a new biotechnology is developed, such as gene probes for inherited diseases, it raises a new set of challenges such as what to do with the information if you are told you have inherited a genetic disease for which there is no cure. The same technology allows for individuals to choose specific characteristics of their offspring. Is it okay to screen offspring to avoid them inheriting a disease? What about for screening to choose eye colour?

Genetic screening and testing

Unique **gene probes** (short sections of complementary nucleotides) can be used to bind to the specific alleles of individuals at risk of genetic diseases. These probes can be used to identify if an individual has inherited the alleles for a disease or if they are at increased risk of developing breast cancer, cardiovascular disease or Alzheimer's disease. While this has advantages in the treatment of the disease, there are many social and ethical issues that must be considered.

Genetic testing is carried out on people who are known to be at risk of a particular genetic disease or condition. This is usually evident from an individual's family history. The genetic material of a person at risk is obtained through a blood sample. DNA from the white blood cells (red blood cells do not have a nucleus) is isolated and replicated. Special probes act like a stain that sticks to specific genes in the chromosomes, identifying the particular allele that is present in people at risk of the trait.

Genetic screening refers to testing that is readily available to a cross-section of people within the community regardless of a previous family history of genetic disease.

Genetic screening and testing services currently available in Australia include:

- maternal serum screening (MSS) – offered to all pregnant women for the detection of Down syndrome and neural tube defects
- newborn screening – the screening of all newborn babies for genetic diseases, including phenylketonuria (PKU), hypothyroidism and cystic fibrosis
- early detection and predictive testing for adults – the screening of adults to detect existing disease, a predisposition to disease or carriers with a reproductive genetic risk.

Genetic screening can increase the early diagnosis of and subsequent intervention in genetic diseases. Potentially, this will minimise the frequency of such diseases in subsequent generations; however, it sometimes involves some very difficult decisions. For example, potential parents who are carriers of genetic mutations must decide whether to have children, who may suffer from the disease. Genetic screening also raises the following questions. What are the risks of the tests and are the parents prepared to take them, or have their children take them? Who should be screened, and for what? What is the impact of false positives? What options are available if it's not good news?

Genetic counsellors can help clarify the situation, but they cannot make the decision for the people involved.

The collection, storage and potential uses of genetic information raise many ethical questions, including who should access the information and the possible misuse of such information.

Stem cells

Stem cells are undifferentiated cells that can mature into many different types of specialised cell types, such as muscle, nerve, liver and blood cells. There are two main types of stem cells. Pluripotent embryonic stem cells (obtained from embryos) can develop into most cell types in the body, whereas multipotent adult stem cells can only develop into certain cell types in the body.

There are many ethical issues associated with the use of embryonic stem cells. The establishment of a stem cell line involves the artificial creation of an embryo solely for the purpose of collecting stem cells. This process results in the destruction of the embryo. At present, such procedures are illegal in Australia. The only embryos that are used for research are those classed as 'excess embryos', having been originally created for use in in-vitro fertilisation. However, some people consider the use of these excess embryos to be unethical.

Most recently, scientists have been able to reverse the differentiation process and turn multipotent adult stems cells back into pluripotent stem cells. These cells are called induced pluripotent cells. In the future, induced pluripotent stem cells may be used to treat a variety of diseases, including cancer, multiple sclerosis (MS), Parkinson's disease, motor neurone disease and spinal cord injuries.

Some potential parents want to choose certain embryos over others. For example, they may want a male or a female child. They may want a child with brown eyes and dark hair.

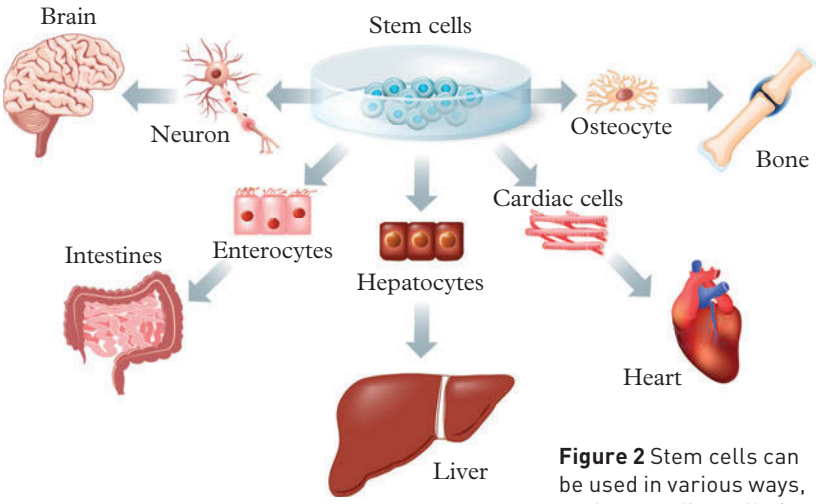


Figure 2 Stem cells can be used in various ways, such as cardiac cells for the heart.

stem cell
a cell that can produce a number of different types of cells. Adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce multiple types of cells

They may choose a healthy embryo over one with, say, cystic fibrosis. This situation has ethical implications. What will parents do with embryos that don't have the desired characteristics?

In-vitro fertilisation

In-vitro fertilisation (IVF) requires a female to take hormones which stimulate the maturation and release of multiple eggs from the ovary. These eggs are removed from the body and are mixed with a male's sperm in a laboratory to allow fertilisation to occur. After fertilisation has occurred, several cell divisions occur before one or more of the embryos are inserted directly into a woman's uterus.

Approximately 1 in 25 children in Australia are born via IVF. Although IVF can increase the chances of pregnancy, it is not guaranteed success.

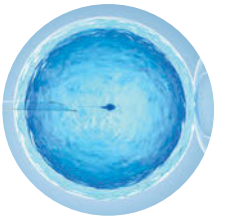


Figure 3 This image shows sperm being inserted into an egg during IVF.

Check your learning 11.10

Recall and explain

1 **Compare** genetic engineering and genetic screening.

2 **Distinguish** between a multipotent stem cell and a pluripotent stem cell.

Apply and analyse

3 Give at least one example where technological developments have led to advances in biological or medical understanding.

4 **Compare** two advantages and two disadvantages of genetic testing and genetic screening.

Evaluate and create

5 The debate around embryonic stem cells is heated. **Investigate** the main reasons for and against using embryonic stem cells. **Decide** whether embryonic stem cells provide benefits to humans. **Justify** your reasoning.

6 **Assess** why induced pluripotent cells are preferable to some people compared with embryonic stem cells.

7 **Evaluate** this statement: 'Genetic testing will benefit society in the future'.

Skill builder: Communicating

8 **Investigate** a biotechnology not addressed in this section; for example, cloning or vaccination.

a **Explain** how the technology is created. (THINK: What is the science process?)

b **Assess** the advantages and disadvantages of this biotechnology. (THINK: Who benefits from its use? Does it have further potential in the future? Are there ethical issues involved?)

REVIEW

Multiple choice

1 Which is not a constituent component of nucleotides?
- **A** Deoxyribose
- **B** Nitrogen base
- **C** Adenine
- **D** Phosphate molecule

2 Mutations are _____ whereas a mutagen is _____.
- **A** Permanent changes in DNA; the agents that cause the change
- **B** Agents that cause permanent change in DNA; permanent changes in DNA
- **C** A substance that causes permanent change to a gene; changes in the chromosomes
- **D** A change in genetic structure; a substance that causes a temporary change

3 Pedigrees are:
- **A** a cross that shows inheritance
- **B** a diagram to show the inheritance pattern of a trait
- **C** a particular breed of a species
- **D** a plot of chromosomes.

Recall and explain

4 **Identify** the four nucleotides found in DNA.

5 Use the terms 'gametes' and 'fertilisation' to **explain** how DNA is transferred from one generation to the next.

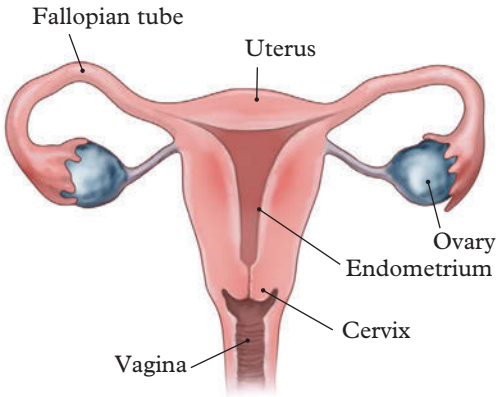


Figure 1 The human female reproductive system. The first division of meiosis happens in the ovaries.

6 Relate a chromosome to a molecule of DNA and **explain** how the replication of DNA is important for both mitosis and meiosis.

7 **Describe** three differences between the structure or function of DNA and RNA.

8 Use diagrams or words to **explain** the differences between:
- **a** nucleotide and codon
- **b** diploid and haploid.

9 **Recall** what a monohybrid cross is.

10 **Summarise** Mendel's conclusions from his work on breeding peas.

11 **Explain** what is meant by the following formula: Phenotype = genotype + environment

12 **Define**:
- **a** GMO
- **b** transgenic organism.

13 **Explain** the process of:
- **a** gene cloning
- **b** gene therapy.

14 **Explain** why a defect in a sex-linked gene affects males more than females.

Apply and analyse

15 **Distinguish** between the following pairs of terms:
- **a** autosome and sex chromosome
- **b** gene and allele
- **c** heterozygous and homozygous.

16 If a gene contains 600 nitrogenous bases, **deduce** how many amino acids would be incorporated into the resulting protein.

17 **Identify** which of the following is not a function of mitosis.
- **A** Replenishing the epithelial cells of the small intestine that are shed daily
- **B** Forming new red blood cells to replace those that are worn out
- **C** Forming cells for sexual reproduction
- **D** Repairing cuts and abrasions of the skin

18 **Describe** the sort of information that can be determined from the pedigree shown in Figure 2. **Identify** as many points as possible.

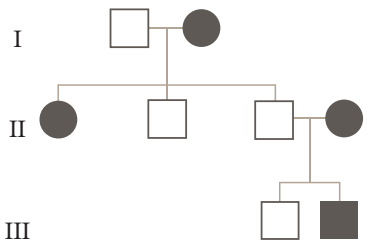


Figure 2 A pedigree chart

19 **Assess** whether large-scale genetic screening programs reduce the prevalence of genetic diseases. **Justify** your answer.

20 Gene therapy has been proposed as a treatment for a young boy suffering from Duchenne muscular dystrophy, a degenerative disorder of the muscles. **Describe** three factors that should be considered by the boy's health team prior to treatment.

21 **Determine** the complementary DNA sequence of GTTAGCCAGT.

22 **Assess** whether all mutations are heritable. **Justify** your answer.

23 If a man has a mutated gene on his Y-chromosome, **explain** which grandparent he inherited it from.

Evaluate and create

24 Does a chromosome or a gene provide the most information about the make-up of an individual? **Evaluate** the reasons why.

25 A newborn baby shows distinct facial abnormalities. A karyotype (Figure 3) was prepared to determine whether there were any chromosomal abnormalities.

- a **Identify** the total number of chromosomes shown.
- b **Identify** if the child is male or female. **Explain** how you know.
- c As the geneticist, **identify** what you would need to **explain** to the parents about the health of their baby.

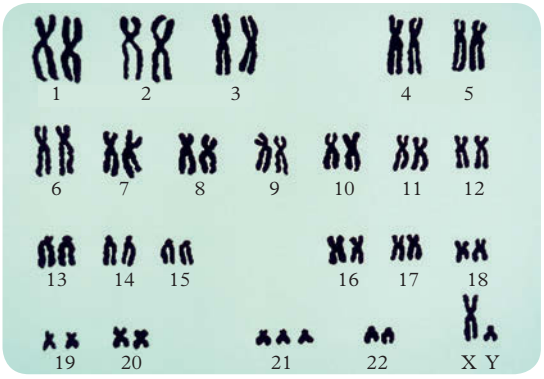


Figure 3 A karyotype

26 Phenylketonuria is an autosomal recessive genetic disorder. It results in the lack of production of an enzyme that is needed to metabolise the amino acid phenylalanine to the amino acid tyrosine. A diet low in phenylalanine and high in tyrosine is prescribed to people with phenylketonuria to avoid progressive intellectual disability. Every child born in Australia is now screened for phenylketonuria within weeks of birth. **Explain** the benefit of such genetic screening.

27 **Construct** a teaching resource that could be used to teach a year 7 student about the process of cell division.

28 **Investigate** a genetic disease and create a pamphlet for display in the reception area of a doctor's surgery. The pamphlet should **outline** information about the cause of the disease (gene or chromosomal abnormality), pattern(s) of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.

29 **Construct** a poster that promotes the benefits of purchasing organic and non-GM foods. Alternatively, **construct** a brochure promoting the benefits of GM foods.

30 The debate around embryonic stem cells is heated. **Identify** the reasons for and against using embryonic stem cells. **Investigate** how governments have intervened in this area. Based on your research, **evaluate** if using embryonic stem cells could provide benefits to humans.

31 Wilkins showed Franklin's results to Watson and Crick without her knowledge. If she had been given a choice, should she have shared her results with other scientists? **Assess** whether all scientists should share their results with each other. Provide reasons why and why not.

32 **Investigate** a chromosome mutation. **Identify** the type of mutation, how common it is, how it is found or diagnosed, and if there are common symptoms or treatments. Present your findings as an informative pamphlet or multimedia presentation. Include an appropriate bibliography of your sources.

Critical thinking

33 While some mutations can be harmful, they can also reflect changes in human survival. Some people are born without wisdom teeth. Scientists have proposed that this is a genetic mutation influenced by the fact that we do not require them anymore. **Investigate** this theory, and **assess** whether you think this benefits human survival.

34 Japan famously has a variety of different foods, including white and pink strawberries, and fruit that is grown in the shape of a square. **Investigate** whether these are genetic mutations or if they are caused by another factor. **Explain** your findings in three paragraphs.

Go further

35 **Investigate** a disease that is currently being successfully treated with gene therapy. **Describe** its main symptoms and create a diagram to **explain** how gene therapy is administered for this disease.

36 **Evaluate** the following statement: 'In the future, people will rely on genetically modified food.' (Hint: You might need to conduct some further research.)

- a Write a scientific question for this statement.
- b **Assess** the advantages and disadvantages.

Research

37 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Breast cancer

Breast cancer is a type of cancer that typically begins in breast tissue. To what extent does a family history affect an individual's chances of developing breast cancer? How is breast cancer detected and treated?

»A shrinking Y chromosome

The Y chromosome has been losing genes over the course of time so that it is now only a fraction of the size of the X chromosome. How has this happened? Will it disappear altogether? What is the future of the Y chromosome? What effect will this have on humans?

»Cloning

Dolly the sheep was the first animal to be cloned. What other sorts of animals have been cloned since Dolly the sheep in 1997? What are some of the arguments for and against cloning?

»Stem cell survival technique

Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them. Why is this technique a breakthrough? What does the technique involve? What are the immediate uses of this technique?

Figure 4 Dolly the Sheep was the first animal to be cloned.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Relate the organs involved in human reproductive systems to their function.	☐	☐ Go to pages 208-209
Identify that during reproduction the transmission of heritable characteristics from one generation to the next involves DNA and genes.	☐	☐ Go to pages 210-211
Identify that genetic information is transferred as genes in the DNA of chromosomes.	☐	☐ Go to pages 212-215
Outline how the Watson-Crick model of DNA explains: • the exact replication of DNA • changes in genes (mutation).	☐	☐ Go to pages 216-219
Describe, using examples, how developments in technology have advanced biological understanding, e.g. vaccines, biotechnology, stem-cell research and in-vitro fertilisation.	☐	☐ Go to pages 226-231
Discuss some advantages and disadvantages of the use and applications of biotechnology, including social and ethical considerations.	☐	☐ Go to pages 226-231

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EVOLUTION

How does the theory of evolution by natural selection explain the diversity of life on planet Earth?

12

Have you ever wondered ...

- How did people develop the theory of evolution?
- Why do giraffes have such long necks?
- How did the rise of the 'superbug' come about and how might it affect you?

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- describe scientific evidence that present-day organisms have evolved from organisms in the past
- relate the fossil record to the age of the Earth and the time over which life has been evolving
- explain, using examples, how natural selection relates to changes in a population, e.g. in the development of resistance of bacteria to antibiotics and insects to pesticides
- outline the roles of genes and environmental factors in the survival of organisms in a population

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Check your Student obook assess for these digital resources and more:

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Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

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QuizletLive
Launch a quiz for your students on key concepts in this chapter.

12.1 The theory of evolution *

In this topic, you will learn that:

- Lamarck developed the theory of inheritance of acquired characteristics, where organisms changed in response to their environment
- this was countered by Darwin and Wallace who independently proposed the theory of evolution by natural selection, where organisms best suited to the environment are those that survive and pass on favourable traits to the next generation.

Figure 1 These layers of rock are an indication of different time periods. Pale layers can sometimes represent volcanic ash released during an eruption.

Scientific theories are explanations of the natural world that are based on well-substantiated evidence. These theories are contested and refined over time through a process of review by the scientific community. The statement 'organisms change in response to environmental pressures' is an observation. Natural selection as the mechanism of evolution, as proposed by Charles Darwin and Alfred Wallace, is a scientific theory that has over 200 years of reproducible experimental evidence supporting it.

Before evolutionary theory

The generally accepted belief for many thousands of years was that life was 'created' by gods. Even events such as volcanoes and earthquakes were considered to be the consequences of the emotions of the gods. Societies could have one or more gods, which could be human or animal-like in appearance.

There was little thought given to whether organisms changed over time. The idea of extinction was not proposed until the 1790s, when William Smith uncovered fossils while analysing the geology of a mine in England. Fossils were already known to be the remains of living organisms, but Smith identified organisms that had never been seen before and was able to 'date' them by the layer of rock in which they were found. This later became known as relative dating.

Georges Cuvier, a French zoologist, collected and examined many fossils. He concluded that many of the animals represented were from the remains of species which are now extinct.

Early evolutionary theory

Evolutionary theories were all proposed without any knowledge or understanding of DNA and genetic inheritance – making the following stories even more remarkable.

Lamarckian theory

One of the first documented theories of evolution was by Jean-Baptiste de Lamarck, a French naturalist. Lamarck believed in evolutionary change – organisms change over time because of changing environmental conditions. He is best known for his hypothesis of inheritance of acquired characteristics, which was first presented in 1801. In this hypothesis, Lamarck proposed that if an organism changes during its lifetime in order to adapt to its environment, those changes are passed on to its offspring. This is how he explained the long necks of giraffes (Figure 2).

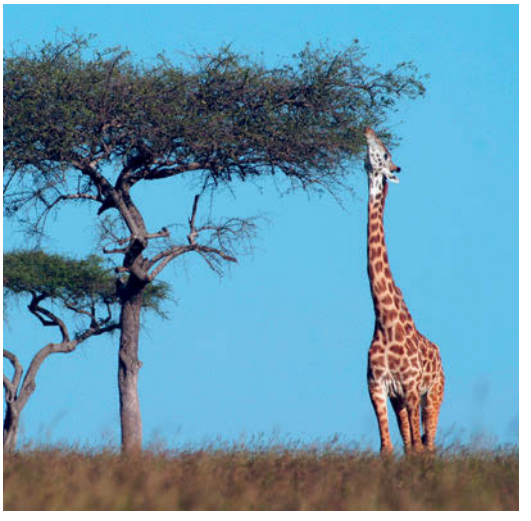

Figure 2 Lamarck believed that giraffes stretched their necks to reach food and that their offspring, and later generations, inherited the resulting long necks.

There are many problems with Lamarck's hypothesis. For example, Lamarck's hypothesis implied that the children of a man who had lost his arm would also have weak or deformed arms as a result. This was obviously not the case. August Wiesmann finally provided scientific evidence when he cut off the tails of 22 generations of mice, continually allowing them to breed with each other. Unsurprisingly, all their offspring were born with tails.

Charles Darwin

Charles Darwin (Figure 3) was well educated and had been exposed to the sciences from an early age through his father and grandfather, who were both physicians. Darwin had also read the works of Lamarck. In 1832, the young 23-year-old set sail on a 5-year world cruise as the unpaid naturalist on the HMS *Beagle*.

During the final stages of the voyage, the ship visited the Galapagos Islands, about 1000 km off the coast of South America. Here, Darwin made his most significant observations.

Darwin and his helpers collected specimens, seeking to obtain at least one of each species. Among the specimens collected were 13 finches, all of which resembled one another in terms of the structure of their beaks, the form of their bodies and their plumage. Yet each specimen represented a new species, and most had been found on different islands.

In his journal, Darwin noted that these birds were strikingly similar to those found on the mainland of South America. He wondered why the different populations looked so similar, if new and different beings had been placed on the islands at the time of Creation.

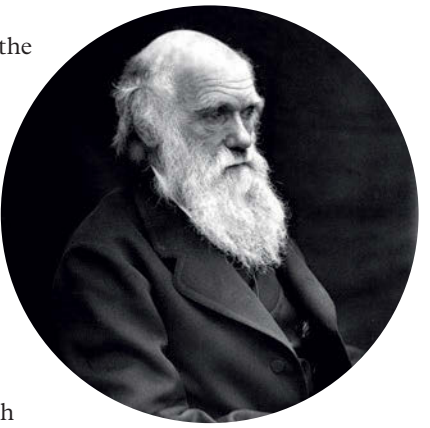

Figure 3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation.

Figure 4 Darwin studied several species of finches on the Galapagos Islands.

Figure 5 On the Galapagos Islands, tortoises' shells vary in shape according to habitat.

The dry, volcanic Galapagos archipelago is also home to different species of tortoise. Darwin noted that the different types of tortoise had different-shaped shells (Figure 5). Tortoises that live on dry islands, such as Hood Island, have shells that are raised at the front so they can reach up for vegetation. In contrast, tortoises that live on islands with dense vegetation have domed shells to help them push through the shrubbery.

Darwin was also aware that humans have selectively bred pigeons and racehorses for more than 10 000 years by choosing breeding partners for animals and other organisms in an effort to 'select' for certain traits in their offspring. Over many generations, the 'wild' traits are often lost and the species is considered 'domesticated'.

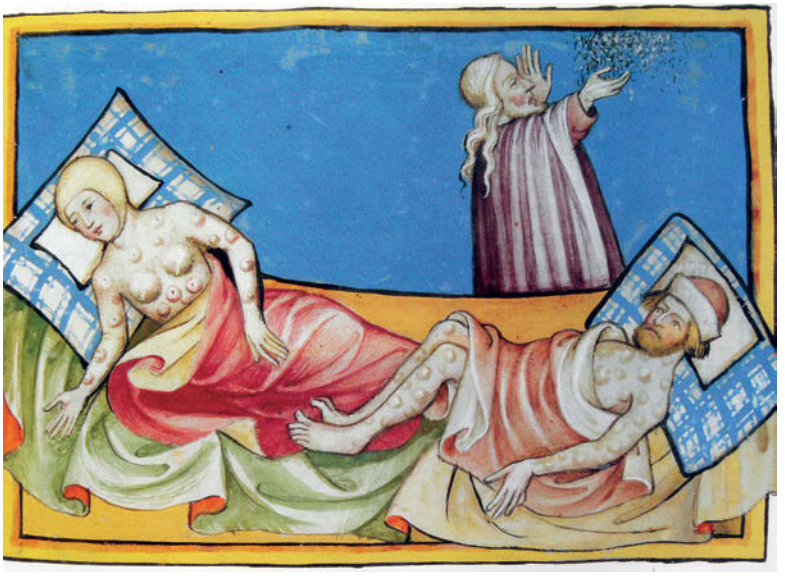

Figure 6 Was the plague simply nature's way of keeping the human population in check?

Darwin then wondered how 'selection' occurred in nature. Thomas Malthus's paper *An Essay on the Principle of Population* gave Darwin the insight he needed. Malthus argued in his paper that the human race would completely overrun the Earth if it were not held in check by war, famine and disease such as the plague (or 'Black Death') in the 14th century (Figure 6). Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last Darwin had a hypothesis to test. But it would take another 20 years of painstaking hard work before he was convinced that his hypothesis had enough support to be developed into a theory.

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) (Figure 7) was a naturalist working at the same time as Darwin. Wallace collected specimens from tropical regions, particularly the Malay Archipelago, which is now Malaysia and Indonesia. Wallace collected thousands of insects, shells and bird skins, as well as mammal and reptile specimens, many of which were new species to science at the time. One of his best-known discoveries was Wallace's golden birdwing butterfly.

During his time in the Malay Archipelago, Wallace proposed the theory of natural selection as the mechanism of evolution. In 1858, he wrote a series of letters to Darwin outlining his idea. Darwin and his friends were worried about who should get the credit for the two theories that

were essentially identical. They decided to read Wallace's letter and Darwin's paper one after the other at the Royal Linnaean Society of London. We now associate Darwin with the theory of evolution because, in 1859, Darwin published his book *On the Origin of Species by Means of Natural Selection*.

Darwin and Wallace's theory of evolution by natural selection

Darwin and Wallace independently proposed the theory of evolution by natural selection.

The key points are the following.

- There is an excess of individuals within a population.
- There is **variation** within a population.
- Individuals that are 'fitter' due to favourable traits (i.e. better adapted to the environment) will survive. This is **natural selection**.
- The individuals with favourable traits will contribute more to the next generation than those that are less fit. This is known as **survival of the fittest**.

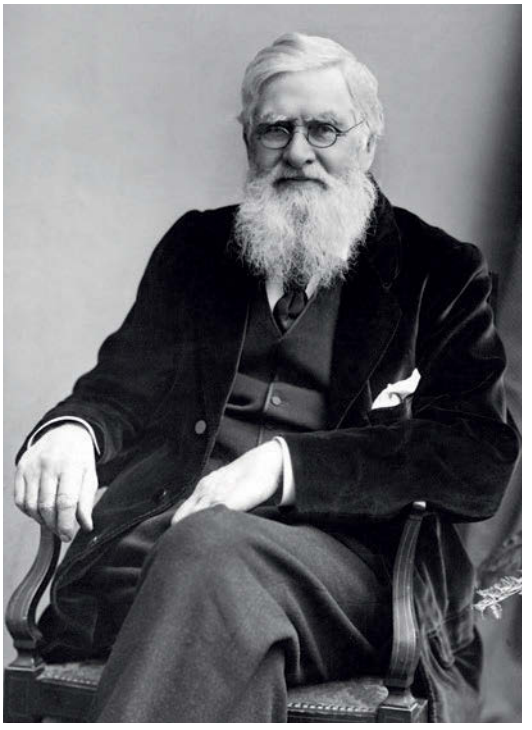

Figure 7 Alfred Russel Wallace formed the same theory as Darwin and at the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in South America. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.

variation
differences that exist between individuals

natural selection
the process by which individuals with favourable traits are 'selected' by nature

survival of the fittest
individuals with favourable traits are more likely to survive and pass on these traits

Check your learning 12.1

Recall and explain

1. **Describe** Lamarck's hypothesis about evolution.
2. **Explain** the theory of evolution by natural selection.
3. **Recall** how the variation of life was explained before the theory of evolution.

Apply and analyse

4. One of the biggest questions asked by humans is 'where did we come from?' **Recall** how different people have answered that question.
5. **Explain** what it was about the tortoises of the Galapagos Islands that helped Darwin develop his ideas about evolution and natural selection.
6. View Figure 4. Conduct research about where each finch lived. **Identify** the features of the finches that show similarity. Pay attention to the shape and size of the beak, and **explain** how this might relate to the habitat and food that the finch had available.

Evaluate and create

7. **Assess** why Darwin waited so long before arriving at his hypothesis and publishing his theory of evolution.
8. **Outline** a timeline of ideas before and after the theory of evolution.
9. **Discuss** if you think it is fair that Darwin receives all of the credit for his theory of evolution. **Justify** your answer.

Skill builder: Communicating

10. This section presented several evolutionary theories. **Construct** a timeline to present this information succinctly. (THINK: What are the key events? Where do I need to include these?)

12.2 Natural selection is the mechanism of evolution

In this topic, you will learn that:

- evolution is a permanent change in allele frequency in a population due to natural selection
- mutations introduce new alleles to the gene pool.

Figure 1 These Siberian huskies have different versions, or alleles, of the gene for eye colour.

evolution
the permanent change in the frequency of alleles in a population due to natural selection

mutation
a permanent change in a sequence of DNA

selection pressure
environmental factors that affect an organism's ability to survive

Evolution is the permanent change in the frequency of alleles in a population due to natural selection. **Mutations** introduce new alleles into the gene pool. **Selection pressures** cause these new phenotypes to survive or die out. If an organism displays traits that make it suited to its environment, then it is able to mate and produce offspring. The offspring will have the same survival characteristics (and alleles) as their parent. This gradually changes the frequency of alleles in the gene pool.

Observations and inferences

Although scientists knew that living organisms change over time, how the change occurred was first described by Charles Darwin and Alfred Wallace. They did this through a series of observations.

1. Members of a species are often different from each other.
2. There are always more children than parents.
3. The size of a population does not change.
4. Some offspring do not survive (survival of the fittest).
5. Offspring look like their parents.

These five observations led Darwin to make two key inferences.

1. In the struggle to survive, those individuals that are most suited to their environment survive.
2. Those individuals that survive pass their traits on to their offspring.

gene pool
all the genes or alleles in the entire population

Variations in populations

Natural selection depends on the variation of traits within a population, but where does this variation come from?

Much of the variation between individuals is due to genetic differences that can be inherited – something that Darwin and his contemporaries observed but did not understand.

Individuals of the same population generally have the same number and types of genes but different alleles (variations of the genes). For example, all humans will have the gene for eye colour, but the alleles they have for this gene may be blue, brown or even hazel. New alleles arise because of small changes in the DNA sequence. Some mutations cause variations in the physical appearance (phenotype) of the individual. For example, it was a single mutation about 6000–10 000 years ago that resulted in one of our ancestors having blue eyes.

All the different types of genes in the entire population can be thought of as a **gene pool** – a pool of genetic information. The gene pool includes all the alleles for all the genes in the population. New alleles arise through changes (or mutations) in the DNA that makes up the genes.

A mutation may give an individual an advantage, making them better able to survive than other individuals within the population.

INVESTIGATION
12.2: What if the habitat of bean prey was changed?
Go to page **392**

This means they have a greater chance of mating and passing their genetic advantage on to their offspring.

Allele frequencies

Populations are always evolving. The frequency of an allele is how common that allele is within a population. The allele frequency is affected by environmental conditions. If the environmental conditions are favourable, then more of that allele is passed on to the next generation.

Mutating moths

In the 1950s, scientists in England documented changes in the colour of the moth species *Biston betularia*. These moths range in colour from light grey to nearly black (Figure 2). During the day, the moths rest motionless on tree trunks. In unpolluted areas, tree trunks are covered with light-grey lichens, against which the light-grey moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so the tree trunks are lichen-free and dark, exposing lighter moths to predation from birds.

It seemed to researchers that, as areas became more polluted, dark moths increased in frequency. In this example, levels of pollution acted as the selection pressure. The darker coloured bark enabled the dark moths to survive (be selected for), and the lighter moths to be eaten (be selected against). Natural selection seemed to be increasing the frequency of the allele for dark colour in the population. This was selection pressure in favour of the 'dark' allele.

Figure 2 Dark-coloured moths of the species *Biston betularia* increased in numbers when air pollution killed lichen on trees. Lighter coloured moths were then more visible to predators and were selected against.

In 1952, strict pollution controls were introduced in England, the lichens returned, and the tree trunks became mostly free of soot. As may have been predicted, selection pressures started to operate in the reverse direction. In areas where pollution levels declined, light moths were selected for, and dark moths selected against. The frequency of dark moths declined.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of chemicals (i.e. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

Check your learning 12.2

Recall and explain

1 Variation in individuals can occur in different ways, but there is only one way in which new alleles can arise. **Identify** this process.

2 Darwin made a series of inferences based on observations he made over 20 years. **Identify** each of Darwin's observations and link these with the appropriate inference he made.

3 **Describe** the selection pressures that caused the allelic frequency of white moths to decrease in England in the 1950s.

4 In your own words, **describe** the mechanism by which natural selection can influence the frequency of alleles in a population.

Apply and analyse

5 Natural selection cannot increase or decrease the frequency of some mutations in a population. **Explain** why this is.

6 You are given 50 red toothpicks and 50 green toothpicks. Using grass as the environment, **construct** an experiment to model natural selection.

7 **Propose** why mutations of somatic (body) cells will have no effect on evolution.

Evaluate and create

8 **Contrast** the concept of 'fitness' as used in mass media with what Darwin meant when he referred to a 'fit' organism and 'survival of the fittest'.

Skill builder: Planning investigations

9 An experiment aims to model the effects of natural selection on the allele frequency of a population. The experiment lists the following materials: 30 red counters, 30 yellow counters and 30 blue counters, and a six-sided die.

a **Propose** a hypothesis for this experiment. (THINK: What is it measuring? What could you manipulate?)

b Write a brief method based on this hypothesis. (THINK: What steps could you achieve with the materials listed? Would you need different materials?)

12.3 Selection pressures can cause divergent or convergent evolution

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

speciation
the process that results in the creation of a new species

allopatric speciation
speciation caused by physical separation of populations

geographic isolation
the isolation of populations based on geography, for example, mountains and rivers

homologous structure
a structure that is found across organisms and has a similar pattern but different function

In this topic, you will learn that:

- selection pressures can cause speciation to occur, where different species evolve as a result of location
- homologous structures are common structures across organisms that have similar patterns but different functions.

When a variation within a species is favoured by the environmental conditions, it is referred to as an **adaptation**. Variations provide 'options' for the species when environmental conditions change. Although individual organisms may die, some members of the population with the favourable phenotype will survive and continue the species gene pool.

Along the way, entire species may become extinct and a new species will emerge, increasing the biodiversity of organisms in the environment.

Under normal conditions, genes in a given population are exchanged through breeding. This means the genes will be passed from one generation to the next as different families or groups in the population choose partners and mate. This is called *gene flow*. However, the gene flow is interrupted if the population becomes divided into two groups so that the groups experience **isolation** from each other. Isolation is not always physical. **Temporal isolation** occurs when different populations reproduce at different times. **Behavioural isolation** occurs when there are differences in behaviour in a species, such as mating rituals. **Mechanical isolation** occurs when two potential mates are physically incompatible. For example, flowers of certain plants vary in size and shape; this excludes certain pollinators from being able to access them.

Over time, different selection pressures occur in the two groups. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding to produce fertile offspring should they ever come together again. They become reproductively isolated and therefore are different species (**speciation**). The two species have then **diverged**.

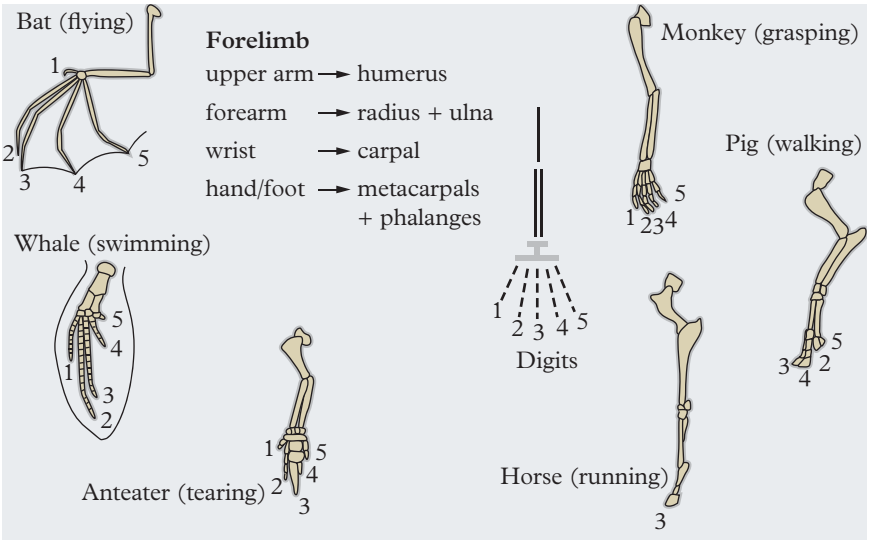

Figure 1 The homologous forelimbs of different mammals show the same basic structure, with a single upper bone, two lower limb bones, small wrist or ankle bones and five digits that are adapted to different uses.

Allopatric speciation

Allopatric speciation occurs when species divide as a result of **geographic isolation**, for example, a mountain range might form or a river might widen. Continental drift also results in geographic isolation. These changes lead to different environmental selective pressures. An example of this is thought to have occurred among rock wallabies in Australia. There are approximately 20 different species of rock wallaby in Australia, which are separated by long distances.

Common structures that are found in different species often have a similar pattern but different function. These structures are known as **homologous structures**.

The most commonly discussed homologous structure is the **pentadactyl limb** – the pattern of limb bones in all groups of tetrapods (i.e. four-legged vertebrates) that ends in five digits (Figure 1). This structure is found in the fins of certain fossil fishes from which the first amphibians are thought to have evolved. Throughout the tetrapods, the basic structure of the pentadactyl limbs is the same.

This indicates that these organisms originated from a common ancestor. However, during the course of evolution, these structures have become modified and are used for different purposes as a result of different selection pressures.

Analogous structures are structures in organisms that perform the same function but are structurally different (suggesting no recent common ancestor). For example, a dolphin (mammal) and a shark (fish) have the same environmental selection pressures. This is an example of **convergent evolution**. The wings of birds and butterflies are also analogous structures.

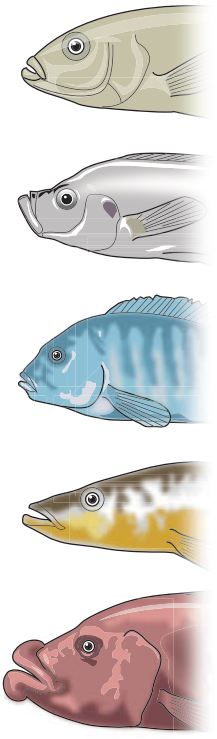

Figure 2 Sympatric speciation may explain the diversity of African cichlid fish that consume different food sources.

pentadactyl limb
a limb with five digits

analogous structure
a structure that is found across organisms and performs the same function but is structurally different

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

sympatric speciation
speciation caused by reproductive separation of populations that maintain physical contact

Sympatric speciation

Sympatric speciation is where new species arise within an existing species that share the same geographical location. Sympatric speciation is more common in plants than animals and may be the result of the failure of chromosome separation during meiosis or the cross between two species. The new species that results from this cannot breed with the parent species, though plants may be able to reproduce asexually.

Sympatric speciation commonly occurs where individuals of a species take advantage of a niche. A niche is a small area within a habitat that has specific and limited conditions. Sympatric speciation is less common than allopatric speciation because there is not disruption to gene flow.

African cichlid fish are an example of sympatric speciation. They live in some African lakes, where the competition for resources is so great that the isolation of populations without a physical barrier may have occurred.

Check your learning 12.3

Recall and explain

1 **Explain**, using an example, how physical isolation could create a new species.

2 **Define** the term 'homologous structure'.

Apply and analyse

3 **Identify** two ways in which populations of a species may become isolated.

4 **Compare** and **contrast** the two main processes of speciation.

Skill builder: Questioning and predicting

5 Imagine creatures similar to animals have been found on a planet previously thought to be uninhabited. Scientists have noticed that there appear to be two species. These two species look the same except that one is blue and one is pink. Between the two species there is a valley; either side of the valley has different coloured flowers that the species eat. There also appear to be young species that are both colours.

Predict the type of speciation that has occurred here. (THINK: What are the similarities and differences? What key information do you have?)

12.4 Fossils provide evidence of evolution

In this topic, you will learn that:

- fossils support the theory of evolution; they are traces or remains of an organism that once existed – they form when an organism dies and is buried without oxygen
- transitional fossils show traits of two groups of organisms
- relative dating determines the relative order the fossilised remains were buried; older fossils are buried under deeper layers than more recent fossils.

Figure 1 The fossil of *Archaeopteryx* is an important transitional fossil. It displays a number of features common to both birds (hollow wishbone and feathers) and reptiles (teeth, flat sternum/breastbone, three claws on the end of its wings and a long bony tail).

absolute dating
a method that uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age

fossil
the remains or traces of an organism that once existed

fossilisation
the process of an organism becoming a fossil

transitional fossil
a fossil or an organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

half-life
the time it takes for half the nuclei of a radioisotope to decay

The existence of fossils is one form of evidence supporting evolution. Fossils are remains or traces of an organism that once existed. The fossilisation process requires the dead organism to be buried rapidly, remain relatively undisturbed and be in an environment that is without oxygen. Transitional fossils are intermediary fossils that have traits of two groups of organism, such as birds and reptiles. Relative dating determines the relative order the fossilised remains were buried. Older fossils are found in deeper layers than more recent fossils. **Absolute dating** uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age.

Evolution

Support for any theory, including evolution, requires evidence from a range of sources that all point towards the same explanation. Early evidence for evolution came from the discovery of fossils that identified extinct species. Evidence of large-scale extinctions reinforced the fact that life forms change with changing environmental pressures – even if that simply means that many die and only a few survive.

What are fossils?

Fossils are the remains or traces (footprints, imprints, or coprolite or fossilised faeces) of organisms from a past geological age embedded in rocks or other substances by natural processes.

Fossilisation requires the organism, or its traces, to be buried quickly so that weathering and total decomposition do not occur. Skeletal structures or other hard parts of the organisms that resist weathering are slower to decompose. These are the most common form of fossilised remains. Figure 2 shows how the process of fossilisation occurs.

Transitional fossils

Darwin's theory suggests that life originated in the sea, crawled onto land and then took to the skies or grew fur. The evidence that links these stages is in the form of **transitional fossils**, which are sometimes referred to as 'missing links', although the reality is a 'chain of missing links'.

When Darwin first published his theory, he stressed that the lack of transitional fossils was the largest obstacle to his theory because, at that time, very little was known about the fossil record. Since then, many excellent examples of transitional fossils have been found, such as *Archaeopteryx*, which was discovered in the Solnhofen area of Germany just two years after Darwin's work was published.

Dating fossils

It is possible to find out how a particular group of organisms evolved by arranging its fossil records in a chronological sequence. Relative dating can provide approximate dates for most fossils because fossils are found in sedimentary rock. Sedimentary rock is formed by layers (or strata) of silt or mud on top of each other (Figure 3). The deeper the layer, the older the rock. Each layer contains fossils that are typical for that specific time period. Older fossils are buried deeper than younger fossils.

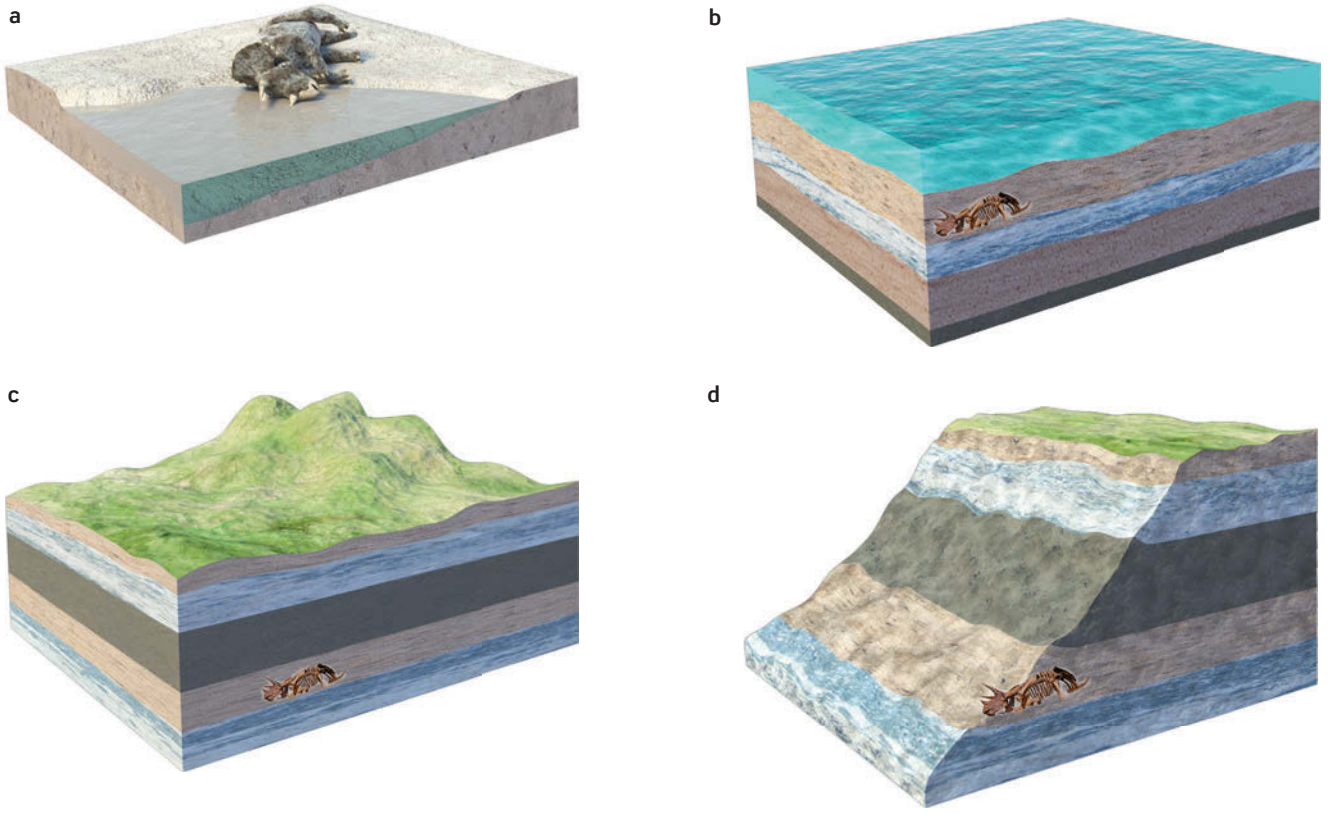

Figure 2 Formation of a fossil. **a** and **b** If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. **c** Over millions of years, more sediment is deposited and the remains are transformed gradually into sedimentary rock. **d** Years of geological movement, weathering and erosion may eventually expose the fossil.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils. Absolute dating relies on the level of radioactivity in rocks containing radioisotopes. Every living organism maintains a constant low level of radiation. When an organism dies, the amount of radioactivity starts decreasing. The time it takes for half the radioactivity to decrease is called the **half-life**. In one half-life, there is a 50% decrease in the initial radioactivity level. In the second half-life, the remaining radioactivity decreases by half again, leaving only 25% of the starting radioactivity level. This will continue until only very small levels of radioactivity are left. If scientists know the length of an element's half-life, they can determine how many half-lives have passed by measuring the amount of radioactivity. Therefore, they can determine the age of the fossil or rock.

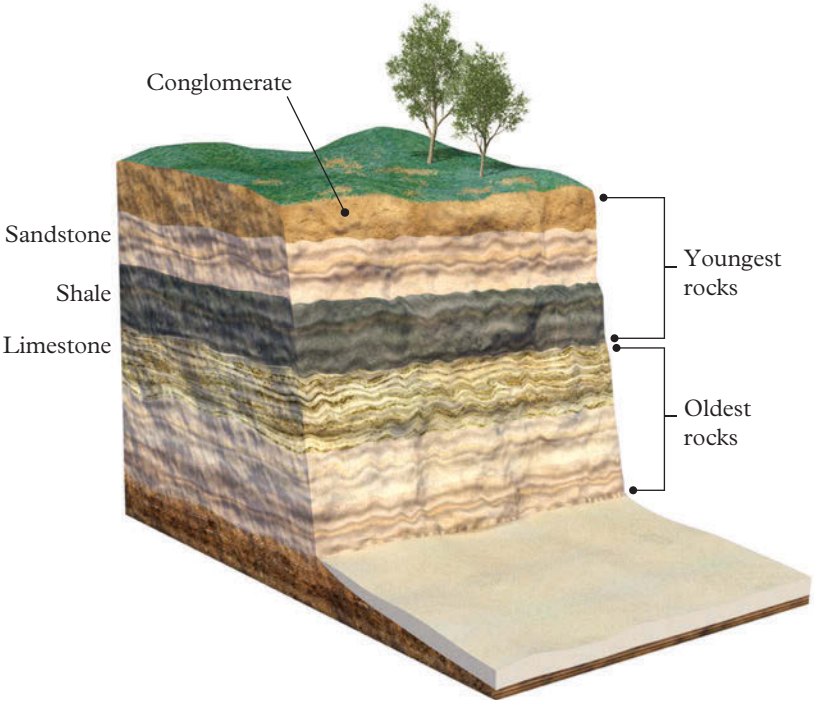

Figure 3 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.

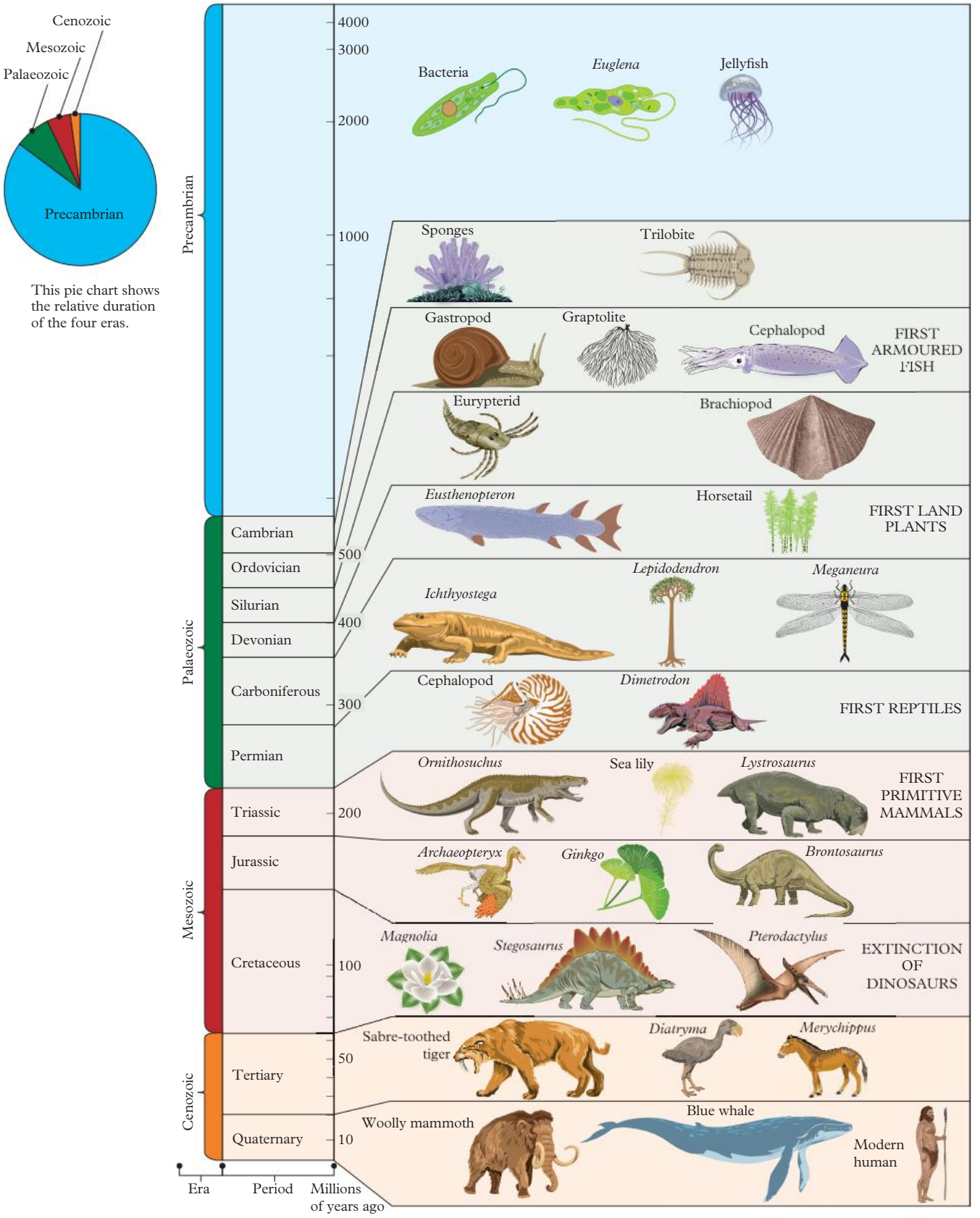

Figure 4 The history of living things, as determined by palaeontology (the study of fossils)

Figure 5 Fossil stromatolites in Pilbara, Western Australia

Living fossils

According to fossil records, some modern species of plants and animals are almost identical to species that lived in ancient geological ages. **Living fossils** are existing species of ancient lineages that have not changed in form for a very long time. This means the selection pressures for these organisms have not changed and therefore there is no selection pressure for the organism to change.

Figure 6 Unique in the animal kingdom, the coelacanth is a 400-million-year-old species of living fossil fish. The coelacanth pre-dates dinosaurs by millions of years and was thought to have become extinct with them. In 1938, the coelacanth was discovered living in caves off the continental shelf. This environment has changed little over the past 400 million years and, as a result, neither has the coelacanth.

living fossil
an existing species of ancient lineage that has remained unchanged in form for a very long time

Check your learning 12.4

Recall and explain

1 **Recall** the parts of an organism that are most likely to be found in fossils. **Explain** your answer.
2 **Explain** how relative dating works and why it is often used before absolute dating is used.
3 **Describe** what a transitional fossil is.
4 Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. **Explain** how this has been possible.

Apply and analyse

5 **Discuss** how observations of extant (living) organisms might contribute to the evidence for evolution.

Evaluate and create

6 **Discuss** methods you could use to **investigate** the hypothesis that birds are more closely related to reptiles than to mammals.
7 Some people argue that the theory of evolution is just 'one' theory on how new species arise. **Assess** the difference between a scientific theory and the common usage of the word 'theory'.

Skill builder: Processing and analysing data and information

8 Fossils were found at four locations (see Figure 7). Use relative dating to **deduce** which fossil is the oldest.
(THINK: What evidence is there in the image? What do the different types of soil tell you?)

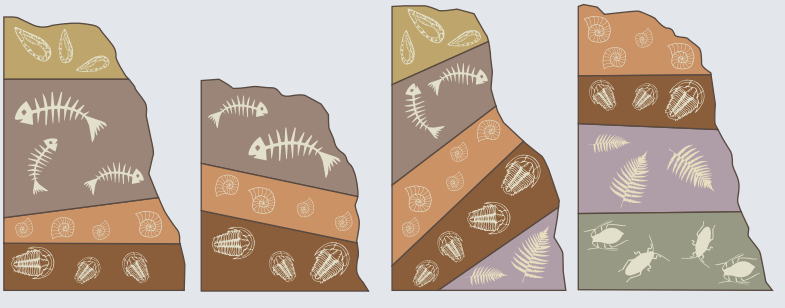

Figure 7 Fossils found at four locations

12.5 Multiple forms of evidence support evolution

In this topic, you will learn that:

- biogeography is the study of how the continents move across the Earth and how this affects the location of organisms
- Pangaea was a supercontinent that broke into Laurasia and Gondwana and when this happened organisms diverged
- comparative embryology compares embryos of different animals: the closer the relationship between species, the more similar the embryos are
- comparative anatomy compares structures of different animals: the more closely related the species, the more similar the structures appear.

biogeography
the study of the geographical distribution of animals and plants

Biogeography studies the geographical distribution of animals and plants. The breaking up of the supercontinent Pangaea into Laurasia and Gondwana caused the isolation of populations of different species. As continental drift occurred, environmental conditions changed, the isolated populations evolved, and speciation occurred. The comparison of embryos and adult anatomy of different species also provides overwhelming evidence for the theory of evolution.

Figure 1 The jigsaw fit of Africa and South America supports the theory of continental drift.

Biogeography

At the beginning of the 17th century, the English philosopher Francis Bacon noted that the east coast of South America and the west coast of Africa looked as though they could fit together like pieces of a jigsaw (Figure 1). Since then, our knowledge of the structure of the Earth has developed, and the theory of continental drift through plate tectonics continues to be supported by observations of various phenomena across the planet. It is now thought that at one time all the continents were connected in a single landmass – Pangaea (Figure 2). This supercontinent then broke in two to form Gondwana in the south and Laurasia north of the Equator.

The theory of continental drift has had a major impact on evolutionary theory because living organisms were carried on the landmasses.

The distribution of the fossils of extinct plants and animals, as well as modern-day species, supports the theory of continental drift (Figure 3). Some continents have very similar organisms even though they are separated by large stretches of ocean. Animals that can fly or swim could travel from continent to continent, but for the rest, continental drift is the only convincing explanation for their distribution.

Continental drift provides a well-supported explanation for the geographical isolation of species that eventually results in speciation – divergent evolution. Groups of similar species, such as the ratites (flightless birds), and the existence of marsupials on several continents can be explained by biogeography (Figures 3 and 4).

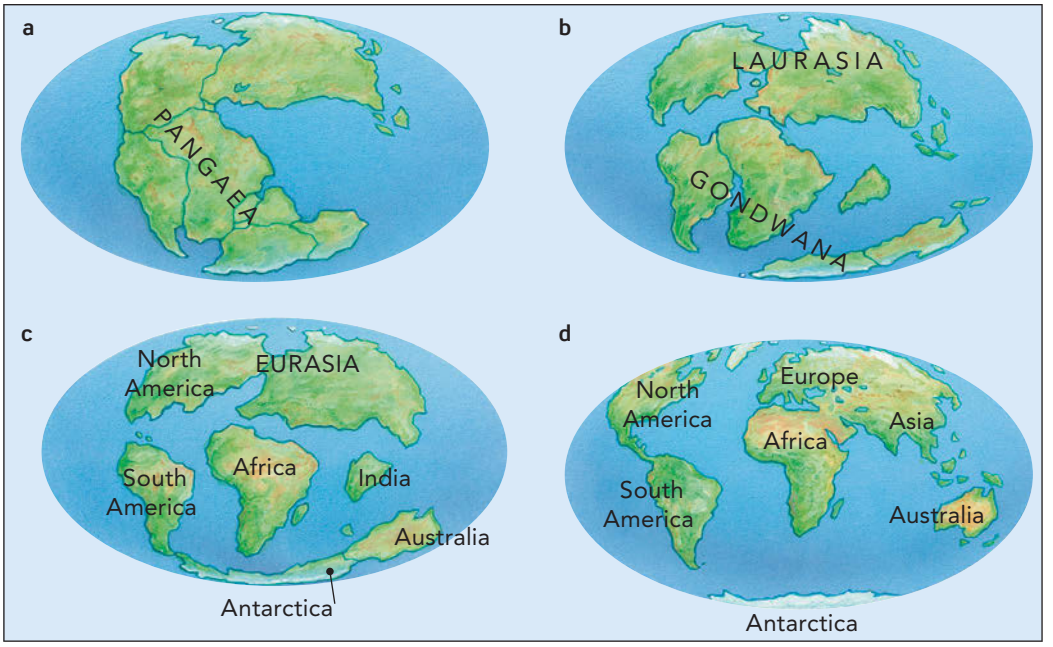

Figure 2 How the continents have drifted: **a** 220 million years ago; **b** 135 million years ago; **c** 65 million years ago; and **d** today.

'Coincidence' is simply not a scientific explanation.

Comparative anatomy and vestigial structures

In section 12.3 you examined homologous structures of seemingly unrelated species. The pentadactyl limb provides strong evidence of a shared ancestry between the different species.

Vestigial structures are functionless structures found in organisms. They have puzzled naturalists throughout history and were noted long before Darwin first proposed the concept of evolution from a common ancestor (also called common descent). We now understand that individual organisms contain, within their bodies, abundant evidence of their histories. Some of these structures are clearly selected to perform a certain function that is

vestigial structure
a structure in an organism that no longer has an apparent purpose

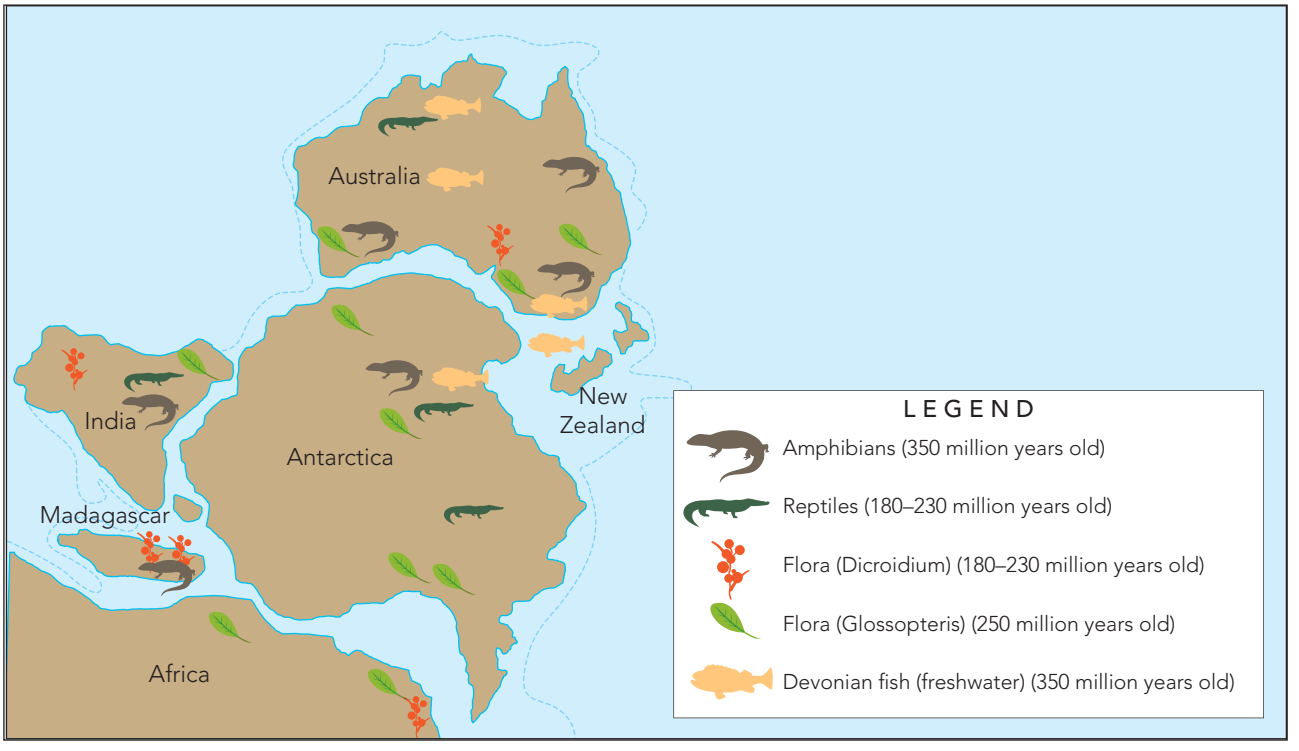

Figure 3 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

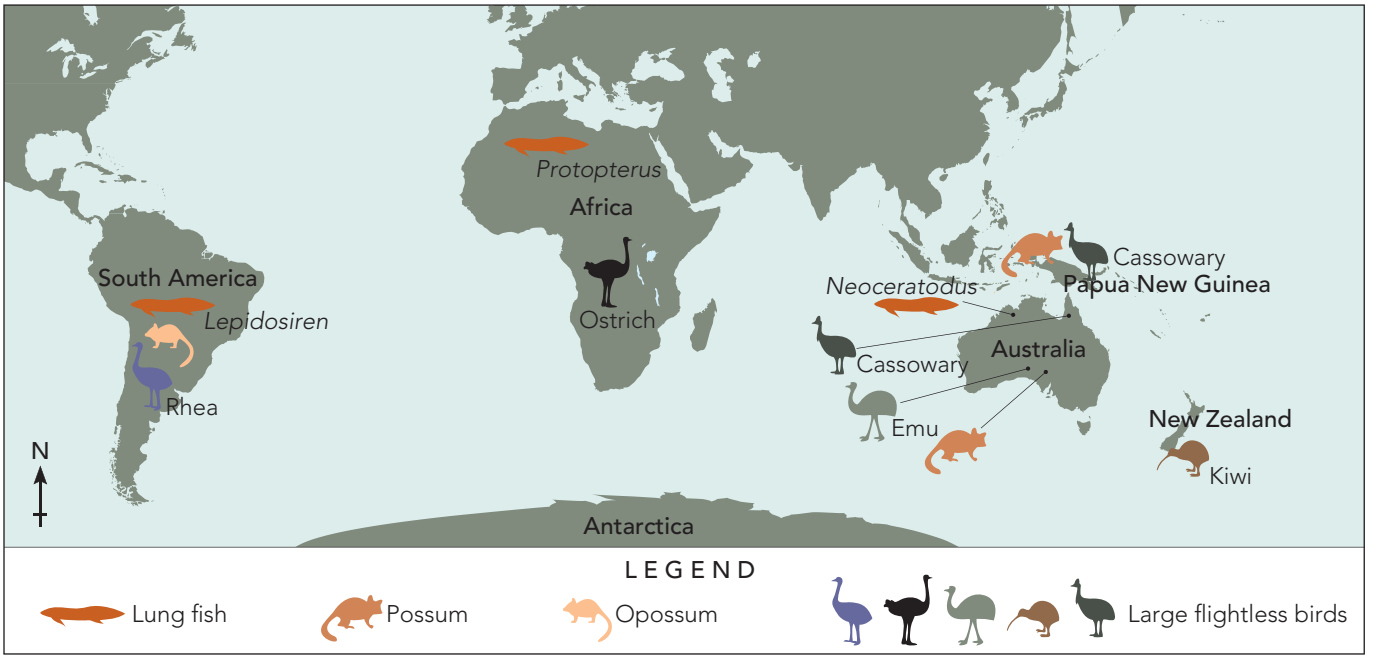

Figure 4 Similar lungfish are found in South America, Africa and Australia. Similar marsupials are found in South America and Australia.

no longer required. However, these features were not selected against and so they remained. Without the theory of evolution, the tiny wings of a cassowary are a puzzling structure. So, too, are the hindlimb buds of many snake species, which still carry vestigial pelvises hidden beneath their skin.

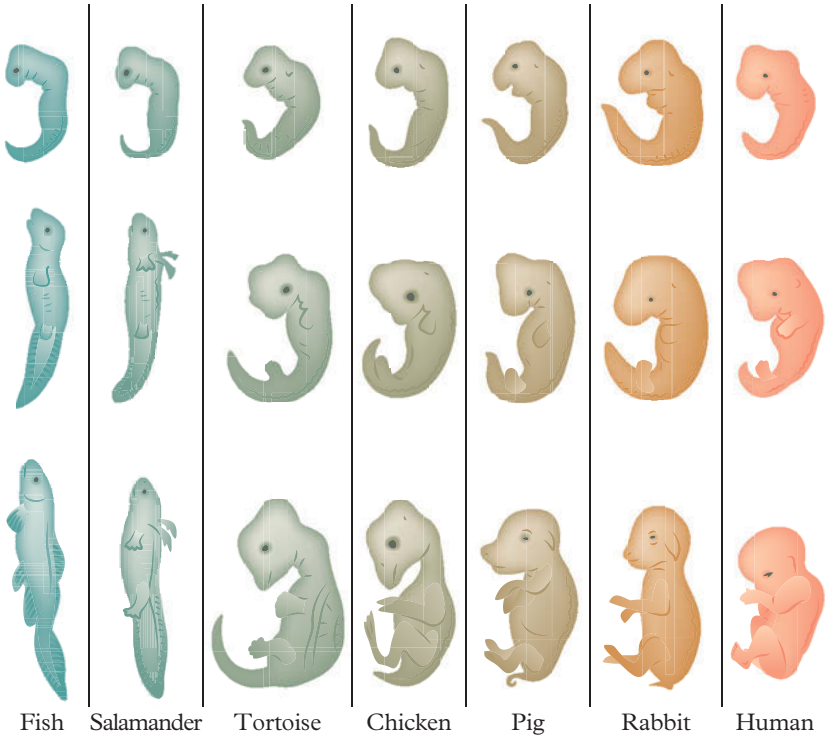

Figure 5 Common structures in the embryonic development of vertebrates

Vestigial structures are now interpreted as evidence of an ancestral heritage in which these structures once performed other tasks. The wings of a cassowary are a reminder that a distant relative of this organism once used its wings to fly. Similarly, snakes evolved from a four-legged ancestor. Humans, too, carry the evolutionary baggage of our ancestry. The ancestors of humans are known to have been herbivorous, and molar teeth are required for chewing and grinding plant material. More than 90% of all adult humans develop third molars (otherwise known as 'wisdom teeth'). Usually these teeth never erupt from the gums, and in one-third of all individuals they are malformed and impacted. These useless teeth can cause significant pain and an increased risk of injury and may result in illness and even death.

Comparative embryology

Scientists have noticed that, although adult vertebrates have certain differences, many embryos demonstrate similarities during the early stages of development. For example, a chicken and a human are very different when fully formed, but chicken embryos are very similar to human embryos (Figure 5). Even reptile embryos are similar to human embryos. Embryos may also show many interesting features that are not seen in the fully developed animal. As the embryo develops, it goes through

a variety of stages. Many of these stages show homologous structures with different species. Furthermore, the more recent the common ancestor, the more similar the embryos appear for a longer period of time; for example, fish and amphibians, and reptiles and birds.

If the various life forms developed independently, one would think that their embryonic development would be different and reflect what the organism would look like when it was fully developed.

It would make more sense for a horse to develop a hoof directly rather than first develop five finger-like digits that are then modified into a hoof.

The embryological similarities are explained by inferring that these organisms all had a common ancestry with common genes. Whales start developing teeth embryonically because they evolved from ancestors that had the genes for teeth. Human embryos develop gill-like structures and tails during their early development because they have the genes for these structures. These genes get turned up or down or 'switched off' during later stages of development.

Figure 6 As an embryo, the 'finger genes' of the bat become more active. As a result, the bat's fingers grow much faster than the fingers of other embryos.

For example, the gene for a bat's fingers become 'supercharged' during embryological development so that the fingers start growing faster than the rest of the body. This makes the fingers of the bat extra-long compared to the rest of its body. The long fingers then develop into support structures in the bat's wing.

Resource
STEM activity: Wallabat evolution

Check your learning 12.5

Recall and explain

1 The frogs of Australia show their closest evolutionary relationships to frogs in Africa and South America. **Explain** how this is possible. Did humans carry them on boats?

2 **Explain** the presence of similar extinct plant species in Antarctica, Australia, Africa and South America.

3 **Identify** which of the following species are more closely related: humans, great white shark, dolphin. **Justify** your answer.

Apply and analyse

4 **Explain** why human embryos temporarily develop gill-like structures.

5 If native marsupials were found in North America, would this disprove the theory of continental drift? **Explain** your answer.

6 **Explain** how the presence of vestigial structures supports the theory of evolution.

7 **Discuss** how the gene that forms fingers can be changed to form the wings on a bat.

Evaluate and create

8 Create a short presentation to **explain** the theory of evolution and the evidence for it.

Skill builder: Problem solving

9 Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years.

a **Explain** how this information could be used to support the theory of continental drift, and how this could impact the theory of evolution. (THINK: What does this evidence suggest?
Can you think of a scientific theory to apply to this evidence?)

b **Identify** the information that would support how this could change the theory of evolution. (THINK: What is the theory of evolution based on? Is this information more likely to support or refute the theory of evolution?)

12.6 DNA and proteins provide chemical evidence for evolution

In this topic, you will learn that:

- the basic structure of DNA and proteins is identical for all species on Earth
- mutations can cause small differences in the nucleotide sequences of amino acids that can be used to determine the evolutionary relationship between species.

Comparing amino acids in proteins

Proteins are like long necklaces made up of a series of beads. The beads are called amino acids. Genes in DNA provide the instructions for the order of the amino acid beads. Proteins range in size from approximately 50 to thousands of amino acids and are among the most important molecules of life. They can be structural molecules that support cell integrity, enzymes that control chemical reactions, or hormones, the chemical messengers in the body. The characteristics and function of a protein are determined by the order or sequence of amino acids.

All organisms use the same 20 amino acids to make proteins. If life evolved from a common ancestor with only these 20 amino acids, we may expect that these same amino acids are always used.

The same type of proteins in different species can be very much alike (conserved). *Cytochrome c* is one such example. Several types of cytochrome c proteins are found among different vertebrates and invertebrates. These cytochrome molecules are all very similar in structure, and all serve the function of making energy in the cell (through cellular respiration), yet the order of their amino acid sequences can be slightly different (Table 1).

Comparing the sequence of amino acids in a protein can show the evolutionary relationship between different species. Before the two species diverge, they will have exactly the same protein with an identical sequence of amino acids. When the two species diverge, the number of mutations gradually accumulates. This may not affect the structure or function of the protein, but it can change a few amino acids in the long chain. The more time that passes, the more the changes to the amino acid sequence can accumulate. Therefore, the more similar the proteins, the more closely related the species. This means organisms with similar proteins share a very recent common ancestor.

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of gene sequences. Comparing DNA sequences examines the relationship between different species. If the theory of evolution is supported, then species that share a common ancestor will have inherited that ancestor's DNA sequence. Any mutations (permanent changes in the order of DNA nucleotides) will cause slight differences

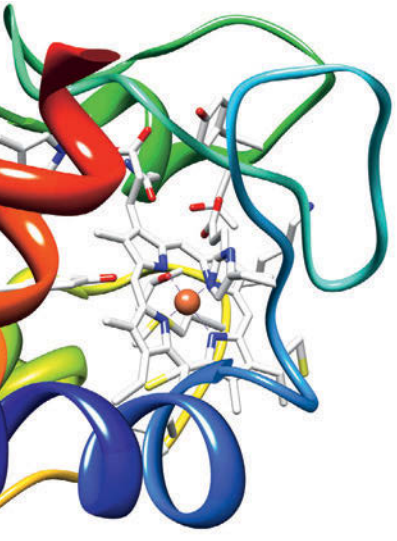

Figure 1 There are many different sequences of amino acids that could make a functional cytochrome c molecule.

Table 1 The sequence of amino acids that make up cytochrome c in different animals

Human	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile
Chicken	He	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Val
Lungfish	Val	Glu	Lys	Gly	Lys	Lys	Val	Phe	Val
Fly	Val	Glu	Lys	Gly	Lys	Lys	Leu	Phe	Val

Note: Val = Valine; Glu = Glutamic acid; Lys = Lysine; Gly = Glycine; Ile = Isoleucine; Phe = Phenylalanine; Leu = Leucine.

between the species. The more alike the two DNA sequences are, the more closely related the two species are. The more differences in the DNA sequence, the more time has passed since they had a common ancestor and the less related the species are now.

The human genome project has revealed the full nucleotide sequence of the human genome. This has allowed scientists to demonstrate evolutionary similarities and differences between humans and chimpanzees, gorillas and orangutans (our closest living relatives). Each of these species has 48 chromosomes. This sequencing has indicated there is a shared common ancestor and an evolutionary event where a pair of chromosomes fused to create the human 46 chromosome karyotype. The chimpanzee has a 98% similar genome to humans.

Phylogenetic trees

Before scientists were able to compare proteins and DNA, they examined the structures of organisms to determine if they were related. The difficulty with this is some organisms, such as dolphins and sharks, look very similar because of convergent evolution. Currently, scientists use the differences in DNA sequences to compare the **evolutionary relationship**. This relationship is shown in a phylogenetic tree (Figure 2).

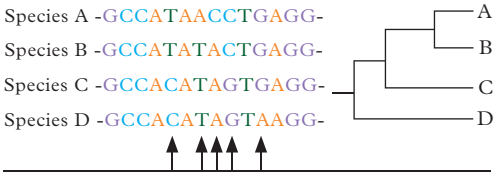

Figure 2 Comparing the DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is more closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

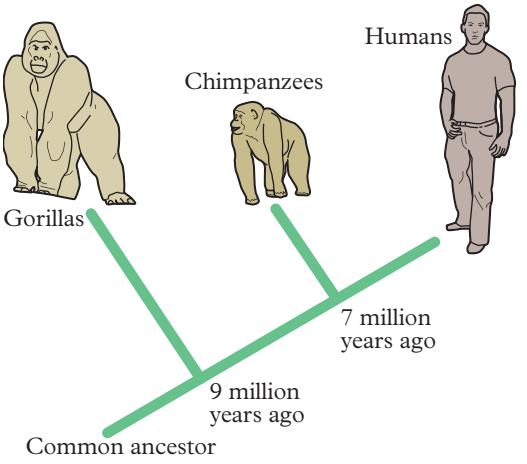

Figure 3 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

evolutionary relationship a relationship that is based on distant common ancestry

Check your learning 12.6

Recall and explain

1 **Explain** what causes gradual changes to the sequence of nucleotides in DNA.

Apply and analyse

2 Table 1 shows a small section of the cytochrome c molecule for humans, chickens, lungfish and flies. **Identify** which species shows the greatest similarity to humans. **Justify** your answer.

Evaluate and create

3 In small groups, create a summary table of the different lines of evidence for the theory of evolution that have been covered in this chapter. Then present your group's summary to the class.

Skill builder: Processing and analysing data and information

4 Interpret the phylogenetic tree in Figure 4 to determine which species is most closely related to species A.

a **Identify** the species that are more closely related. (THINK: Where are they on the tree?)

b **Explain** how you knew this from the phylogenetic tree. (THINK: What is their relationship?)

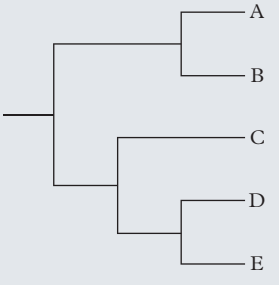

Figure 4 A phylogenetic tree

12.7 Humans influence natural selection

In this topic, you will learn that:

- humans have influenced natural selection through a range of activities
- antibiotic-resistant bacteria pose a significant threat to human health
- pesticide-resistant insects pose a significant threat to food production.

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

selective breeding
the breeding of individuals with desirable traits

Humans play a role in evolution, both intentionally and unintentionally. New breeds and species of domestic animals and plants are created by artificial selection. These breeds and species make it possible to feed and clothe the rapidly growing human population. However, our use of pesticides and antibiotics has had unintended negative consequences. Natural selection has led to the rise of insect pest populations that no longer respond to pesticides and bacteria that are immune to the effects of antibiotics.

Selective breeding and artificial selection

Artificial selection is when humans selectively breed organisms that have desirable traits. This increases the likelihood of that trait occurring in the next generation. Over time, these organisms become domesticated and dependent on humans for survival.

Humans have practised **selective breeding** for more than 10 000 years. When many human populations moved from the hunter–gatherer way of life to more permanent settled communities, they captured and tamed wildlife for their own purposes. Wild sheep grew wool in winter climates to keep warm. During the warmer summer months, they shed their wool in large clumps. Early humans chose the wild sheep that produced the most wool and bred from them. A random mutation caused the wool to grow all year round. These sheep were selected by breeders, and the offspring of these wild animals became more reliant on humans to survive. Over many generations, the 'wild' traits were lost and the species was considered 'domesticated'.

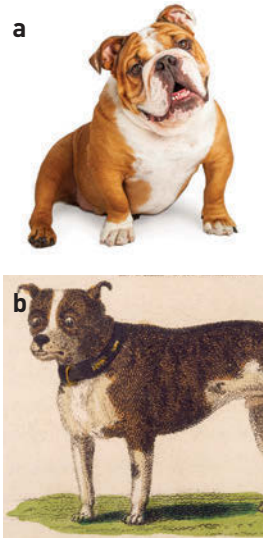

Figure 1 a Modern bulldog and **b** the bulldog of 200 years ago. Over the last 200 years, bulldogs with flat faces have been selected for breeding, which has resulted in birthing difficulties. Up to 90% of bulldogs are born by caesarean.

Evolution of antibiotic-resistant bacteria

The first true antibiotic, penicillin, was introduced in the 1940s, and by the 1960s had widespread use. The introduction of penicillin to treat disease caused by bacterial infection eventually resulted in the rise of penicillin-resistant bacteria.

One of the deadliest bacteria in hospitals is methicillin-resistant *Staphylococcus aureus* (MRSA or golden staph). It is a result of humans overusing and misusing antibiotics. *Staphylococcus aureus* is normally found on the skin and in the noses and throats of many individuals in the population. Antibiotics prevent these cells from repairing or producing new cell walls, causing the cells to die rather than reproduce. In some populations, random mutations caused a *Staphylococcus aureus* cell to be unaffected by antibiotics. These bacteria are then considered to be resistant to the current range of antibiotics.

When a person has a bacterial infection, a doctor will often prescribe an antibiotic. If there is a single bacterium present that is able to resist the antibiotic for a short time, then it will survive longer than the rest of the bacteria. If the person feels better and stops taking the antibiotic, that partially resistant bacteria will start reproducing again through a process called **binary fission**. This makes the person sick again, so they take the rest of the antibiotics. Once again, the partially resistant bacteria slows its growth, but this time another random mutation causes a fully resistant bacteria to start growing.

Sometimes the gene for antibiotic resistance can be transferred from one bacteria to another in a process called **horizontal transfer**. Because bacteria reproduce so quickly, they are able to evolve quickly and adapt to new conditions.

Evolution of pesticide-resistant insects

The pesticide DDT (dichlorodiphenyltrichloroethane) was introduced in the 1940s to kill insects that spread human disease, such as mosquitoes, which transmit malaria. The program was a great success. For example, the number of malaria cases in Sri Lanka was reduced from 3 million per year before the program to just 18 in 1963. Five or six years after the start of spraying for both mosquito control and agricultural use, insects resistant to DDT began to increase. Those that were not resistant died, while those that were resistant survived, bred and passed on their resistant genes to following generations. DDT is now virtually useless for mosquito control in Sri Lanka and many other countries.

As insects gained resistance to DDT, other pesticides were developed.

There are now four major classes of pesticides in use across the globe. In all cases, insects have developed resistance to the chemicals within several years. This raises significant concerns for world food production.

Evolution of viruses

Viruses affect humans every year. One of the most common viruses is influenza. It is common for people to receive a flu vaccination each year to reduce the likelihood of them catching influenza. The rate of mutation of the influenza virus results in the evolution of dozens of new strains each year. In the race to continue human survival, health authorities across the globe continually monitor the annual spread of influenza strains and develop new vaccines in response to the mutations.

New viruses are continually forming, and each requires a vaccine to prevent spread among the human population.

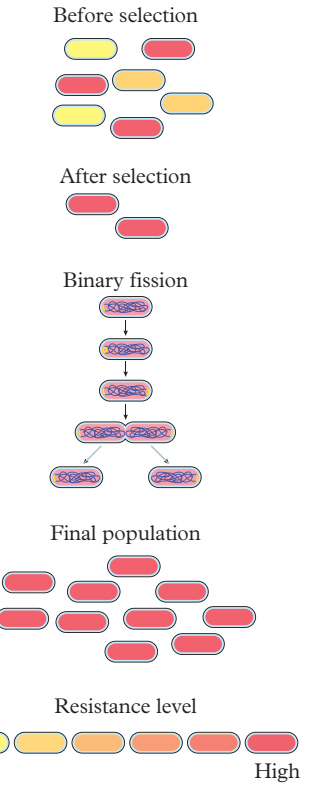

Figure 2 Frequent use of antibiotics selects for bacteria that are resistant to antibiotics. This increases the allelic frequency of resistance.

binary fission
form of asexual reproduction used by bacteria

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) between different bacteria

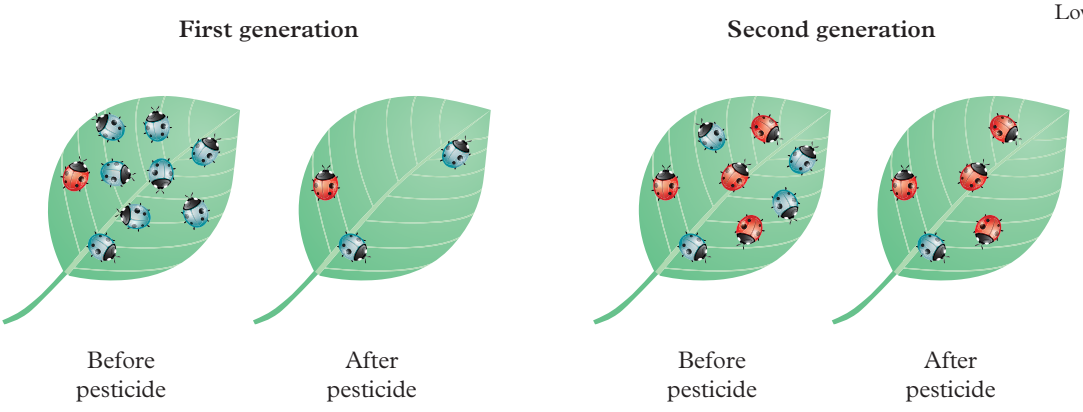

Figure 3 The effect of pesticide resistance

Check your learning 12.7

Recall and explain

1 **Explain** what selective breeding is.
2 **Summarise** what MRSA is.

Apply and analyse

3 A student claimed that artificial selection has interfered with nature. Provide two reasons to support their claim. Provide two reasons that disagree with their claim. **Assess** which view you agree with.

Evaluate and create

4 **Investigate** an animal or plant species that humans have influenced by artificial selection; for example, dogs, cats, corn, broccoli. Create a short presentation.

Skill builder: Problem solving

5 Humans are susceptible to bacteria and viruses. Consider how the misuse of antibiotics contributed to the existence of MRSA.

a Write a pros and cons list for the use of antibiotics. (THINK: Do the benefits outweigh the negatives? Are there equal pros and cons?)

b **Apply** your understanding of antibiotics to the MRSA bacteria. (THINK: What is the impact of the pros and cons on this situation?)

12.8* Nature versus nurture

In this topic, you will learn that:

- epigenetics studies how the environment causes changes in gene expression without actually changing the genetic code itself.

The relative influence of nature versus nurture (genes versus environment) on making an individual who they are has been a long-standing debate. The general consensus, however, is that both play a role and depending on the trait being studied one may be more influential than the other.

Epigenetics

Cells from different tissue types will have very different structures and distinct functions. But how is that possible if each cell in the body contains the same genetic information? The answer is epigenetics.

epigenetics
the study of how gene expression is influenced by the environment

Epigenetics is the study of how the environment causes changes in gene expression without actually changing the genetic code itself (mutation). For example, histone modification (the protein around which DNA coils) can tighten or relax regions of DNA and in doing so impact the ability of genes to be 'read'. This leads to different proteins or different amounts of the same protein being produced between cells.

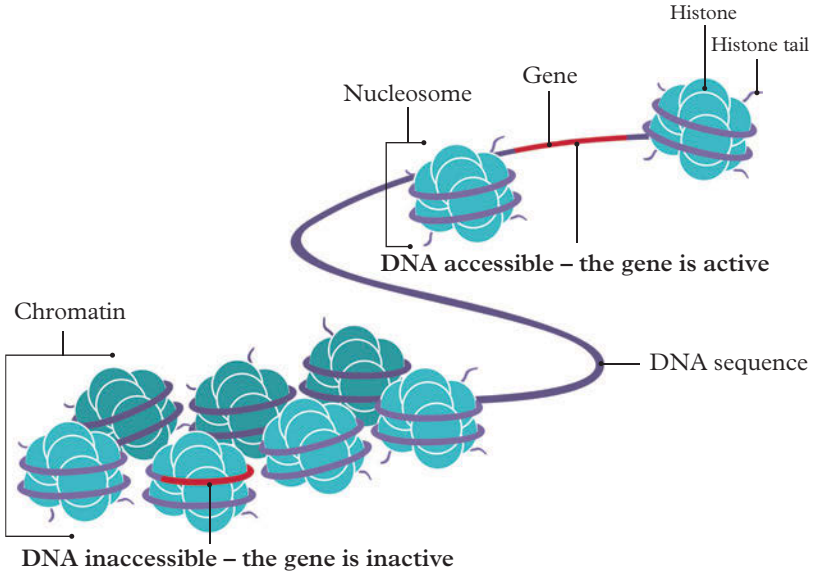

Figure 1 DNA wrapped around histone proteins. The degree of packing can influence gene expression.

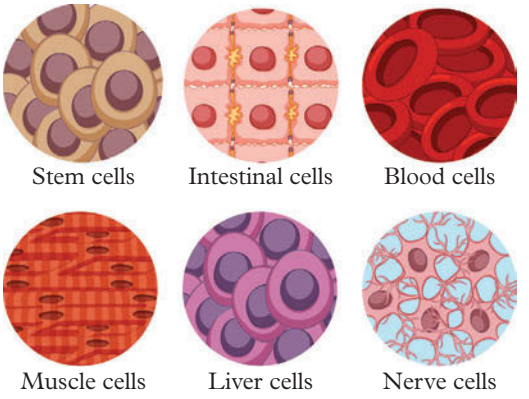

Figure 2 Despite the same genetic material, cell types differ due to different gene expression.

Environmental factors, including diet, work and life events can all influence epigenetics. It is also important to understand that the environment doesn't begin after birth. Foetus development is heavily influenced by the blood exchange that occurs with the mother via the placenta. The mother's diet and general health, for example, influence gene expression within the foetus.

Once a person is born, gene expression is influenced by nutritional intake, relationships with family members and the behaviour and action of those individuals.

Twin studies

Studies have indicated that the influence of the environment on genetics impacts personality and behaviour. This is best evidenced in the study of twins, both identical and fraternal. Because identical twins share the same DNA, any trait that occurs in both less than 100% of the time is influenced by the environment. This can be compared to the occurrence of the trait in fraternal twins (who are no more genetically identical than non-twin siblings) to determine the extent the trait is genetic. Schizophrenia has been studied in twins to determine the relative influence of genes and environment. If an identical twin suffers from schizophrenia, there is a 50% likelihood that the other twin

will have the disease. In fraternal twins this drops to around 15%. This indicates a strong genetic link that can also be influenced by environmental factors.

Identical twins separated at birth are of particular interest. Studies have provided examples of twins with similar habits, interests, careers and even those that have married partners with the same name and then given the same names to their children and pets, all despite being separated decades before.

Gene versus environment studies

Several genes can influence the likelihood of an individual developing a disease. Some examples of this include the following.

- Apolipoprotein E or apoE – Changes in this protein have been linked to the development of Alzheimer's disease. There are three types of the protein: apoE2, apoE3 and apoE4. An individual homozygous for apoE4 is 15 times more likely to develop Alzheimer's, but it is not a guarantee an individual will develop Alzheimer's.
- BRCA1 and BRCA2 are genes coded for proteins involved in cell growth and the repair of damaged DNA. Mutations in these genes are associated with increased risk of developing breast or ovarian cancer but having these mutations does not guarantee an individual will develop these.

Every human on the planet has a gene that is responsible for the production of haemoglobin, the protein responsible for carrying oxygen in red blood cells. Individuals that live at higher altitudes produce higher amounts of haemoglobin. This is a response to the environmental change in altitude. Producing more haemoglobin means the body can utilise more of the available oxygen.

These examples all demonstrate that interaction between genes and environment will influence an individual's phenotype.

Environmental conditions affect plant phenotype

Hydrangeas are a species of plant grown for its flower colour. It can be grown asexually through cuttings. As the name suggests, this involves taking a cutting of a branch below a leaf bud and dipping it in rooting hormone before placing it in soil. Each of the cuttings are genetically identical (clones) of the parent plant. The colour of the flowers, however, can be different depending on the soil pH. This clearly indicates that the environment has determined the colour of the flower.

Figure 3 Twin studies indicate a strong genetic link can be influenced by environmental factors.

Check your learning 12.8

Recall and explain

1 **Define** epigenetics.

2 **Explain** how human cells have distinct structures and functions despite having exactly the same DNA.

Apply and analyse

3 **Explain** the importance of twins in studying the influence of genes and environment on the appearance of an individual.

4 Design a plant experiment that tests the effect of an environmental factor on the physical appearance of individuals within a population.

Evaluate and create

5 **Evaluate** this claim: 'Genes are more important than environment for the survival of an organism in a population.' **Justify** your answer.

Skill builder: Communicating

6 Male bees have no father, they have a grandfather, they can be a father to daughters, and they can have granddaughters and grandsons, but they can't have sons. A new queen starts as a genetically identical larvae to the other female larvae. However, the queen bee in waiting is fed a different diet of 'royal jelly', which significantly influences her life outcomes. **Investigate** and **explain** the genetic and environmental influences that determine each of the described honeybee scenarios.

Present this information in short clear dot points. (THINK: What is the key information? How can I present this as dot points? Should I use subheadings?)

REVIEW

Multiple choice

1 **Identify** the evolutionary theory which proposed that organisms acquired inherited characteristics.
- **A** Darwinism
- **B** Lamarckian theory
- **C** Wallace's theory
- **D** Natural selection

2 When different populations reproduce at different times this is called:
- **A** temporal isolation
- **B** speciation
- **C** behavioural isolation
- **D** mechanical isolation.

3 Relative dating is used to work out the age of rocks. Look at Figure 1 to determine which is likely the oldest of the layers.
- **A** Conglomerate
- **B** Limestone
- **C** Shale
- **D** Sandstone

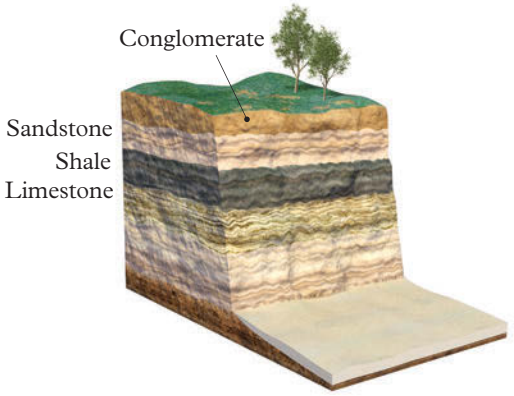

Figure 1 Layers of rocks

Recall and explain

4 **Explain** the difference between a hypothesis and a theory.

5 **Explain** what natural selection is and what the four essential factors for this process are.

6 *Archaeopteryx* had features of both birds and lizards. **Recall** what term is applied to fossils that show the evolutionary progression between two very different forms.

7 **Explain** what Gondwana is/was.

8 The layering of sedimentary rocks is useful in relative dating. **Explain** the basic principle of comparative dating.

9 **Distinguish** between the terms 'transitional fossil' and 'living fossil'.

10 **Explain** precisely how fossils provide evidence for evolution.

11 **Explain** the difference in outcomes of mutations caused by environmental factors and epigenetics.

Apply and analyse

12 Use examples to illustrate the two critical deductions that Darwin made – the struggle for existence and the survival of the fittest.

13 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers. Instead, the stem keeps growing out past the old flower. Consequently, a mature plant may contain the ripe seeds of numerous years in its branches. **Explain** how this adaptive feature enables *Callistemon* to exploit the current Australian environment.

14 Connect the terms 'allopatric speciation' and 'gene flow'.

15 **Propose** why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

16 Cheetahs have very little genetic diversity and, consequently, little variation in the species. Lions have several genetically and physically distinct populations, demonstrating much greater variation. **Explain** why cheetahs are more at risk of extinction than lions.

17 Linnaeus described his biological classification system based on similarities between organisms in 1735, long before the theory of evolution was developed. He divided organisms into distinct groups such as fish, birds, dinosaurs and mammals, based on their structural similarities. **Propose** two reasons why Linnaean classification may need to be replaced, using your knowledge of evolution.

18 Geographic isolation is a well-understood and obvious cause of speciation. **Analyse** the mechanisms of sympatric speciation, and **explain** how it might result in geographic isolation after a long period of time.

19 List the types of evidence for evolution that may be gained from living organisms and those that may be gained from fossil evidence. **Explain** how the two types of evidence complement each other.

20 Like all good scientific theories, evolution can be used to make testable predictions. **Investigate** the discovery of the transition fossil *Tiktaalik*. **Outline** the evidence scientists used when deciding where to look for this fossil. What predictions did they make? What did they find? **Explain** how the story of the discovery of *Tiktaalik* demonstrates the scientific method in action.

21 **Explain** how DNA sequencing supports the concept of evolution from a common ancestor.

22 In the movie *Jurassic Park*, dinosaurs were created by using DNA from the stomachs of mosquitoes, and gaps were filled in using frog DNA. In reality, there is no DNA left in mosquitoes that have been trapped in amber for millions of years, and the frog would be a very bad choice for 'filler' DNA. **Propose** a better method of investigating the dinosaur genome using living species. **Justify** your choice based on at least two types of evidence for evolution.

Evaluate and create

23 The evolution of humans is well documented in the fossil record. Unlike other species, modern humans modify their own environment and avoid most agents of natural selection. Do you think humans are continuing to evolve? Would humans evolve if they colonised another planet? **Justify** your predictions about the future of humans, and present your findings as a poster, short story or comic strip.

24 Australia and New Guinea are the only places in the world where monotremes (egg-laying mammals) are found. Both landmasses sit on the same continental plate and have been connected frequently throughout geologic history. Monotreme fossils are the oldest Australian mammal fossils, dating back 123 million years ago to the Mesozoic Period, better known as the age of dinosaurs. A 61-million-year-old monotreme fossil has also been found in South America. Using this information, **propose** the site where monotremes first evolved and **explain** both the fossil and current distributions of these animals. **Predict** whether other continents might have undiscovered monotreme fossils.

25 The tortoises of the Galapagos Islands either have a domed shell and a short neck (on islands with significant rainfall) or a shell with the front flared up and a long neck (on islands that are more arid). The tortoises feed on prickly pear cactus. On islands with no tortoises, the prickly pear plant is low and spreading, but on islands with long-necked tortoises, the prickly pear plant is tall and has harder spines protecting it.

- a **Explain** why the tortoises may have two very different phenotypes.
- b **Assess** whether the tortoises that originally reached the islands would be likely to resemble any of the tortoises that live there today.
- c Using the terms 'variation' and 'survival of the fittest', **explain** why the prickly pear plant is so different on islands with long-necked tortoises compared with those plants growing elsewhere.
- d **Identify** the type of speciation occurring on these islands.

26 Only two species of native non-marine mammals (both bats) existed in New Zealand before the Polynesians introduced rats and dogs some 1500 years ago. This unusually small number of mammal species, along with New Zealand's separation from Gondwana 60–80 million years ago, has led many to speculate on which land mass mammals originally evolved. The earliest known mammal-like fossil remains are over 160 million years old. Considering this information, **explain** whether a Gondwanan origin for mammals is likely.

27 **Discuss** how the study of DNA sequences help in our understanding of evolution.

28 Through selective breeding, humans are able to make speciation occur. **Discuss** the various scenarios in which this may occur now, in the past and in the future. Provide three examples of human intervention being positive and three examples of detrimental intervention. **Justify** your choices.

Critical thinking

29 *Homo sapiens* (today's humans) evolved alongside several other species of the genus *Homo*, including *Homo neanderthalensis*. **Investigate** these species.

- a **Identify** when each species disappeared from the evolutionary record.
- b **Summarise** theories of why each species died out.
- c **Evaluate** whether you think *Homo sapiens* will see the evolution of a new species of *Homo*.

Go further

30 **Investigate** the various explanations for changes in the natural world before evolutionary theories. Select one example and present your findings and analysis to the class in an appropriate and interesting format.

31 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. Prepare a three-part cartoon strip for each theory that clearly **identifies** the similarities and differences between these theories.

32 Present the strengths and weaknesses of the various forms of evidence that support evolution.

33 **Evaluate** the ways that the terms 'diversity' and 'evolution' are linked. **Explain** how one relies on the other, and **discuss** whether evolution can occur without diversity, and if diversity can occur without evolution.

Research

34 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Darwin and the Galapagos Islands

Much of Darwin's theory developed while he was visiting the Galapagos Islands. Which new species did he find there? What was so unique about these species? How did Darwin's findings help him develop his ideas? What was unique about the Galapagos Islands that helped Darwin develop his theories?

»Climate change and natural selection

How do you think climate change will affect species on Earth? Which species do you think will be most affected? Why is this? What could these species do to avoid becoming extinct as a result of changing habitats? How could they do this? Would all species be able to avoid the effects of climate change? Do you think new species may evolve as a result of climate change?

»Modern-day evidence for evolution

There is evidence of current populations evolving by natural selection all around us. Research one of the following topics and see whether you can find evidence of evolution by natural selection occurring today.

- Can controlled breeding modify organisms?
- When fewer predators are present, how does brighter colouration evolve?
- How does natural selection lead to pesticide resistance?

»Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in general agriculture are monitored closely. Why are these examples important? Why do they need close monitoring? Why do these organisms demonstrate evolution at such a fast rate?

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this.	
Describe scientific evidence that present-day organisms have evolved from organisms in the past.	☐	☐	Go to pages 248-251
Relate the fossil record to the age of the Earth and the time over which life has been evolving.	☐	☐	Go to pages 244-247
Explain, using examples, how natural selection relates to changes in a population, e.g. in the development of resistance of bacteria to antibiotics and insects to pesticides.	☐	☐	Go to pages 240-241; 254-255
Outline the roles of genes and environmental factors in the survival of organisms in a population.	☐	☐	Go to pages 252-253

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INSIDE THE ATOM

What makes an atom?

Have you ever wondered ...

- How were atoms discovered?
- Is krypton an element?
- How is radiation used in medicine?

13

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- identify that all matter is made of atoms which are composed of protons, neutrons and electrons
- describe the structure of atoms in terms of the nucleus, protons, neutrons and electrons
- outline historical developments of the atomic theory to demonstrate how models and theories have been contested and refined over time through a process of review by the scientific community
- identify that natural radioactivity arises from the decay of nuclei in atoms, releasing particles and energy
- evaluate the benefits and problems associated with medical and industrial uses of nuclear energy

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

13.1* The history of the atom

In this topic, you will learn that:

- atoms are the basic form of matter
- discovering atoms was a process that several scientists contributed to
- atomic theory was developed by John Dalton.

atom
the basic unit of a chemical element

Although we cannot see atoms, there is much evidence to say that this basic form of matter exists. Our current understanding of the structure of an **atom** is described in the atomic theory that was originally proposed by John Dalton in 1810.

In around 450 BCE, the Greek philosopher Democritus said:

> By convention there is colour, by convention sweetness, by convention bitterness, but in reality there are atoms and the void.

Democritus was a true philosopher. He did not carry out experiments but proposed hypotheses based on thought and reasoning. Over the next 1500 years, scientists tried many experiments to detect these invisible particles that make up all life on Earth. By the 1780s, French chemist Antoine Lavoisier had made accurate measurements of the composition of chemical compounds. He found that compounds containing more than one element always had the same relative amounts of each element. For example, the compound now known as carbon dioxide used to be called 'fixed air'. This was because it was heavier than air and did not allow other substances to burn in it. It was discovered that the mass of oxygen in 'fixed air' was always 2.66 times the mass of carbon in the compound. This meant there was always the same ratio of oxygen atoms to carbon atoms in the 'fixed air'. English scientist John Dalton was fascinated by this research and in 1810 he stated:

> Matter, though divisible in an extreme degree, is nevertheless not infinitely divisible. That is, there must be some point beyond which we cannot go in the division of matter ... I have chosen the word atom to signify these ultimate particles.

Dalton was one of the first scientists to consider the link between elements and atoms. He was the originator of what is now called the **atomic theory**.

atomic theory
the theory that all matter is made up of atoms

Figure 1 Antoine Lavoisier measured the composition of chemical compounds.

Dalton's atomic theory

One of the pieces of evidence that Dalton published was the weights of atoms compared to that of the lightest atom, hydrogen. He assigned weights to atoms such as oxygen, carbon and nitrogen, by using results of chemical analysis carried out by other chemists on compounds such as ammonia (NH_3), water (H_2O) and carbon dioxide (CO_2). Evidence such as this led to Dalton proposing the law of simple multiple proportions. It means that when elements combine, they combine in simple ratios, like 2:1 as in water (H_2O), 1:4 as in methane (CH_4) or 2:3 as in aluminium oxide (Al_2O_3). These ratios are referred to as formulas.

This might seem obvious to us now but only because of Dalton's atomic theory. This theory gave scientists a way to explain the evidence about atoms.

Evidence supports atomic theory

A scientific theory is written to explain existing evidence and observations. A good theory supported by a range of evidence can be used to make testable predictions. Ever since Dalton first proposed his atomic theory, it has been used to make predictions, and evidence that was not even available in Dalton's time still supports his theory.

- Elements can join together to form compounds.
- Water always contains twice as much hydrogen as oxygen.
- When chemicals react with each other, the total mass of the chemicals does not change.
- Pure oxygen has the same properties wherever it is found on Earth or even in space.
- Gases (some of which are invisible) have mass, and different gases have different masses.
- Modern scanning tunnelling microscopes produce images of surfaces that look 'bumpy'.
- Under a microscope, tiny particles of pollen in water move in strange ways as if bumping into invisible objects.

Figure 2 John Dalton

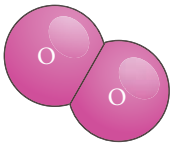


Figure 3 An oxygen molecule is made up of two oxygen atoms.

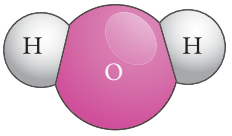


Figure 4 A water molecule is made up of one oxygen atom and two hydrogen atoms.

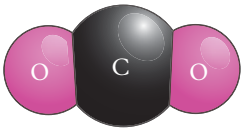


Figure 5 Carbon dioxide is a compound made up of one carbon atom and two oxygen atoms.

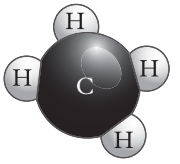


Figure 6 Methane is formed from one carbon atom and four hydrogen atoms.

Check your learning 13.1

Recall and explain

1 **Explain** the main difference between a philosopher such as Democritus and a scientist such as John Dalton.

2 Write the formula of:
- **a** carbon dioxide
- **b** ammonia
- **c** methane.

3 The formula of water is H_2O. **Explain** what the '2' in the formula tells you.

4 Draw and label a carbon dioxide molecule.

Apply and analyse

5 **Assess** why it is important for us that scientists record the methods used in their experiments. List two reasons.

6 It wasn't until around 1906 that many other scientists finally became convinced that Dalton's ideas were correct and that atoms really existed. **Discuss** why you think they doubted his hypothesis.

Evaluate and create

7 It is said that Dalton's atomic model gave 'a physical explanation for reactions that could be expressed in quantitative terms' (American Association for the Advancement of Science, 1993). **Evaluate** this statement.

8 Marie Curie was a physicist and chemist who worked alongside her husband Pierre Curie. After his death, Marie Curie continued with their research and was subjected to a number of prejudices, one being a woman in scientific research. **Investigate** and **describe** the difficulties that she faced and describe her achievements during this time.

Skill builder: Processing and analysing data and information

9 Evaluating evidence to determine how it supports a theory is an important part of working scientifically. Choose three of the forms of evidence given on this page, and **assess** why you think these can be used as evidence to support the existence of atoms. (THINK: Are they scientifically measured? Were they confirmed experimentally? Are there alternative explanations? Are there sources of uncertainty?)

13.2 Atoms are made of subatomic particles

In this topic, you will learn that:

- atoms are made of a nucleus, protons, neutrons and electrons
- the current atomic theory was developed by several scientists.

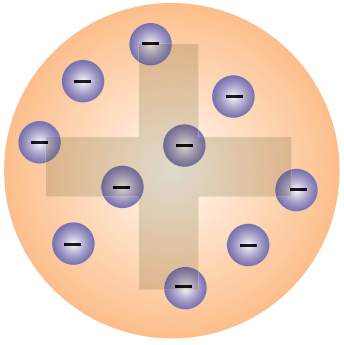


Figure 1 Thomson's plum pudding model of the atom

electron
a negatively charged subatomic particle that moves in the space around an atomic nucleus

Thomson plum pudding model
an early model of an atom that suggested that the positively charged nucleus had negatively charged electrons scattered through it (like a plum pudding)

nucleus
(chemistry) the centre of an atom that contains protons (positive) and neutrons (no charge)

proton
a positively charged subatomic particle in the nucleus of an atom

neutron
a neutral (no charge) subatomic particle in the nucleus of an atom

The Rutherford model of the atom is now widely accepted by the scientific community. It suggests that an atom has a central nucleus containing positively charged protons and neutrons with no charge. Negatively charged electrons travel around the space outside the atom's nucleus. Atoms have no overall charge.

Discovering more about atoms

A century after Dalton proposed his theory, in the early 20th century, the physicist Joseph John Thomson (known as 'JJ' by his colleagues) discovered that atoms were actually divisible and were made up of even smaller particles. His experiments showed that inside the atom are far smaller, negatively charged particles, which we now call **electrons**. He also showed that the atom contained positively charged material, although it was not yet clear what this material was. From this evidence, and knowing that oppositely charged objects attract each other and move towards each other, Thomson suggested that the atom is like a plum pudding, in which the positively charged material is the 'cake' and the electrons are the fruit. This was called the **Thomson plum pudding model** of the atom.

Rutherford's experiments on atoms

Ernest Rutherford was born in New Zealand in 1871. His experiments changed the way people thought about the inside of the atom. In 1911, he supervised Hans Geiger and Ernest Marsden, who carried out what is known as the 'gold foil' experiment. They set up a very thin layer of gold and fired a stream of radioactive particles at it. Detectors to record the radioactive alpha particles were set up around the gold foil to identify whether the particles had gone straight through the foil, or had been deflected (made to change course) by the gold atoms in the thin sheet of gold foil.

Two aspects of the results surprised the scientists. The first evidence was that most of the alpha particles passed straight through the gold foil with hardly any deflection at all. Somehow they seemed to have passed through the gold and therefore the atoms that made up the gold, without 'touching' anything. More amazing was the second piece of evidence. Alpha particles that were travelling with a high amount of energy bounced straight back in the direction that they had come from.

Rutherford concluded that the gold atoms must contain a lot of space, but some part of the atom must contain a relatively large amount of positive charge. This was called the 'nucleus' of the atom.

Rutherford's model of the atom

Rutherford's model has been supported by further research on the structure of the atom. The current accepted model of an atom is as follows.

- The **nucleus** of an atom is made up of protons and neutrons.
- **Protons** carry a positive electric charge.
- **Neutrons** are neutral – they have mass but no electric charge.
- The mass of the atom is almost entirely due to the mass of the nucleus; electrons have very little mass in comparison.
- Electrons move around in the space outside the nucleus.
- Electrons have a negative electric charge.

Figure 2 Imagine the size of a pinhead compared to the Sydney Cricket Ground.

Huge parts of atoms are empty space. If you expanded one atom to the size of the Sydney Cricket Ground, the nucleus of that atom would still be no bigger than a pinhead.

An important thing to know about electric charge and atoms is that atoms are neutral. This means that overall they have no electrical charge – in any atom there is always the same number of positive protons as negative electrons.

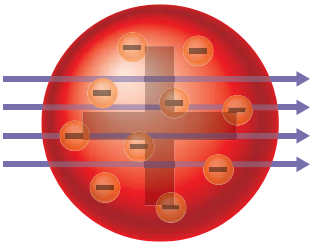


Figure 3 If the 'plum pudding' model of the atom was correct, it would be expected that most of the high-energy alpha particles would move through the gold with only minimal deflection.

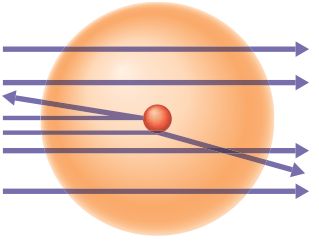


Figure 4 The gold foil experiment showed that high-energy alpha particles were deflected.

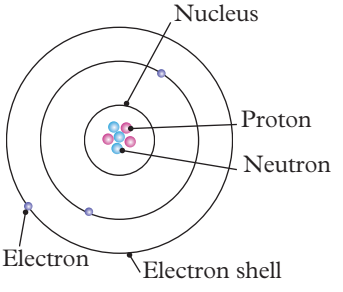


Figure 5 A model of an atom of the element lithium

Check your learning 13.2

Recall and explain

1 **Apply** the evidence described to explain why you think Rutherford concluded that:
   - **a** the atom contained a lot of space
   - **b** there was a central area of positive charge.

2 **Describe** Thomson's plum pudding model of the atom.

3 **Explain** what Rutherford said about electrons in his model of the atom.

4 **Identify** and **describe** three types of particles we now know are found inside an atom.

Apply and analyse

5 **Analyse** why you think the neutron was the last subatomic particle to be discovered of the three subatomic particles.

6 **Analyse** the limitations of Rutherford's atomic model.

Evaluate and create

7 Working with a partner, make a three-dimensional model of an atom from modelling clay or other suitable materials. Make sure you label all parts correctly and state which model of the atom you are representing.

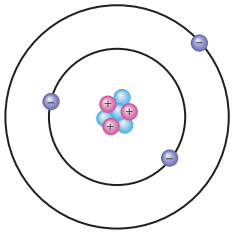
Skill builder: Conducting investigations

8 Rutherford conducted experiments by firing radioactive particles at a thin layer of gold. Detectors would then record whether the particles had gone straight through the foil or had been deflected.
   - **a** **Investigate** the method used in Rutherford's experiment and note any safety risks or hazards. (THINK: How did they manage radioactive materials?)
   - **b** Select one of the risks and **assess** how this could be managed to keep future experiments safe. (THINK: What protective measures should be taken? What PPE would assist?)

13.3* Atoms have mass

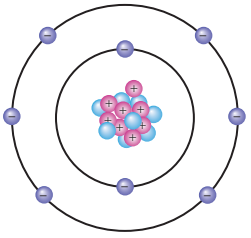
In this topic, you will learn that:

- atoms have mass, which is made up of the protons and neutrons in the nucleus of the atom
- atoms form elements, and these elements are represented in the periodic table.



Lithium
Number of protons = 3
Atomic number = 3
Number of neutrons = 4
Mass number = 7
Number of electrons = 3

Figure 1 A lithium atom with mass number 7 and atomic number 3



Oxygen
Number of protons = 8
Atomic number = 8
Number of neutrons = 8
Mass number = 16
Number of electrons = 8

Figure 2 An oxygen atom with mass number 16 and atomic number 8

periodic table
a table that places elements in order of their atomic number and groups them according to similar properties

All atoms have mass. The mass of an atom is made up mainly of the protons and neutrons in the nucleus of the atom. Because atoms are so small, chemists have devised a relative mass scale for atoms that is more convenient to work with than actual units. It is this scale that is represented on the periodic table.

Size is relative

Relative scales are often helpful when objects or events are being compared. Relative scales are used when it is more important to know the differences between objects and events than the actual measurement (e.g. size, mass, time). The following conversation uses relative measurements.

> 'Mum, Chloe has been in the shower for twice as long as I was.' 'I know, but you used three times as much shampoo as her!'

Being able to compare the masses of different atoms is very important when investigating the behaviour of different atoms and elements. It is not so helpful to know the actual mass of atoms, partly because the mass is so small.

Atomic mass

The atomic mass of an atom of an element is approximately equivalent to the number of protons and neutrons the atom has in its nucleus. This is due to the protons and neutrons having a greater mass than that of electrons (see Table 1).

Table 1 Masses of subatomic particles

Subatomic particle	Mass (amu)	Mass (kg)
Proton	1.007	1.672×10^{-27}
Neutron	1.008	1.675×10^{-27}
Electron	0.00055	0.911×10^{-32}

The number of protons, electrons and neutrons can be deduced if you know an element's atomic number (Z) and mass number (A).

- Number of protons = atomic number = Z
- Number of electrons (in its atomic state) = number of protons
- Number of neutrons = mass number – atomic number = $A - Z$

Worked example

Cobalt has an atomic mass of 59 and an atomic number of 27.

Solution

Number of protons = 27
Number of electrons = 27
Number of neutrons = 59 – 27 = 32

Representing atoms

When it is important to show the number of particles within each atom, the method of representation shown in Figure 3 can be used. As a whole, the elements can be presented in a form called the **periodic table**. The periodic table arranges the elements according to their properties. The vertical columns, called *groups*,

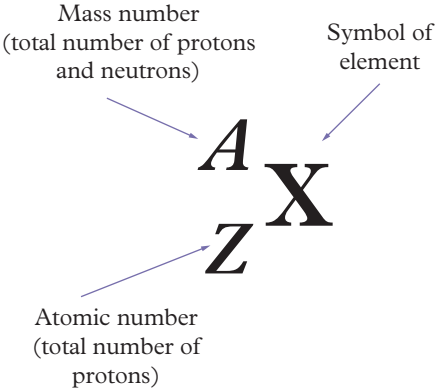


Figure 3 The conventional representation of an element

consist of elements that behave in similar chemical ways. The horizontal rows are called *periods*.

On the relative atomic scale, the mass of a proton is equal to a value of 1. Neutrons have almost the same mass as protons, so they can also be said to have mass of 1 on this scale. Therefore, the mass of an atom can be worked out by considering how many protons and neutrons there are in the nucleus. Remember that electrons do not affect the mass of atoms very much because they are so light in comparison to the particles in the nucleus.

For example, a helium atom that contains two protons and two neutrons will have a relative mass of 4. A carbon atom that contains six protons and six neutrons will have a relative mass of 12. The total number of protons and neutrons in an atom is called the **mass number**.

Different atoms are defined by the numbers of protons, neutrons and electrons that they are made from. Because neutral atoms have no overall negative charge, the number of electrons in an atom is always the same as the number of protons (the atomic number). Figures 1 and 2 show examples of two common atoms.

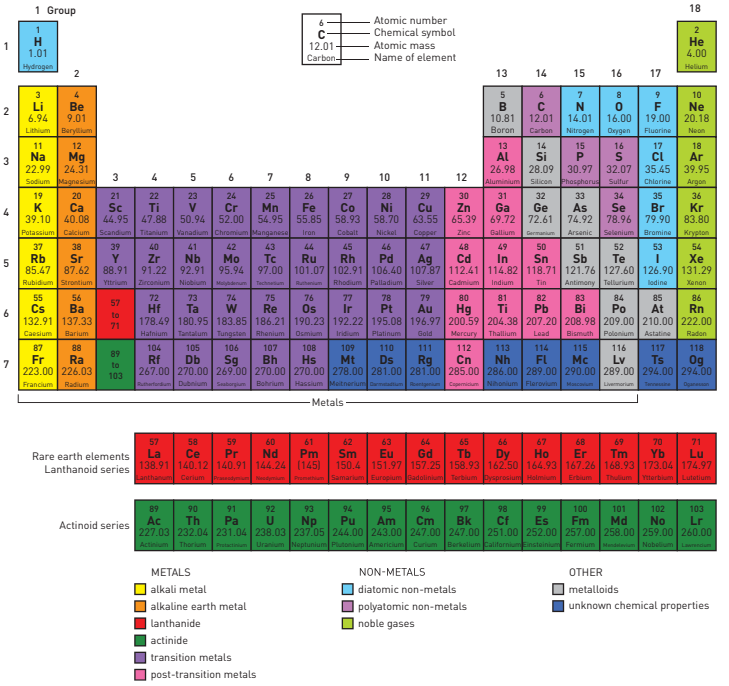


Figure 4 The periodic table of the elements; see page 424 for a larger version of the periodic table.

mass number
the number that represents the total number of protons and neutrons in the centre of an atom

Check your learning 13.3

Recall and explain

1 Table 2 shows the numbers of subatomic particles in a range of atoms.
   - **a** Complete the table.
   - **b** **Explain** how you were able to calculate the number of neutrons in the argon atom.
   - **c** **Explain** how you were able to work out the atomic number and the mass number of the sulfur atom.

Apply and analyse

2 Imagine all the elements did not have names and were just identified by their atomic numbers. **Assess** if this would make chemistry easier to understand. Consider the problems that this could cause and also what the advantages might be.

3 **Recall** the subatomic particle that is not found in the nucleus of the atom.

Evaluate and create

4 Is there always the same number of neutrons as protons in an atom? **Explain** your answer with an example.

Table 2 Numbers of subatomic particles in some atoms

Atom name and symbol	Atomic number	Mass number	Number of protons	Number of neutrons	Number of electrons
Calcium (Ca)	20	40	20	20	20
Fluorine (F)	9	19	9		
Sodium (Na)	11		11	12	
Argon (Ar)		40	18		
Sulfur (S)			16	16	

Skill builder: Communicating

5 Consider whether it is more appropriate to use the whole periodic table or atomic mass when you are describing the elements to be used in an investigation. (THINK: What information would people require?)

13.4 Electrons are arranged in shells*

In this topic, you will learn that:

- the Bohr model of the atom arranges electrons in shells
- these shells are a set of orbits around the nucleus.

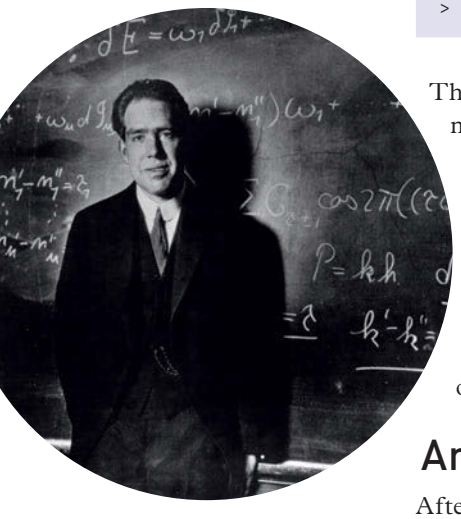


Figure 1 Niels Bohr proposed the idea of electron shells.

The Bohr model describes how electrons move in specific areas of space around atoms called electron shells. Each shell can contain a limited number of electrons. When an electron gains energy, it moves to an outer shell of higher energy. When the electron moves back to its lower-energy shell, the excess energy is given off as light. The number of electrons in the outer shell is called its valency.

Arranging electrons

After Rutherford had refined his model of the atom, another scientist, Niels Bohr, concluded that the electrons in the atom do not behave quite like the planets around the Sun but move about the nucleus in circular orbits that are at certain distances from the nucleus. The more energy they have, the further their orbit is from the nucleus. These sets of orbits are known as **electron shells**. There is a limit to the number of electrons that can be found in any of the shells. This is called the **Bohr model of the atom**.

Bohr also stated that the electrons of an atom are normally located as close to the nucleus as possible, because this is a lower energy state and is more stable. Therefore, electrons fill the shells closest to the nucleus first.

The arrangement of electrons in an atom is called its **electronic configuration**. Table 1 shows the number of electrons each shell can contain. For the first 20 elements, the third shell can only hold 8 electrons. For atoms with atomic numbers greater than 20, the third shell can accommodate up to 18 electrons. You will only have to consider the first 20 elements (up to calcium) in terms of electronic configuration.

The electronic configurations of oxygen and calcium are compared in Figure 2. These electronic configurations are often represented by **shell diagrams** that show the electron shells as circles. The electrons are shown in pairs. The outermost occupied shell of uncharged atoms is known as the valence shell. The number of electrons in the **valence shell** of an atom determines the chemical properties of the element, and it affects how the atom will bond with other atoms.

In 13.3 you examined how the periodic table is arranged in groups and periods. This arrangement is determined by the electronic configuration and therefore the chemical properties of the element. For example, atoms that are found in group 1 all have one electron in their outer shell. Atoms in group 17 have seven electrons in their outer shell. The periods of the periodic table provide an indication of the number of electron shells that are occupied. For example, oxygen is in period 2, group 16. This means it has two electron shells, with six electrons in the outer valence shell.

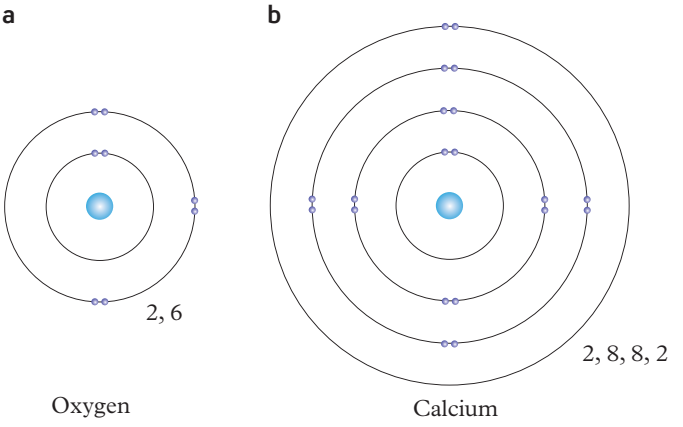


Figure 2 The electronic configurations for **a** oxygen (period 2, group 16) and **b** calcium (period 4, group 2).

electron shell
the area of space around a nucleus where a specific electron may be found

Bohr model of the atom
a way to represent the electrons of an atom in a series of shells around the atomic nucleus

electronic configuration
the distribution of electrons of an atom or molecule in atomic or molecular orbitals

shell diagram
a diagram that shows the number of electrons in each electron shell around a particular atomic nucleus

valence shell
the outermost electron shell that contains electrons

Evidence for electron shells

Many substances give off coloured light when small samples are introduced into a flame. This light can be seen through a spectroscope – an instrument that breaks the light up into its colours. A pattern of coloured lines is observed.

Table 1 Electronic configurations for electron shells of an atom

Electron shell	Maximum number of electrons in shell
First	2
Second	8
Third	Up to calcium: 8 Above calcium: 18
Fourth	32

This pattern is known as an **emission spectrum** and is unique for each element. Bohr explained this by saying that a particular atom was given energy in a flame. The electrons absorb the exact amount needed to jump from their normal shell to one further out from the nucleus. He described the electrons as being excited. Because this higher energy state was unstable, the electrons then jumped back to their normal levels almost instantly. The extra energy that the electrons no longer needed was released as light energy. The wavelength of the light (and therefore its colour) represented the energy difference between each electron shell. This unique combination of colours (or spectrum) is linked to a particular type of atom (element) with its unique number of electrons arranged in shells. This spectrum is therefore like the 'fingerprint' for that element. This is how flame tests work.

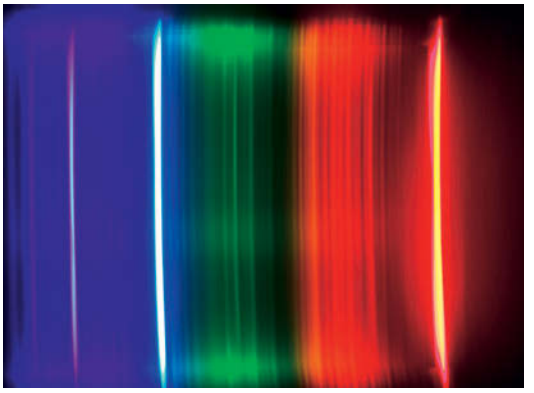


Figure 3 The emission spectrum of hydrogen

Interactive
Elements and compounds

emission spectrum the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

Check your learning 13.4

Recall and explain

1 In the Bohr model of the atom, **recall** the maximum number of electrons that the second electron shell can contain.

2 **Identify** the element that would be found in period 3, group 1. Then draw its electronic configuration.

Apply and analyse

3 **Propose** why the second shell can contain more electrons than the first shell.

4 Complete the information in Table 2.

Table 2 Some elements with atomic numbers and electronic configurations

Element	Atomic number	Electronic configuration
Helium		
Carbon	6	
Neon		2, 8
	1	
Magnesium		
	17	
		2, 8, 3

5 **Describe** what the emission spectra would look like if an electron did not jump up in discreet energy levels (shells) in an atom.

6 When a piece of metal heats up, it turns red, then yellow and then other colours. **Explain** why.

Evaluate and create

7 Fireworks are all different colours. **Evaluate** why this occurs.

Skill builder: Processing and analysing data and information

8 A potassium atom contains 19 protons.

a How many electrons are present in a potassium atom? **Justify** your answer. (THINK: Where can you find this information?)

b What is the electronic configuration of a potassium atom according to the Bohr model? (THINK: Recall the Bohr model and apply that to potassium; consult the periodic table.)

c How many electrons are in the valence shell of a potassium atom? (THINK: Recall what a valence shell is.)

d What could be done to potassium atoms to make electrons jump into the fifth shell? (THINK: How can elements be altered?)

13.5 Ions have more or less electrons

*

In this topic, you will learn that:

- ions are charged atoms
- a positively charged atom is a cation
- a negatively charged atom is an anion.

ion
a charged atom that results from an unequal number of electrons and protons

An atom can gain or lose electrons to become an ion. If an atom gains an electron, then there are more negative electrons than positive protons. This means a negative ion, called an anion, is formed. If an atom loses an electron, then there is an overall positive charge due to the extra proton compared to electrons. This is called a cation.

Atoms and ions

Atoms are neutral. This means that the amount of negative charge within the atom is the same as the amount of positive charge. The number of protons (positive) is always the same as the number of electrons (negative). However, if electrons are lost or gained from the outside of the atom, there will no longer be the same number of protons and electrons, and the atom becomes charged. Charged atoms are called **ions**, and the process for the formation of ions is called ionisation.

Ionisation can happen when atoms come together to form chemical bonds. It can also happen when atoms are exposed to radiation. When ions are formed, it is the electrons in the outer electron shell (the valence shell) that are affected. Normally when ions are formed, the resulting ion has a full outer shell of electrons. This is because a full outer shell of electrons is a stable arrangement. The first three shells are full, with 2, 8 and 8 electrons, respectively.

For example, an atom that originally had two electrons in its valence shell, such as magnesium, would lose both of these electrons to achieve a full outer shell – it is easier to lose two electrons than to gain six.

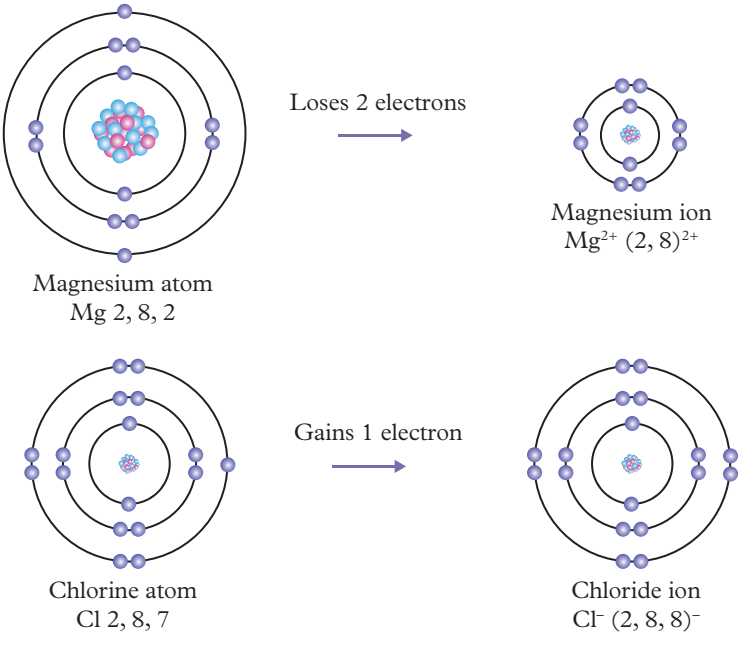


Figure 1 How magnesium and chloride ions are formed.

An atom with seven electrons in its outer shell, such as chlorine, would gain one electron to complete this outer shell with eight electrons – it is easier to gain one electron than to lose seven.

Calculating ion charge

When ions are formed, the number of protons in an atom stays the same because protons are held in the nucleus and are not affected by changes occurring on the outside of the atom. When electrons are gained or lost, an imbalance is formed between the number of positive charges and the number of negative charges.

Electrons are negatively charged, so when an atom gains an extra electron, the charge on the whole atom becomes negative. If two electrons are gained, then there is an overall charge of negative two. A negatively charged ion is called an **anion**.

If an electron is lost from an atom, the resulting ion will have a charge of positive one. There will now be more protons than electrons. One electron lost means there is effectively one extra proton. A positively charged ion is called a **cation**. Table 1 contains some examples.

anion
a negative ion that results from an atom gaining electrons

cation
a positive ion that results from an atom losing electrons

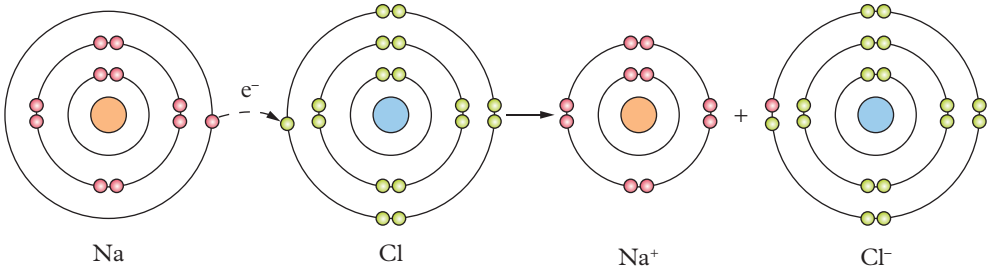


Figure 2 Sodium atoms lose an electron to become a positively charge cation. Chlorine gains an electron to become a negatively charged anion. In this way, salt is formed.

Table 1 Examples of positive and negative ions

Name and symbol of atom	Electron configuration of atom	Electron configuration of ion	Change	Charge of ion	Name and formula of ion
Oxygen (O)	2, 6	2, 8	Gained 2 electrons	–2	Oxide ion (O^{2-})
Chlorine (Cl)	2, 8, 7	2, 8, 8	Gained 1 electron	–1	Chloride ion (Cl^-)
Sodium (Na)	2, 8, 1	2, 8	Lost 1 electron	+1	Sodium ion (Na^+)
Calcium (Ca)	2, 8, 8, 2	2, 8, 8	Lost 2 electrons	+2	Calcium ion (Ca^{2+})

Check your learning 13.5

Recall and explain

1 **Describe** a cation.

2 Use an example from the periodic table to **explain** how an anion is formed.

Apply and analyse

3 In Table 1, what patterns do you notice about the:
- **a** names of the negative ions?
- **b** electronic configurations of the ions?
- **c** differences between the metals and non-metals?

Evaluate and create

4 The elements neon (atomic number 10) and argon (atomic number 18) do not normally form ions. **Propose** why this is.

5 The Aurora Australis is an amazing phenomenon that occurs in the Southern Hemisphere. **Construct** a tourism pamphlet that includes information to **explain** how and why it occurs.

Skill builder: Questioning and predicting

6 Using the ideas explained previously, **predict** the charges on the following ions. (THINK: What has been added? What has been removed? Are they positive or negative?)
- **a** Potassium (atomic number 19)
- **b** Aluminium (atomic number 13)
- **c** Nitride (produced from nitrogen atoms with atomic number 7)

13.6 Metal cations and non-metal anions combine to form ionic compounds

In this topic, you will learn that:

- metals form cations when they lose electrons
- non-metals form anions when they gain electrons
- polyatomic ions form when two or more atoms combine to form a charged ion.

Positive cations are attracted to negative anions and form ionic compounds. The properties of ionic compounds reflect the ionic bonds that hold the ions together.

Figure 2 Sodium chloride crystals (salt)

Properties of ionic compounds

Compounds that are held together by ionic bonds are called ionic compounds. As an ionic compound forms, the like-charged ions repel each other and the oppositely charged ions attract each other.

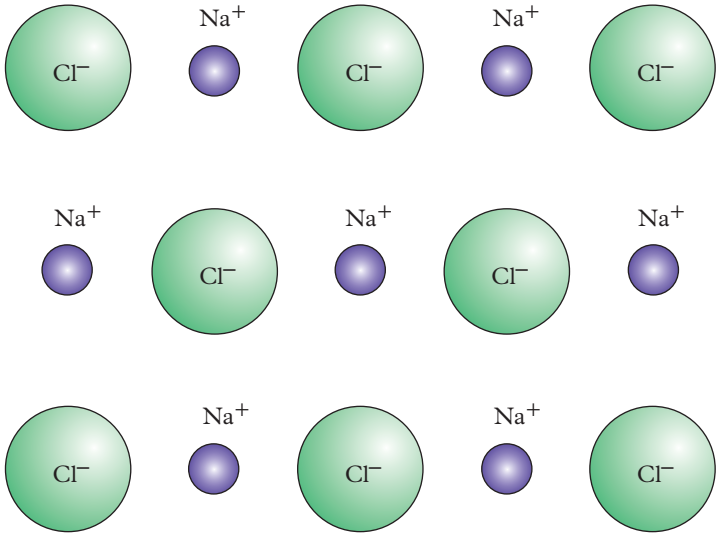


Figure 1 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.

After all the pushing and pulling, the ions settle into alternating positions, as shown in Figure 1, because this is the most stable arrangement. The particles are held together by strong electrostatic forces of attraction between the positively charged ions and the negatively charged ions. Because these forces bind the ions together, this is known as ionic bonding.

A lot of energy is required to move the ions out of their positions. This means that ionic compounds are hard to melt. At room temperature, they are in the form of hard, brittle crystals. The most commonly known example of an ionic compound is sodium chloride (table salt). Its melting point is 801°C. If you use a salt grinder at home, you will be aware of how hard and brittle salt crystals are.

Polyatomic ions

A number of ions are made up of more than one atom. These are termed polyatomic ions. Figure 3 shows some examples of polyatomic ions.

These clusters of atoms have a charge because the total number of protons does not equal the total number of electrons present. For example, in the hydroxide ion, which is made up of two atoms (one each of oxygen and hydrogen), there are nine protons and ten electrons. This means the two atoms that form the ion have an overall charge of 1–.

Calcium carbonate, the main constituent of marble, is an example of an ionic compound that contains a polyatomic ion. Calcium carbonate contains calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}). These ions must be present in the ratio 1:1 so that the total positive charge equals the total negative charge. The formula of calcium carbonate is $CaCO_3$.

Ammonium carbonate is used in smelling salts. It contains ammonium ions (NH_4^+) and carbonate ions (CO_3^{2-}). In this case, the ions need to be present in the ratio 2:1. The formula of ammonium carbonate is $(NH_4)_2CO_3$.

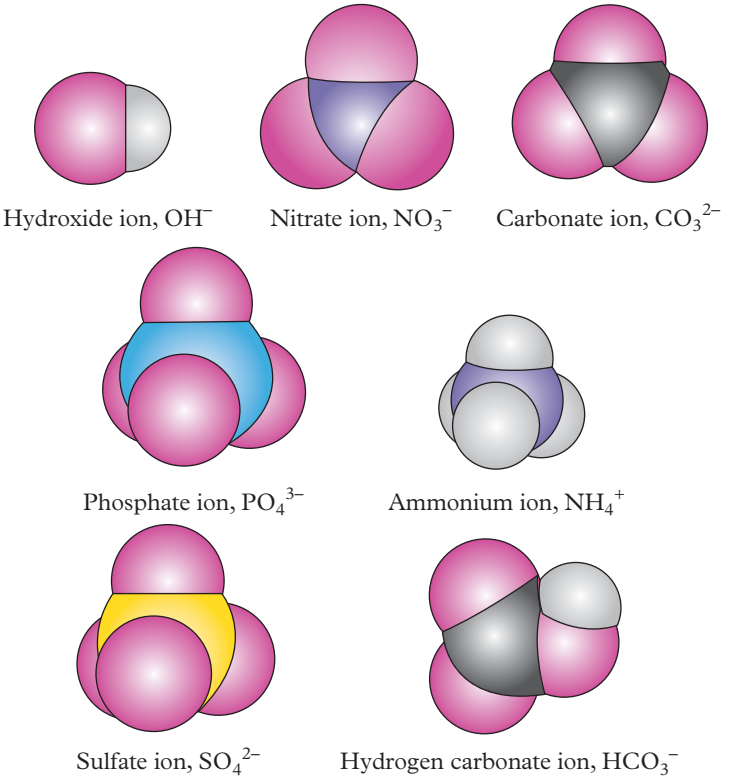


Figure 3 Common polyatomic ions

Check your learning 13.6

Recall and explain

1 Carefully **examine** the periodic table on page 424.
   - **a** Which elements are likely to form positively charged ions?
   - **b** Which elements are likely to form negatively charged ions?
   - **c** What does this tell you about which elements will combine to form ionic compounds?

2 **Identify** the kinds of particles present in ionic compounds.

Apply and analyse

3 **Explain** how the group in which an element is found in the periodic table quickly identifies one or more of its properties.

4 **Recall** the maximum number of electrons that can be gained or lost by an atom. **Explain** why.

Evaluate and create

5 **Construct** a stop-motion video or draw a cartoon that shows the donation of electrons from one atom to another to form an ionic compound.

Skill builder: Problem solving

6 Atomic structure and valence electrons can be used to explain why many ionic compounds are made up of a metal and a non-metal. **Construct** a pros and cons list for using this information to **explain** these ionic compounds.
   - **a** **Identify** the benefits of using this information. (THINK: Where did the information come from? Why is it helpful?)
   - **b** **Identify** the negatives of using this information. (THINK: Is this factual? Is it based on predictions? Where is the evidence coming from?)

13.7 Isotopes have more or less neutrons

In this topic, you will learn that:

- isotopes are atoms that have more or less neutrons in the nucleus
- the number of neutrons in the nucleus affects the mass of the atom.

Figure 1 Marie Curie was one of the first scientists to study isotopes. Her notebook is still radioactive over 100 years later.

isotope
an atom that has more or less neutrons in its nucleus

An isotope is an atom that has more or less neutrons in its nucleus. This affects the mass of the atom. The periodic table lists the relative atomic mass of an atom, which represents the average mass of all the isotopes of that atom.

Atomic mass and isotopes

The periodic table lists the atomic masses of the elements. These masses are not whole numbers and are not the same as the mass numbers of the atoms (although they are pretty close). They are a more accurate way of comparing the masses of the atoms of different elements, but why are many of them not whole numbers? We certainly cannot have part of a proton or part of a neutron in an atom. Electrons do have some mass but not really enough to make much difference to the overall mass of the atom. So where do these atomic masses come from?

Generally, not all the atoms within an element have the same mass. This is because they are not identical. Why is this? What do they have in common and what is different? All the atoms of an element have the same unique number of protons – their atomic number, sometimes shown by the letter *Z*.

The atomic number is used to identify the element. For example, all carbon atoms contain six protons in their nucleus, so their atomic number is 6. In the periodic table of the elements (page 424; also Figure 2 below). You can see that the elements are listed in order of their atomic number. However, although all the atoms of one particular element have the same number of protons, they may well have different numbers of neutrons.

Isotopes

For many of the elements, the number of neutrons in the atoms can vary. For example, most carbon atoms have six neutrons in their nucleus but some have seven and some have eight. The different forms of the atoms of an element that have different numbers of neutrons are called **isotopes**.

21 **Sc** 44.95 Scandium	22 **Ti** 47.88 Titanium	23 **V** 50.94 Vanadium	24 **Cr** 52.00 Chromium	25 **Mn** 54.95 Manganese	26 **Fe** 55.85 Iron	27 **Co** 58.93 Cobalt	28 **Ni** 58.70 Nickel	29 **Cu** 63.55 Copper	30 **Zn** 65.39 Zinc
39 **Y** 88.91 Yttrium	40 **Zr** 91.22 Zirconium	41 **Nb** 92.91 Niobium	42 **Mo** 95.94 Molybdenum	43 **Tc** (98) Technetium	44 **Ru** 101.07 Ruthenium	45 **Rh** 102.91 Rhodium	46 **Pd** 106.4 Palladium	47 **Ag** 107.87 Silver	48 **Cd** 112.41 Cadmium
57 to 71	72 **Hf** 178.49 Hafnium	73 **Ta** 180.95 Tantalum	74 **W** 183.85 Tungsten	75 **Re** 186.21 Rhenium	76 **Os** 190.23 Osmium	77 **Ir** 192.22 Iridium	78 **Pt** 195.08 Platinum	79 **Au** 196.97 Gold	80 **Hg** 200.59 Mercury
89 to 103	104 **Rf** (205) Rutherfordium	105 **Db** 105 Dubnium	106 **Sg** (271) Seaborgium	107 **Bh** (272) Bohrium	108 **Hs** (277) Hassium	109 **Mt** (276) Meitnerium	110 **Ds** (281) Darmstadtium	111 **Rg** (280) Roentgenium	112 **Cn** (285) Copernicium

Figure 2 Some atomic numbers and atomic masses in the periodic table.

Carbon-12 is the most common form of carbon atom in the natural world – 1.1% of natural carbon on the Earth is carbon-13 atoms (6 protons and 7 neutrons), and even smaller quantities are made up of carbon-14 atoms (6 protons and 8 neutrons).

Like most elements, carbon has more than one naturally occurring isotope. In these cases, chemists use the average mass of the isotopes of the element for calculations. This average mass is termed the **relative atomic mass** of the element. For example, almost all carbon atoms exist as the carbon-12 isotope and only a very small proportion are present as the two heavier isotopes. Therefore, the relative atomic mass is only just above 12. The relative atomic masses of the elements are usually shown in the periodic table, correct to one or two decimal places. Be careful not to mix this up with their atomic numbers.

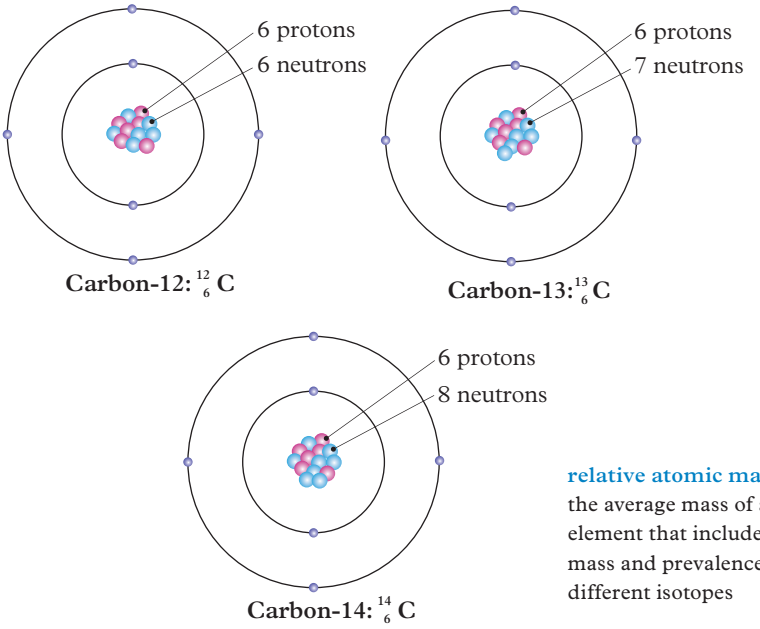


Figure 3 The three isotopes of carbon

relative atomic mass the average mass of an element that includes the mass and prevalence of its different isotopes

Check your learning 13.7

Recall and explain

1 A student wrote that all the atoms of an element are identical. Is this correct? **Discuss**.

2 **Explain** the meaning of 'mass number' and how this name arose. Use an example to assist your explanation.

3 **Explain** why the atomic number of an element is always a whole number but the relative atomic mass of an element is often not a whole number.

Apply and analyse

4 Using your knowledge of isotopes and looking at the periodic table on page 424, complete the information in Table 1.

Table 1 Different isotopes

Isotope symbol	Isotope name	Atomic number of element	Number of protons	Number of neutrons	Number of electrons in uncharged atom
$^{238}_{92}U$					
	Oxygen-16				
			10	20	
				36	29
		30		34	

Skill builder: Planning investigations

5 Before you can conduct scientific investigations, you need to be familiar with existing information about the topic. **Investigate** one of the natural isotopes of carbon.

a Find one source that identifies the natural isotope.
(THINK: Is this source reliable?)

b **Explain** what this natural isotope is.
(THINK: Can you write this in your own words? Do you need to use a diagram?)

c **Recommend** whether this is a good source of information.
(THINK: Do I understand what this natural isotope is?)

13.8 Isotopes can release alpha, beta or gamma radiation

In this topic, you will learn that:

- there are three types of radioactive decay: alpha, beta and gamma
- isotopes decay at known rates called 'half-life'.

radioactive decay
the conversion of a radioactive isotope into its stable form, releasing energy in the form of radiation

radionuclide
a radioactive isotope

alpha
a radioactive particle containing two protons and two neutrons; can be stopped by a piece of paper

beta
a radioactive particle (high-speed electron or positron) with little mass; can be stopped by aluminium or tin foil

gamma
high-energy electromagnetic rays released as a part of radioactive decay; can be stopped by lead

Figure 1 Some smoke detectors contain a radioactive source.

Some isotopes are unstable. This means they may decay or change into another isotope and produce alpha, beta and/or gamma radiation. This is known as radioactive decay. The time it takes for half the remaining unstable isotopes to decay is called the half-life of the isotope.

Isotopes and radioactive decay

Earlier in this chapter you learned about isotopes. Hydrogen, for instance, has three isotopes: hydrogen-1 $\left({}^{1}_{1}\mathrm{H}\right)$, hydrogen-2 $\left({}^{2}_{1}\mathrm{H}\right)$ and hydrogen-3 $\left({}^{3}_{1}\mathrm{H}\right)$.

Each isotope of hydrogen has one proton but different numbers of neutrons. In some isotopes, when the ratio of neutrons to protons becomes too high, the nucleus is unstable and it decays or changes into another isotope.

This process causes the emission of radiation and is known as **radioactive decay**. Hydrogen-1 and hydrogen-2 are stable, but hydrogen-3 is unstable and breaks down. Therefore, hydrogen-3 is a radioactive isotope and is called a **radionuclide**. Radionuclides can occur naturally or they can be manufactured in a nuclear reactor.

Types of nuclear radiation

Alpha (α), **beta** (β) and **gamma** (γ) radiation all originate from an unstable nucleus. An alpha particle is identical to the nucleus of a helium nucleus. It contains two protons and two neutrons. Americium-241, which is commonly used in smoke detectors, is an example of an alpha particle emitter. It decays to neptunium-237, which is a more stable isotope.

The decay of americium-241 to neptunium-237 can be shown in a nuclear equation:

$$^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\alpha$$

In a nuclear equation, the mass numbers on each side of the arrow add to the same value. In this case, they both add to 241. This demonstrates that the total mass of the particles before and after the decay is the same.

Beta particles are produced when a neutron in the nucleus decays into a proton and an electron. The electron is the beta particle that leaves the atom. An example of beta decay is the decay of carbon-14 to nitrogen-14:

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + \beta$$

The beta particle has very little mass, so the mass of the new nucleus formed is very similar to the original carbon-14 nucleus. As the beta particle is released, a neutron in effect becomes a proton so the atomic number of the resulting nucleus increases by one.

Gamma rays are high-energy electromagnetic rays similar to X-rays that are emitted after alpha particle or beta particle emission when the nucleus is still excited.

An example is when cobalt-60 decays to form nickel-60:

$$^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{N} + \beta + \gamma$$

Cobalt-60 is an artificially produced radioisotope that is used in medical radiotherapy, sterilisation of medical equipment and irradiation of food. Because the gamma radiation is an electromagnetic wave (rather than a particle emission like alpha and beta radiation), the gamma radiation is highly penetrating and can cause cell damage deep within the body if exposure levels are high.

Radioactive half-life

Radioactive decay is a random process and we cannot predict which radioactive nuclei in a sample will decay at any given moment. However, the rate of radioactive decay follows a pattern. As a radioactive sample decays, less and less of the original substance is left and the radioactivity drops. The **half-life** of a radioactive material is the time taken for half of the radioactive nuclei in a sample to decay (see Table 1 for some examples). This is also equivalent to the time taken for the radioactivity to drop to half of its original value.

When the radioactivity reaches one-half of its original level, one half-life has passed. When it reaches one-quarter of its original level, two half-lives have passed and the pattern continues. A graph of radioactive decay against time gives a characteristic shape called an exponential decay curve.

Table 1 Half-lives of important medical radionuclides

Radionuclide	Half-life
Bismuth-213	46 minutes
Technetium-99m	6 hours
Lutetium-177	6.7 days
Iodine-131	8 days
Chromium-51	28 days
Strontium-89	50 days

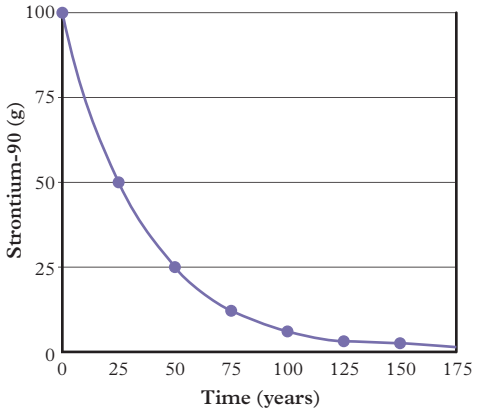


Figure 2 A radioactive decay curve for strontium-90, which has a half-life of 28.8 years.

Figure 3 Alpha particles are stopped by paper. Beta particles are stopped by aluminium foil. Gamma rays can only be stopped by lead.

half-life
the time it takes for half the nuclei of a radioisotope to decay

Check your learning 13.8

Recall and explain

1 **Explain** the meaning of the following terms.
- **a** Isotope
- **b** Radioactive decay
- **c** Radionuclide
- **d** Half-life

2 Write the conventional representation of an isotope for each of the following in the form ${}^{A}_{Z}\text{X}$. You may need to use the periodic table on page 424 to find out the atomic number of the elements.
- **a** Iodine-131
- **b** Cobalt-60
- **c** Technetium-99
- **d** Fluorine-18

3 Complete the following beta decay:

${}^{227}_{89}\text{Ac} \rightarrow$

Apply and analyse

4 If thorium-232 undergoes one alpha and beta decay, what radioactive isotope is produced?

5 The rate of decay of a radionuclide falls from 800 counts per minute to 100 counts per minute in 6 hours.
- **a** What is the half-life of this radionuclide?
- **b** Draw a radioactive decay curve for this radionuclide.
- **c** **Predict** what the count rate would be in another 4 hours.

6 Uranium-238 undergoes a series of decay. Complete the following portion of the decay chain, identifying each of the radioactive isotopes or nuclear radiation emitted.

${}^{238}_{92}\text{U} \xrightarrow{\alpha} \square \xrightarrow{\beta} \square \rightarrow {}^{234}_{92}\text{U} \xrightarrow{\alpha} \square \xrightarrow{\alpha} \square$

Evaluate and create

7 **Investigate** one radioactive isotope that is used in medicine. Include its symbol, and write a brief summary of its uses.

Skill builder: Processing and analysing data and information

8 Look at Figure 2, which shows the radioactive decay curve for strontium-90.
- **a** **Identify** the level of strontium-90 at 25 years. (THINK: Which axis in the graph represents time?)
- **b** How many years did it take for the levels of strontium-90 to change from 75 to less than 10? (THINK: What scale does the graph use?)

13.9 Radiation is used in medicine

In this topic, you will learn that:

- radiation has benefits in medical treatments
- carbon dating is an important technique used to identify the age of an artefact.

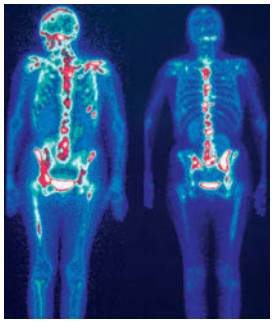


Figure 1 A technetium-99m bisphosphonate bone scan shows up abnormalities within bones.

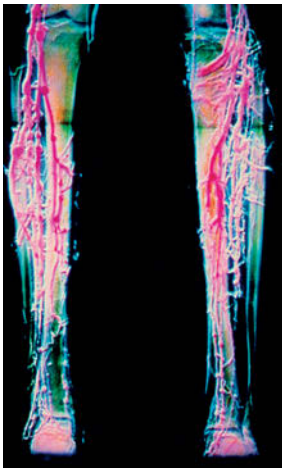


Figure 2 Radioactive dye injected into the blood shows blood flow in the blood vessels.

The radiation produced by isotopes can damage the cells in our body, or it can be used to identify and cure diseases. Nuclear medicine is a diagnostic imaging method often situated within X-ray departments in hospitals or in private clinics.

Effects of radiation

The main reason that radiation can be harmful is that it can cause atoms in other substances to become ions. The alpha and beta particles have enough mass and/or energy to remove electrons from the outside of atoms. This will change the properties of the atoms. This process also causes the release of reactive particles called free radicals. If this occurs in our bodies, these free radicals can go on to damage other important molecules in the body. If DNA is damaged, this can have serious effects because DNA is the molecule that contains instructions for other biochemical processes. It is also a molecule that has the ability to reproduce itself, so the effect of one damaged DNA molecule can be multiplied thousands or even millions of times as copies of the affected DNA are created. Many cancers linked to radiation start in this way.

Radiation and medicine

Despite the damage that can be caused by radiation, it has many uses in medicine. The most common medical application is using X-rays to identify damaged or broken bones. Less common is the injection of radioactive isotopes into a patient. This allows the radiation that accumulated at the site of a cancer, or other damaged tissue, to be detected by special monitors.

Radiation therapy uses the ability of radioactive isotopes to kill off cancer cells. Cancer cells are normal cells that have had

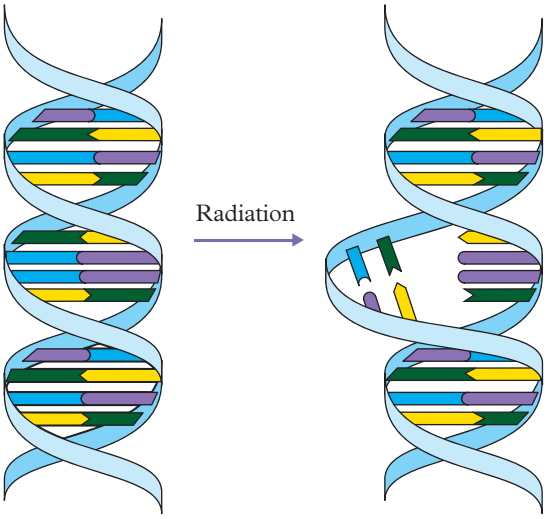


Figure 3 Radiation can damage the structure of DNA molecules.

their DNA slightly changed. This change is not enough to kill the cancer cell – instead it allows it to grow very quickly. Radiotherapy uses radioactive isotopes to cause more damage to the cancer cell. Eventually when the cell is damaged enough, it dies (a process called apoptosis).

Careers in radiation

Fran Maestrale is a nuclear medicine technologist. Before the first patient arrives at her department, Fran must measure the amount of radioactivity delivered to the department. The isotope, in liquid form, is drawn up into the required amounts and added to 'cold' kits, so that the day's scans can be performed. A cold kit is a vial containing a particular chemical agent that, once introduced into the human body, will travel to a particular organ.

Each test uses a particular compound, which travels to a known organ of the body based on its chemical composition and the way it is introduced into the body.

Most people referred to nuclear medicine departments require bone scans. These may be performed to diagnose cancer, investigate the extent of arthritis, screen for fractures that do not show on a plain X-ray, or look at infection of bone.

In other cases, the blood is of interest. The blood of a patient can be 'labelled' – mixed with a small amount of radionuclide. This is used to locate the site of an internal bleed. Once the bleed has been located, surgeons can operate knowing exactly where to begin finding the haemorrhaging vessel so that it may be sealed to prevent further blood loss.

Fran typically performs a number of these different tests each day, looking at a variety of different pathologies. Nuclear medicine technologists must be familiar with many organs in the body in order to know whether the images obtained appear normal or abnormal. There is also the opportunity to learn about the various treatments for different conditions patients can have. Although through practice they may be able to interpret images and determine what pathology a person has, nuclear medicine technologists are not qualified to do this. They must present the images to the radiologist, who is responsible for making a diagnosis. Nuclear medicine technologists have a close working relationship with radiologists, surgeons and nurses.

Radiocarbon dating

Archaeologists use a technique called 'carbon dating' to determine how old an artefact is (e.g. bone, wood, organic fibres). The radioactive isotope carbon-14 is created in our atmosphere and is taken in by plants through photosynthesis. Animals that eat plants also acquire the carbon-14 radioisotope. When the plant or animal dies, it stops taking in carbon-14 and the decay process reduces the amount of carbon-14 present over time (it has a half-life of 5730 years), while the amount of carbon-12 remains constant because it is stable.

Through radiation detection, the amount of carbon-14 can be deduced. As all living things have the same ratio of carbon-12 to carbon-14 (about 1 in a trillion carbon atoms are carbon-14), the ratio present in the dead sample can be compared to the ratio of a living organism to determine the age of the artefact.

Because of carbon-14's half-life of 5730 years, it can only be used to identify the age of specimens no older than 50 000–60 000 years. Also, because of the nature of where artefacts are usually found (in dirt with other carbon compounds, near flowing water), the age of the artefact can be determined to be older or younger than it actually is, due to this contamination.

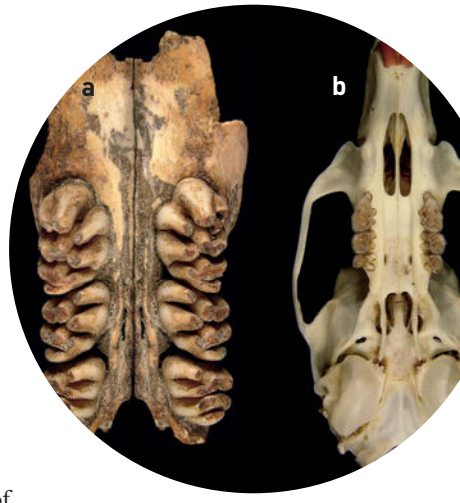


Figure 4 a The top teeth of Timor's giant rat (which is extinct) and **b** the skull of a common black rat. Carbon dating of Timor's giant rat, the biggest rat to have ever lived, shows that it survived until about 1000–2000 years ago. It weighed about 6 kg!

Check your learning 13.9

Recall and explain

1 **Identify** two uses of radiation in medicine.
2 **Describe** the process of an X-ray.
3 **Explain** what carbon dating is.

Apply and analyse

4 **Propose** why the day begins with measuring the amount of radioactivity delivered to the nuclear medicine department.
5 **Explain** why a nuclear medicine technologist must give the images to a radiologist to make a diagnosis.
6 When used in medicine, radioactive isotopes that decay relatively quickly are used. **Explain** why this might be.
7 **Explain** why carbon-14 is used in carbon dating and not any other isotope of carbon.

Evaluate and create

8 **Investigate** the type of training a nuclear medicine technologist might need. **Explain** why.
9 **Propose** where else we see elements and chemicals being used to treat disease. **Assess** the benefits and risks of such treatments.

Skill builder: Planning investigations

10 Stella has been told she has to receive an X-ray to see if her ribs are broken. Sometimes X-rays to the ribs need to be repeated to get a clear image. Stella is concerned about the amount of radiation this may involve, so she is conducting a risk assessment.
   a **Identify** the risk of high radiation to Stella. (THINK: Is the X-ray likely to deliver high levels of radiation?)
   b **Identify** measures that could be taken to prevent unnecessary radiation exposure. (THINK: Is there PPE Stella and the radiologist could wear?)

*REVIEW

Multiple choice

1 Which of these is not evidence of atomic theory?
- **A** Elements can join together to form compounds.
- **B** The periodic table.
- **C** Gases have mass.
- **D** Water always contains twice as much hydrogen as oxygen.

2 The nucleus of an atom is:
- **A** made of protons and neutrons
- **B** made of electrons and neutrons
- **C** made of protons and electrons
- **D** always negatively charged.

3 Which of these is a transition metal?
- **A** Caesium
- **B** Palladium
- **C** Fluorine
- **D** Radon

Recall and explain

4 **Explain** what the '2' represents in the formula CO_2.

5 **Identify** where each of the following particles are found in an atom and their charges.
- **a** Proton
- **b** Neutron
- **c** Electron

6 **Explain** why the mass numbers of isotopes are exact whole numbers but the relative masses of most atoms are not exact whole numbers.

7 Titanium is element 22 in the periodic table. It has five naturally occurring isotopes. **Describe** what the isotopes of titanium will have in common and in what way(s) they will be different.

8 **Recall** what a beta particle is. Write its symbol, including the atomic and mass numbers in the correct positions.

9 **Explain** what it means if a substance is radioactive.

10 **Describe** Rutherford's experiment.

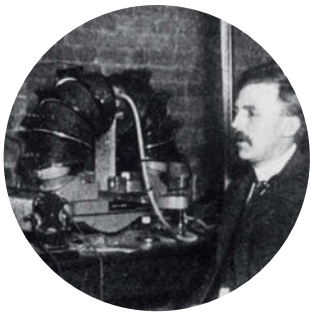


Figure 1 Ernest Rutherford in one of his laboratories.

11 In a periodic table, the vertical columns are called _____, and the horizontal rows are called _____.

12 **Identify** the most important new understanding of the structure of the atom that Rutherford inferred from his experiment with alpha particles.

Apply and analyse

13 **Explain** why the molecules of water are impossible to see, even with powerful microscopes.

14 $^{238}_{92}U$ is an isotope of uranium that is used in nuclear reactors. In an uncharged atom, how many:
- **a** protons are present?
- **b** neutrons are present?
- **c** electrons are present?

15 Only 0.7% of the uranium atoms in naturally occurring uranium exist as uranium-235. The other isotopes present are uranium-234 (0.01%) and uranium-238 (99.3%). Write the symbols for these other two isotopes.

16 According to the Bohr model of the atom, the electronic configuration of the uncharged atoms of a particular element is 2, 8, 8.
- **a** **Identify** the atomic number of the element.
- **b** **Identify** what element it must be.
- **c** What will be the electronic configuration of the next element on the periodic table? **Explain** your reasoning.

17 Draw a radioactive decay curve for a substance that starts with an activity of 1600 counts per minute and has a half-life of 2 hours.

18 If a radioactive substance decays from 400 counts per minute to 50 counts per minute in 9 hours, **calculate** its half-life.

19 **Describe** the trends when moving down and across a periodic table with respect to the ions that are formed.

20 An atom has a mass number of 7 and has 4 neutrons. How many protons does it have? What is the name of the element?

21 The atomic number of a nitrogen atom is 7 and the mass number is 14. How many electrons are in this atom?

22 **Identify** the atom that has twice as many protons as an oxygen atom.

23 A number of the elements have radioactive isotopes. In each case, it is the nucleus of the atom that is unstable. **Investigate** the kinds of particles and/or rays that can be emitted by radioactive atoms.

Evaluate and create

24 Tellurium is element number 52. It has a relative atomic mass of 127.6. The next element, iodine, has a relative atomic mass of 126.9.
   a Write the symbol for the isotopes of tellurium-127 and iodine-127.
   b **Explain** why the atoms of these two different elements can have the same mass number.

25 Scientists have had to infer what it is like inside the atom from indirect evidence, in the same way that astronomers have worked out the temperature and composition of stars. Write a list of the advantages and disadvantages of using indirect evidence to develop theories in science.

26 **Describe** the differences between a scientist and a natural philosopher.

27 Consider the composition of alpha and beta particles. When a beam of alpha particles and a beam of beta particles are fired into an electric field, they move in opposite directions. **Propose** why you think this is.

28 **Describe** why the Bohr model of the atom gives us much more information than Dalton's early model of the atom.

29 A primary school student who was learning about solids, liquids and gases was told by her teacher that everything around her is made of particles that she cannot see. Her response was that this is silly, because if you can't see it, it can't be there. Write a paragraph persuading the student that her teacher was correct.

30 **Construct** a poster that shows the models of the atom, from the original theory that it was a solid sphere (as proposed by the English chemist John Dalton) to the Bohr model. Use the internet to find images of the scientists involved and place copies onto your poster. **Investigate** the year in which each model was proposed and include a timeline.

31 **Apply** your understanding of atoms and elements to suggest reasons for the following.
   a Carbon dioxide is a heavier gas than oxygen.
   b Hydrogen and oxygen can be produced from water.
   c The relative atomic mass of calcium (atomic number 20) is actually higher than the relative atomic mass of argon (atomic number 18).
   d Beta particles can be stopped by a few millimetres of lead foil, but gamma rays will pass through several centimetres of lead.

32 Design an experiment that would allow you determine the type of radiation emitted by a radioactive sample.

33 **Explain** what cathode ray tubes are. How can these be used to help explain the atomic model?

34 Create a webpage or a poster that explores how JJ Thomson, Ernest Rutherford and Niels Bohr have contributed to our understanding of the atom and their impacts on science. **Explain** how their models changed the history of science and why their models were significant at the time they were developed.

Critical thinking

35 **Investigate** how the structures of diamond and graphite are different even though they are both carbon based. **Identify** and **explain** one other form that carbon can take. **Describe** how their properties are affected by their structure.

36 Understanding of the periodic table of elements is continuously growing. **Discuss** the following claim: 'Eventually there will be no new elements to add to the periodic table of elements.'

Go further

37 **Investigate** additional uses of radiation in medical treatment. Then, **propose** what safety measures need to be taken to ensure patients are not harmed.

Figure 2 X-rays use radiation to make images of the bones in the body.

38 The amount of mass of an isotope can be calculated after a specific period of time using the following equation.

$$N_t = N_0 \times \frac{1}{2^n}$$

where N_t is the mass remaining, N_0 is the initial mass, and n is the number of half lives.

A patient is administered 20 g of I-131 for a medical test. **Construct** a table and draw a graph showing how much I-131 is remaining after each half-life for a total of 5 half-lives. (Note: I-131 has a half-life of 8 days.)

Research

39 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Targeted alpha therapy

Targeted alpha therapy (TAT) is a new therapy for the control of some cancers. How does this form of therapy work? What types of cancer are treated by this method? How widespread is its use? What are the risks associated with this form of radiotherapy and how are they reduced?

»Henri Becquerel

Henri Becquerel shared a Nobel Prize with Marie Curie for work in discovering radioactivity. What did he contribute to this important work? What scientific units are named after him? Did his children, like those of Marie and Pierre Curie, also follow careers in science?

»CERN

The European Organization for Nuclear Research is known as CERN and is based on the border of France and Switzerland. It has been responsible for developing scientists' understanding of atoms. What countries collaborate on this project? What types of scientists work at CERN? What current work is occurring at CERN? What is the Large Hadron Collider?

Figure 3 CERN

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Identify that all matter is made of atoms which are composed of protons, neutrons and electrons.	☐	☐ Go to pages 264-265
Describe the structure of atoms in terms of the nucleus, protons, neutrons and electrons.	☐	☐ Go to pages 266-267
Outline historical developments of the atomic theory to demonstrate how models and theories have been contested and refined over time through a process of review by the scientific community.	☐	☐ Go to pages 262-263
Identify that natural radioactivity arises from the decay of nuclei in atoms, releasing particles and energy.	☐	☐ Go to pages 278-279
Evaluate the benefits and problems associated with medical and industrial uses of nuclear energy.	☐	☐ Go to pages 278-279

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THE PERIODIC TABLE

Why do scientists use the periodic table?

Have you ever wondered ...

- Why is the periodic table ordered the way it is?
- Why is the symbol for sodium Na and not S or So?

14

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- identify the atom as the smallest unit of an element and that it can be represented by a symbol
- distinguish between the atoms of some common elements by comparing information about the numbers of protons, neutrons and electrons
- describe the organisation of elements in the Periodic Table using their atomic number
- relate the properties of some common elements to their position in the Periodic Table
- predict, using the Periodic Table, the properties of some common elements
- outline some examples to show how creativity, logical reasoning and the scientific evidence available at the time, contributed to the development of the modern Periodic Table

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

14.1 The periodic table was refined over time

In this topic, you will learn that:

- the periodic table was developed over time, by several scientists
- various advancements in technology allowed the knowledge about elements to be refined.

The development of the periodic table involves scientists building on the work of previous generations. The discovery of new elements together with the ability to recognise patterns and predict the existence of previously unknown elements all result from scientists analysing and refining models. The creation of the periodic table is often credited to Dimitri Mendeleev, who constructed a table with gaps for elements that were yet to be discovered. However, the ideas he used were first suggested decades before and refined centuries after his work began.

Resource
STEM activity: Creating a periodic table

2000 years ago

The ancient Greeks thought that everything was made of four 'elements' mixed together in different ratios.

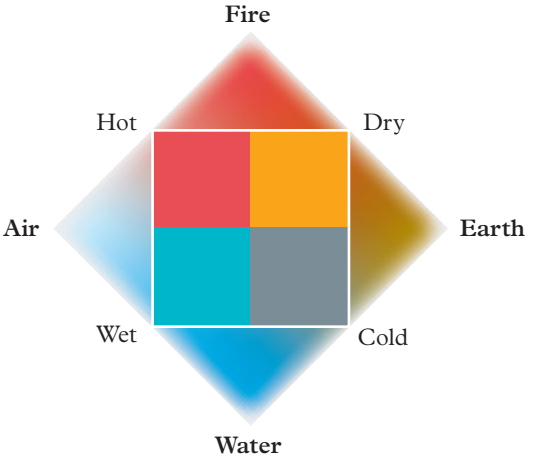

Figure 1 The four Greek 'elements'

1661

Irish-born chemist Robert Boyle suggested that an element was a substance that cannot be broken down into a simpler substance in a chemical reaction.

Figure 2 Robert Boyle

1789

Antoine Lavoisier, a French nobleman, made a detailed list of the substances that he believed to be elements.

Figure 3 Antoine Lavoisier

Assisted by his wife Marie-Anne, his list contained 33 elements grouped into metals and non-metals. Lavoisier's list also included some substances that we now know to be compounds.

1820s

Jakob Berzelius was a Swedish chemist who replaced the geometric patterns used as chemical symbols with letters that were an abbreviation of the element's name. Berzelius chose the first letter(s) of the Latin name for each element. In addition, Berzelius used the weight of hydrogen to develop an organised system of atomic weights. Because hydrogen was the lightest element, it was given a value of 1, with all remaining elements believed to have a whole number above 1.

Figure 4 Jakob Berzelius gave the elements their symbols.

1829

As more elements were identified, more chemists studied them and their properties. In Germany, Johann Döbereiner was aware of the 40 elements. He noted that some groups of three elements had similar properties and named these groups 'triads'. These groupings were important in identifying patterns of behaviour, which helped with more accurate predictions about atomic structures.

1864

English chemist John Newlands arranged the elements according to their atomic weights. He noticed that every eighth element had similar properties. This pattern was considered a recurring, or 'periodic', feature among the elements. Newlands made the mistake of comparing the properties of the elements to music, with musical notes being grouped eight per octave. This comparison, called the law of octaves, was not taken seriously by Newlands' peers.

1869

Dmitri Mendeleev is hailed as the creator of the modern periodic table. Building on the ideas of his contemporaries, Mendeleev, who lived in Russia, knew of 63 elements. It is said that Mendeleev wrote the names and properties of each element on a small card that he then arranged in order of atomic weight.

The cards were then rearranged, maintaining their order, into groups with similar properties. With this organisation complete, Mendeleev proposed the periodic law:

> 'Elements have properties that recur or repeat according to their atomic weight.'

More importantly, Mendeleev's organisation of cards identified 'holes' that he attributed to elements that had yet to be discovered. Mendeleev predicted the properties of 21 unknown or undiscovered elements.

Figure 5 Dmitri Mendeleev

Table 1 Predicted properties of ekasilicon compared with the actual properties of germanium

Ekasilicon (symbol Es) as predicted in 1871	Germanium (symbol Ge) as discovered in 1886
Atomic mass: 72	Atomic mass: 72.6
Density: 5.50 g/mL	Density: 5.36 g/mL
Colour: grey metal	Colour: grey metal
Forms oxide EsO_2: density 4.70 g/mL, slightly basic	Forms oxide GeO_2: density 4.70 g/mL, slightly basic
Forms chloride $EsCl_4$: boiling point 100°C, density 1.90 g/mL	Forms chloride $GeCl_4$: boiling point 86°C, density 1.88 g/mL

His predictions started scientists searching for the missing elements. When these elements were discovered, their properties were found to be very close to the properties that had been predicted by Mendeleev. This convinced many chemists of the accuracy and value of Mendeleev's periodic table. Table 1 compares the properties of germanium with an element Mendeleev predicted called ekasilicon.

Mendeleev is given sole credit for the development of the periodic table. This is because of the evidence he provided to support his table and because he assumed that there were missing elements and he accurately predicted the properties of these elements.

1894

William Ramsay, a Scottish chemist, used the then new technology of refrigeration to liquefy and separate the components of air. He successfully removed water, carbon dioxide, oxygen and nitrogen, but he found he had some unknown gas left behind. This was argon: the first in its group to be discovered. Further experimentation identified helium, neon, krypton and xenon. All these gases form the group of noble gases at the far right of the periodic table.

1911

Marie Curie was one of the many female scientists who identified and purified elements of the periodic table. Marie Curie won two Nobel Prizes for her work on radiation. One of her most notable finds was polonium, which she named after her home country, Poland.

1913

By the early 1900s, X-rays could be used to determine the atomic number of each element. Using this technology, Henry Moseley, a young English physicist, refined the order of some of the elements in Mendeleev's periodic table and proposed a minor change to the periodic law:

> 'Elements have properties that recur or repeat according to their atomic number.'

Figure 6 Marie Curie developed the theory of radioactivity. She won the 1911 Nobel Prize in Chemistry for her discovery of radium and polonium.

Figure 7 Henry Moseley's name is linked to significant advances in X-ray-related chemistry and physics, with many believing him worthy of a Nobel Prize. His work was cut short when he died at just 27 years of age in the Battle of Gallipoli during World War I.

1940

With the development of nuclear processes, elements heavier than uranium could be created. The US scientist Glen Seaborg, winner of the 1951 Nobel Prize in Chemistry, led a team of scientists who used a cyclotron to bombard uranium atoms with neutrons. This produced the very first atoms of neptunium and plutonium.

Today

Since the 1940s, similar nuclear processes have been used to synthesise the elements up to and including element 118. These elements are given names based on their atomic number: 118 is called 'ununoctium' (1-1-8-ium).

Figure 8 Atoms heavier than uranium are called the 'transuranium' or 'transuranic' elements. None of them occur naturally. The image shows a sample of neptunium.

Check your learning 14.1

Recall and explain

1 **Recall** who proposed the modern idea of an element and when they proposed this.
2 **Explain** what a triad was and why it was important.
3 **Identify** the first chemist to lead a team that made elements that did not occur naturally.
4 When Mendeleev proposed the periodic table, he went one step further. **Recall** what else he did and **explain** why this was significant.
5 **Recount** the development of the periodic table from 1869 until 1940.

Apply and analyse

6 **Explain** why the gases that Ramsey discovered couldn't be discovered any earlier.
7 Moseley changed the periodic law proposed by Mendeleev by changing one word. **Recall** what word was changed, and **explain** how this improved the periodic table.

Evaluate and create

8 Henry Moseley used X-ray technology to find some new elements. **Describe** this technology and **explain** how some of the new elements have been discovered by using this piece of technology. **Outline** your findings on a flyer that could be used to sell this machine.
9 **Outline** how logical reasoning and scientific evidence available at the time contributed to the development of the periodic table we use today.

Skill builder: Problem solving

10 Originally, geometric symbols were used to represent each element. Create a cause and effect diagram (e.g. fishbone diagram) to **identify** some of the problems associated with using geometric symbols for the elements today.
   a **Identify** the problem. (THINK: Why is using symbols a problem?)
   b **Identify** the cause of the problem. (THINK: Have there been more elements discovered?)
   c **Identify** where you should place the causes and sub-causes in your cause and effect diagram. (THINK: The head of the fish is the problem.)

14.2 The structure of an atom determines its properties

*

In this topic, you will learn that:

- the rows of the periodic table are called periods
- the columns of the periodic table are called groups
- the number of electrons in a valence shell determines many of the properties of an element and, with this, its position on the periodic table.

An atom is the smallest unit of any element, and the elements are represented using symbols. As mentioned in the previous section, Berzelius used chemical symbols with letters that were an abbreviation of the element's name. He chose the first letter(s) of the Latin name for each element. So, some symbols make more sense to us in English, such as O for oxygen. However, Ag comes from the Latin word for silver (which is 'argentum'), and gold is 'aurum' in Latin and therefore has the symbol Au. If elements start with the same letter, subsequent letters (in lower case) are used. For example, carbon is C and copper is Cu (which has the Latin name 'cuprum').

atomic number
the number of protons of an atom

The atomic number and name of an atom is determined by the number of protons it contains in its nucleus. The relative atomic mass is the sum of the number of positive protons and number of neutral neutrons. Negatively charged electrons have negligible mass and move about the nucleus in electron shells. The outermost electron shell is called the valence shell of the atom. The number of electrons in the valence shell determines many of the properties of the element and therefore its position in the periodic table.

The periodic table

The periodic table shows the types of atoms, or elements, in rows and columns. The rows are called **periods**. The atomic number increases by one for each element as you go across a period. The vertical lists of elements are called **groups**, with the elements in each group having similar properties. These groups are similar to the triads described by Döbereiner.

period
a horizontal list of elements found in the periodic table

group
a vertical list of elements found in the periodic table that have characteristics in common

The columns and rows in the periodic table have been given names and numbers. This makes communication easier, because these elements have similar properties and trends.

Atoms and their electrons

The protons and neutrons of an atom are located within the nucleus. These subatomic particles are responsible for most of the mass of the atom and therefore have a strong influence on the properties of the atom. The number of protons is called the **atomic number** and is used to order the elements in the periodic table.

In contrast, electrons have almost negligible mass. However, because they orbit the nucleus, these subatomic particles interact with other atoms.

Electronic configurations

The Bohr model of the atom can be used to consider how electrons are arranged in an atom. In this model, the electrons are arranged in areas of space around the nucleus. These areas are called shells. The electron shells are numbered from the nucleus outward. These are shown in Table 1, along with the maximum number of electrons in each shell.

Table 1 The Bohr model of the atom

Shell number (from the nucleus outwards) (n)	Maximum number of electrons in the shell ($2n^2$)
1	2
2	8
3	18*
4	32

*The formula $2n^2$ works for most atoms until we get to atomic number 19 (potassium). Once the third electron shell has eight electrons, remaining electrons start moving into the fourth shell.

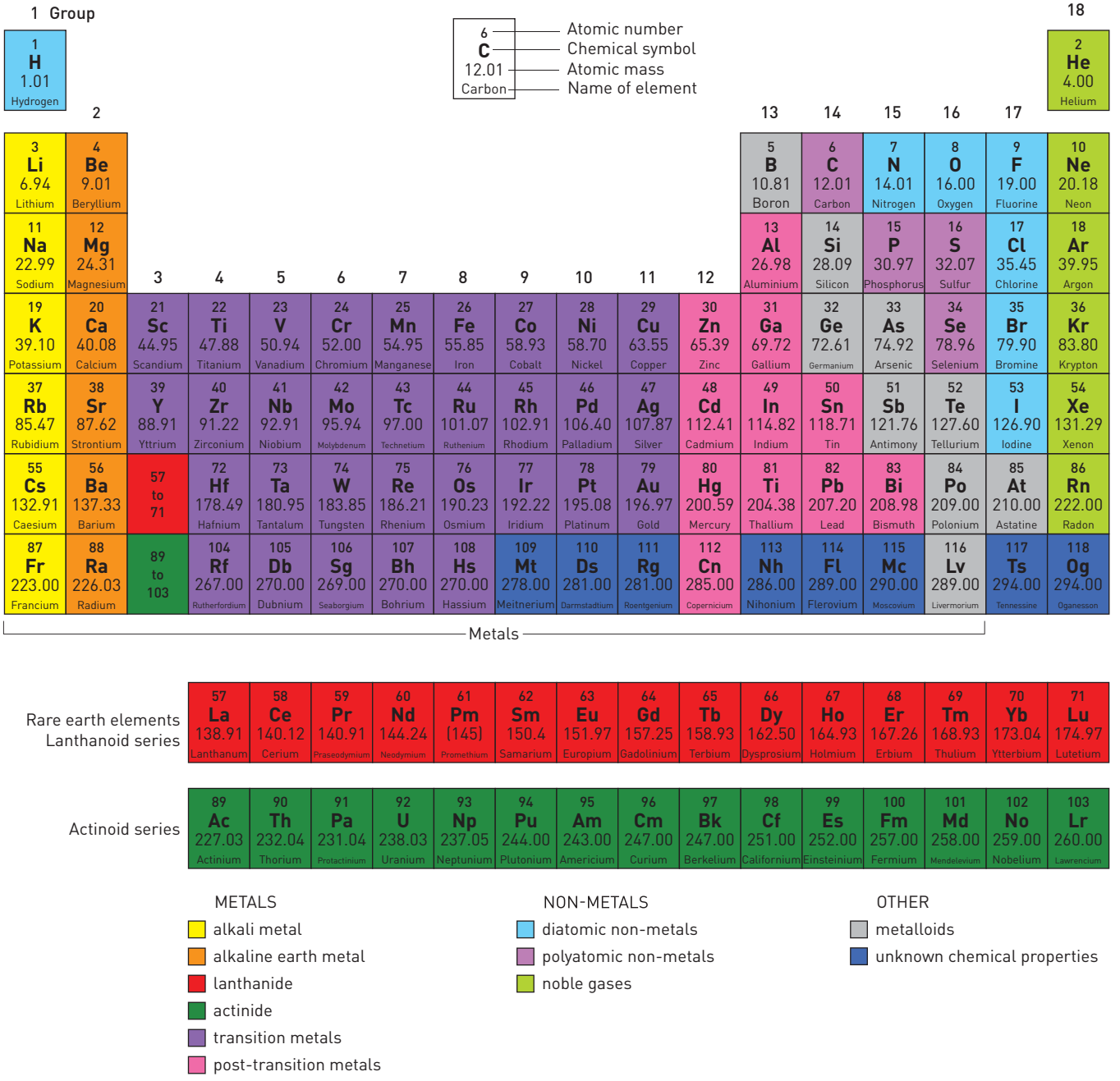

Figure 1 The periodic table

Table 1 shows that the further the electron shell is from the nucleus, the more electrons it can contain. The maximum number of electrons a shell can hold is related to its shell number by the simple formula $2n^2$, where n is the number of the shell from the nucleus.

Bohr also stated that the electrons of an atom are normally located as close to the nucleus as possible. This is because the negatively charged electrons are attracted to the positive charges of the protons. This is a lower energy state for the atom and is therefore more stable.

The arrangement of electrons in an atom is termed its electronic configuration. Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are presented in pairs. This makes it easier to draw the diagrams and is scientifically correct because, in atoms, electrons exist in pairs within the shells. The outermost occupied shell of atoms is known as the **valence shell**.

shell diagram
a diagram that shows the arrangement of electrons and electron shells in an atom

valence shell
the outermost electron shell in an atom that contains electrons

Electronic configuration of oxygen

The atomic number of oxygen is 8, so an uncharged atom contains eight electrons.

- Oxygen is in period 2, so it has two electron shells.
- The first shell can only hold two electrons.
- The second shell holds the other six electrons.
- The electronic configuration of oxygen is written as 2, 6.

Electronic configuration of calcium

The atomic number of calcium is 20, so an uncharged atom contains 20 electrons.

- Calcium is in period 4, so it has four electron shells.
- The first shell can only hold two electrons.
- There are 18 electrons left to place in shells. The second shell can only hold eight electrons. The third shell is stable with eight electrons (even though it holds a maximum of 18).
- The fourth shell holds the last two electrons.
- The electronic configuration of calcium is written as 2, 8, 8, 2.

Electrons and properties of elements

The electronic configurations of the elements can explain the properties of the elements. Being able to confidently navigate the periodic table enables you to identify trends in electrons, the properties of elements and the uses of compounds formed from them.

Groups and valence electrons

The groups of the periodic table are numbered 1–18. Elements in the same group have similar chemical properties that we now know are due to the arrangement of their electrons.

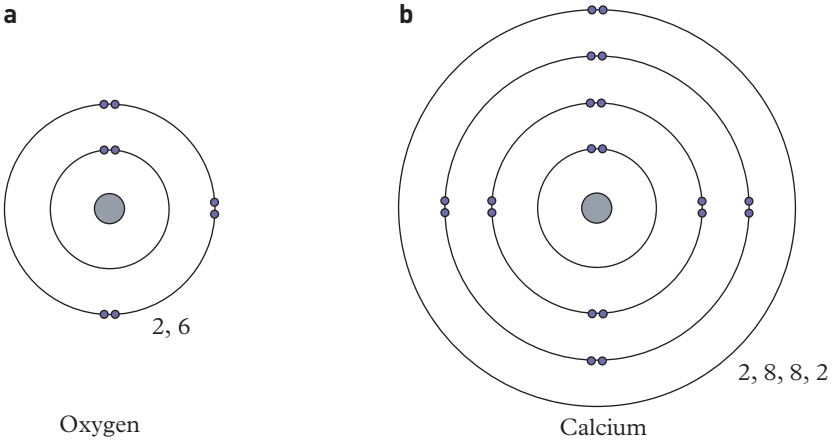

Figure 2 The electronic configurations for **a** oxygen and **b** calcium are shown as simple shell diagrams.

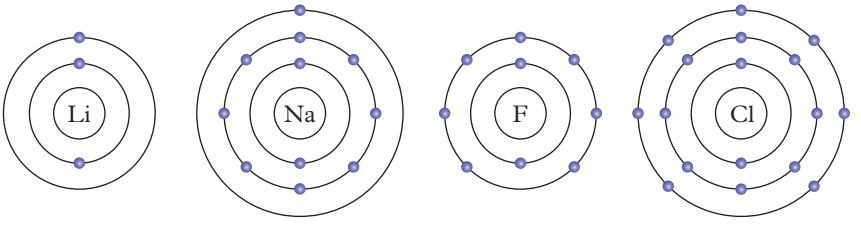

Figure 3 In group 1, the electronic configuration of lithium is 2, 1 and that of sodium is 2, 8, 1. The atoms of all group 1 elements have one electron in their outer shell. Elements in group 17 all have seven electrons in their outer shell; for example, the electron configuration of fluorine is 2, 7 and that of chlorine is 2, 8, 7.

Elements in the same group have the same number of electrons in their outermost or valence shell. The valence shell electrons often interact with other atoms.

Emission spectra and electron shells

When atoms are heated in a flame, the electrons gain heat energy from the flame and become 'excited', jumping from their normal shell to one further from the nucleus. When the electrons move back to their usual shell, this 'extra' energy is given out in the form of light. Because the energy gaps between electron shells vary from one atom to the next, the energy released by the different atoms also varies. This variation is seen as different levels of light energy, which have different frequencies; different frequencies of light have different colours. Hence, the emission spectrum of each atom will be a 'fingerprint' of different colour patterns. These spectra cause different-coloured flames when different elements are burned.

Check your learning 14.2

Recall and explain

1 **Explain** what the valence shell of an atom is.

2 **Recall** what determines the atomic number of an atom.

3 In the Bohr model of the atom, **identify** the maximum number of electrons that the fourth electron shell can contain.

Apply and analyse

4 A potassium atom contains 19 protons.

- **a** How many electrons will be present in a potassium atom? **Justify** your answer.
- **b** **Describe** the electronic configuration of a potassium atom according to the Bohr model.
- **c** From the electronic configuration of potassium, it is clear that electrons do not normally occupy the fifth shell. **Explain** what could be done to potassium atoms for electrons to jump into this shell.

5 Copy and complete Table 2, using the periodic table to help you.

Table 2 Elements and their atomic numbers and electron configurations

Element	Atomic number	Electron configuration
Beryllium		
	9	
Magnesium		
Neon		
		2, 8, 3
	11	
		2, 8, 7
Sulfur		

Evaluate and create

6 Emission spectra is unique for each type of element. **Investigate** how this could be useful in modern society.

7 Electron configurations are actually far more complex than using the 2,8,8 rule (where the first shell is filled with 2 electrons, the second with 8 and the third with 8). Research what subshells and orbitals are, and determine the arrangement of electrons for boron, neon and sodium. What relationship can you observe between this explanation of electron configuration and the 2,8,8 rule?

Skill builder: Processing and analysing data and information

8 The periodic table communicates information about all the known elements. When you are discussing these elements, it is useful to use the correct terminology as well as atomic mass and number. Correct the following sentences based on your understanding of the periodic table. For each of the options, state the group and period of the periodic table the element is found in.

- **a** Krypton has an atomic number of 83.80 and mass of 36.
  (THINK: Read the periodic table correctly.)
- **b** Tungsten is a polyatomic non-metal, with an atomic number of 74.
  (THINK: Where is tungsten on the periodic table?)
- **c** Silver (Au) is a transition metal, and it has a mass of 107.87.
  (THINK: What needs to be corrected to make this scientifically accurate?)

14.3 Groups in the periodic table have properties in common

In this topic, you will learn:

- that there are three main groups of metals – alkali, alkaline earth and transition metals
- about the properties of different groups of metals.

alkaline earth metals
the group of elements found in group 2 of the periodic table

transition metals
the elements found in groups 3–12 of the periodic table

alkali metals
the group of elements found in group 1 of the periodic table

metals
a collection of elements found on the left-hand side and centre of the periodic table that are malleable, lustrous, ductile and highly conducting

Figure 1 Freshly cut sodium, a group 1 metal

The two main types of elements are metals and non-metals, with metals constituting nearly three-quarters of all elements. Metals are defined by their lustrous appearance and their ability to conduct heat and electricity. The alkali metals in group 1 of the periodic table have a single electron in their outer shell and, as a result, are highly reactive when mixed with water. The alkaline earth metals have low melting points and are relatively flexible. Transition metals have properties that are unique to groups 3–12.

Metals

Metals have many properties in common. Pure metals are:

- lustrous (shiny)
- able to conduct heat and electricity
- malleable (can be beaten into a new shape)
- ductile (can be drawn into a wire).

Metals are very reactive and can react with oxygen, water and acids. There are different groups of metals; these are known as the alkali metals, alkaline earth metals and transition metals.

Group 1 metals

The **alkali metals**, such as sodium and potassium, are found in group 1 – the far left column. Their position tells you that their uncharged atoms have just one electron in their outer shell. The alkali metals have quite low melting points and are soft and highly reactive. In their pure state, they often resemble plasticine that, when cut, is very briefly shiny silver before reacting with the air to become white again (Figure 1). Alkali metals react very strongly – some violently – with water, producing hydrogen gas and an alkaline solution. (An alkali is a soluble base.) As you go down the group, this reaction becomes more violent.

Group 2 metals

The **alkaline earth metals**, such as magnesium and calcium, are found in group 2. Their position tells you that their atoms have two electrons in their outer shell. The alkaline earth metals have quite low melting points and are relatively soft and very reactive; although in general they are not quite as reactive as group 1 alkali metals. Like the alkali metals, alkaline earth metals react with water (some strongly), producing hydrogen gas and an alkaline solution. As you go down the group, the metals become more reactive (Figure 2).

Transition metals

The **transition metals** are found in a large block of the periodic table that consists of the ten groups across the centre (groups 3–12). Many transition metals have special properties that are not shown by group 1 or group 2 metals.

- A small number are magnetic.
- Gold and copper are the only metals that are not silvery in colour.
- Many form coloured compounds.
- Many form more than one compound with a non-metal such as chlorine. For example, iron forms $FeCl_2$ and $FeCl_3$.

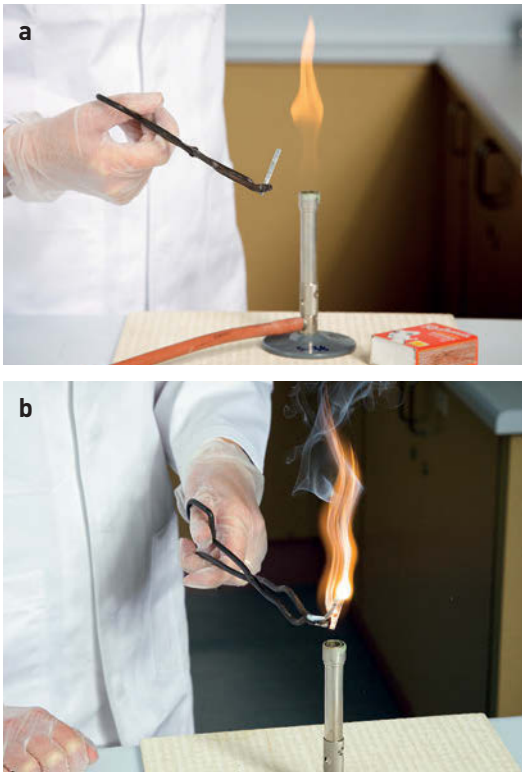

Figure 2 Magnesium, an alkaline earth metal, **a** before burning and **b** during burning.

Figure 3 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.

Figure 4 Gemstones contain atoms of different metals, which results in different colours.

Check your learning 14.3

Recall and explain

1 **Explain** the difference between a period and a group within the periodic table.

2 **Examine** the periodic table (page 424).
- a **Identify** the period and group for each of the following elements: fluorine, bromine, tin, radium, potassium, platinum, arsenic.
- b **Identify** if any of the elements in part a are in the same group. **Explain** what this could tell you about them.
- c **Identify** if any of the elements in part a are in the same period.

3 **Recall** which proportion of the periodic table is composed of metals.

4 **Clarify** what properties are shared by all metallic elements.

Apply and analyse

5 **Identify** two properties shown by some transition metals that are not shown by group 1 or group 2 metals.

Evaluate and create

6 **Propose** a way to represent the different groups of metals clearly and informatively, identifying the distinguishing properties of each group.

Skill builder: Communicating

7 Niamh is presenting information about metals to a group of students – specifically, alkali metals (sodium and potassium) and transition metals (cobalt and nickel). Niamh wants to present this information visually for ease of understanding and to compare the properties of each metal.
- a **Explain** whether Niamh should present this as a diagram or as a table. (THINK: Is there an experimental set-up required? Can this be presented as a table?)
- b Should Niamh include information about the type of metal, the atomic number and mass of each metal? (THINK: Should this information be placed in the same location for each element?)
- c **Construct** a visual representation for Niamh. (THINK: Do I have the correct information with the right element? Have I included all the required information? Are my headings and labels correct?)

14.4 Non-metals have properties in common

In this topic, you will learn that:

- non-metals are found in groups 14–16 of the periodic table
- non-metals do not conduct electricity or heat well
- metalloids are found between metals and non-metals in the periodic table
- the properties of metalloids are a combination of those of metals and non-metals.

non-metals
a collection of elements that are found on the right-hand side of the periodic table

Non-metals are elements found in groups 14–16 of the periodic table. They do not conduct electricity or heat very well and are very brittle. They do not reflect light and, as a result, have a dull appearance. Metalloids are found between metals and non-metals in the periodic table. Their properties are a combination of those of metals and non-metals.

Metalloids

metalloids
a small collection of elements that have a mixture of characteristics of metals and non-metals

Metalloids are the small set of elements along the 'staircase' diagonal boundary between the metals and non-metals (Figure 2). As might be expected from this location, metalloids exhibit properties between those of metals and non-metals. Most of their properties would be considered un-metallic; however, metalloids conduct electricity like the metals. Three of the metalloids are semiconductors, which means that they only conduct electricity in a certain way under certain conditions.

Figure 1 Silicon and germanium are widely used in electronic devices because of their semiconductor properties – they conduct electricity in a very controlled way.

Non-metals

Non-metals, as the name suggests, are elements that do not have the set of properties common to all metals. Non-metals are not lustrous (shiny), or ductile (easily manipulated); a small number of non-metals are coloured; and some are brittle. In addition, non-metals have a much larger range of melting points and boiling points than the metals do. At room temperature, several non-metals are gases and one (bromine) is a liquid, whereas all the metals except for one (mercury) are solids at room temperature. Only 18 elements in the periodic table are considered non-metals, compared with more than 80 metals. Despite this, non-metals make up most of the crust and atmosphere of the Earth, as well as the bulk of living organisms' tissues.

Only two groups (vertical columns) in the periodic table are made up entirely of non-metals: groups 17 and 18.

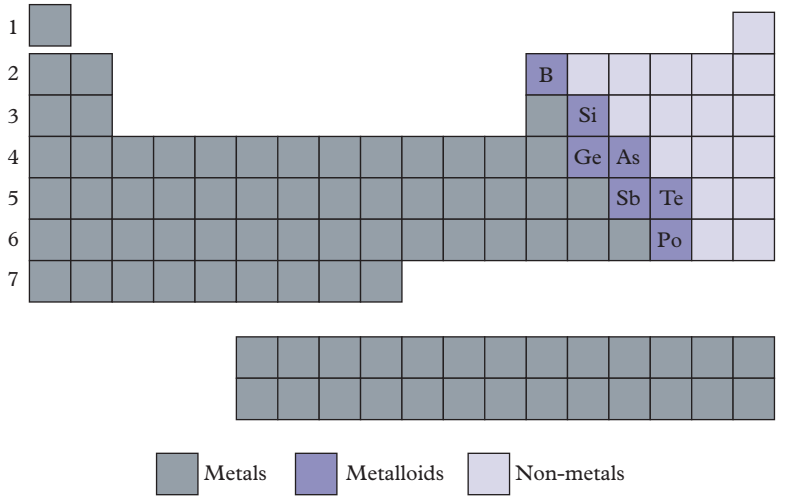

Figure 2 Regions of the periodic table

Group 17: The halogens

The **halogens**, such as fluorine and chlorine, are found in group 17. The atoms of all the halogens have seven electrons in their outer shell. The halogens are mostly known for their capacity to react with metals to form salts. The word 'halogen' means 'salt-forming', and the term was coined for this group by Jakob Berzelius. Some halogens have bleaching properties as well.

As you go down the group, the melting points and boiling points of the halogens increase. At room temperature, fluorine and chlorine are gases, bromine is a liquid, and iodine and astatine are solids. This is the only group in which the elements range from gas to liquid to solid at room temperature. Astatine is radioactive and very unstable.

Figure 3 Bleaches often contain halogens.

Unlike the metals in groups 1 and 2, the further down you go in this group of non-metals, the less reactive the element. Fluorine is the most reactive non-metal of all and is extremely dangerous to handle (Figure 4). Halogens are very effective cleaning and sterilising substances because of the lethal effects they can have on bacteria and fungi.

Group 18: The noble gases

The **noble gases**, such as neon and argon, are found in group 18. The uncharged atoms of the noble gases have eight electrons in their outer shell, except for helium, which has two. The noble gases are so called because they are all gases at room temperature and are unchanged if mixed with other elements; that is, they are very unreactive, or inert.

The first three in the group (helium, neon and argon) do not react with any other element and form no compounds. It was first thought that the same was true of xenon and krypton, but recently chemists have discovered that these two elements will react with fluorine under certain conditions and form a very small number of compounds. The last member of the group, radon, is very dangerous – not because of any chemical reactivity, but because it is a radioactive gas.

halogens
the group of elements found in group 17 of the periodic table

noble gases
a collection of gaseous elements found in group 18 of the periodic table

Figure 4 Fluorine, the most reactive non-metal, is used to etch glass; it is extremely dangerous to handle.

Check your learning 14.4

Recall and explain

1 **Explain** why non-metals are named according to what they are 'not' rather than what they have in common.
2 **Recall** what a semiconductor is.
3 **Identify** the dominant state of matter within the groups of non-metals.
4 The two main groupings of non-metals are in groups 17 and 18.
   a **Explain** what the group number tells you about the elements it contains.
   b **Describe** the properties that members of each group share.

Apply and analyse

5 **Identify** the properties that metalloids share with non-metals and with metals.
6 The melting points and boiling points of halogens increase as you move down the group. **Interpret** this statement with respect to their states at room temperature.

Evaluate and create

7 **Evaluate** why the term 'metal-like' could be used to describe metalloid elements. Suggest a better name for this group of elements. **Explain** your answer.

Skill builder: Planning investigations

8 Dani and Jay wanted to conduct an experiment that investigated the boiling point of different halogens. Dani thinks they should place each of the different halogens (iodine, chlorine and fluorine) in different sized beakers and boil them at different temperatures.
   a **Identify** why different sized beakers and different temperatures would not help the experiment.
   (THINK: Would the results be accurate or reliable? Would the different sized beakers have an impact on the rate of boiling?)
   b **Explain** why Dani's method would not produce reliable results.
   (THINK: Are the variables being kept constant?)

*REVIEW

Multiple choice

1 **Identify** the year that chemists stopped using geometric patterns as symbols for the elements and started representing them using their names.
- **A** 1601
- **B** 1820
- **C** 1869
- **D** 1913

2 Rows of the periodic table are called:
- **A** groups
- **B** periods
- **C** valences
- **D** electronic configurations.

3 **Identify** the correct statement about calcium.
- **A** It is in period 2.
- **B** It has an atomic number of 20 and a mass of 40.08.
- **C** Its electronic configuration is 2, 8, 6, 2.
- **D** It has 6 electron shells.

Recall and explain

4 **Identify** the atomic number of the element known as ununpentium.

5 **Recall** what the overall order of elements in the periodic table is based on.

6 **Explain** what an element is.

7 **Distinguish** between an atom and an element.

8 **Identify** the name given to the following features of the periodic table.
- **a** Horizontal row
- **b** Vertical column
- **c** The set of 10 groups from group 3 to group 12

9 **Identify** the group number of the:
- **a** alkaline earth metals
- **b** halogens
- **c** noble gases
- **d** alkali metals.

Figure 1 Indium is an alkali metal.

10 **Explain** what the valence shell is.

11 **Recall** the features that elements all in the alkali metals group have in common.

12 **Propose** why transition metals are much more widely used than alkali metals.

13 **Recall** the maximum number of electrons that can be found in each of the first four shells in an atom.

14 **Define** a 'noble gas'.

15 **Propose** why radon is responsible for most background radiation experienced in public spaces.

Figure 2 Radon is responsible for most background radiation experienced in public spaces. It occurs naturally as the decay product of uranium and can be found in natural springs.

Apply and analyse

16 **Explain** how the position of an element in the periodic table affects its properties.

17 What is the electron configuration of potassium?

18 **Identify** where in the periodic table you would find an element that has the physical property of magnetism.

19 **Describe** the general trend of the periodic table from left to right with respect to the physical and chemical properties of elements.

20 Draw electron shell diagrams of the following atoms.
- **a** Beryllium
- **b** Helium
- **c** Silicon
- **d** Bromine

21 **Assess** why boron and silicon are used to form borosilicate glassware, like Pyrex®.

Figure 3 Boron and silicon are combined to form borosilicate glassware, such as the common Pyrex® brand. This glassware is tough and has excellent heat-conduction properties that make it suitable for cooking.

Evaluate and create

22 Scientists such as Berzelius and Mendeleev worked on their own to produce new ideas. Others, like Seaborg, worked in a team. Now most scientists work in teams. **Discuss** the advantages of working in a team.

23 Scientists have had to deduce what it is like inside an atom from indirect evidence, similar to how astronomers determine the temperature and composition of stars. **Identify** three advantages and three disadvantages of using indirect evidence to develop scientific theories.

24 Using a blank periodic table template, **construct** a periodic table using the following rules.

- **a** Write the symbol of each element that exists at room temperature as:
  - **i** a gas in red
  - **ii** a solid in black
  - **iii** a liquid in blue.
- **b** Colour the periodic table using the following colours for each group.
  - **i** Halogens: blue
  - **ii** Noble gases: yellow
  - **iii** Alkali metals: purple
  - **iv** Alkaline earth metals: red
  - **v** Transition metals: green
  - **vi** Lanthanides: orange
  - **vii** Actinides: light blue

Figure 4 Potassium reacts spectacularly with water.

25 **Construct** a brochure for one element in the periodic table (choose from atomic numbers 1–36). Include the following information.

- **a** **Identify** the element and how it got its name.
- **b** **Identify** the symbol, atomic number, atomic mass and electron configuration.
- **c** **Explain** where it can be found and in what form (i.e. compound).
- **d** **Describe** physical facts such as melting point, boiling point, density and abundance in the Earth's crust.
- **e** **Explain** uses of the element.
- **f** Include references of where you found your information.

Critical thinking

26 **Assess** whether there is an alternate format for representing the elements, other than the periodic table. Then, try to **construct** the alternate option. Based on the alternative, **evaluate** the current periodic table's success.

27 **Investigate** the research of US scientist Glen Seaborg, who won the 1951 Nobel Prize in Chemistry. In your research **identify**:

- **a** if Glen Seaborg's discovery led to the discovery of further elements
- **b** what his research has contributed to understanding of atomic structure.

Go further

28 In Chapter 13 you learnt about how ions are formed. Write the electron configurations and draw the electron diagrams for sodium and fluorine. Now do the same for the ions they each form. Which noble gas does their electron configurations look like?

29 Elements are organised in the periodic table according to atomic number. **Discuss** how the periodic table may predict how certain elements would react together.

Research

30 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»The noble gases

The story behind the discovery of the noble gases is a fascinating one. The challenge was this: how do you detect the existence of something that only exists as a gas which does not react with anything and, except for argon, is only present in the air in extremely small concentrations? How was the first noble gas found? What role did the periodic table of that time play in helping chemists hunt for other noble gases?

»Marie Curie

Marie Curie was awarded a Nobel Prize for her discovery of polonium, which she named after her home country (Poland). Names of the elements are sometimes taken from their properties, and in other instances like polonium, from something personally related to the scientist who discovered them. Investigate calcium, magnesium and krypton. What are the reasons for their names? Do their names represent their chemical properties? Were their names influenced by the elements surrounding them?

Figure 5 Helium

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Identify the atom as the smallest unit of an element and that it can be represented by a symbol.	☐	☐ Go to pages 288-291
Distinguish between the atoms of some common elements by comparing information about the numbers of protons, neutrons and electrons.	☐	☐ Go to pages 292-293
Describe the organisation of elements in the Periodic Table using their atomic number.	☐	☐ Go to pages 288-291
Relate the properties of some common elements to their position in the Periodic Table.	☐	☐ Go to pages 292-293
Predict, using the Periodic Table, the properties of some common elements.	☐	☐ Go to pages 294-295
Outline some examples to show how creativity, logical reasoning and the scientific evidence available at the time, contributed to the development of the modern Periodic Table.	☐	☐ Go to pages 284-285

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CHEMICAL REACTIONS

How do chemical reactions occur?

15

Have you ever wondered ...

- Why do different substances decompose at different rates?
- How are chemical formulas written?
- Can matter be destroyed?

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- recall that all matter is composed of atoms and has mass
- identify a range of compounds using their common names and chemical formulae
- classify compounds into groups based on common chemical characteristics
- investigate a range of types of important chemical reactions that occur in non-living systems and involve energy transfer, including:
  - combustion
  - the reaction of acids including metals and carbonates
  - corrosion
  - precipitation
  - neutralisation
  - decomposition
- identify some examples of important chemical reactions that occur in living systems and involve energy transfer, including respiration and reactions involving acids such as occur during digestion
- construct word equations from observations and written descriptions of a range of chemical reactions
- deduce that new substances are formed during chemical reactions by rearranging atoms rather than creating or destroying them

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

15.1 Mass is conserved in a chemical reaction

In this topic, you will learn that:

- in a chemical reaction, the substances on the left-hand side of the arrow are the substances that we start with, that is, the reactants
- in a chemical reaction, the substances on the right-hand side of the arrow are the products of the reaction
- the law of conservation of mass states that the total mass of the reactants is equal to the total mass of the products.

Representing chemicals

When examining chemical reactions, we can represent the substances in different ways. The substances that are present at the start of a chemical reaction are called the **reactants**. The substances formed by the chemical reaction are called the **products**. We can write this using a simple word equation. Consider the reaction of the acid in vinegar with sodium bicarbonate. This reaction produces water, carbon dioxide gas and a substance called sodium acetate, and it can be represented as:

acetic acid (in vinegar) + sodium bicarbonate → sodium acetate + carbon dioxide + water

reactant
the substances present at the start of a reaction and that undergo change during a chemical reaction

product
the substances formed by a chemical reaction

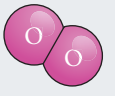
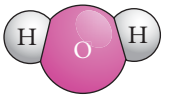
Figure 1 Acetic acid in vinegar reacts with sodium bicarbonate.

The acetic acid and sodium bicarbonate are the reactants for this reaction. The products formed by this reaction are sodium acetate, carbon dioxide and water.

The law of conservation of mass

If you did Investigation 15.1, you found out that when the products of a chemical reaction are not allowed to escape, the mass of the products after the observed reaction is the same as the mass of the reactants that you started with. This is a very important observation. It shows that the total mass of the chemicals is not changed in a chemical reaction. When a chemical reaction takes

Table 1 Representations of four chemicals

Chemical name	Formula/ symbol	Diagram
Methane	CH_4	
Oxygen	O_2	
Water	H_2O	
Carbon dioxide	CO_2	

INVESTIGATION
15.1: Comparing mass before and after a chemical reaction
Go to page **399**

place, the chemicals interact, causing the atoms to break apart from each other before forming new arrangements. However, no atoms are produced in the process and no atoms are destroyed. This is one of the most important laws in science.

Example of a chemical reaction

Methane gas (CH_4) is the main gas present in natural gas, which is used in the home for cooking and heating. When it burns, it combines with oxygen (O_2) in the air to form carbon dioxide (CO_2) and water (H_2O).

Figure 3 shows what is happening to the atoms during this reaction. Different atoms are represented by different colours.

1 Count the number of each type of atom in the reactants (left-hand side of the arrow), and count the number of each type of atom in the products (right-hand side of the arrow). What do you notice?
2 Describe what has happened to the hydrogen atoms during the chemical reaction.
3 Describe what has happened to the oxygen atoms. Make sure you use the correct names of the chemicals in your description.

Figure 2 Methane gas burning on a stove

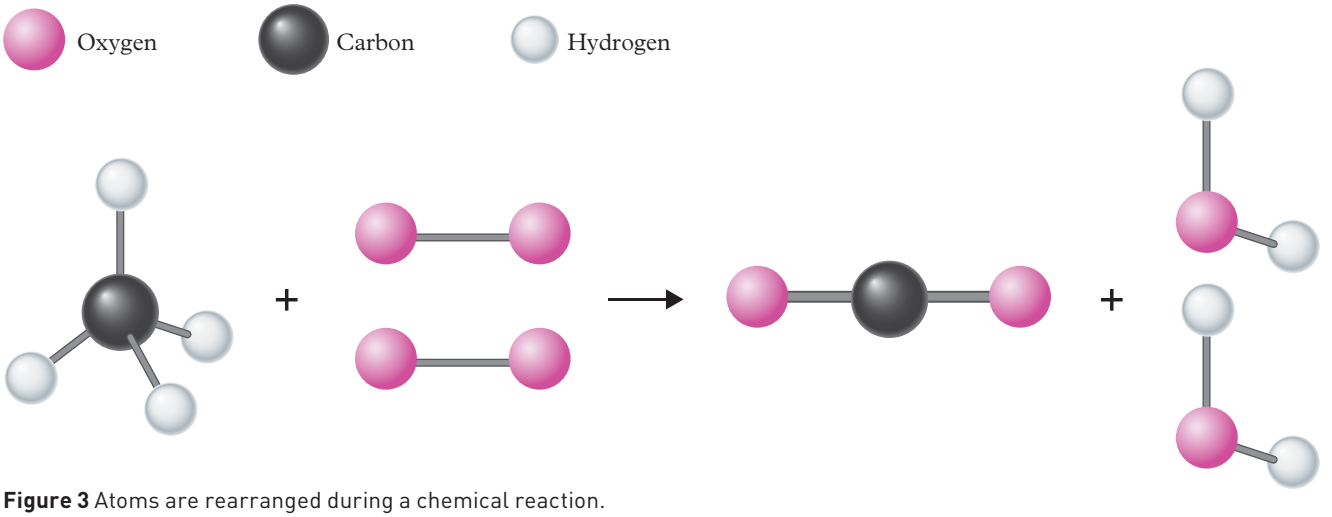


Figure 3 Atoms are rearranged during a chemical reaction.

Check your learning 15.1

Recall and explain

1 **Explain** what mass is.
2 Use Table 1 to **identify**:
   a an element composed of molecules
   b a compound composed of molecules.
3 If no mass is lost or gained in a chemical reaction, **describe** what this tells you about the atoms involved in the reaction.

Apply and analyse

4 **Explain** how the products of a reaction have properties very different from those of the reactants, even though the total mass remains the same.
5 Early alchemists repeatedly tried to turn lead into gold. **Explain**, using the law of conservation of mass, why this would be impossible.

Evaluate and create

6 Consider each of the following reactions – do they abide by the law of conservation of mass? **Explain** why or why not.
   $C + O_2 \rightarrow CO$
   $Na + Cl_2 \rightarrow NaCl$
   $Mg + O_2 \rightarrow 2MgO$

Skill builder: Processing and analysing data and information

7 Presenting information and data in the most appropriate way will help you interpret and analyse the data. Consider the following reactions and write them as word equations. This can help you understand the reaction.
   a A piece of magnesium reacts with oxygen in the air to form magnesium oxide. (THINK: What is the product? What is the reactant?)
   b When a piece of copper is added to a solution of silver nitrate, it creates a solution of copper nitrate and solid silver. (THINK: What is the product? What is the reactant?)

15.2 Chemical equations show the rearrangement of atoms in a chemical reaction

In this topic, you will learn that:

- chemical reactions can be described through observations, word equations or symbols
- the law of conservation of mass is used to write a balanced chemical equation
- a balanced chemical equation has equal numbers of each type of atom on both sides of the equation.

Figure 1 Sodium metal reacts violently with water, undergoing chemical change.

Almost every substance that you will use today was made in a chemical reaction. Classifying reactions into different types helps us predict the products produced by reactions and understand what reactants are required to produce particular products. To assist in classifying reactions, we can sort compounds into types, such as acids, bases, salts, hydrocarbons and polymers. Balanced chemical equations use the law of conservation of mass.

Describing chemical reactions

Figure 1 shows sodium metal reacting with water. There are different ways to describe this reaction.

- *Describing observed changes:* The sodium metal dissolves in the water; heat is produced; fizzing is caused by the production of hydrogen gas. If there is enough heat, the hydrogen gas catches fire above the sodium metal.
- *Using a word equation:* The reactants are sodium and water, and they interact to form the products, which are sodium hydroxide and hydrogen gas. A word equation summarises the changes:

sodium + water → sodium hydroxide + hydrogen

- *Using a chemical equation:* This includes the formulas of all the substances involved and the ratio in which they react:

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

Each representation tells us something different about the changes occurring in the chemical reaction.

Reacting hydrogen and oxygen

When hydrogen gas burns in oxygen, large amounts of heat energy are produced. If this reaction happens in uncontrolled conditions, it is very dangerous. Under controlled conditions, hydrogen can be used safely as a fuel. In the future, your family might be driving a car fuelled by hydrogen. An advantage of using hydrogen as a fuel is that the only product is water (there are no carbon emissions).

In this reaction, the oxygen atoms and hydrogen atoms have split up from each other and have joined to form molecules of water (H_2O). The atoms have not been created or destroyed. You can show what is happening by using a diagram or by using a chemical equation.

Remember, never touch the *subscripts* when balancing chemical equations – subscripts tell us how many atoms are in the compound. For example, for H_2O there are two hydrogen atoms and one oxygen atom in the compound of water. This is very different to H_2O_2 (also known as hydrogen peroxide), which is not safe to drink at all! Changing the subscripts changes the chemical compound. The *coefficient* tells us how many of each compound is either needed or produced in a chemical reaction.

For example:

$$2Mg + O_2 \rightarrow 2MgO$$

This equation tells us that for two magnesium molecules, there must be one molecule of oxygen (which is made of two oxygen atoms). This reaction produces two molecules of magnesium oxide (which is made of one magnesium atom and one oxygen atom).

Worked example: Writing chemical equations

Hydrogen combines with oxygen to produce gaseous water. The equation can be written by using the following steps.

1 Write out the word equation for the reaction:
hydrogen + oxygen → water

2 Write a simplified chemical equation using the formulas of the substances involved:
$\mathbf{H_2 + O_2 \rightarrow H_2O}$

3 Work out the numbers of each type of atom in the reactants (left-hand side) and in the products (right-hand side) (see Table 1).

4 Compare the number of each type of atom in the reactants with the number in the product. In this case, there are three atoms in the products and four atoms in the reactants. This doesn't fit the law of conservation of mass. We can't have just 'lost' an oxygen atom. To ensure that there are the same numbers of each atom at the end of the reaction as there were at the start, we include coefficients before the formulas of the substances. This allows the number of reactant atoms to equal the number in the product (see Table 2) – the equation is said to be balanced.
$\mathbf{2H_2 + O_2 \rightarrow 2H_2O}$

5 Add states (see Table 3) to each of the compounds.
$\mathbf{2H_2(g) + O_2(g) \rightarrow 2H_2O(g)}$

This balanced equation shows how the atoms are rearranged to form the water molecules.

Table 1 The numbers of each type of atom in the reactants and products

	Reactants		→	Products	
Type of atom:	H	O	→	H	O
Number of atoms:	2	2		2	1

Table 2 Reactants and products for the reaction between hydrogen and oxygen

Reactants		→	Products	
H	O	→	H	O
4	2		4	2

Table 3 States and their symbols for chemical equations

State	Symbol
Solid	(s)
Liquid	(l)
Gas	(g)
Aqueous	(aq)

There are rules that are applied when choosing which atom to balance first.

1 Save hydrogen and oxygen for last, as they are often on both sides.
2 Start with elements that exist in compounds on both sides.
3 Balance any elements that are on their own.
4 Balance the hydrogen atoms.
5 Balance the oxygen atoms.
6 Continue to change the coefficients until all species are balanced.

A helpful hint that can be used is to look for any polyatomic ions (which are ions that contain more than one atom) on both sides and balance them as a unit. For example, hydroxide ion is a polyatomic ion and has the formula OH^-. Sulfate ion is also a polyatomic ion and has the formula SO_4^{2-}.

Check your learning 15.2

Recall and explain

1 Which representation of a chemical reaction tells us the most about the chemicals? **Explain** your reasoning, or **discuss** your answer with others.

2 When balancing a chemical equation, is it the coefficients or the subscripts that are adjusted? **Explain** why.

Apply and analyse

3 **Identify** what the '(s)', '(l)', '(g)' and '(aq)' stand for in the chemical equation for the reaction of sodium and water.

4 Balance the following equations by adding numbers as required.
a _____Na + _____H_2O → _____NaOH + _____H_2
b _____H_2 + _____O_2 → _____H_2O

Skill builder: Communicating

5 Balancing equations is a clear way of communicating to other scientists the chemical change in an experiment. Answer the following questions about when sodium reacts with chlorine gas to form sodium chloride.
a Write the word equation for this reaction. (THINK: What was present at the start? What is present at the end?)
b Write the word equation as a chemical equation using the formulas of the substances involved. (THINK: What is the original formula for each substance?)

15.3 Synthesis and decomposition reactions can be represented by equations

In this topic, you will learn that:

- molecules can combine to form new compounds
- compounds can decompose into smaller molecules.

Synthesis reactions

synthesis
the combination of two or more substances to form one compound

Synthesis is the building up of compounds by combining simpler substances (normally elements):

$$A + B \rightarrow AB$$

This equation is a general equation, and it helps you determine what will be produced in a synthesis reaction. In synthesis reactions, the two reactants combine to form a new product. For example:

sodium + chlorine → sodium chloride

Ammonia

Ammonia (NH_3) is a very important chemical produced by the direct combination of its elements, nitrogen and hydrogen. It is used in a large number of fertilisers, as well as in a range of household cleaning products. The modern method used to produce ammonia is called the Haber process, which relies on the reaction:

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$

Nitrogen is not a very reactive element, so specific conditions are required for this reaction to occur. It involves heating the two gases so that the reaction will happen quickly enough.

Decomposition reactions

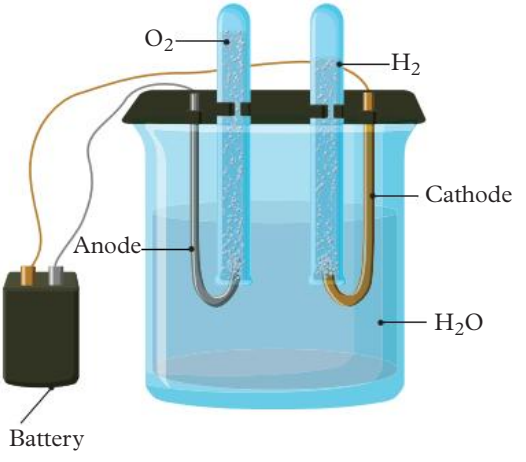
decomposition
a reaction where a compound breaks down into two or more elements

Decomposition reactions are the breakdown of compounds into simpler substances (either elements or more simple compounds). These reactions often require energy in the form of electricity or heat.

Electrolytic decomposition is the breakdown of a compound as a result of an electric current passing through a solution. An example is the formation of hydrogen and oxygen from water:

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

Electrolysis equipment has two diodes – an anode and a cathode. A different chemical reaction occurs at each diode (Figure 1). These reactions are endothermic because they need energy for the reaction to occur.



$$2H_2O \longrightarrow 2H_2 + O_2$$

Figure 1 The electrolysis of water decomposes it into hydrogen gas and oxygen gas.

INVESTIGATION
15.3: Direct synthesis with a 'pop'
Go to page **401**

Electrolytic decomposition is used in the smelting of aluminium. Aluminium ore (bauxite) contains alumina (Al_2O_3). When an electrical current is passed through a solution of alumina, a decomposition reaction occurs:

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Quicklime, or calcium oxide (CaO), is an important industrial product. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also a key component in building materials, such as mortar. Calcium oxide is produced by the thermal decomposition of calcium carbonate ($CaCO_3$):

calcium carbonate → calcium oxide + carbon dioxide

$$CaCO_3 \rightarrow CaO + CO_2$$

The most common and cheapest naturally occurring form of calcium carbonate is limestone. For many centuries, calcium oxide was produced from limestone in lime kilns (Figure 2). These stone structures were fuelled by coal, with blocks of limestone broken up (often by hand) and added to the kiln, where the temperatures could reach close to 1000°C.

Figure 2 An old limestone kiln in Walkerville, South Australia

Today, limestone is roasted in more modern furnaces (which are often fuelled by gas), where the temperature can be regulated by controlling the flow of gas and air into the furnace.

Check your learning 15.3

Recall and explain

1 **Explain** why decomposition reactions always produce more of one product.
2 **Recall** the general formula for a synthesis reaction.
3 **Recall** the names of the two diodes in electrolytic decomposition.

Apply and analyse

4 **Summarise** why energy is required in:
   a decomposition reactions
   b direct synthesis reactions.
5 **Describe**, in terms of the types of chemical reactions, the major differences between the reaction used to produce ammonia and the reaction used to produce calcium oxide.
6 **Explain** why synthesis reactions are sometimes called combination reactions.
7 **Predict** the products of the following synthesis reactions, and write a balanced chemical equation for each one.
   a Calcium and oxygen
   b Hydrogen and chlorine

Evaluate and create

8 **Propose** a reason why different volumes of gas are produced in the decomposition of water (see Figure 1).

Skill builder: Planning investigations

9 When working with chemicals, care must be taken to ensure that risks are minimised. To investigate decomposition reactions, a group of scientists propose to place a balloon over the top of a test tube, and then heat copper carbonate in the test tube so that the balloon inflates.
   a **Identify** safety concerns based on the information provided. (THINK: What chemicals are involved? What equipment is being used? Is there heating or cooling in the method?)
   b Select one risk and **explain** how this could be controlled. (THINK: Do the chemicals require specific treatment? What PPE can be worn to minimise risk? Can the procedure be modified?)

15.4 Acids have a low pH and bases have a high pH

In this topic, you will learn that:

- acids taste sour and contain at least one hydrogen ion; bases taste bitter
- a base that dissolves in water is called an alkali
- a pH scale is used to determine the strength of an acid (less than 7) or base (more than 7)
- an indicator is used to determine the pH of a solution.

alkali
a base that dissolves in water

alkaline solution
a solution that contains a base

Acids

Acids are commonly found around us. Unripe fruits taste sour because of the presence of acid. Weak acids in fruit include citric acid in oranges and lemons, tartaric acid in grapes, malic acid in green apples and oxalic acid in rhubarb. Vitamin C is ascorbic acid. Sour milk and yoghurt contain lactic acid. Vinegar contains acetic acid. Lemonade contains carbonic acid.

Acids are a group of chemical compounds, all with similar properties. As well as tasting sour, acids produce a prickling or burning sensation if they contact skin. All acids contain at least one hydrogen atom. They tend to react with many metals.

Acids can be strong or weak (see Table 1 for some examples). Strong acids are dangerous because they can burn through objects.

Weak acids are much safer, and we can eat and drink some of them. Acid also acts as a preservative by preventing the growth of microorganisms.

Figure 1 Many cleaning products are alkaline solutions.

Bases

Bases can be described as the 'chemical opposite' of acids. They are bitter and feel slippery or soapy to touch. Bases that dissolve in water are called **alkalis**, and solutions that are formed by these soluble bases are described as **alkaline solutions**.

Bases have many uses. They react with fats and oils to produce soaps. Some bases, such as ammonia solution, are used in cleaning agents. One very effective base is household cloudy ammonia. Sodium hydroxide is used in the manufacture of soap and paper. It is also used in drain cleaner. Calcium hydroxide is used to make plaster and mortar.

Table 1 Examples of common acids and bases

Strong acids	Strong bases
Hydrochloric acid, HCl	Sodium hydroxide, NaOH
Nitric acid, HNO_3	Potassium hydroxide, KOH
Sulfuric acid, H_2SO_4	Barium hydroxide, $Ba(OH)_2$
Weak acids	**Weak bases**
Ethanoic acid, CH_3COOH	Ammonia, NH_3
Carbonic acid, H_2CO_3	Sodium carbonate, Na_2CO_3
Phosphoric acid, H_3PO_4	Calcium carbonate, $CaCO_3$

How to tell if a substance is an acid or a base

It is possible to identify acids and bases by taste, touch and smell, but it is often not safe to do so. A safer alternative is to use an indicator.

CHALLENGE
15.4: Testing with pH paper
Go to page **402**

INVESTIGATION
15.4: What if plants were used to create an indicator?
Go to page **402**

An **indicator** is a substance that changes colour in the presence of an acid or a base. Some plants are examples of these substances.

In the laboratory, scientists use **litmus paper** and **universal indicator** as indicators. Litmus paper is the most commonly used indicator for quickly testing whether a substance is an acid or a base. Litmus paper turns red in acidic solutions and blue in basic solutions. Universal indicator is a mixture of different indicators and is a more accurate indicator because it indicates the strength of the acidic or the basic solution that it is testing.

pH scale

The **pH scale** describes the relative acidity or alkalinity of a solution. If a solution is **neutral** – that is, it is neither an acid nor a base – it has a pH of 7. Pure water has a pH of 7 because it is neutral.

Acidic solutions have pH values less than 7. The stronger the acid in a solution, the lower the pH of the solution will be. A pH of 1 or less indicates a very acidic solution.

Alkalis have pH values greater than 7. Strong bases, such as caustic soda (sodium hydroxide), can form solutions with a pH of up to 14.

indicator
a substance that changes colour in the presence of an acid or a base

litmus paper
a paper containing an indicator that turns red when exposed to an acid and blue when exposed to a base

pH scale
a scale that represents the acidity or basicity of a solution; pH < 7 indicates an acid; pH > 7 indicates a base; pH 7 indicates a neutral solution

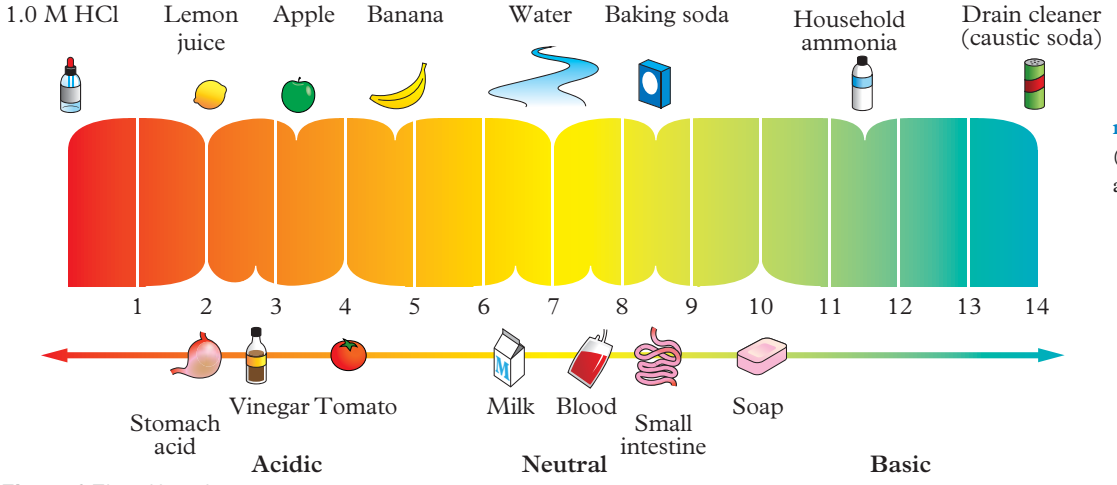


Figure 2 The pH scale

neutral
(pH 7) neither an acid nor a base; for example, water

Check your learning 15.4

Recall and explain

1 **Identify** the main properties of acids.
2 **Identify** the main properties of bases.
3 **Recall** the pH that would indicate a strong base and the pH that would indicate a strong acid.

Apply and analyse

4 **Distinguish** between a strong acid and a weak acid.

Evaluate and create

5 **Investigate** four other kinds of indicators and their pH ranges. Other than using litmus paper or universal indicator, choose an appropriate indicator for testing each of the following substances. (Note: You will need to research their pH.)
   a Lemon juice
   b Black coffee
   c Vinegar
   d Ammonia

Skill builder: Questioning and predicting

6 A student hypothesised that a drink made of lemon juice would have the lowest pH and be more acidic than a drink made of cola because lemon juice has malic, citric, pantothenic and ascorbic acids.
   a **Identify** the independent variable. (THINK: What is being manipulated?)
   b **Identify** the dependent variable. (THINK: What is being measured?)
   c **Propose** one variable that would need to be controlled. (THINK: What are the drinks being tested in? What else could impact acid and base levels?)

15.5* Acids can neutralise bases

In this topic, you will learn that:

- neutralisation happens when acids and bases react and produce water and a salt; if the base contains carbonate, then carbon dioxide is also produced
- increasing levels of carbon dioxide in the atmosphere are causing the oceans to become acidic.

Resource
STEM activity: Acid and your teeth

Reactions of acids

There are certain reactions that all acids have in common. A general reaction is a word equation that summarises the reaction, without naming a particular acid. General reactions help you to learn the common reactions of acids. Also, you can use them to predict the products of a reaction if you know the reactants being used.

Acids reacting with bases

When acids and bases react, they neutralise each other to form substances called **salts**. This is not the salt you will find on your dinner table. A chemical salt is a molecule that contains a metal cation (positive ion) and a non-metal anion (negative ion). Water is also produced in this reaction. This type of reaction is called a **neutralisation reaction**:

salts
formed in a reaction between an acid and a base; a substance that contains a metal cation and a non-metal anion

neutralisation reaction
a reaction between an acid and a base that produces water and a salt

acid + base → salt + water

Different acids will produce different salts in neutralisation reactions. For example, citric acid will produce salts called citrates, and sulfuric acid will produce salts called sulfates.

For example, when hydrochloric acid reacts with sodium hydroxide, the salt sodium chloride (which is common table salt) and water are produced.

The word equation is:

sodium hydroxide + hydrochloric acid → sodium chloride + water

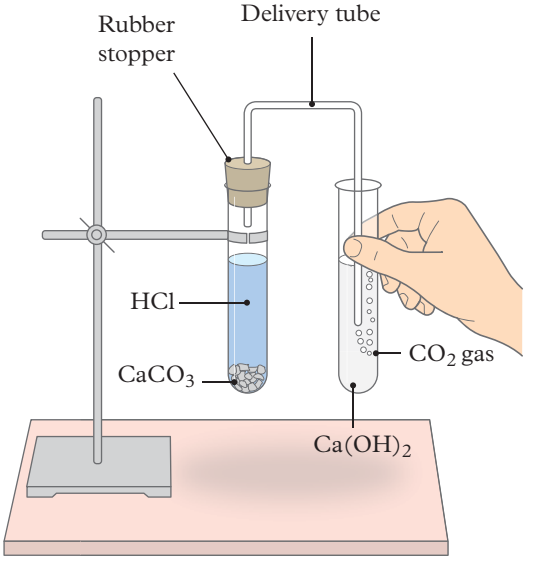
The chemical equation is:

$NaOH + HCl \rightarrow NaCl + H_2O$

Acids reacting with metal carbonates or bicarbonates

When an acidic solution reacts with a metal carbonate or bicarbonate, a salt, carbon dioxide and water are produced. The general reaction is:

metal carbonate + acid → salt + carbon dioxide + water



$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Figure 1 Test for a carbonate

INVESTIGATION **15.5:** Neutralisation reactions
Go to page **403**

CHALLENGE **15.5:** Making sherbet
Go to page **404**

For example, the reaction of citric acid ($C_6H_8O_7$) with sodium bicarbonate ($NaHCO_3$) is used in sherbet to produce carbon dioxide. This causes the fizzy sensation in your mouth.

A positive test for carbon dioxide is to bubble the gas through limewater (dilute solution of calcium hydroxide). This will turn the limewater from clear to milky in colour.

Acidic oceans and coral carbonates

Rising carbon dioxide levels in the atmosphere have caused the oceans to become acidic. Our oceans are a major carbon 'sink' and absorb much of the carbon dioxide (CO_2) in the atmosphere. Before the Industrial Revolution, the oceans were in equilibrium with the atmosphere, absorbing as much carbon dioxide as they released. When carbon dioxide dissolves in water, it forms carbonic acid (H_2CO_3).

Carbon dioxide levels have increased in our atmosphere due to large-scale burning of fossil fuels and industrial processes in which carbon dioxide is produced (e.g. the production of steel, aluminium and cement).

The oceans have responded by absorbing more carbon dioxide, thus increasing their acidity. Scientists estimate that the oceans now absorb 30 million tonnes of carbon dioxide every day.

As the oceans become increasingly acidic, the effect on marine ecosystems is devastating.

Coral reef ecosystems rival rainforests in the huge diversity of species present. They also help protect coastlines from erosion. However, coral reefs across the world are now struggling. One problem is that the coral itself is built from calcium carbonate ($CaCO_3$), which is a weak base. This reacts with the weakly acidic water, causing the calcium carbonate to slowly neutralise and crumble away. This affects the ability of molluscs, such as sea snails, to produce adequate protective shells. The lower pH of the water affects many species of marine organisms that reproduce by ejecting their sperm and eggs into the increasingly acidic water. If the number of successfully fertilised eggs decreases and some of these species die out, this will affect the entire food chain and hence the diversity of species that can survive.

Figure 2 Dead coral

Check your learning 15.5

Recall and explain

1 **Identify** the two products of a neutralisation reaction between an acid and a base.

2 **Identify** the gas that is produced when an acid and a carbonate react.

3 **Explain** the major cause of the increase in acidity of the oceans.

4 As the acidity of the oceans increases, **explain** how the pH changes.

Apply and analyse

5 If the carbon dioxide levels in the atmosphere stopped increasing and became stable, do you think that acidity levels in the oceans would change back to the levels of before the Industrial Revolution? **Explain** your answer.

6 Complete the following:

a sulfuric acid + potassium hydroxide → _____

b _____ + _____ → magnesium nitrate + water

c sodium carbonate + hydrochloric acid → _____

Evaluate and create

7 **Evaluate** the effect of rising carbon dioxide levels on our environment.

Skill builder: Problem solving

8 The world's oceans are becoming more acidic due to rising carbon dioxide levels in the atmosphere. As carbon dioxide dissolves in water, it forms carbonic acid (H_2CO_3). Increasing acidity particularly affects any animal that has an exoskeleton made of calcium carbonate, for example, sea snails. Create a cause and effect diagram to explain the impact of increasing acidity on the survival of sea snails. (THINK: What are the changes in acidity that are impacting sea snails? Where are these changes in acidity coming from?)

15.6 Acids react with metals to produce hydrogen and a salt

In this topic, you will learn that:

- acids can react with metals in a predictable way
- the products of a reaction between an acid and metal are hydrogen and a salt.

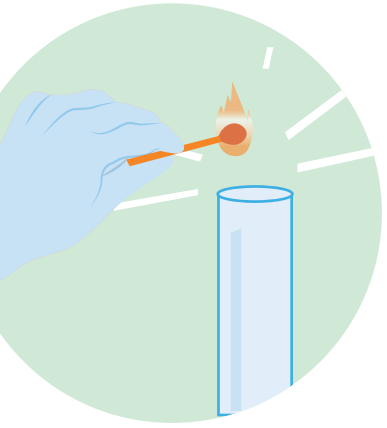


Figure 1 Placing a lit match on the top of a test tube that contains hydrogen gas will make a very distinct 'pop' sound.

Chemical reactions are happening all around us all the time. They affect living and non-living systems, and they involve acids and bases, metals, gases – all sorts of substances. Understanding these chemical reactions allows us to control some of them, start others, or use them to our advantage.

Acids reacting with metals

When an acid reacts with a metal, hydrogen gas is produced, as well as a salt. The general reaction is:

metal + acid → salt + hydrogen gas

Some metals, such as magnesium, react rapidly with acids. Magnesium reacts with hydrochloric acid to produce magnesium chloride and hydrogen gas. The word equation is:

magnesium + hydrochloric acid → magnesium chloride + hydrogen gas

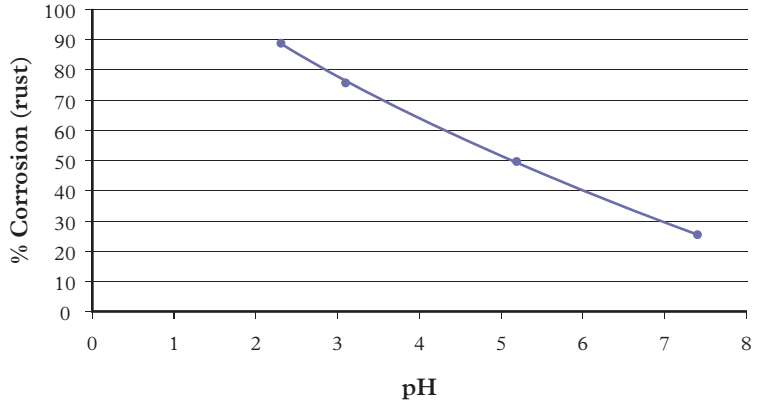


Figure 2 Effect of pH on corrosion

The chemical equation is:

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

Other metals, such as lead, need to be heated before they react with acids such as hydrochloric acid.

A positive test for hydrogen gas is the 'pop' test. When a flame is held over a test tube containing hydrogen, it makes a loud 'popping' sound. It is also sometimes called the 'squeaky pop test'.

Metal etching

The reaction between metals and acids is used in many industries. One example of this is how decorative metal is used for jewellery, belt buckles or artwork. A design is drawn on the metalwork and a protective resin is applied to the area. When the remaining areas are exposed to a strong acid, a reaction occurs that causes the metal to become a salt. The protected areas do not react, allowing the design to appear.

Disadvantages of acid–metal reactions

One problem caused by carbon dioxide and certain other gases in the atmosphere is acid rain.

As rainwater condenses from water vapour in the air and falls, it can dissolve carbon dioxide from the atmosphere. A product of this reaction is a weak acid called carbonic acid (H_2CO_3). As a result, rainwater can have a pH of 5 or 6.

INVESTIGATION
15.6: What if a metal was protected from an acid?
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Cars, other vehicles, factories and power plants all give off pollutants that enter the atmosphere. These pollutants include sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), which may also dissolve to produce much stronger acids such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3). The result is acid rain. Acid rain can have a pH as low as 3. The stronger the acid, the quicker it reacts with metal.

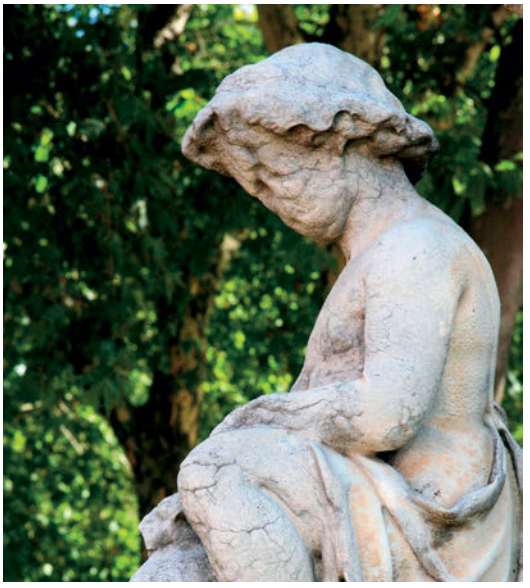

Figure 3 Acid rain damage on a limestone statue

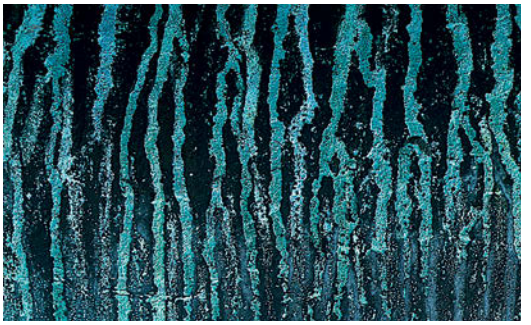

Figure 4 Acid rain damage on a roller door

Acid rain is corrosive to building materials, marble and limestone. Many buildings have metal components that corrode as a result of acid rain. Vulnerable metals include bronze, copper, nickel, zinc and certain types of steel. Scientists have determined that acid rain with a pH of 3.5 can also corrode mild steel, galvanised steel and some stainless steel. This interaction between a metal and its environment is called **corrosion**. The stronger the acid, the quicker it is able to cause damage to the metal.

One way to protect statues and bridges is to cover the exposed areas with a protective resin such as the one used in metal etching. This acts as a barrier between the acid and the metal, preventing a reaction from occurring.

Video
Acid rain

corrosion
the gradual destruction of materials by a chemical reaction with their environment

Check your learning 15.6

Recall and explain

1 **Identify** the products of the reaction of an acid and a metal.
2 Write an equation for dilute nitric acid reacting with magnesium metal.
3 **Explain** what corrosion is.
4 **Recall** the acid that is formed when levels of carbon dioxide in the air increase.

Apply and analyse

5 **Assess** whether acid rain with a lower pH would cause more, less or the same amount of damage on a metal bridge.
6 **Explain** how you could protect the metal numbers on the front fence of your house from corrosion.
7 Complete the following reactions:
   a sodium + nitric acid → _____
   b _____ + _____ → calcium sulfate + hydrogen gas

Evaluate and create

8 **Construct** an infographic that explains the harmful nature of acid rain on both buildings and agriculture.

Skill builder: Conducting investigations

9 A group of students predicted that rust would make steel heavier. They decided to compare the weight of a rusted steel bicycle frame with the weight of a non-rusted steel bicycle frame. The students took repeated measurements of the bicycle frames over two weeks. The rusted bicycle frame was left outside, exposed to rain and wind for the duration of the investigation.
   a **Assess** the methodology used. (THINK: Was this a fair test? Were the variables appropriately controlled?)
   b **Discuss** the reliability of the results this investigation would achieve. (THINK: Were there repeat tests? Did the test accurately measure the variables?)

15.7 Metals react with oxygen to form new products

In this topic, you will learn that:

- corrosion reactions are a type of oxidation reaction
- a metal oxide is formed when a metal is oxidised (i.e. a chemical reaction with oxygen)
- coating one metal over another metal can help slow down corrosion.

metal oxide
a molecule containing a metal and oxygen

Figure 1 This bicycle wheel has been corroded as the metal was exposed to oxygen and formed rust.

Reactions involving oxygen

Oxygen is one element that is key to our survival. We rely on oxygen to provide us with energy through cellular respiration (see Chapter 10). Oxygen makes up 21% of our atmosphere. It is a key component in many chemical reactions. Any substance that reacts and combines with oxygen is said to be oxidised. One type of an oxidation reaction is when a metal reacts with the oxygen in air. This is called a corrosion reaction. It is an exothermic reaction.

Metals reacting with oxygen

When metal elements react with oxygen, a **metal oxide** is formed:

metal + oxygen → metal oxide

In the case of very reactive metals, this oxidation reaction is rapid and produces a lot of heat. For example, if magnesium metal is briefly exposed to a flame or is heated, it will start to react with the oxygen in the air, producing a brilliant white light (Figure 2). Never watch this reaction directly because the light can damage your eyes.

The word equation for this reaction is:

magnesium + oxygen → magnesium oxide

The chemical equation is:

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

For moderately reactive metals like iron, the oxidation reaction still produces heat but it is slow. When an iron object is left out in air and moisture, the iron molecules in contact with the oxygen become oxidised and form iron oxide.

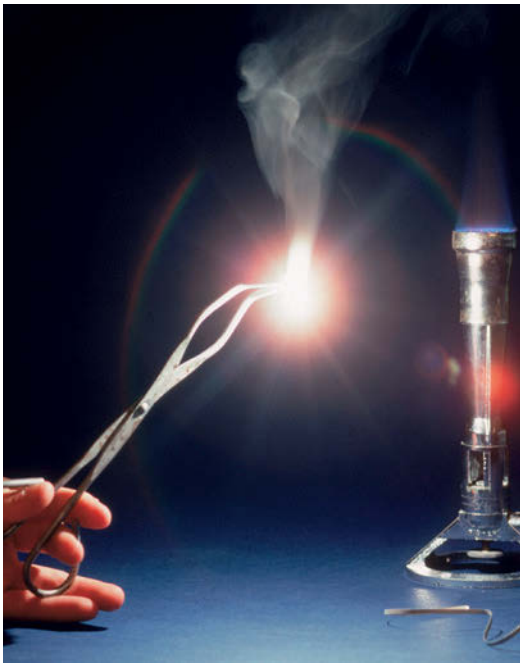

Figure 2 Burning magnesium produces a dangerously white light.

We see this as the flaky, red–brown rust that forms on the surface of objects. The problem with rust is that it is porous. Liquid water can penetrate through the rust to the metal below, as can oxygen. This allows the chemical reaction to continue and the metal oxide can continue to form, often unseen.

Common corrosion reactions

A common type of corrosion reaction is when iron reacts with oxygen to form iron(III) oxide, which is also known as rust. This is commonly seen in metals that are in contact with water, such as pillars in the ocean, or metal signs by the beach.

INVESTIGATION **15.7:** Oxidation of steel wool
Go to page **405**

Figure 3 After a period of time a roof made from galvanised steel will need to be replaced as the zinc coating has deteriorated causing holes and leaks.

Figure 4 When a metal sign is placed by the beach, the moisture in the air helps the oxygen react with the metal, causing the sign to corrode.

iron + oxygen → iron(III) oxide

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$

In order for this reaction to take place, there also needs to be water present. The water helps to break up the oxygen molecule, allowing it to react with iron.

A technique used to reduce the likelihood of a metal oxidising is **galvanising**. The process of galvanising is where a thin coat of zinc is placed over the iron or steel.

The zinc stops the oxygen and the water from reaching the iron. Here, oxygen will react with the zinc before it can react with the iron. However, after a period of time, the zinc will deteriorate and the corrosion of iron will take place; therefore, either the galvanised steel will need to be replaced or a new coating of zinc will need to be applied.

galvanising
to coat iron or steel in a layer of zinc for protection

Check your learning 15.7

Recall and explain

1 **Explain** what an oxidation reaction is.
2 **Explain** what rust is, and how the presence of rust suggests that a metal object is weakened.
3 **Recall** a technique used to reduce the likelihood of rusting.
4 **Recall** the general formula for when a metal reacts with oxygen.

Apply and analyse

5 **Assess** why you think a piece of galvanised steel isn't shiny.
6 **Explain** why a metal sign by the beach will corrode faster than a metal sign in the desert.

Evaluate and create

7 **Investigate** a technique used to minimise corrosion of metal pylons in the ocean. Non-metals can react with oxygen too. Research the products of this type of reaction and evaluate how they can affect our oceans.

Skill builder: Planning investigations

8 Bondi Beach has several metal signs along the foreshore that offer directions and instructions to beach goers. A local mayor has assigned a team of scientists to investigate how corrosion on the signs can be prevented because replacing the signs is costing a lot of money.

a **Propose** a method that would prevent corrosion of the signs. (THINK: What materials are more likely to corrode? What materials can be applied to materials that will corrode?)
b Write a list of equipment needed for the newly designed signs. (THINK: How does the substance need to be applied? How long will this take?)

15.8 Combustion reactions need fuel and oxygen to produce carbon dioxide and water

In this topic, you will learn that:

- combustion is a chemical reaction in which a fuel reacts with oxygen to produce a large amount of heat very quickly
- hydrocarbons are one of the most common fuels used to produce energy in generators, engines and motors.

fuel
a substance that undergoes a chemical reaction to produce a large amount of energy at a fast but controllable rate

combustion
an exothermic reaction between a fuel and oxygen that produces heat, carbon dioxide and water

hydrocarbon
a compound of hydrogen and carbon

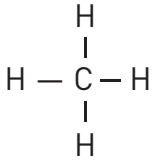

Figure 1 Methane

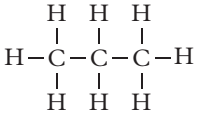

Figure 2 Propane

In science, a **fuel** is a substance that will undergo a chemical reaction in which a large amount of useful energy is produced at a fast but controllable rate. It is an exothermic reaction. We use fuels to produce heat and/or electricity and to run engines and motors.

When fuels react in the presence of oxygen, it is called a **combustion** reaction. These reactions produce carbon dioxide and water.

fuel + oxygen → carbon dioxide + water

Hydrocarbons contain the elements hydrogen and carbon. When hydrocarbons burn in unlimited air, carbon dioxide and water are produced.

hydrocarbon + excess oxygen → carbon dioxide + water

When air supply is more limited, which occurs when the combustion occurs in a confined space, carbon monoxide can be produced.

hydrocarbon + limited oxygen → carbon monoxide + water

Writing equations for the combustion of hydrocarbons

When hydrocarbons burn in excess air (and hence excess oxygen), they produce carbon dioxide and water. Consider the combustion of the simplest hydrocarbon, methane. The chemical structure of the methane molecule can be represented as shown in Figure 1.

The combustion of methane can be described using a word equation:

methane + oxygen → carbon dioxide + water

The balanced chemical equation for this reaction is:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

For more complex hydrocarbons, balancing the equation can be more difficult. However, there is a systematic procedure you can use to make this easier (see Balancing chemical equations on page 315). When you are used to writing these equations, you will be able to do steps 2–5 on one line.

Our carbon economy

The chemical fuels that our society relies upon are based on carbon. Our ancestors burnt wood, which is mainly the carbon compound cellulose. Later generations burnt coal, which is close to pure carbon. Coal is made by the dehydration and compaction of buried plant remains. Our generation uses coal to produce electricity and petroleum as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Cellulose is a chain of $C_6H_{10}O_5$ units arranged end-to-end, coal is 95% pure carbon (depending on the type), and petroleum is a mixture of hydrocarbons. Petrol is mostly octane (C_8H_{18}), diesel is a mixture with the average formula $C_{12}H_{23}$, natural gas is mainly CH_4, and liquefied petroleum gas (LPG) contains propane (C_3H_8). Petrol, diesel, natural gas and LPG are fossil fuels. They

Worked example: Balancing chemical equations

Let us consider propane, which has the formula C_3H_8. Propane can be represented as shown in Figure 2.

1 Write the word equation.
propane + oxygen → carbon dioxide + water

2 Write the correct formulas of the reactants and products.
$\mathbf{C_3H_8 + O_2 \rightarrow CO_2 + H_2O}$

3 Balance the carbon atoms – make sure the number of carbon atoms on the right is the same as on the left. There are 3 carbon atoms on the left, so we must have 3 on the right:
$\mathbf{C_3H_8 + O_2 \rightarrow 3CO_2 + H_2O}$

4 Balance the hydrogen atoms. There are 8 hydrogen atoms on the left, so there must be 8 on the right. However, two at a time are used to make H_2O, so we must produce half that number of water molecules (4):
$\mathbf{C_3H_8 + O_2 \rightarrow 3CO_2 + 4H_2O}$

5 Balance oxygen atoms. This is tricky, because both products contain oxygen atoms. First, count how many are on the right. There are 6 + 4 = 10 oxygen atoms. So, we must have 10 oxygen atoms on the left. Because two at a time are used in the O_2 molecule, we must halve that number; that is, 5 oxygen molecules:
$\mathbf{C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O}$

are obtained from the Earth and were formed from the fossilised remains of plants and animals. The energy in them was captured by photosynthesis millions of years ago. This carbon has been locked away out of the atmosphere for millions of years.

Even renewable fuels, such as biodiesel and ethanol, contain carbon atoms. The carbon atoms in renewable fuels were captured by photosynthesis in the last growing season. It is fair to say that our society runs on carbon. It is a very important fuel. Carbon is the mainstream of our economy. This is why is it called a carbon economy.

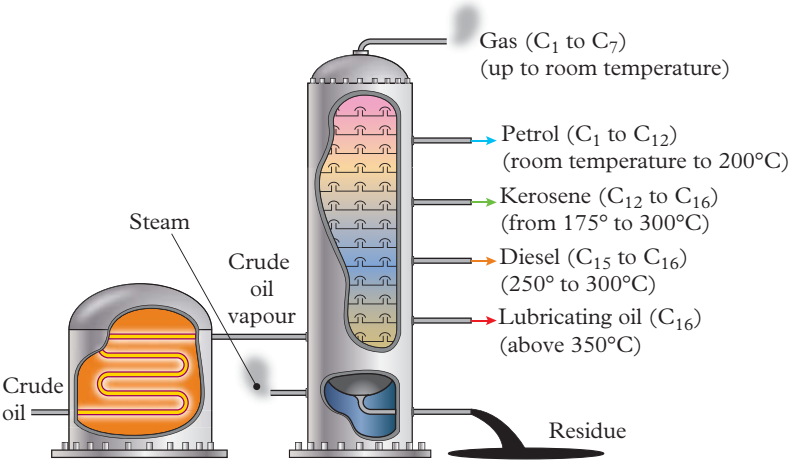

Figure 3 As the crude oil is slowly heated, vapour (gases) form. As the vapour rises, it cools. When the vapour reaches the height where the temperature is equal to the fraction's boiling point, it condenses into a liquid.

Check your learning 15.8

Recall and explain

1 **Recall** the gas that is essential for combustion reactions.

2 Butane gas C_4H_{10} has many uses. Set out the steps for writing a balanced equation for the combustion of butane in excess air.

3 **Identify** the main hydrocarbon that is burnt in natural gas.

4 **Explain** why carbon fuels are so important to our society.

Apply and analyse

5 Write a balanced equation for the combustion of each of the following hydrocarbons in excess oxygen.
- **a** Petrol
- **b** LPG
- **c** Natural gas
- **d** Diesel

Evaluate and create

6 Another product of combustion is carbon, also known as soot. **Assess** why this is the case and provide an example of when this occurs in society.

Skill builder: Planning investigations

7 Design a method that could be conducted to measure the amount of energy provided by different fuels.
- **a** **Identify** how this would be measured. (THINK: What tests and equipment would you use to measure the amount of energy provided by different fuels?)
- **b** **Identify** how many repeats this would require to produce reliable results. (THINK: How many fuels would you test? How many times would each fuel need to be tested?)
- **c** Present each step of your method in the correct order. (THINK: What needs to be done first and why? What needs to be done last and why?)

15.9 The solubility rules predict the formation of precipitates

In this topic, you will learn that:

- if a salt that is formed in a chemical reaction is insoluble in water, it forms a precipitate
- precipitates can be all different colours depending on the ions in the salts.

If a compound is soluble, it can dissolve in a liquid solvent. A precipitation reaction involves two soluble ionic solutions being mixed to form an insoluble solid product called a precipitate. The ions that do not take part in the reaction are called spectator ions. The solubility of a compound can be predicted from the solubility rules.

Precipitation reactions

precipitate
an insoluble compound formed in a precipitation reaction

A **precipitate** is an insoluble solid that can form as part of a reaction between two ionic solutions.

This can be written in a general form:

$$AB(aq) + CD(aq) \rightarrow AD(s) + CB(aq)$$

In a water (aqueous) solution, the ions A and B separate, as do the ions C and D. Positive ion A forms a bond with negative ion D, and positive ion C forms a bond with negative ion B. It is important to note that the positive ions (A and C) are always written first. This is called a double displacement reaction because both substrates change (or displace) their partners. It becomes a **precipitation reaction** if either AD or CB is insoluble and forms a solid. The formation of an insoluble solid precipitate can be predicted by using a set of solubility rules. The data shown in Table 1 can be used to decide whether a precipitate will form.

precipitation reaction
a reaction where two soluble ionic solutions mix to form an insoluble substance as a product

For example, a solution of lead(II) nitrate ($Pb(NO_3)_2$) consists of lead ions (Pb^{2+}) and nitrate ions (NO_3^-) together with many water molecules.

When a solution of lead(II) nitrate is added to potassium iodide (where both are colourless solutions), a bright yellow precipitate of lead iodide (PbI_2) is formed.

The reaction can be written as:

lead(II) nitrate + potassium iodide → lead(II) iodide + potassium nitrate

$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$

The lead ions and the iodide ions have combined to form an insoluble precipitate of lead(II) iodide. This new compound forms as a solid in the solution. The potassium and nitrate ions are still dissolved in solution. They are not taking part in the reaction. They are called spectator ions. Because of this, it is possible to write the equation in a different way that shows only those ions that are changing in the reaction:

$$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$$

Because the lead ions and iodide ions are dissolved in the solution, they are described as aqueous (aq). This reaction is shown in Figure 1.

Lead compounds were used in a number of pigments until the 1970s, when it was discovered that the lead in these pigments could damage the nervous system.

Table 1 Solubility of some common ionic compounds in water

Soluble	Insoluble	Slightly soluble
Group 1 elements		
All ammonium salts		
All nitrate salts		
Most chlorides, bromides and iodides	AgCl, AgI, AgBr, PbI_2, $PbBr_2$	
	Most carbonate and phosphate compounds	
Group 1 hydroxides, $Ba(OH)_2$, $Sr(OH)_2$	Most hydroxides and sulfates	$Ca(OH)_2$, Ag_2SO_4, $CaSO_4$

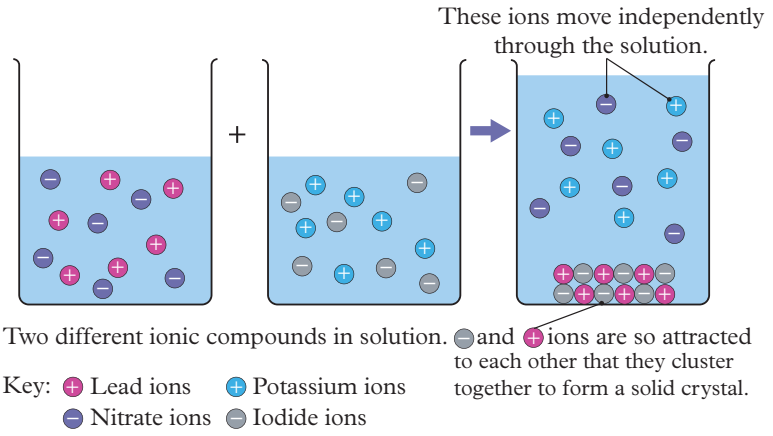

Figure 1 At the particle level, when a solution of lead nitrate is added to a solution of potassium iodide, the ion partners are swapped.

Figure 2 Test tubes containing (left to right) precipitates of copper hydroxide, iron(III) hydroxide and iron(II) hydroxide. All were made by adding sodium hydroxide to metal solutions.

Using precipitation reactions

Precipitation reactions are important for chemical analysis. PbI_2 is insoluble, so if any soluble lead(II) compound is mixed with any soluble iodide, a precipitate of PbI_2 will form. Similarly, Table 1 tells us that $Cu(OH)_2$ is insoluble. This means that if any soluble hydroxide, such as NaOH, is mixed with any soluble copper(II) compound, such as $CuSO_4$, a precipitate of $Cu(OH)_2$ will form.

Chemists sometimes use precipitation reactions to find out which chemicals are present in a substance or how much is present.

Common table salt (NaCl) is essential in our diet because the sodium is needed to maintain the correct concentration of body fluids, assist in the transmission of nerve impulses, and help cells absorb nutrients.

Chemical analysis can determine the amount of salt in foods by using a precipitation reaction with silver nitrate. The salt reacts with the silver nitrate to form a precipitate of silver chloride. The amount of sodium chloride present can be calculated by using the amount of silver chloride that has precipitated:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$

Check your learning 15.9

Recall and explain

1 Draw a diagram to show which particles are present in a beaker containing a sodium chloride solution.

2 **Identify** the symbol that is used to show the state of an insoluble compound.

Apply and analyse

3 What precipitate would form if solutions of lead(II) nitrate and sodium sulfate were mixed?

4 Complete the following word equations and then write balanced chemical equations for each reaction, identifying the precipitate formed.

a zinc nitrate + potassium hydroxide → _____

b calcium nitrate + sodium carbonate → _____

Evaluate and create

5 Precipitation is used in many processes, including wastewater treatment. **Investigate** this process and create a presentation that communicates your findings.

Skill builder: Questioning and predicting

6 **a** Based on your understanding, **predict** which of the following substances would be insoluble in water. (THINK: What makes a chemical soluble?

Where can you find this information?)

Copper(II) chloride, calcium hydroxide, silver nitrate, magnesium bromide, silver bromide, magnesium nitrate, potassium chloride, lead(II) nitrate, potassium nitrate, lead(II) chloride.

b **Explain** why this substance would be insoluble in water. (THINK: What are its chemical properties? What are the chemical properties of water?)

*REVIEW

Multiple choice

1 **Identify** the correct product for this reaction: $2Mg + O_2$
- **A** 2MgO
- **B** Mg_2O_2
- **C** MgO
- **D** $2Mg_2O_2$

2 A decomposition reaction is:
- **A** substances that are present at the start of a chemical reaction
- **B** the building up of compounds by combining simpler substances
- **C** the breakdown of compounds into simpler substances
- **D** bases that dissolve in water.

3 Galvanisation is best described as:
- **A** a reaction involving oxygen
- **B** when iron reacts with oxygen to form rust
- **C** fuel reacting when oxygen is present
- **D** coating iron or steel in zinc to prevent rusting.

Recall and explain

4 **Explain** what an acid is.

5 **Identify** two acids and two bases.

6 **Classify** each of the following statements as true or false.
- **a** Reactants are the substances made in chemical reactions.
- **b** Oxygen is a fuel.
- **c** Bushfires are endothermic reactions.
- **d** Hydrocarbons require oxygen to burn.
- **e** Sulfur dioxide will dissolve in water to form an alkali.

7 **Recall** the names of the products when methane burns in an excess supply of oxygen.

8 Write down the chemical formula of:
- **a** carbon dioxide
- **b** carbon monoxide.

9 Many lollies are now deliberately made sour. **Explain** whether a weak acid or a weak base would be added to the lollies in order to achieve this taste.

10 **Recall** what a precipitation reaction is.

11 **Explain** the advantages and disadvantages of using alcohol instead of petrol in our cars.

12 **Identify** the formula of two gases that contribute to the formation of acid rain.

13 **Identify** how many atoms of carbon, hydrogen and oxygen are present in a molecule of ethanol (CH_3CH_2OH).

14 **Describe** the differences between decomposition reactions and direct synthesis reactions.

15 Give an example of a substance that might be considered a fuel by a:
- **a** firefighter
- **b** chemist.

16 **Explain** why a galvanised roof may need replacing after 10 years.

17 **Explain** why a precipitate may form when two salts are added together.

18 Which way of describing the chemical reaction between hydrogen and oxygen tells us the most about what is happening to the atoms?

19 **Identify** the type of substance that would have a pH of 7.

20 What colour is litmus paper in a solution of:
- **a** an acid?
- **b** a base?

21 Write out the chemical equations for two of the reactions you have investigated in this chapter. Count the number of each type of atom on both sides of the equation. What do you notice about the numbers of atoms? Are the equations balanced? What does this tell you about what is happening to atoms in these reactions?

22 **Identify** the two elements that are present in hydrocarbons.

Apply and analyse

23 A student told another student that they should never drink orange juice because it contains acid. **Evaluate** the student's comment, and draft a response.

24 Consider each of the following reactions, and **identify** them as either: acid + base, acid + metal, synthesis, precipitation or decomposition.
- **a** Magnesium burning in oxygen
- **b** Sulfuric acid reacting with sodium
- **c** Heating calcium carbonate
- **d** Carbonic acid reacting with calcium hydroxide
- **e** Sodium hydroxide reacting with magnesium chloride

25 Consider each of the following reactions. **Identify** their products and write word and balanced chemical equations for each of them.
- **a** Nitrogen reacting with hydrogen
- **b** Silver nitrate reacting with potassium chloride
- **c** Hydrochloric acid reacting with magnesium hydroxide
- **d** Sulfur burning in oxygen
- **e** Shining sunlight onto silver chloride

26 A reaction takes place, and a student is unsure of whether the gas that has been produced is hydrogen or carbon dioxide. **Describe** a method the student can use to determine the identity of the gas.

27 A student carried out a chemical reaction, and the final mass of the products was not equal to the starting mass of the reactants. **Explain** why the student was expecting the mass to be the same, and suggest reasons why they were different.

28 Balance the following equations by adding numbers as required.

a $____CH_4 + ____O_2 \rightarrow ____CO_2 + ____H_2O$

b $____Mg + ____HCl \rightarrow ____H_2 + ____MgCl_2$

29 **Explain** why chemical reactions that are not 'balanced' are always incorrect.

30 The following equations are not balanced. Rewrite them correctly.

a $C_4H_8 + 6O_2 \rightarrow 4CO_2 + 3H_2O$

b $C_5H_{12} + 5O_2 \rightarrow 5CO_2 + 6H_2$

31 The fuels used in cars, trucks and buses are generally liquefied petroleum gas (LPG), petrol or diesel. These fuels are mainly hydrocarbons.

a What are the two main substances present in their exhaust gases?

b **Explain** why scientists are warning that excessive use of these vehicles is contributing to the enhanced greenhouse effect.

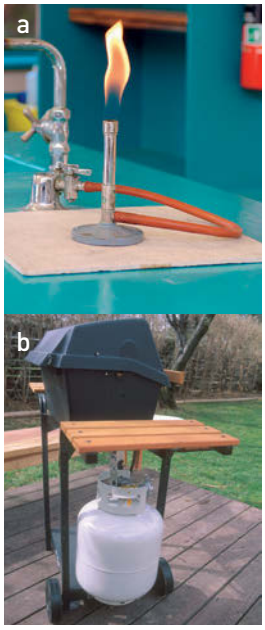

Figure 1 a Bunsen burners use natural gas, which is mainly methane. **b** Propane gas is one of the components of LPG, which is used in household barbecues.

Evaluate and create

32 Do you think the process occurring in cold packs is a chemical or physical change? **Explain** your answer.

33 Carry out a PNI ('positive', 'negative', 'interesting') analysis on the effect of acids on our lives.

34 **Construct** a poster on the use of ethanol as a fuel. **Explain** the advantages and disadvantages of using ethanol in this way. Include any relevant diagrams or images.

35 Consider two changes that occur as chemicals interact with each other:

- carbon in brown coal reacts with oxygen in the air to form carbon dioxide
- carbon dioxide dissolves in water (containing universal indicator) to form a solution of carbonic acid (H_2CO_3).

For each change, **describe** the reaction in terms of:

a the expected observations

b a word equation

c a chemical equation.

36 **Evaluate** the impacts of using lead-based paints.

Critical thinking

37 Steel is an alloy of iron, which is produced from iron ore. Steel often rusts as iron reacts with oxygen. Rusting will occur more quickly if water is present, as the water encourages oxygen and iron atoms to be in contact with each other, which increases the chance of a reaction occurring. Coating steel in tin can prevent rusting. **Investigate** why tin can prevent rust in steel.

38 Acid rain occurs when carbon dioxide reacts with other gases in the atmosphere. Acid rain is corrosive to buildings, marble and limestone, as well as being destructive to ecosystems. **Discuss** how buildings can be protected from acid rain, and whether acid rain can be prevented.

Go further

39 **Explain** what the term REDOX means. Then, **explain** how this is applied to corrosion reactions.

40 Many natural ecosystems use a 'natural buffering system' to maintain pH. **Explain** this process and why it is important to aquatic life.

Research

41 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Phosphoric acid

Phosphoric acid has a wide variety of uses – as a fertiliser, rust remover and food additive. It is even an ingredient in cola drinks. Find out how it is produced and more about its uses.

»Explosives

The history of the development of explosives is fascinating. Who discovered them? When were explosives first used and how do they work? What are the main chemicals used and what types are there? What part did Alfred Nobel play?

»pH of blood

If the pH of our blood is too low or too high, we can become seriously ill. Find out the name given to the conditions in which the pH of blood becomes too low or too high and the effects of these conditions.

»Carbon footprints

Your carbon footprint is the amount of carbon dioxide released into the atmosphere as a result of your behaviour. What chemical reactions contribute to an increase in carbon dioxide in the atmosphere? What other gases contribute to the enhanced greenhouse effect? How are carbon footprints measured? What is meant by the phrase 'carbon offset'?

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.
Recall that all matter is composed of atoms and has mass.	☐	☐ Go to pages 300-301
Identify a range of compounds using their common names and chemical formulae.	☐	☐ Go to pages 300-301
Classify compounds into groups based on common chemical characteristics.	☐	☐ Go to pages 306-309
Investigate a range of types of important chemical reactions that occur in non-living systems and involve energy transfer, including: • combustion • the reaction of acids including metals and carbonates • corrosion • precipitation • neutralisation • decomposition.	☐	☐ Go to pages 304-305
Identify some examples of important chemical reactions that occur in living systems and involve energy transfer, including respiration and reactions involving acids such as occur during digestion.	☐	☐ Go to pages 308-311
Construct word equations from observations and written descriptions of a range of chemical reactions.	☐	☐ Go to pages 302-303
Deduce that new substances are formed during chemical reactions by rearranging atoms rather than creating or destroying them.	☐	☐ Go to pages 312-315

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USING CHEMISTRY

How can reactions be manipulated to suit society's needs?

Have you ever wondered ...

- How do heat or ice packs work?
- Why some reactions happen really quickly, and why some take a really long time?
- Do scientists have the potential to change the way we live our lives?

16

SCIENCE UNDERSTANDING

In this chapter, you will learn how to:

- identify that chemical reactions involve energy transfer and can be exothermic or endothermic
- compare combustion and respiration as types of chemical reactions that release energy but occur at different rates
- describe the effects of factors, e.g. temperature and catalysts, on the rate of some common chemical reactions
- analyse how social, ethical and environmental considerations can influence decisions about scientific research related to the development and production of new materials
- describe examples to show where advances in science and/or emerging science and technologies significantly affect people's lives, including generating new career opportunities in areas of chemical science such as biochemistry and industrial chemistry

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Check your Student obook assess for these digital resources and more:

QuizletLive
Compete in teams to test your knowledge as you go through the chapter.

Assess quiz
Before you start this chapter, check your science skills with a quick quiz.

Check your Teacher obook assess for these resources and more:

QuizletLive
Launch a quiz for your students on key concepts in this chapter.

16.1 Endothermic reactions remove energy. Exothermic reactions produce energy

In this topic, you will learn that:

- exothermic reactions release energy in the form of heat and light because the reactants have more stored energy than the products require
- endothermic reactions cause temperature to decrease because more energy is needed to create the products than the reactants have.

A chemical reaction that releases energy in the form of heat and light is called an exothermic reaction. The reactants of this reaction have more stored energy than is needed to produce the products. In an endothermic reaction, more energy is needed to manufacture the products than is stored in the reactants. Therefore, energy is taken from the surroundings, causing the temperature to decrease.

Energy changes in reactions

endothermic reaction
a chemical reaction that absorbs energy in the form of heat

exothermic reaction
a chemical reaction that releases energy in the form of heat or light

You may have noticed that a test tube or beaker sometimes feels warmer after a chemical reaction. All chemicals contain a certain amount of stored energy. Reactions that release energy are called **exothermic reactions** (*exo* = 'to give out'; *thermic* = 'heat'). The energy released is usually heat energy but can also be light or electrical energy. An exothermic reaction can be as fast as a match burning or as slow as the rusting of iron.

In an exothermic reaction, the reactants have a lot of energy stored in the bonds between the atoms. When these bonds break, the energy is released. Some of this energy is taken up when the product is formed, but the bonds between the atoms of the product may not need as much energy. This means there is energy left over. We observe this energy as heat and light.

Reactions that absorb energy are called **endothermic reactions**. For example, for photosynthesis to happen, plants need energy from the Sun to produce glucose and oxygen from carbon dioxide and water.

In an endothermic reaction, the energy produced by the breaking of the bonds in the reactants is not enough to form the products. Extra energy is taken from the surroundings to make the high-energy products. The extra energy comes from the thermal energy of any molecule near the reaction. This means the surrounding molecules lose thermal (kinetic) energy and become cooler.

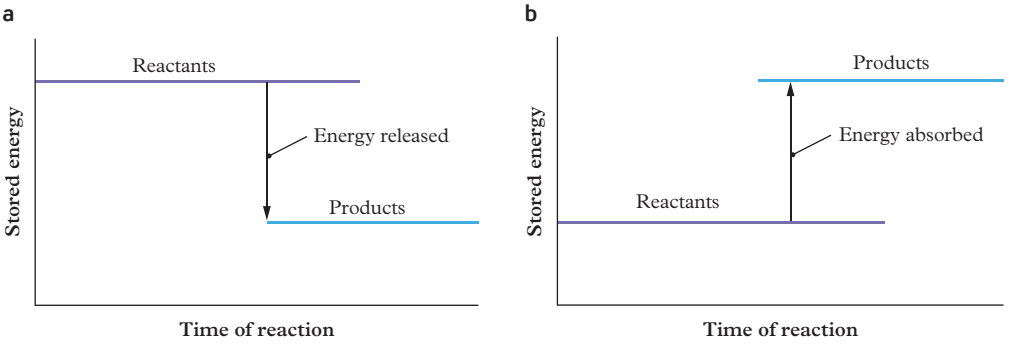


Figure 1 a In an exothermic reaction, energy is released and the products have less stored energy than the reactants. **b** In an endothermic reaction, energy is absorbed from the surroundings and the products have more stored energy than the reactants.

Using energy changes

Compounds contain atoms held together by **chemical bonds**. Chemical reactions involve the breaking and making of these chemical bonds.

A familiar example of processes that involve energy changes is the use of heat and cold packs. Heat packs are used for treating sore muscles. They work by dilating (widening) the blood vessels and allowing the soft tissues to relax. One type of heat pack uses a supersaturated solution of sodium acetate. This means it contains more sodium acetate than would normally dissolve at a particular temperature. Bending the pack is enough to cause the sodium acetate to form crystals. This is an exothermic reaction. The extra energy is released as heat.

chemical bond
an attraction between atoms or ions that allows for the formation of chemical compounds

Figure 2 Athletes use cold packs to reduce swelling and pain.

Cold packs reduce swellings and numb pain caused by injuries. They usually contain ammonium nitrate, which undergoes an endothermic reaction when the inner bag is broken. This allows the salt to dissolve in water, absorbing the thermal energy of the water in the process. This cools the water and makes the bag feel cold.

Check your learning 16.1

Recall and explain

1 **Classify** the following as exothermic or endothermic processes. **Explain** your answers.
   - **a** A candle burning
   - **b** Ice changing to water
   - **c** A cake baking

2 **Describe** three examples of exothermic chemical reactions.

3 Complete the following sentences.
During an exothermic reaction, the temperature of the surroundings _____. The energy of the product is _____ than the energy of the reactants. An example of an endothermic reaction is _____.

4 **Explain** how heat packs help athletes.

Apply and analyse

5 **Explain** what happens to the thermal kinetic energy of the surrounding molecules during an exothermic reaction.

6 A student placed some ammonium chloride in some water and stirred it. They had a temperature probe that showed the temperature of the solution before and after the ammonium chloride was added. The temperature changed from 23°C to 4°C. **Explain** whether this is an exothermic or endothermic reaction.

Evaluate and create

7 **Investigate** how glow sticks work, and **construct** a poster communicating your findings.

Skill builder: Processing and analysing data and information

8 Figure 3 shows the energy changes of a chemical reaction. From the graph, **interpret** if the reaction is endothermic or exothermic. (THINK: What is an endothermic reaction? What is an endothermic reaction? What hints do the graph's labels give you?)

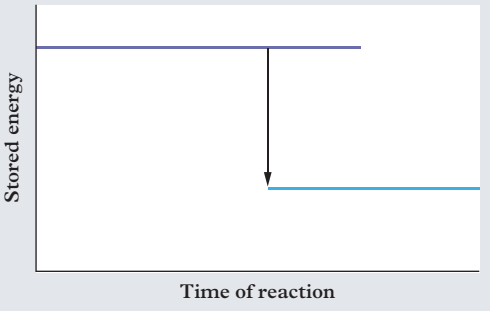


Figure 3 Energy changes of a chemical reaction

16.2 Both combustion and respiration release energy, but they do so at different rates

In this topic, you will learn that:

- both combustion and respiration are exothermic reactions
- exothermic reactions can occur in different conditions depending on the environment.

Exothermic reactions can occur at different rates. Let's take a look at two types of exothermic reactions: cellular respiration and combustion.

Combustion reactions

When fuels react in the presence of oxygen, it is called a combustion reaction. These reactions produce carbon dioxide and water and a lot of energy that is detected as heat and light.

Different fuels have different amounts of energy contained within their bonds (the more bonds, the more energy), so when these break apart to form carbon dioxide and water (whose bonds don't use very much energy to form), we are left with a lot of energy left over and hence the heat and light.

Table 1 Energy in some fuels

Fuel	Formula	Energy (kJ/mol)
Methane	CH_4	890
Propane	C_3H_8	2220
Octane	C_8H_{18}	5460

Note: In chemistry, the term 'mol' is used as a way to compare masses of different compounds. 1 mole of any substance contains 6.02×10^{23} molecules of that compound!

If we look at the energy given off by some fuels (see Table 1), we can see that fuels that have lots of bonds have more energy stored in them compared to some smaller molecules.

When a fuel is ignited in the presence of oxygen, it occurs in a single step and we immediately see the combustion reaction.

Figure 1 Spreading bushfire is an example of an uncontrolled combustion reaction.

The process occurs reasonably quickly and is an uncontrolled reaction. The heat causes the temperature of the surrounding environment to rise. Think of a bushfire and the way it spreads: as long as there is fuel (trees and shrubs) and oxygen (from the air), the fire will spread very quickly and can be difficult for firefighters to control.

Cellular respiration

Cellular respiration is an aerobic (i.e. it requires oxygen) biological process (i.e. it takes place in the cells of all living things). It occurs in the mitochondria of cells.

Cellular respiration is when a substance that has a high amount of energy, like glucose or starch (which are types of carbohydrates), is broken down into smaller substances, giving off chemical energy.

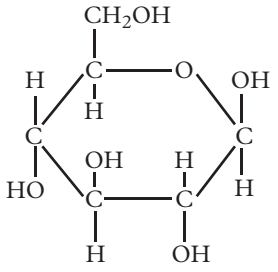


Figure 2 The structure of glucose. Oxygen reacts with glucose in living systems.

However, this process occurs in steps, and this slows down the release of energy. The process of cellular respiration is a very controlled reaction, and the temperature of its surroundings doesn't rise.

There are several steps in cellular respiration, and Krebs cycle is a sequence of these reactions that produces ATP (adenosine triphosphate). ATP is a high-energy molecule and is responsible for transporting chemical energy within the cell.

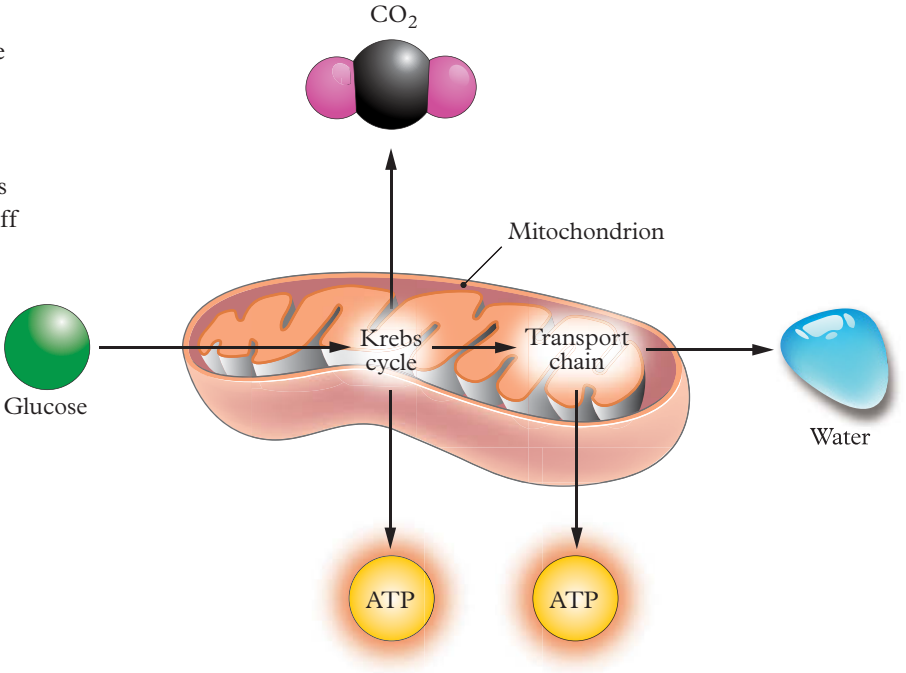


Figure 3 Cellular respiration in cells takes in glucose and produces CO_2, water and ATP, so energy can be distributed around the cell.

Check your learning 16.2

Recall and explain

1 **Recall** the names of the products in combustion reactions.

2 **Identify** where cellular respiration takes place.

3 **Explain** why cellular respiration is a slower process compared to combustion.

4 **Recall** the name of the molecule that is responsible for distributing chemical energy around a cell.

5 **Explain** why some fuels produce more energy compared to others.

Apply and analyse

6 **Propose** why you think cellular respiration reactions don't involve a temperature increase.

7 **Construct** a table that compares the similarities and differences of combustion and cellular respiration reactions.

Evaluate and create

8 **Investigate** how cellular respiration and combustion of fuels are linked to the carbon cycle.

Skill builder: Questioning and predicting

9 The reaction rate dictates how fast a reaction is. Combustion reactions require ignition and are fast, whereas a respiration reaction requires the slow release of energy to start the reaction. **Predict** whether the following reactions would be best as a fast or slow reaction. (THINK: What kind of reaction is occurring? What are the requirements of this reaction?)

- **a** Your bicycle rusting
- **b** A car's ignition
- **c** The ingredients of a cake in the oven
- **d** Your body's neurons reacting to aspirin

16.3 Temperature, concentration, surface area and stirring affect reaction rate

*

In this topic, you will learn that:

- the speed at which a reaction occurs is called the rate of reaction
- collision theory states that for a reaction to occur, reactants must collide in the correct orientation.

The speed at which a reaction occurs is called the rate of a reaction. For a reaction to occur, the reactants must collide in the correct orientation. This is called collision theory. The rate of a reaction can be increased by increasing the temperature, concentration or surface area, or by stirring the reactants.

Why reaction rates are important

reaction rate
how fast or slow a reaction proceeds

collision theory
a theory that states that particles involved in a chemical reaction must collide in order to react

A **reaction rate** is how fast a reaction proceeds. It is important to realise that this does not mean more products are formed in the reaction. This can be illustrated by a 100-metre race. A runner can run fast or slow; the only difference is how quickly the runner finishes the 100 metres. A fast reaction has a high reaction rate; a slow reaction has a low reaction rate.

In the chemical industry, controlling the rate of a reaction is vital. Reactions that are too slow are not economical, because equipment is tied up for a long time. Reactions that are too fast need to be controlled. Chemists and chemical engineers have the role of making chemical reactions as cheap as possible. A large part of this is achieved by controlling the rate of the reaction.

Collision theory

For a chemical reaction to occur, the atoms or ions or molecules must collide with enough energy for that reaction to occur. This model is known as **collision theory**. One reaction that has been studied is the decomposition reaction of hydrogen iodide. The reaction (in symbols) is:

$$2HI(g) \rightarrow H_2(g) + I_2(g)$$

Hydrogen iodide is a gas and its molecules travel quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in order to react. Some collisions do not result in a reaction. In these unsuccessful collisions, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 1.

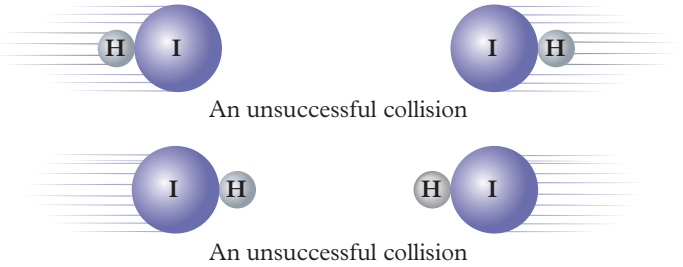
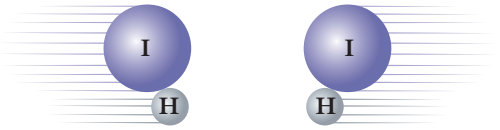


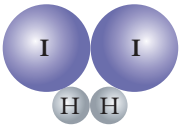
Figure 1 Not all collisions result in a chemical reaction.

In the collision shown in Figures 2–4, there is a reaction. A weak chemical bond forms between the iodide ions and the hydrogen ions. This intermediate substance is unstable and only exists for a short period of time before it breaks apart. Only some collisions result in a reaction. The molecules must collide in the correct orientation for a reaction to occur.



A successful collision

Figure 2 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.



H_2I_2 is unstable and short lived.
It is called an intermediate complex.

Figure 3 An intermediate stage during the reaction. The products of this reaction move apart. (This is partly due to electrical repulsion.)

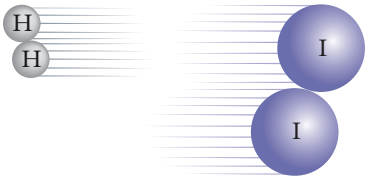


Figure 4 The final products are formed.

Increasing the rate of collisions

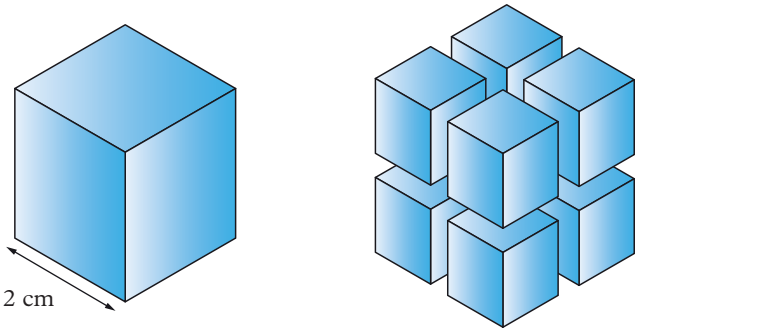
To increase the rate of a reaction, you need to increase the number of collisions occurring. This can be done by increasing the:

- surface area of the particles reacting
- concentration of the reactants
- temperature of the reaction.

Increase the surface area

A metal such as magnesium reacts with dilute hydrochloric acid. For a reaction to occur, hydrogen ions in the acid have to collide with magnesium atoms. There are more metal atoms exposed to the hydrogen ions if the metal is in small pieces. Because the reaction occurs on the surface of the magnesium, breaking it up into smaller pieces provides a larger surface area on which the reaction can occur.

Powders have a much larger surface area than large-sized bits of material. The surface area is not the size of the pieces but rather the total area exposed to possible collisions (Figure 5).



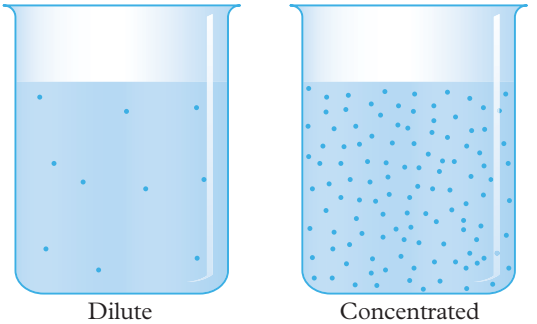
Total surface area
= 2 cm × 2 cm × 6 sides
= 24 cm^2

Total surface area
= 1 cm × 1 cm × 6 sides × 8 cubes
= 48 cm^2

Figure 5 Many small particles have a larger surface area than a single large particle of the same volume.

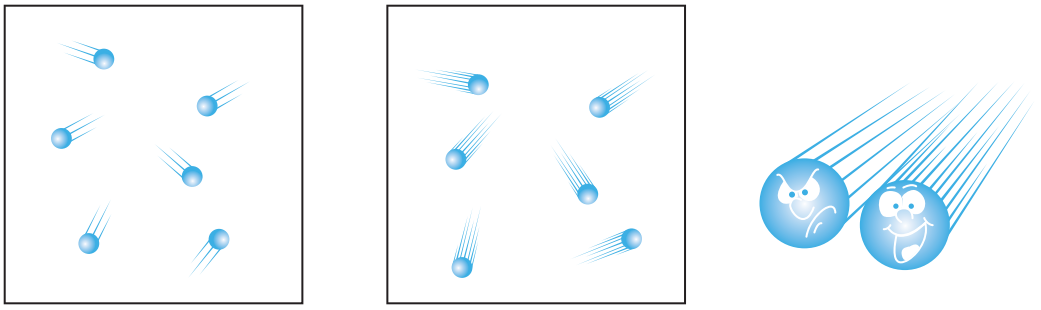
Increase the concentration

In a dilute solution, the particles (molecules or ions) of the reactant are spread out in a solvent, such as water. There is a lot of space between the reactant particles. In a concentrated solution, there are many more reactant particles in the same volume, so they are much closer together (Figure 6).



Dilute Concentrated

Figure 6 A concentrated solution will contain more dissolved particles than a dilute solution.



Cold substance (particles have low kinetic energy)

Hot substance (particles have high kinetic energy)

Step aside. I have more kinetic energy than you.

Figure 7 At higher temperatures, the average energy of the particles is increased and the particles travel faster.

In the reaction between magnesium and hydrogen ions, the reaction will occur faster if there are more hydrogen ions in a given volume. So, using a hydrochloric acid solution with a higher concentration (i.e. more hydrogen ions in a given volume) will speed up the reaction. When there are more particles, there are more collisions and therefore a higher reaction rate.

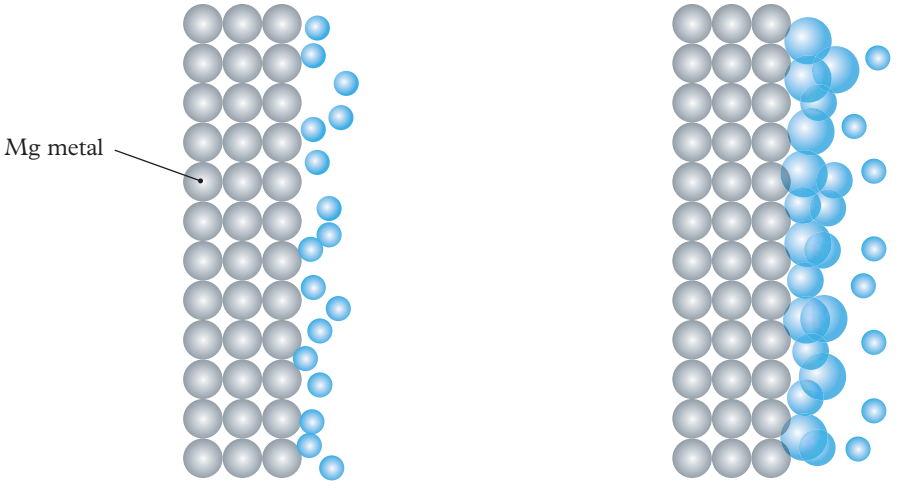
Increase the temperature

Particles in a hot substance have more kinetic energy than particles in a cold substance. This means that the particles in a hot substance travel faster than the particles in a cold substance (Figure 7).

Hotter particles will collide faster and more often than cold particles will. A higher frequency of collisions, with a greater energy, means a greater proportion of collisions will result in a reaction. Slow-moving gas molecules will be pushed apart by the repulsion of the electrons that orbit the atoms: they never come close enough to form new chemical bonds. Fast-moving molecules can 'push through' the repulsion, and their electrons can orbit around a different atom. The faster the molecules, the higher the proportion of molecules with sufficient energy to change into products.

Stir and mix

As a chemical reaction proceeds, the particles of the reactants get used up; when there are fewer reactants, there are fewer collisions and so the reaction rate slows. To maintain the reaction rate, the products of the reaction should be removed and replaced with more reactants. A basic way of doing this is by stirring or mixing the reactants.



Initially, hydrogen ions react with magnesium.

Later, hydrogen bubbles that cover the magnesium stop the ions from reacting.

Figure 8 Sometimes the presence of the product can slow down a chemical reaction.

In the reaction between magnesium and acid, one of the products is hydrogen gas. The gas forms bubbles that gather on the surface of the magnesium, covering the unreacted magnesium (Figure 8). This prevents the reaction from continuing. Stirring sweeps the hydrogen gas away so that more hydrogen ions can react with the fresh magnesium surface.

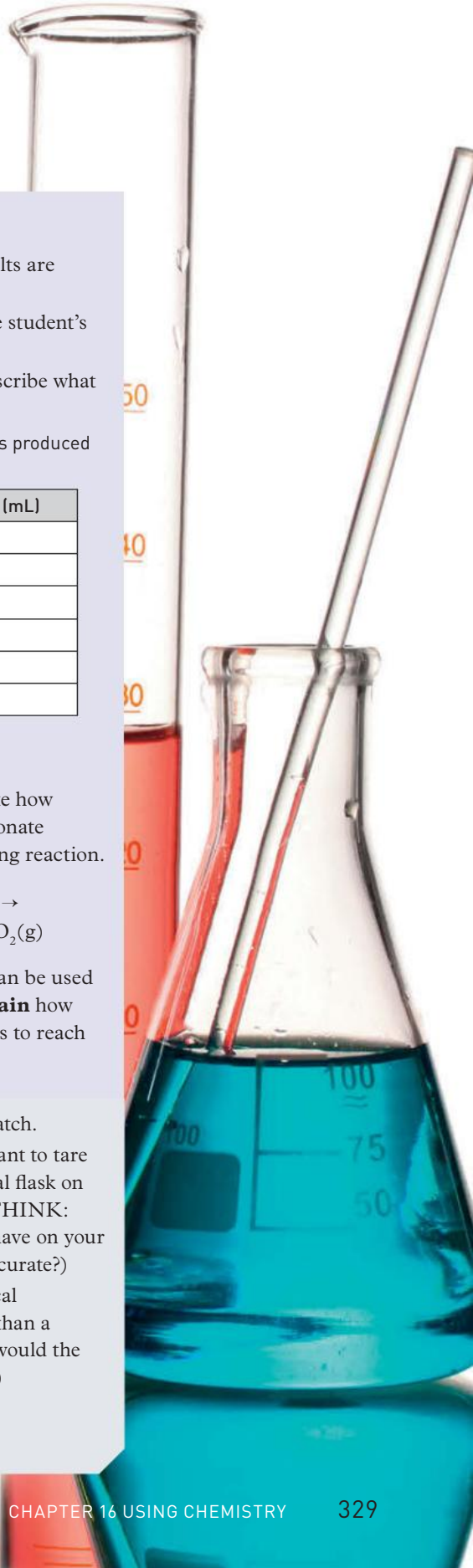


Figure 9 Stirring keeps reactant particles in motion and increases the rate of reaction.

Check your learning 16.3

Recall and explain

1 **Explain** whether products are formed every time molecules of reactants collide.

2 **Recall** why a greater surface area increases the rate of reaction.

3 **Summarise** why a more dilute solution decreases the rate of reaction.

4 **Explain** why a reaction occurs faster when the reactants are stirred together.

5 **Explain** how collision theory explains the dramatic increase in the rate of a reaction as the reactants are heated.

Apply and analyse

6 A reaction is carried out in a well-ventilated environment with outside air regularly circulating. A chemical engineer noticed that a reaction that gave a high yield of a product in winter gave a low yield of that same product in summer, despite the reagents and concentrations being identical. **Recommend** a possible explanation for the different yields.

7 A student investigated the rate of reaction between magnesium and 1 mol/L of hydrochloric acid. They measured the amount of hydrogen gas that was produced during their reaction every 30 seconds. Their results are shown in Table 1.

a **Construct** a graph of the student's results.

b **Analyse** the data and describe what is occurring.

Table 1 Amount of hydrogen gas produced during the reaction

Time (s)	Volume of gas (mL)
0	0
30	51
60	70
90	82
120	91
150	91

Evaluate and create

8 A student wants to investigate how surface area of calcium carbonate affects the rate of the following reaction.

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

Design an experiment that can be used to investigate this aim. **Explain** how you will **interpret** the results to reach your conclusion.

Skill builder: Conducting investigations

9 Your teacher wants you to investigate the effect of concentration on reaction rate. You are provided with the following list of potential materials:

- 20 mL of 0.5 M HCl, 20 mL of 0.1 M HCl, 20 mL of 2.0 M HCl
- 30 g small marble chips
- 100 mL conical flasks, 25 mL measuring cylinder
- electronic balance, stopwatch.

a **Explain** why it is important to tare the balance of your conical flask on the electronic balance. (THINK: What impact would this have on your results? Would they be accurate?)

b **Assess** why using a conical flask is more appropriate than a beaker. (THINK: What would the difference in reaction be?)

16.4 Catalysts increase the rate of a reaction

In this topic, you will learn that:

- catalysts increase the rate of a chemical reaction without being permanently changed.

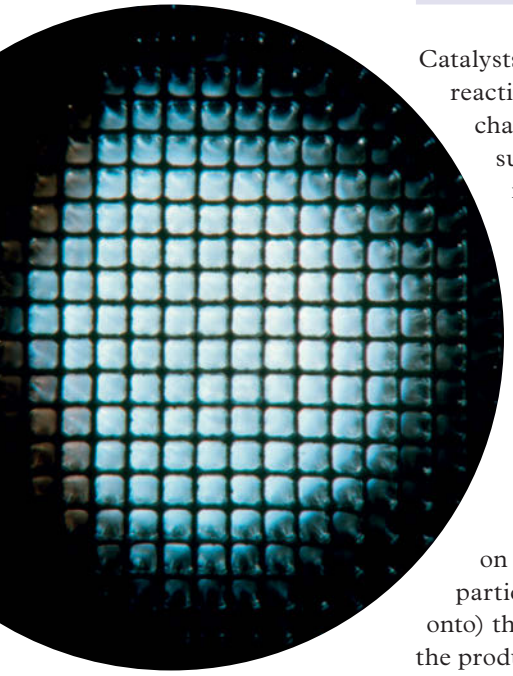


Figure 1 Catalysts are often used in the form of a grid to maximise the surface area.

catalyst
a substance that increases the rate of a reaction but is not used up in the reaction

Catalysts increase the rate of a chemical reaction without being permanently changed. Some catalysts provide a surface for the two reactants to meet in the correct orientation, allowing the products to be formed. The products are then released. Other catalysts take part in the initial reaction and are regenerated in the final reaction.

A **catalyst** is a substance that speeds up a chemical reaction but is not used up in the reaction. Catalysts work in many different ways.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants get adsorbed (stuck onto) the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

Pollution control in cars

Solid catalysts are used in the catalytic converters of cars. A honeycomb-like grid of metals provides a large surface area (Figure 1). As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The metals adsorb pollutant gases but not clean gases such as nitrogen and carbon dioxide. These clean gases are passed through the car exhaust. The metals that act as catalysts are platinum, palladium and rhodium. The overall reaction that occurs in the catalytic converter is:

$$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$$

Figure 2 Catalytic converters are used to reduce pollution from exhaust gases.

Reactions in the ozone layer

Another way in which catalysts work is to take part in the reaction and be regenerated later. This occurs in the destruction of ozone by chlorofluorocarbons (CFCs). The ozone layer is part of the stratosphere. It is the region in the stratosphere from 10 to 50 km high, with the greatest concentration at an altitude of 30 km. Ozone in this region absorbs the UV light that would otherwise cause many more skin cancers and eye problems.

CFCs are the main destroyers of ozone. CFCs were developed as refrigerants for use in refrigerators. CFCs are non-flammable, non-toxic, cheap to manufacture, easy to store and chemically stable, and they were used in aerosol cans (Figure 4), fire extinguishers and asthma inhalers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers.

CFCs such as CCl_3F (trichlorofluoromethane or freon-11) are broken apart by the UV rays from the Sun, releasing a free chlorine atom. This chlorine atom catalyses the destruction of ozone and is regenerated.

Figure 3 Ozone offers some protection from some harmful ultraviolet radiation.

Figure 4 Chlorofluorocarbons (CFCs) were used to pressurise the gas used in aerosol cans before it was proven that the CFCs damaged the ozone layer.

In this way, one chlorine atom from the original CFC can destroy up to 10 000 ozone molecules. The reactions occurring can be shown as follows.

CCl_3F breaks down to produce a chlorine atom:

$$CCl_3F \xrightarrow{\text{UV light}} CCl_2F + Cl$$

The chlorine atom reacts with ozone:

$$Cl + O_3 \rightarrow ClO + O_2$$

ClO reacts with O atoms, making more Cl:

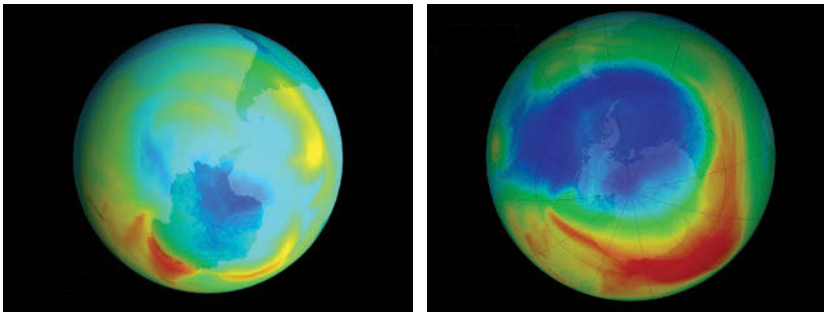
$$ClO + O \rightarrow Cl + O_2$$

The Cl atoms are then free to react with more ozone. In 1987, the Montreal Protocol (an agreement made in Montreal, Canada) phased out the use of CFCs. Chemicals that were 'ozone friendly' were developed and used as replacements for the ozone-depleting substances.

Enzymes as catalysts

An **enzyme** is a catalyst made and used in living cells. Enzymes play an important part in all cellular processes. All the reactions that occur inside a cell are catalysed by enzymes. There are numerous enzymes in our bodies to help speed up reaction rates. For example, enzymes in the digestive system help break down food. Enzymes only work with specific reactants and so will only catalyse certain reactions.

enzyme
a catalyst that is used in living cells



Sep 18 1979 Sep 08 2019

Figure 5 Ozone levels reduce over the Southern Hemisphere every year. The darker blue colours show where the 'hole' in the ozone layer had grown.

Check your learning 16.4

Recall and explain

1 **Explain** what a catalyst is.
2 **Explain** the two ways in which catalysts can work.
3 **Describe** a catalytic converter and **explain** why they are used.
4 **Explain** what a CFC is.

Apply and analyse

5 **Explain** why it is important that the amount of ozone in the atmosphere remains stable.
6 **Recall** what has caused the change in the amount of ozone in the atmosphere over time.
7 **Identify** which part of the CFC molecule destroys ozone. **Explain** how this atom becomes detached from the CFC molecule.

Evaluate and create

8 The reaction $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ is very slow at room temperature. The reaction occurs in two steps, which are shown below. The reaction occurs more quickly in the presence of nitrogen dioxide gas.

Step 1
$2SO_2(g) + 2NO_2(g) \rightarrow 2SO_3(g) + 2NO(g)$
Step 2
$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

Explain two reasons why the nitrogen dioxide is regarded as a catalyst.

Skill builder: Planning investigations

9 **Investigate** a catalyst that is used in the natural world.
a **Explain** how the catalyst is used in the natural world. (THINK: What is the catalyst? What everyday tasks is it used for?)
b **Identify** the source of your information and **assess** its credibility. (THINK: Where did it come from? When was the information published?)

16.5 Green chemistry reduces the impact of chemicals on the environment

In this topic, you will learn that:

- green chemistry is positive for the environment.

biodegradable
an object or a substance that can be broken down by bacteria, fungi and other living organisms

Figure 1 Agriculture can use different types of pesticides.

Being 'green' means doing something positive for the environment. Scientists with special knowledge in ecology, biochemistry, zoology and botany study the environment and how it responds to changes. These scientists detect changes caused by natural events, as well as by human actions. They monitor the environment for changes that may have been caused by the actions of society.

Low-impact chemicals

Some chemicals have a negative impact on the environment and living things. When these substances are identified, scientists act to reduce their use and prevent them from entering the environment. Some substances are banned altogether.

New chemical products and processes are described as 'green' if they have less impact on the environment than the product or process they replace. The study and development of new substances that have a low impact on the environment is called 'green chemistry'. Some examples of the development of 'green' alternatives are described below.

Pesticides and herbicides

Pesticides and herbicides have been used to kill organisms that eat our food crops and the plants that compete with these crops for sunlight and nutrients. In the past, some of these products killed all living things, not just the target species. Most were non-degradable (i.e. did not break down) and remained in the environment long after they were no longer needed. These substances are now banned and have been replaced with **biodegradable** poisons. In many cases, chemical poisons have been replaced with new farming practices, such as crop rotation and planting pest-resistant crop varieties.

Heavy metals

Heavy metals include lead, mercury and cadmium. Heavy metals had many uses, especially in dyes, and were used in chemical processes, especially as catalysts. However, these metals accumulated in the bodies of living things, including people. The most dramatic example is that of Minamata disease, which was caused when people in Minamata, Japan, in 1956 were poisoned by mercury after eating contaminated seafood. The use of these metals in situations where they could enter the environment has been largely stopped. They have been replaced by different catalysts and even different production processes.

Solvent-based paints

Acrylic paints have replaced solvent-based enamel paints and lacquers. The solvent used in the old paints was a hydrocarbon, such as turpentine, and it evaporated as the paint dried. The hydrocarbon solvents in enamel paint were toxic to aquatic life in waterways, and the fumes from the paint caused 'painter's disease' in the workers who inhaled them. These solvent-based paints have been replaced with acrylic paints, which are water-based and set by polymerisation of the paint, not by evaporation of a solvent.

Green chemistry is sometimes called 'sustainable chemistry'. It is about reducing the impact of chemicals on the environment

– chemists produce substances using processes that have less impact on the environment than the substances they replace.

Social, ethical and environmental considerations in research

When scientists are conducting research, there are many considerations and questions that need to be answered before the research can even begin.

- Social considerations – This is where scientists look at what factors of the research may concern society. One example is how the research affects different genders, cultures and ages.
- Ethical considerations – Scientists have to be very careful when it comes to the ethical obligations of research. Some examples are has consent been given if it involves humans, has previous research that has led to the current research been acknowledged, and has all data been produced (including data that doesn't support the hypothesis). The area of ethics in scientific research is vast and complex.

Figure 2 Acrylic paints have replaced solvent-based paints.

- Environmental considerations – It is important that during research, scientists aren't negatively impacting the environment. Ensuring safe waste management practices is very important in scientific research. For example, how are the local ecosystems going to be affected by pumping toxins into the air or waterways, increasing the temperature of surrounding bodies of water.

Check your learning 16.5

Recall and explain

1 **Explain** how scientists know how safe a product is.
2 The 'old masters', painters of the 1600s and 1800s, used pigments made of compounds of lead, mercury and cadmium. **Explain** why these paints are no longer available to today's artists.
3 Provide one example each of a social, ethical and environmental consideration in scientific research.
4 **Define** 'green chemistry'.

Apply and analyse

5 **Analyse** the ethical considerations of the collection, storage and uses of human genetic information.
6 A laboratory group wants to research the use of natural pigments in paints. **Assess** some of the environmental issues that would need to be considered.
7 **Analyse** why scientists choose bacteria to clone human genes.

Evaluate and create

8 Debate the following topic: A materials scientist discovers an important new chemical. Could they be responsible for the consequences that might occur 30 years in the future? Could the people who are affected in 30 years' time blame them?

Skill builder: Planning investigations

9 Recently, a farm has started to use a new type of pesticide the farmers developed at home to protect their crops. They want to start producing this pesticide for commercial sale. Before they start this process **assess** the environmental considerations that the farmers would need to consider. (THINK: Is there safe waste management? What is the effect of this pesticide on the crops and the local ecosystems?)

16.6 Advances in science affect people's lives

In this topic, you will learn that:

- the field of Chemistry is essential to how we live our everyday lives
- Australia is an important hub of scientific research and innovation.

polymers
giant molecules made from the joining of many smaller molecules

Scientific research is an important endeavour as it moulds how we live our life. It shapes what we eat, how we live, how we use transport and the technology that we use. However, in a world where we have problems of food shortages, climate change, pollution and poor water quality – scientific research has become even more important. CSIRO (Commonwealth Scientific and Industrial Research Organisation) is an important Australian organisation that has researched and innovated in the areas of climate change, materials, food and agriculture, information technology, space, and transportation, just to name a few!

Career spotlight: Polymer chemists

Polymer chemists are scientists who look at the synthesis, structure and properties of polymers. **Polymers** are giant molecules that are made from the joining of many smaller molecules (monomers) together. Synthetic polymers are used in the manufacture of many household and industrial products such as furniture, packaging, transportation and communication. Polymer chemists develop these chemicals to make products with specific properties related to degradability, durability and conductivity.

Resource
STEM activity: Slime optimisation

Figure 1 Warragamba Dam showing low water levels.

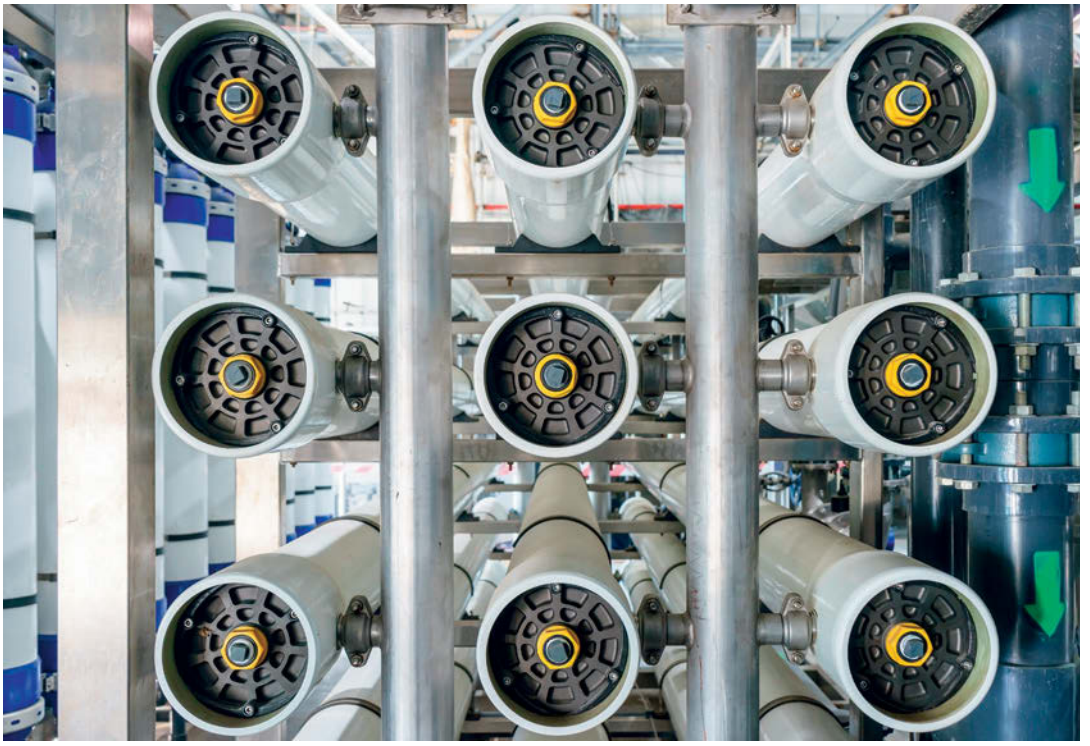


Figure 2 Reverse osmosis filtration for desalination plants.

Michelle Louise Coote FRSC FAA is an Australian polymer chemist. She is a Fellow of the Royal Society of Chemistry and the Australian Academy of Science. She is a published author in the fields of polymer chemistry, radical chemistry and computational quantum chemistry. Michelle Coote is also the first female professor of Chemistry at the Australian National University.

Water quality

In Australia most of our drinkable water comes from water catchments like the Warragamba Dam.

However, due to drought and climate change, water levels have declined over the years. To help supplement the water requirements in Sydney, the Sydney Desalination Plant was built. Using scientific technologies such as reverse osmosis filtration and powered using wind energy, an additional 250 ML of water per day can be added to the water supply of Greater Metropolitan Sydney.

Reverse osmosis filtration uses a thin polymer layer rolled into a tube that traps salt, nutrients, bacteria and viruses from water. Water is pushed through this tube and moves in a cyclical fashion as it moves through the polymer layers becoming more purified.

Bioplastics

Bioplastics are plastics that are made from living things, usually biomass. Examples of biomass come from plants such as vegetable-based oils, corn and wood chips. Polylactic acid (PLA) is a common bioplastic made from corn. Its properties are similar to fossil fuel-derived plastics such as polyethylene (PE).

Figure 3 Biodegradable plastic pellets can be made from plants including corn.

Figure 4 Disposable cutlery made from a bioplastic that uses avocado seeds.

Bioplastics are said to use less energy to manufacture compared to fossil fuel-derived plastics, and they produce significantly less greenhouse gases during production as well. However, it is a major misconception that all bioplastics are biodegradable. A lot of research is currently being done in this area to minimise the environmental impact of bioplastics after their use.

Case Study: Sustainable style – You need to know what happens to your clothes at the dry cleaner

By Clare Press, The Age, August 3, 2017

…The liquid solvents are indeed contained and recycled under government regulation. But what about the stuff that escapes into the air?

George Masselos is president of the NSW branch of the DIA, and has run a Sydney drycleaners for 27 years. He says the industry is like any other – there are careful, professionals doing the right thing, and there are cowboys. "Handled properly there are no dangers. If the drycleaning machine is a properly sealed machine, which all the later models are, and they are properly serviced – and this is vital - then there is less than 4 parts per million of perc come out in the clothes. You can't smell it. If you get your clothes home and they have a chemical smell, you have a problem."

Goud was working for a chemical-free dry cleaners in Port Melbourne when she started getting interested in all this. She took herself off to the Centre for Sustainability Leadership, and is now in the process of setting up an awareness campaign about the problems of perc.

"Drycleaning sites are notorious for soil and ground water contamination," she says. "The people who work in these shops don't wear protective clothing or masks. When the clothes come out of the machines they contribute to indoor air pollution."

Such concerns have been raised elsewhere. In 2007 California banned the installation of new perc-based machines, and committed to a phase-out of existing machines by 2023. France followed suit in 2012.

The American Environmental Protection Agency (EPA) classifies tetrachloroethylene as "reasonably anticipated to be a human carcinogen" and notes a 2002 study conducted in New York that found elevated ambient indoor-air concentrations of the chemical in apartment buildings with drycleaning shops downstairs, "even months after removal of the machines". Also according to the EPA, "homes with freshly drycleaned clothing stored in the closets may [have] 2 to 30 times higher than average background levels [of perc]".

Australia's National Pollutant Inventory (NPI) confirms consumers may be exposed to perc by bringing drycleaned clothes into the home. They say the chemical is not absorbed through the skin; it's inhalation that is the problem. This "may cause central nervous system effects", is a "suspected carcinogen", while long-term exposure can mess with your liver and kidneys.

"The chemicals are locked in the fibres of the garments when you take them home," says Gould. "Then you wear them. How is that common sense?"

Perc, when it escapes, is bad for the environment too. According to the NPI, tetrachloroethylene has "moderate chronic (long-term) toxicity to aquatic life" and bioaccumulates. When it's released into the air it breaks down into other chemicals (including the poisonous gas phosgene) over "a few weeks to a few months", and contributes to smog.

So why are we still using it? Just because we've been merrily doing something for ages, doesn't mean it's a good idea. Back in the 1920s, before perc came on the scene, cleaners used kerosene – until someone worked out it was a fire hazard.

It's expensive to replace the old machines designed for perc but greener alternatives do exist.

New generation solvents use liquid silicone derived from sand, which is gentler and more environmentally friendly.

Increasing numbers of premium drycleaners use these (look for the brand name GreenEarth) and offer wet- and spot cleaning services. How to find them?

"You can trust members of the DIA," says Masselos, adding that's about 30 per cent of drycleaners in Australia. "You can search by location on our website for a member near you. We do checks to make sure machines are serviced, and ensure waste is properly disposed of. We are very conscious of the environment and of new innovations."

Or brush up on your hand-washing skills. Many designers routinely bung "Dry Clean Only" labels on delicate garments in order to avoid customer returns, but there are few clothes that can't handle a careful handwash. I'm positive my poor blouse would have fared better that way. Some fabrics are trickier than others of course – wash crepe at your peril. Satin, same. And yet all but the grubbiest, smelliest coats, jackets and tailored skirts can simply be spot cleaned and aired.

"I'm not a scientist, I'm just a concerned consumer," says Anna Goud. "But I believe in people power, that by talking about an issue we can give it traction. Why aren't we having a conversation about this in Australia, when the debate is much further advanced overseas? I started buying organic food years ago, so chemical free clothes are a no brainer, right?"

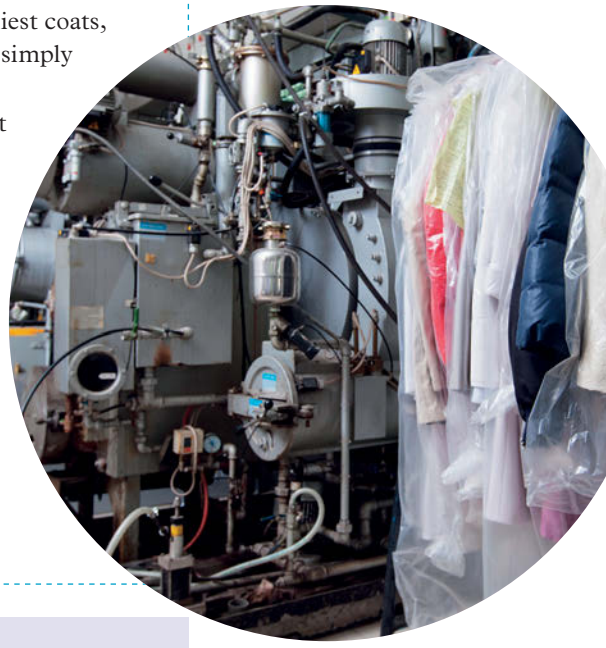


Figure 5 Exposure to perchloroethylene (perc) is associated with adverse health effects.

Check your learning 16.6

Recall and explain

1 **Recall** the name of the Australian organisation that is responsible for scientific research.
2 **Explain** how reverse osmosis works.
3 **Recall** the name of the family of chemicals used in dry cleaning.
4 **Identify** a common bioplastic.

Apply and analyse

5 **Explain** why 'perc', when used in dry cleaning, is hazardous to humans and animals.
6 **Explain** why the research and development of bioplastics is important.

Evaluate and create

7 **Evaluate** the importance of developing alternatives to common chemicals used in industry and commercially. Use examples to support your answer.
8 Create your own bioplastic! Using the internet, research a method to make your own bioplastic either in the laboratory or at home.
9 Research an Australian chemist. Include information such as their field of Chemistry, a summary of their research and any contributions they have made.

Skill builder: Processing and analysing data and information

10 Read through Sustainable style.
   a **Identify** where it was published and the date of publication. (THINK: What is the source of the information? Who wrote the case study?)
   b Use the information from part a to **assess** how credible this case study is. (THINK: What would a newer or older article state? Is there a more reliable source for this information?)

REVIEW

Multiple choice

1 The best way to explain an endothermic reaction is:
- **A** a reaction that releases energy
- **B** a reaction that absorbs energy
- **C** a slow reaction
- **D** a fast reaction.

2 Collision theory is a model that explains:
- **A** a collision must occur with enough energy for that reaction
- **B** how fast a reaction occurs
- **C** the effect of surface area on reaction rate
- **D** the impact of increasing concentration on reaction rate.

3 A catalyst is:
- **A** an exothermic reaction
- **B** an ignition for a reaction
- **C** a substance that speeds up a chemical reaction
- **D** a substance that slows down a chemical reaction.

Recall and explain

4 **Explain** the difference between an exothermic and endothermic reaction.

5 **Define** cellular respiration.

6 **Explain** what makes a reaction exothermic.

7 Give the names of the products when methane burns in an excess supply of oxygen.

8 **Recall** three different ways in which a student could increase the rate of reaction of an experiment.

9 Complete the following sentences.
For a _____ reaction to occur, the _____ or _____ or _____ must collide with enough _____ for that reaction to occur. This is called _____ _____.

10 What is the temperature change of the surroundings in an endothermic reaction?

Figure 1 There are many ways of representing green chemistry.

11 **Describe** two examples of the use of catalysts in the production of chemical products.

12 **Explain** what is meant by the term 'green chemistry'.

Apply and analyse

13 The reaction of butane with oxygen is exothermic. What does this tell you about the energy involved in breaking the bonds and reforming bonds to make carbon dioxide and water?

14 A student conducts an experiment by measuring the temperature before and after various salts are added. The results are shown in Table 1 below.
- **a** Complete the table, by calculating the change in temperature.
- **b** Which salts are exothermic when dissolved in water? **Justify** your response.

Table 1 Temperature changes of water after different salts are added

Salt	Initial temperature of water (°C)	Final temperature of water (°C)	Change in temperature of water (°C)
Sodium hydroxide	23	44	
Sodium nitrate	23	12	
Potassium acetate	23	31	

Figure 2 A glass of water with salt

15 Consider the following experiment, where solid magnesium is reacted with aqueous hydrochloric acid.

Magnesium + hydrochloric acid → magnesium chloride + hydrogen gas

In this experiment, the concentration of a solution of hydrochloric acid was investigated to see whether this changed the time taken for the reaction to go to completion. **Identify** the:

- **a** independent variable
- **b** dependent variable
- **c** control variables.

16 **Analyse** the environmental considerations in the development of solvent-based paints.

Evaluate and create

17 Do you think the process occurring in cold packs is a chemical or physical change? **Explain** your answer.

18 **Evaluate** the use of 'natural pesticides' in gardens.

Figure 3 Some people use chilli and garlic to deter insects from eating their plants.

19 Research human-made bamboo as a 'new material'. Prepare a poster including any advantages or disadvantages.

20 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact on the surface of the catalyst.

- **a** Why would attracting particles onto a surface of another chemical encourage a chemical change to occur?
- **b** Why would a substance that actually bonded chemically to the reacting particles not make a good catalyst?
- **c** Give an example of the use of a surface catalyst, describing in detail the chemical reaction.
- **d** Use your knowledge of collision theory to explain why most catalysts are used in the form of a powder or fine mesh.

21 How does the particle model of matter help us understand the rate of reactions?

22 A student is given three solids that are soluble in water. The student wants to determine whether the solids release or absorb energy when they dissolve in water. Design an experiment that can be used to investigate this aim. **Explain** how the test results will be interpreted to reach a conclusion.

Critical thinking

23 **Investigate** a surface catalyst and provide an example of how it can be used. **Describe** the chemical reaction involved.

24 CSIRO is trialling growing coloured cotton. **Investigate** the chemical reactions involved in this process. Then, **identify** two advantages of growing coloured cotton.

Figure 4 A cotton field

Go further

25 Nylon is produced through a polymerisation reaction. **Investigate** how nylon is made, and **assess** the chemical changes that have taken place.

Figure 5 Nylon can be used in many ways, including nylon rope.

26 **Evaluate** the following claim: 'Exothermic reactions are more powerful than endothermic reactions.'

Research

27 Choose one of the following topics for a research project. A few guiding questions have been provided for you, but you could add more questions that you want to investigate. Present your research in a format of your own choosing, giving careful consideration to the information you are presenting.

»Ammonia

The Haber process is an important industrial process. Research this process, and describe how the reaction conditions are controlled to obtain the maximum yield of the product.

»Illuminating concrete

Scientists have developed a concrete that stores energy and then glows in the dark. Find out more about this process and how it works.

»Sustainable agriculture

Many scientists and farmers have been investigating ways to be more environmentally conscious and sustainable. They might consider things like maintaining healthy soil, water management and how to safely use pesticides.

Research one method of sustainable farming and explain why it is sustainable, how it works and how this has been influenced by society's expectations.

Figure 6 Ammonia is a compound of nitrogen and hydrogen and is used in the manufacture of many products that people use every day.

Reflect

Now that you've completed this chapter, reflect on your ability to do the following:

	I can do this.	I cannot do this yet.	
Identify that chemical reactions involve energy transfer and can be exothermic or endothermic.	☐	☐	Go to pages 322-323
Compare combustion and respiration as types of chemical reactions that release energy but occur at different rates.	☐	☐	Go to pages 324-325
Describe the effects of factors, e.g. temperature and catalysts, on the rate of some common chemical reactions.	☐	☐	Go to pages 326-331
Analyse how social, ethical and environmental considerations can influence decisions about scientific research related to the development and production of new materials.	☐	☐	Go to pages 332-333
Describe examples to show where advances in science and/or emerging science and technologies significantly affect people's lives, including generating new career opportunities in areas of chemical science such as biochemistry and industrial chemistry.	☐	☐	Go to pages 334-337

Source: NSW Science Years 7–10 Syllabus © NSW Education Standards Authority for and on behalf of the Crown in right of the State of New South Wales, 2018.

STUDENT RESEARCH PROJECT

How do I complete my Student Research Project individually?

17

Have you ever wondered ...

- **What topic should I choose for my Student Research Project?**
- **How do I know if the information I am reading is credible?**
- **What format should my results be in?**

SCIENCE SKILLS

- In Stage 4, you should have completed a research project, which you might have done in a group. In Stage 5, you will conduct at least one research project individually. You will have some class time allocated to this but will also be expected to do much of the work outside of class independently.
- The research project gives you the opportunity to test your own science skills and investigate a topic you find interesting further than the textbook!
- This chapter will help you plan, conduct and write up your research project. The Student Research Project is a little different at each school, so always check with your teacher if you are unsure of what you should be doing.

17.1 The Student Research Project investigates a topic of interest

In this topic, you will learn that:

- choosing a topic that you're interested in will make it easier for you to conduct the relevant research.

During Stage 4, you should have completed a research project. You might have done more than one, and it is likely that you did them as a group. In Stage 5, you must complete at least one research project individually.

An individual research project means that you can choose a topic from an area of science that you find interesting!

Selecting a topic

What are you interested in? As you study each area of science, certain topics will stand out to you. This might be because they are directly relevant to your life at the moment (e.g. maybe you are interested in vaccinations as a result of the coronavirus pandemic), or they may be things you are interested in for the future (e.g. maybe you'd like to study engineering after high school). Whatever your area of interest, developing a topic about this will make it easier to work on.

Regardless of the topic you choose, you need to be able to test it scientifically. You should think about the following before you settle on a topic.

- What do you know about the topic? Have you done any background reading about this topic? Are you sure there will be enough information? Before you select your topic, take some time to check that there is information available.
- Is there a claim in your topic, or can you find a claim related to your topic? For example, LED (light-emitting diode) light bulbs use 75% less energy than incandescent light bulbs.
- Can you hypothesise the claim? For example, if a lamp uses a LED light bulb and another lamp uses an incandescent light bulb, then the LED light bulb will last longer. You will need to have an independent variable and a dependent variable.
- Can you plan and conduct an experiment about this? You should think about the type of equipment and materials you need – are they safe? Can you make them safe? Does your school have access to these materials? Will you get enough first-hand data?
- Is it possible to investigate this topic in the time limits set out by your teacher? It might be really interesting to investigate the growth rate of lemons on a tree, but it takes years for a lemon tree to grow, so this would not be practical within the time frame.

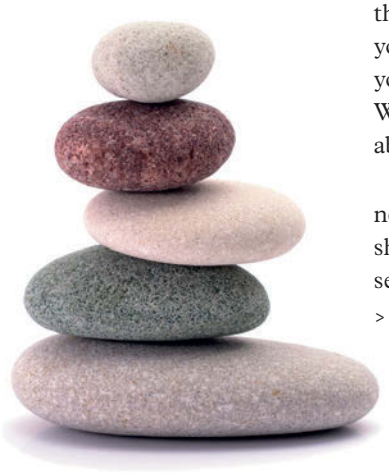


Figure 1 Can stones absorb water? You could investigate this in your Student Research Project.

Topic ideas to get you thinking

If you're struggling to think of a topic, you might want to look at the following list for inspiration. You can also consult your teacher.

- How does salt affect the growth of different plants?
- What effect does the type of soil (e.g. salty, sandy, volcanic) have on plant growth?
- What effect does age have on lung capacity?
- How does age impact reaction time?
- What type of non-stick pan is the most effective?
- Does using beeswax food wrapping keep food as fresh as cling film?
- Do rocks absorb water?
- If you plant more trees, will there be less erosion?
- Will your tea stay warmer in a ceramic or plastic cup?
- Can you make a paper plane fly further if you change the shape?

You might be tempted to select a topic that is the same as your friend's topic, or the same as someone who usually gets really good grades. But the individual research project is *your* project, and you will have to spend a lot of time working on it. It will be easier to stay focused on a topic that you are interested in.

You might also find it useful to use a mind-map to plan your research project. A mind-map can help you link ideas together. They can also visualise relationships between concepts.

Topic checklist

Before you start your research project, go through the checklist in Table 1. Even if you can answer 'yes' to each of the questions in the table, you should speak with your teacher about your research topic before you start. They will be able to flag any potential issues and help you resolve these.

If you answer 'yes' to the first four questions, you can begin to plan your research project. If you answered 'yes' to the last two questions, talk to your teacher as you may need to adjust your idea.

Have a specific logbook

Having a specific logbook for your research project will help you keep track of any information. It is important to keep track of your research because this will help you when it comes time to write your report at the end of the project.

You should use your logbook from the first day of your research project until the end. Keep track of your topic choice decisions, any brainstorming and any research you conduct. You need to submit your logbook with your final report, so making sure it is accurate for the entire project means that you will be ready to hand it in at the end.

Refer to Chapter 1 of this book for more information on what you should include in a logbook.

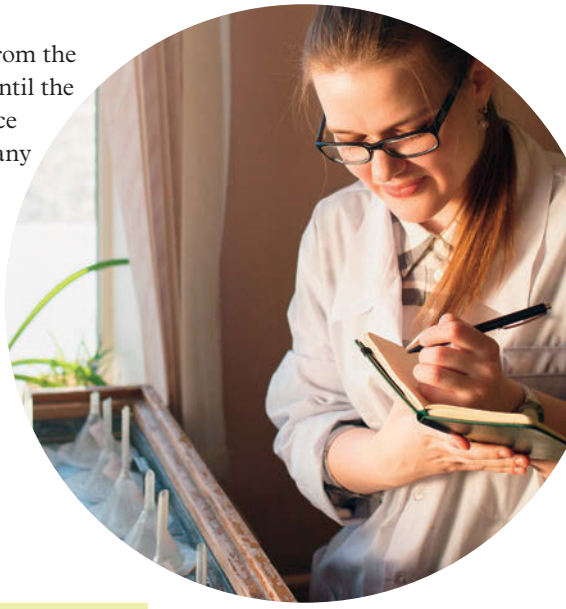


Figure 2 Using a logbook will help you track your investigation.

Table 1 Checklist before starting your research project

Question	Yes	No
Am I interested in this topic?	☐	☐
Can I do this project safely and on my own?	☐	☐
Is the complexity of this project appropriate for my year level?	☐	☐
Can I complete this topic in the time frame?	☐	☐
Does the project involve animals or people?	☐	☐
Do I need special materials or equipment for this project?	☐	☐

Check your learning 17.1

Recall and explain

1 **Identify** two key reasons to speak with your teacher about your topic before you start your research project.

2 **Explain** why you need to have an independent variable and a dependent variable for your research project.

3 **Clarify** if the following are true or false.

- **a** You don't need first-hand data in your research project.
- **b** You will do at least one individual research project.
- **c** Doing a risk assessment is not part of the research project.

4 **Recall** the steps to take when setting up your logbook. Include information about what kind of book you should use for a logbook.

5 **Recommend** whether the following would make a good research topic. Refer to Table 1 to make your decision.

'Does algae grow quicker when there is less movement in your local pond?'

6 Use the following formula to create a hypothesis about increasing salt in soil for flower growth.

Independent variable + change + dependent variable + response

17.2* Planning your time

In this topic, you will learn that:

- planning your research project will make the final process easier to manage.

Your teacher will give you a time limit to complete your research project. Section 17.1 mentioned that you need to check that you can actually complete your topic in the time frame; in this section, you will learn about how you can manage your time.

Creating a timetable

While it's nice to think you could spend all your time doing your research project for science, you will have other assessments from different subjects as well. It is important to set yourself times where you will only focus on the research project. You can include allocated class time in this. Table 1 estimates how long it will take you to complete some of the tasks; this will vary from school to school.

While it may seem like a lot of work, when you break each task down, it will be easier and more manageable. Breaking each task into small blocks of time will help you achieve this.

You will probably have at least 4 weeks to complete the research project. A sample timeline might be similar to Figure 1.

Figure 1 A sample timeline for your research project

Figure 2 Planning your student research project will save you time.

Table 1 Estimate of required time for the research project

Task	Estimated time (approximate hours)
Choose a topic	≈ 1
Research about the topic	≈ 5
Talk to people and your teacher about your topic	≈ 2
Summarise information	≈ 5
Design and conduct the experiment	≈ 6
Analyse data	≈ 2
Prepare your report	≈ 5
Total estimated time	**≈ 26 hours**

Background research

Background research will help direct your own primary research. It will confirm what is already known, and what is yet to be discovered about your topic. But where should you look for research?

Google or your school library are good places to start researching your topic. Other places that you can find information include the following.

- Local library: You can ask the librarian to help you find the right books, or you can search using the library catalogue.
- People: You can interview people to find out more about a topic, especially if they are scientists or experts on a topic.
- Organisations: Some companies are very happy to help you find out more about their industry.
- Magazines, journals and pamphlets: Other types of printed texts can be a good source of information too.

A good Student Research Project should use a variety of resources. If you are going to speak to a person or a company as part of your research, remember to be polite and respectful.

Evaluating sources

Once you have found your information, you need to evaluate the source of information to make sure it is trustworthy. But how can you tell if the information you found is reliable? One good test is to ask the following set of questions.

- Is the source current? When was the information first published? If it was written 200 years ago, or even 20 years ago, it's possible it may be out of date.
- Is the source relevant? How important is it to know this information for your research project? Does it help you to answer your question? If not, it may be better to leave this source out.
- Who wrote this source? Is the author an expert? Websites that end in .org, .edu and .gov are often more reliable.
- Is this source accurate? Is the information supported by evidence?
- Why does this source exist? What is the purpose of this information? Is it trying to persuade or educate? Could it have been written for political or personal reasons?

Note-taking

When you take notes from your sources, make sure you have a system for why you have recorded the information. You might want to place a positive sign (+) next to resources that support your hypothesis and a negative sign (–) next to resources that refute it.

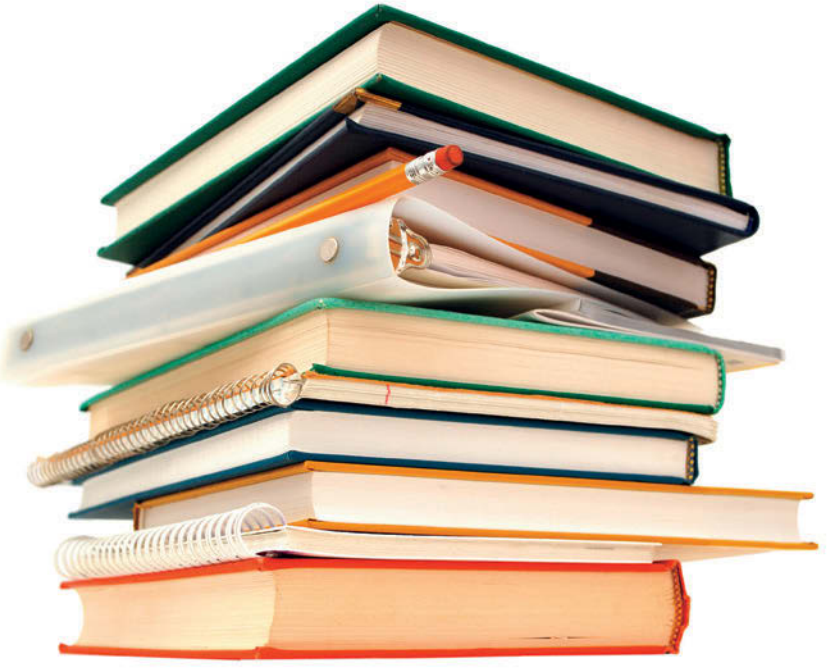


Figure 3 Don't forget to look beyond the internet when conducting research.

Check your learning 17.2

Recall and explain

1 **Construct** a timeline for your research project. Remember you have other subjects and commitments.

2 **Explain** why time management is an important part of your research project.

3 Imagine your friend is asking for advice on where to find good information. **Recommend** two sources that they could use, and **explain** why these are good sources of information.

17.3 Designing your research project

In this topic, you will learn that:

- your research project should be a fair test
- choosing the right type of experimental design will help you achieve this.

When you conduct your research project, you should use a fair test. This is achieved by choosing the right experimental design. A fair test provides consistent conditions so that the data generated is reliable and valid.

Experimental design

Experimental design is concerned with what variables you have and how you are manipulating these.

In a *fair test*, all variables are controlled outside of the independent and dependent variables. Variables that aren't the independent or dependent variables are called *controlled variables*. The way that these variables are controlled should be included in the method for your project. For example, if you were investigating the rate at which different brands of milk boil, you would want to ensure that you used the same heating vessel each time, so that you were sure the rate of change was due to the brand and not the delivery of heat.

You can collect qualitative or quantitative data from fair tests. *Quantitative data* is measurable, such as temperature. *Qualitative data* tends to record characteristics, like the different types of flower on a plant. Quantitative data is typically easier to analyse, so qualitative data is often converted into quantitative data.

Figure 1 Qualitative data records characteristics, like the different types of flowers in an area.

Good experimental design

Good experimental design sets out knowing which variable is being manipulated (e.g. time) and which variable depends on this (e.g. temperature). Knowing how to record your data is part of experimental design.

Typically, you record the independent variable in a left-hand column and the dependent variable in the right-hand column.

You should ensure that you conduct multiple tests to ensure that any changes to the dependent variable are due to the independent variable and not a controlled variable.

You can use this checklist to see if you have designed an experiment that will produce successful data.

- Does your experiment title include the independent and dependent variables?
- Does your hypothesis predict changes in the variables?
- Are your independent and dependent variables clear?
- Have you shown how you will regulate controlled variables?

Figure 2 Design your experiment to have specific measurements.

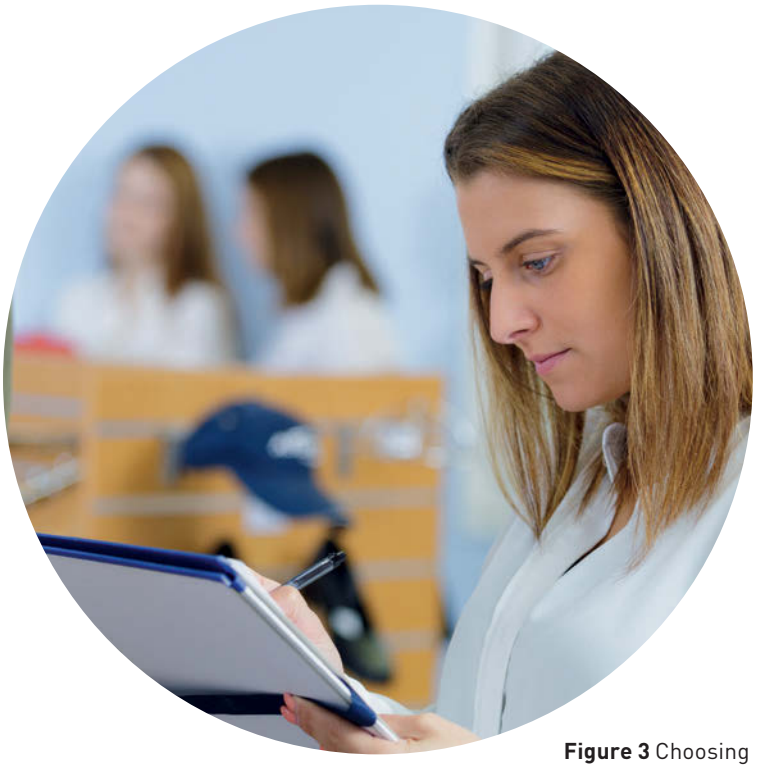


Figure 3 Choosing the right type of experimental design will help you achieve a fair test.

Different types of investigation

Your research project can be structured around your topic. There are different types of investigations in science. These are:

- investigating a relationship between two variables, using repeat trials
- investigating a relationship between two variables, where you use replication
- investigating multiple independent variables with one dependent variable
- questionnaires that sample a population
- comparative studies
- analysing past research.

During your research project you must obtain first-hand data, which means you must investigate the relationship between variables.

Check your learning 17.3

Recall and explain

1. **Explain** what is meant by the term 'fair test'.
2. **Compare** qualitative and quantitative data.
3. For the following hypotheses, **identify** the independent and dependent variables, and suggest a controlled variable.
   - **a** If a pot of water has a lid on it, the water will reach boiling point quicker than a pot without a lid.
   - **b** If a paper plane has curved wings, then it will go further than one with straight wings.
   - **c** If you plant spinach in a shaded area, then it will grow slower than if it was planted in direct sunlight.

17.4 Writing your research report

In this topic, you will learn that:

- your research report should be written scientifically
- you must include specific elements.

As mentioned in Chapter 1, scientific reporting is different from other writing. Scientists report information using technical terms and in concise sentences. Table 1 explains the sections of your scientific report.

Following the sections in the table will guide you in your report writing. If in doubt about any sections, speak with your teacher.

Table 1 Parts of your scientific report

Part	What to include
Title	> Keep your title succinct > Include your independent and dependent variables > What you were investigating should be clear
Abstract	> Summary of your report > No more than 250 words > Brief description of the method > Key finding and results > Major conclusion
Introduction	> Summary of relevant background information that explains how you reached your hypothesis
Aim	> Statement that explains what you were hoping to achieve
Hypothesis	> Write out your hypothesis in full using the 'if', 'then', 'because' formula or the formula: independent variable + change + dependent variable + response
Method	> All materials and equipment used should be listed > Written in the past tense > Include diagrams where relevant > Step-by-step instructions so that your experiment can be repeated
Results	> A summary of what you found – this should not draw conclusions but simply state facts > Present any recorded data in tables, graphs or diagrams
Discussion	> The discussion should have three areas: the introduction, where you summarise what the experiment was about, including the aim; the body, which summarises your observations; and the conclusion, which states the implications of your findings
Conclusion	> Answer your aim > Support for or against your hypothesis should be discussed > Highlight trends in the data > Explore any limitations of your research project > Outline suggestions for further research
References	> Any source you used or cited should be listed here
Appendix	> Any information or data that supports your report – this may include extended results or diagrams

Using scientific language

Scientific reports are written in the third person and should not include the words 'I', 'you', 'me', 'us' and so on. This is so the reports remain objective. Science is objective because it is based on facts and evidence, which can be seen in the data collected. For example, instead of saying 'I placed the pot in the sun', you would state, 'the pot was placed in the sun'.

Society often gives meanings to words that are different to the definition or have adapted over time. Science uses specific language to describe observations. For example, the word 'anomaly' may be interpreted as abnormal or strange by society, but to scientists, 'anomaly' means that it was a change from a trend in data. Similarly, the word 'significant' may mean important, but to scientists, 'significant' means that a result is 'not due to chance'.

Presenting your research project

Your report can be presented in a few ways; it is a good idea to check with your teacher to see if they have a preferred presentation.

It is likely that you will either present it as a written report following the structure in Table 1, or you may choose to use a poster format. If you choose to present this as a poster, the title should be at the top of the page, with your name underneath. You should then present each part of the report in distinct sections.

Figure 1 Your research project should be written and presented scientifically.

Check your learning 17.4

Recall and explain

1 **Outline** the order of sections in a research report.

2 **Explain** where you should talk about the results of your investigation.

3 **Compare** the discussion and the conclusion.

*YOUR STUDENT RESEARCH PROJECT

You can use these questions to help guide you through your research project, or as a prompt for your logbook.

Plan

These questions will help you plan your Student Research Project before you begin.

1 **Identify** the key details of your investigation: What is your project topic? What is your research question? What is the aim of your research project? Have you written your hypothesis? What do you predict will happen?

2 **Identify** the independent variable, the dependent variable and the controlled variables.

3 **Identify** the materials you will need.

4 **Construct** a diagram that shows your experimental set-up.

5 **Explain** how this will ensure a fair test.

6 **Identify** the safety risks of conducting your research project. This must include what the risk is, a description of the risk, how likely it is to occur and what the consequences would be, as well as your strategy to reduce the risk.

Then complete a Safety Data Sheet if required, as well as a risk assessment. Conduct a risk assessment and if necessary complete a Safety Data Sheet.

7 **Assess** the ethics of your research project.

8 **Summarise** the background research you have conducted to aid your planning. **Identify** the sources you used.

9 **Identify** the step-by-step procedure for your research project.

Conduct

These questions will help you conduct your research project.

10 What strategies are you using for working in a group or alone?

11 What kind of data is collected during this project? How is it recorded?

Analyse

These questions will help you think about your data and results.

12 **Identify** the best way to collate and present this data so it can be analysed.

13 **Analyse** the data you have collected. Are there any trends, patterns or answers emerging? If not, account for why not.

14 **Identify** the relationship between your independent and dependent variables.

15 Using your scientific understanding of the topic, **explain** your results.

16 What is your conclusion for this research project? Consider your original prediction. How does it compare to your results?

Evaluate

Before you submit your report, complete this checklist.

	I have done this.
Did you use scientific language throughout your report? Is it clear and concise?	☐
Have you proofread your report and checked spelling and grammar?	☐
Is your hypothesis testable?	☐
Is your aim stated clearly?	☐
Did you identify the variables in your research project?	☐
Did you perform a risk assessment?	☐

	I have done this.
Is all material and equipment identified in your report?	☐
Have you provided a step-by-step method?	☐
Are your results a representation of what you found out?	☐
Have you labelled your graphs and tables appropriately?	☐
Does your conclusion answer your aim?	☐
Did you include all your references?	☐
Is your logbook ready to submit?	☐

INVESTIGATIONS

Science laboratory rules

Being safe in the laboratory is essential to keep you and others from getting hurt. Whenever you are in the laboratory, or conducting any investigational work, you must always follow these rules.

18

DO:

- wear a laboratory coat for practical work and make sure it is done up
- keep any logbooks, workbooks and paper away from heating equipment, chemicals and flames
- tie long hair back whenever you do an investigation
- wear safety glasses when conducting laboratory work
- tell your teacher immediately if you cut or burn yourself
- tell your teacher immediately if you break any glassware or spill chemicals
- wash your hands after any investigations
- listen to and follow the teacher's instructions
- wear gloves when your teacher instructs you to
- check all equipment you are using before you start; don't use anything that is cracked or has exposed wires, and check with your teacher if in doubt

DON'T:

- run in the laboratory
- push others or behave roughly in a laboratory
- eat in a laboratory
- drink from glassware or laboratory taps
- look down into a container or point it at a neighbour when heating or mixing chemicals
- smell gases or mixtures of chemicals; instead, waft them near your nose and only when instructed
- mix chemicals at random
- put matches, paper or other substances down the sink
- carry large bottles by the neck
- enter a preparation room without your teacher's permission
- conduct an investigation on your own or without supervision

1.1 What if the absorbency of different paper towels was compared?

INVESTIGATION

Aim

To measure and compare the absorbency of different brands of paper towels, which vary in cost per square centimetre.

Risk assessment
1.1 What if the absorbency of different paper towels was compared?

Lab tech notes
1.1 What if the absorbency of different paper towels was compared?

CAUTION! Hot water and heating devices can cause burns – handle with care

Materials

- 5 different brands of paper towel (a range of prices)
- Small beaker of water with a dropper
- 250 mL beaker
- 100 mL measuring cylinder
- Scissors
- Ruler and pencil
- Calculator
- Stopwatch

Method

1. Cut a 20 cm by 20 cm square from one sheet of each brand of the paper towel.
2. Record the brand, price, number of sheets and their dimensions.
3. Fill the measuring cylinder with water to the 100 mL mark, using the dropper for the last 2–3 mL. Ensure that your eyes are level with the scale to avoid parallax error.
4. Immerse the square of paper towel in water for 10 seconds. Use the stopwatch for timing. Hold the paper towel above the measuring cylinder, without squeezing the towel for another 10 seconds, and then remove it and place it in the large beaker.
5. Record the level of water left in the measuring cylinder and hence the volume of water absorbed by the paper towel in 10 seconds.
6. Repeat steps 1–5 for two other sheets of the same brand of paper towel.

Inquiry

What if the absorbency of more expensive paper towels was compared to less expensive paper towels?

Answer the following questions with regard to your inquiry question.

- What brands of paper towel will you test?
- What is your independent variable?
- Name three variables you will need to keep the same as the first method.
- How will you measure if a paper towel is more absorbent?
- Predict what results you might expect.
- What equipment will you need to complete this investigation?
- Write down the method you will use to complete your investigation.
- What sort of table will you need to draw to show your results?

Show your teacher your planning for approval.

1. Calculate the total surface area and the cost per square centimetre for each paper towel, and record your results in a table.
   - The total surface area of the paper towel roll is calculated as follows:

     $A = l \times w \times$ number of sheets of paper towel
   - The cost of paper towel per square centimetre is calculated as follows:

     $$\text{Cost of paper towel} = \frac{\text{cost of roll}}{\text{total area of roll}}$$
2. Calculate the average volume of water absorbed per 20 cm square, and record your results in a table.
   - The average volume of water absorbed per 20 cm square is calculated as follows:

     $$\text{Average volume of water} = \frac{\text{volume 1} + \text{volume 2} + \text{volume 3}}{3}$$
3. Draw a column graph to show the average volume of water absorbed for each brand.
   - Place the brands in order from the least expensive to the most expensive. On each bar, state the price per square centimetre of that brand.

Discussion

1. Do the brands with the highest and lowest absorbency coincide with the predictions you made in your hypothesis?
2. Explain the reason for each of the following.
   a. Three readings were taken each time and then averaged.
   b. The same sized square was used each time.
   c. The cost of the paper towel per square centimetre was calculated and used instead of the total cost of the roll.
   d. Each square of paper towel was allowed to drip for precisely 10 seconds before removing it from the water.
3. Comment on how reliable and fair the design of this investigation was.
4. Is it reasonable to conclude that one brand of paper is more absorbent than another just on the basis of tests with water? Give reasons for your answer.

Conclusion

From your graph, was there any apparent relationship between the cost of the paper towel per square centimetre and its absorbency? Provide evidence from your results to support your answer.

1.2 Avoiding errors and improving accuracy

CHALLENGE

Design brief

Complete the following tasks to avoid errors and improve accuracy of measurement.

Risk assessment
1.2 Avoiding errors and improving accuracy

Lab tech notes
1.2 Avoiding errors and improving accuracy

What you need

- Ruler
- Electronic scales
- Item from pencil case
- Analogue clock

What to do

1 Measure the following line.

2 Compare your answer to the person's next to you. Did you both get exactly the same value? Identify some reasons why you may have recorded different measurements.

3 a Use the electronic scales to measure the mass of an item from your pencil case (such as a pen). Make four measurements. Are the measurements the same? Why might they be slightly different?

b Find the average of your measurements. How does the average compare with your individual measurements? Is your average measurement more accurate? Explain your answer.

4 Working in groups of three, read the time on a clock, with each person reading from a different perspective. One person should read the clock from directly in front of the clock. Another person should stand to the right of the first person at an acute angle. The other person should stand to the left of the first person at an acute angle. Each person should read the clock and note the time.

a Are the times the same for all three people?

b What type of error is this?

c How could this type of error be avoided?

Figure 1 An analogue clock is required for this investigation.

2.1 Investigating heating by convection

INVESTIGATION

Aim

To investigate heating water by convection.

Risk assessment
2.1 Investigating heating by convection

Lab tech notes
2.1 Investigating heating by convection

CAUTION! Wear safety glasses, lab coat and tie long hair back, when using a Bunsen burner. Allow all hot equipment to cool before handling.

Materials

- Water
- Food colouring
- Bunsen burner
- Tripod
- Heatproof mat
- Pyrex 600 mL beaker
- Dropper or pipette

Method

1 Set up the equipment as shown in Figure 1.

2 Fill the beaker with water. Add a drop of food colouring to the bottom of the full beaker using a dropper or pipette.

3 Heat the water gently over the Bunsen burner and observe the movement of the food colouring. (If possible, use a small ame and no heatproof mat between the Bunsen burner and the beaker – you can do this with Pyrex beakers.)

4 Note the path that the food dye takes from the burner to the top of the water and back down again.

Results

Draw a labelled diagram showing the movement of the coloured water.

Discussion

1 Describe the movement of the coloured water.

2 Why do you think the coloured water moved like this?

3 What was happening to the particles in the water when the water was being heated?

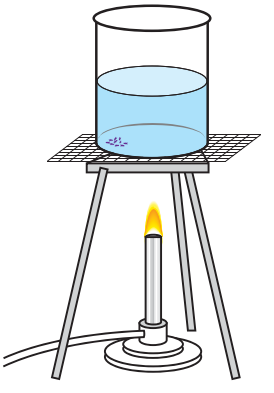


Figure 1 Investigational set-up

Conclusion

What do you know about heating water by convection?

2.2 Modelling sound waves

CHALLENGE

Design brief

Create a model of sound waves using pipe cleaners.

Risk assessment
2.2 Modelling sound waves

Lab tech notes
2.2 Modelling sound waves

What you need

- Slinky spring
- Pipe cleaner

What to do

1 Twist a pipe cleaner around a single curl in the middle of the slinky spring so that the rest of the spring can move easily.

2 Two people slowly stretch the spring out slightly beyond its normal length along the floor.

3 One person pushes their end of the spring firmly towards the other person without letting go. This will create areas where the coils are pushed together (compressions) and areas where the coils are stretched out (rarefactions). These areas will travel along the spring to the other end. The person at the other end needs to hold the spring firmly and still.

4 Try to make the wave have more or less energy by pushing the end harder while keeping the speed of the wave the same. This is the same as making a sound louder. Pushing less models a softer sound.

5 Try to change the frequency (number of waves per second) of your wave. Try to create four waves per second (a higher frequency) and 0.5 waves per second (a lower frequency).

6 Draw labelled diagrams of the waves you created, carefully indicating how the waves show that different frequencies have been achieved.

Discussion

1 How far did the pipe cleaner move as the wave moved along the spring?

2 What happened when the wave reached the other end of the spring?

3 What is this called in real life? Think of what happens to sound waves as they hit a hard surface. What do you hear?

4 What do you notice about how far apart the waves are when they are travelling at the higher frequency?

5 Are the distances between the compressions bigger or smaller at the lower frequency?

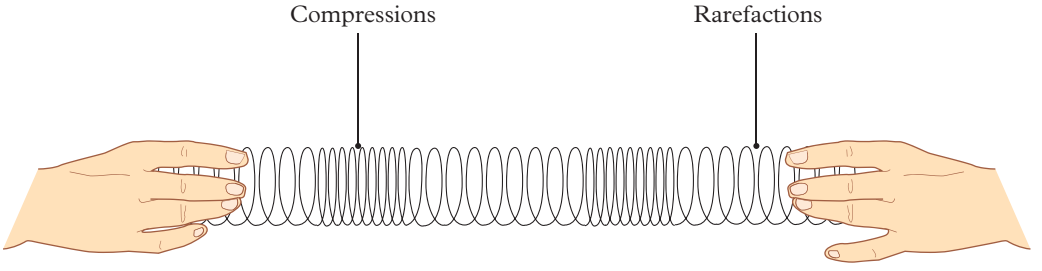


Figure 1 Investigational set-up

2.3a The speed of sound

CHALLENGE

Design brief

As a class, conduct an activity to measure the speed of sound on your school oval.

Risk assessment
2.3a The speed of sound

Lab tech notes
2.3a The speed of sound

What you need

- Tape measure or trundle wheel
- Stopwatches
- 'Slap sticks' (or two large sticks that make a sound when hit together)

What to do

1 On the school oval, measure a distance of 100–200 metres.

2 One person takes the slap sticks to the far end of the measured distance. When everyone is ready, slap the sticks together to make a noise.

3 The rest of the class should start their stopwatches when they see the sticks hit together, and stop them when they hear the 'slap'.

4 Repeat this measurement five times.

5 Record your measurements in a table.

Discussion

1 Why did you need to repeat this measurement many times?

2 What was the average amount of time it took for sound to travel the measured distance?

3 Use the following formula to determine the approximate speed of sound:

$$\text{Speed} = \frac{\text{distance travelled (m)}}{\text{time (s)}}$$

4 How does your measurement compare to the accepted value of 340 m/s? Explain any differences.

2.4 Modelling light waves

CHALLENGE

Design brief

In pairs, model light waves.

Risk assessment
2.4 Modelling light waves

Lab tech notes
2.4 Modelling light waves

What you need

- Slinky spring
- Clear space on the floor

What to do

1 Two people hold the spring, one at each end. On the floor, slowly stretch the spring out slightly beyond its normal length. One person flicks their end of the spring firmly to one side. This will create a sideways 'pulse' in the spring. The other person needs to hold the spring firmly and still. The pulse will travel along the spring to the other end (Figure 1).

2 Continue flicking the spring to create a continuous transverse wave. Can you see the peaks and troughs of the wave?

3 Make the wave have more or less energy by changing how hard you flick the end. Try to keep the speed of the wave the same.

4 Increase the number of waves per second. You have just modelled a wave of higher frequency.

5 Try to reduce the number of waves. This model represents a lower frequency wave.

6 Draw labelled diagrams of the waves you created, carefully indicating how the waves show that different wavelengths have been achieved.

Discussion

1 What is the link between frequency and the distance between the peaks of the wave?

2 What else in your world behaves as a transverse wave?

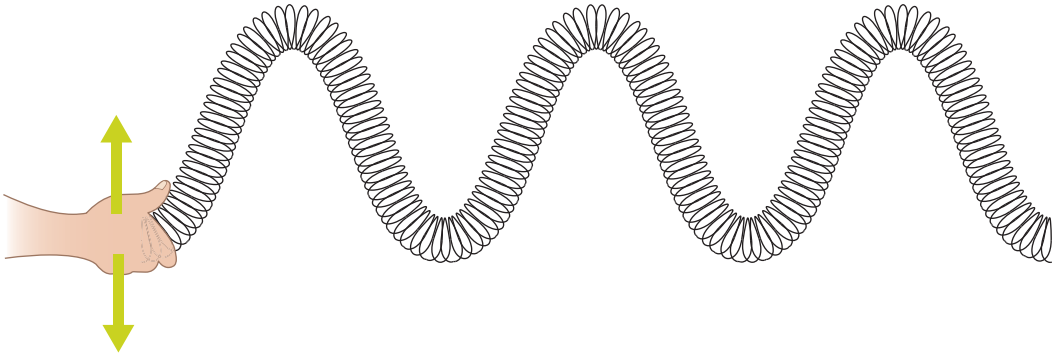


Figure 1 Flicking the slinky creates a pulse.

2.5b Using curved mirrors

CHALLENGE

Design brief

Investigate the behaviour of a convex mirror.

Risk assessment
2.5b Using curved mirrors

Lab tech notes
2.5b Using curved mirrors

CAUTION! Hodson light box is used with a power box which is connected to mains electricity. There is the possibility of an electric shock. Follow operational and safety instrutions. Keep clear of water.

What you need

- Convex mirror
- Concave mirror
- Power supply
- Pen
- Hodson light box

What to do

1 Place an object, such as a pen tip, close to the mirror and observe the image. Try to describe the nature of the image.
   - Is it upright or inverted (upside down)?
   - Is it larger (magnified) or smaller (reduced) than the object?
   - Is it real (capable of being captured on a screen or piece of paper) or virtual?

2 Move the object further from the mirror and repeat your observations.

3 Repeat step 1 with a concave mirror. It is possible to form a real image with a concave mirror and there is more variation in the nature of the image as the object is moved further from the mirror. Summarise your findings in a table that compares the two types of mirrors.

Figure 1 A curved mirror

4 Use the Hodson light box kit to investigate curved mirrors. There should be a convex and concave mirror in the kit. Use the three-slot former in the kit to draw diagrams of the incident and reflect rays for both types of curved mirror.

2.6a Bending of light

INVESTIGATION

Aim

To investigate the path of light rays during the process of refraction.

Risk assessment
2.6a Bending of light

Lab tech notes
2.6a Bending of light

CAUTION! Hodson light box is used with a power box which is connected to mains electricity. There is the possibility of an electric shock. Follow operational and safety instructions. Keep clear of water.

Materials

- Hodson light box kit
- Power supply
- Sheet of white A4 paper
- Perspex block from light box kit
- Blu Tack®
- Ruler
- Pencil
- Protractor

Method

1 Place the Perspex block in the centre of the A4 paper. Trace around the outside of the Perspex block with your pencil.

2 Remove the block and use the protractor to construct a normal at 90° to one of the long sides of the block.

3 Position the block on the paper again. Keep it in place with the Blu Tack®.

4 Set up the Hodson light box, darken the room and aim a single incident ray at the face of the block at the normal line. Does the light bend as it enters and then exits the block?

5 Move the light box so that the ray is aimed at the face of the block at an angle of approximately 45°. Mark the position of the incident ray and the ray that exits the block on the other side with pencil dots. Ignore any reflected rays at this time.

6 Remove the block and turn off the light box.

Results

1 Join the end of the incident ray to where it exits the block on the other side. Construct a normal to the face of the block where the ray exits.

2 Use the protractor to measure the four angles on your diagram. Line up the 0° line of the protractor along the normal each time and read the angles between the normal and incident rays and between the normal and the refracted rays. Record your results in two tables for refraction from air to Perspex and refraction from Perspex to air.

Discussion

1 Explain your observation when the incident light travelled along the normal.

2 Compare your angles of incidence to your angles of refraction as the light entered the Perspex block. Explain your observation.

3 Do your results support the rules of light passing from a less dense medium into a denser medium and vice versa? Explain your answers.

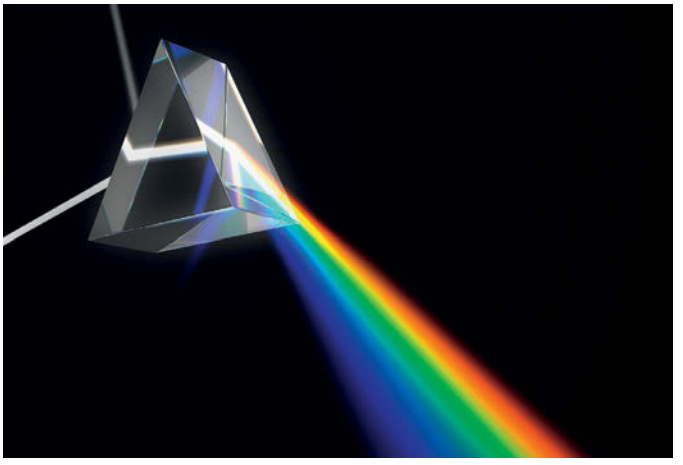


Figure 1 Light rays

4 List some sources of error in this investigation.

Conclusion

What do you know about the path of light rays during the process of refraction?

2.6b Creating images with convex lenses

INVESTIGATION

Aim

To investigate the behaviour of a convex lens and the nature of the image produced at different object–lens distances.

Risk assessment
2.6b Creating images with convex lenses

Lab tech notes
2.6b Creating images with convex lenses

CAUTION! Hodson light box is used with a power box which is connected to mains electricity. There is the possibility of an electric shock. Follow operational and safety instructions. Keep clear of water. Ensure lit matches and candles are extinguished. Ensure lit matches and candles are extinguished.

Materials

- Hodson light box kit
- Candle
- Matches
- Convex lens
- Power supply
- Lens holder
- Rulers (30 cm, 1 m)
- White paper screen
- Blu Tack®

Method

1 Determine the focal length of the lens by placing the lens on a piece of paper and shining three rays of light through it so the light converges into a single focal point. Measure the distance from the centre of the lens to the focal point. This is the focal length, *f*. Double the focal length. This is called 2*f*.

2 Light the candle. Mount the lens in the lens holder and check to see if the centre of the lens is in line with the candle flame. If not, raise it to the correct height.

3 Darken the room and position the lens at a distance of more than twice the focal length from the candle flame (the object). Try to capture an image on the paper screen by moving the screen slowly until a focused image of the candle is formed. Describe the size of the image compared to the object (magnified, same size or reduced), the type of image (real or virtual) and the orientation of the image (inverted or upright).

4 Move the lens closer to the candle so that the object–lens distance is between *f* and 2*f*. Repeat your observations.

5 Repeat for the other lens positions in Table 1. In some cases, the image may not form on the screen. Instead, it can be found by looking into the lens towards the candle flame. This will be a virtual image. In one case, there may be no image – real or virtual.

Results

Record your results in a table like Table 1 on the following page.

Discussion

1 When did the lens produce a real image and when did it produce a virtual image?

2 Try to explain any other observations you made or ask your teacher about them.

3 How do your results compare with those of other members of the class?

4 Can you suggest any changes to your method that might have improved your results?

Conclusion

What do you know about the behaviour of a convex lens and the images it produces?

Table 1 Observations from using a convex lens

Object–lens distance	Size of image	Type of image	Orientation of image	Any other observations
Larger than 2*f*				
Equal to 2*f*				
Between *f* and 2*f*				
Equal to *f*				
Less than *f*				

2.7 What colour is it?

INVESTIGATION

Aim

To investigate the addition of coloured light and explore the behaviour of coloured filters.

Risk assessment
2.7 What colour is it?

Lab tech notes
2.7 What colour is it?

CAUTION! Hodson light box is used with a power box which is connected to mains electricity. There is the possibility of an electric shock. Follow operational and safety instructions. Keep clear of water.

Materials

- Hodson light box kit
- Power supply
- Sheet of white paper

Method

1 Connect the light box to a power supply and place it on the sheet of paper.

2 Place the three primary filters (red, green and blue) in each of the three separate slotted sections in the light box. Adjust the mirror flaps so that the colours can overlap on the paper. Change the combination of filters, and complete Table 1.

Table 1 Colours from using primary filters

Addition of primary colours	Colour produced
Red + green + blue	
Red + blue	
Green + blue	
Red + green	

3 Replace one of the primary filters with the secondary filters (yellow, cyan and magenta), and complete Table 2.

Table 2 Colours from using secondary filters

Addition of colours	Colour produced
Yellow (side slot) + blue (front slot)	
Magenta (side slot) + green (front slot)	
Cyan (side slot) + red (front slot)	

4 Switch off the light box and remove the filters. Select a red, green, blue and yellow surface from the light box kit. Hold each of the coloured surfaces against the back of each primary filter. Record the colour that each surface appears, and complete Table 3.

Table 3 Colours of surfaces

Surface colour	Colour surface appears when viewed through a		
	Red filter	Green filter	Blue filter
Red			
Green			
Blue			
Yellow			

Discussion

1 What patterns did you observe in each of the tables? Explain the patterns you observed.

2 Name two possible sources of error in the investigation.

3 What difficulties did you have and how did you overcome them?

Conclusion

What do you know about what happens when coloured lights are added to each other?

2.8 What is the wavelength of a microwave?

INVESTIGATION

Aim

To determine the wavelength of a microwave.

Risk assessment
2.8 What is the wavelength of a microwave?

Lab tech notes
2.8 What is the wavelength of a microwave?

CAUTION! Allergy alert: Some students may be allergic to eggs. Ensure all traces of eggs are disposed of thoroughly. Teacher supervision is required while a microwave oven is being used.

Materials

- Microwave oven with the turntable removed
- Large flat plate at least 20 cm in diameter (safe for use in a microwave)
- Oven mitts
- Egg
- Ruler

Background

A microwave oven uses electromagnetic waves to heat food. These waves move through the cooking area in a set fashion. All microwave ovens have turntables to rotate food so that it cooks evenly. This is because of the wave-like motion of the energy. Without the turntable, the energy is focused in fixed parts of the oven.

You can use this to determine the wavelength of the microwaves in your microwave oven.

Figure 1 A microwave oven with the rotating platter removed and drive mechanism removed

Method

1 Crack the egg and separate the egg white from the egg yolk.

2 Spread the egg white evenly over the large flat plate.

3 Place the plate in the oven and turn on for 15–30 seconds (depending on the power of the microwave). The egg should start cooking in stripes or patches.

Figure 2 Using the cooked portions of the egg white to measure the distance between 'hot spots' in the microwave oven

4 Remove the plate from the microwave and identify the centre of the cooked stripes or patches. Measure the distance between two of the stripes.

5 Repeat this investigation several times and determine an average distance between the cooked egg white.

Results

1 Record all your observations in a table.

2 Multiply the average distance between the cooked egg white by 2 to determine the length of a full wavelength.

Discussion

1 What is the wavelength of the microwaves in your microwave oven?

2 How difficult was it to determine the centre of the cooked portion of egg? Can you determine the error margin of your calculation (± the width of the cooked egg bands)?

3 Why did you have to repeat your investigation several times?

Conclusion

Summarise what you have learnt about the length of microwaves.

3.1 Bringing graphs to life

CHALLENGE

Design brief

Working in pairs, act out the position–time graph in Figure 1.

Risk assessment
3.1 Bringing graphs to life

Lab tech notes
3.1 Bringing graphs to life

What you need

- Clear space (maybe outside)
- Tape measure
- Masking tape
- Marker pen

What to do

1 Lay out a 4-metre piece of masking tape on the floor and mark it at intervals of 1 metre.

2 Rehearse the motion shown in Figure 1 by discussing it with your group and even doing a walk-through rehearsal.

3 Start the stopwatch and try to match your motion to the graph. The person timing you will give you feedback on how you went.

4 Swap roles and repeat the activity until everyone in your group has had a turn.

5 Repeat the activity with another piece of masking tape on the floor going 4 metres in the opposite direction.

Discussion

1 How did your group perform in this task?

2 What difficulties did you have in demonstrating the motion?

3 Draw your own position–time graph and try to act out the motion. How did you go this time?

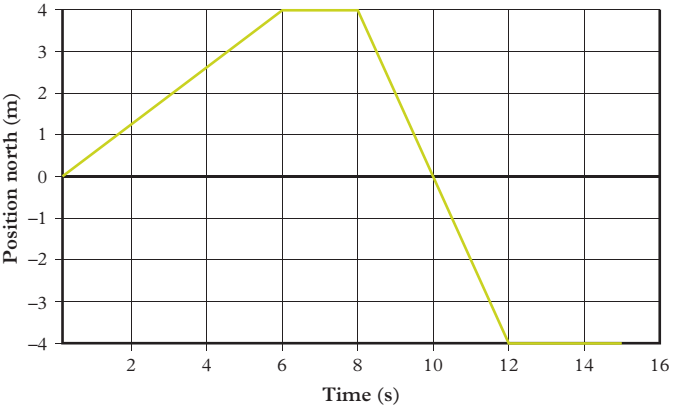


Figure 1 A position–time graph

3.2 The ticker timer

INVESTIGATION

Aim

To learn how a ticker timer operates and to use it to produce a speed–time graph.

Risk assessment
3.2 The ticker timer

Lab tech notes
3.2 The ticker timer

CAUTION! Ticker timers are used with a power box which is connected to mains electricity. There is the possibility of an electric shock. Follow operational and safety instructions. Keep clear of water.

Materials

- Ticker timer
- Scissors
- Power supply
- Graph paper
- 2 electrical wires
- Glue
- Ticker tape
- Carbon circles
- Ruler

Method

1 Connect the ticker timer to the AC terminals of the power supply using the two electrical wires (Figure 1).

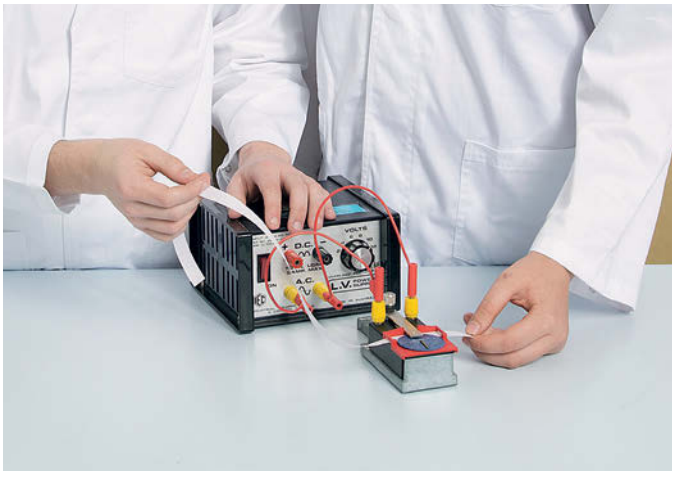


Figure 1 Connecting the ticker timer to the power supply

2 Thread a 30 cm length of ticker tape through the slots in the ticker timer. Turn on the power and pull the tape through the timer. Examine the tape to see if the dots are clear (Figure 2)

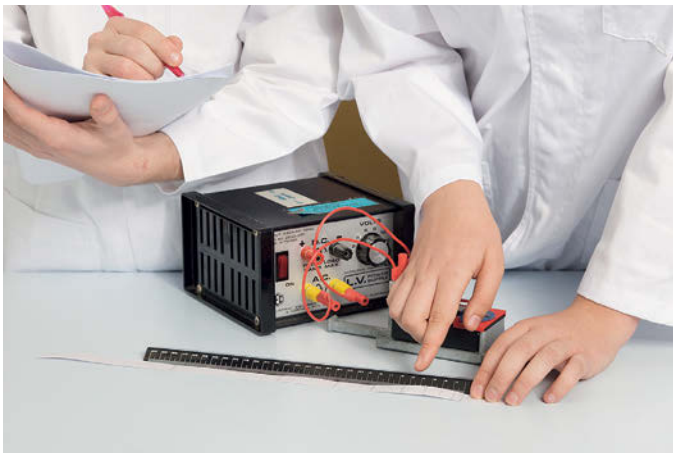


Figure 2 Checking the ticker tape

3 If the dots are too faint, adjust the equipment by increasing the voltage of the power supply. A new carbon disc may be required if this doesn't solve the problem. It can also help to loosen or tighten the screw holding the 'arm' of the ticker timer.

4 Repeat with a 1 m length of ticker tape. As you pull the ticker tape through, adjust your pulling speed so that there is a very slow section, a medium speed section and a very fast section, in any order.

Results

1 Start your analysis by finding the first clear dot. Number this dot '0'. Count along another five dots and rule a line right through the middle of the fifth dot. This gives a five-'gap' section of tape. The gap between successive dots is 0.02 seconds, so five gaps equals 5×0.02 or 0.1 seconds.

2 Divide the rest of your tape into five-gap sections by ruling lines through the middle of every fifth dot.

3 Number the sections of your tape and cut along the lines.

4 Glue each section of tape onto your graph paper, side by side, to form a column graph.

5 Add axes to your graph (speed on the *y*-axis and time on the *x*-axis) and work out a scale for each axis (see the hint below).

Discussion

1 Why does the length of each tape column indicate the speed?

2 How could you work out the average speed of each section? (Hint: Average speed = distance ÷ time)

3 Why is it only the 'average' speed?

4 Design another investigation you could do using a ticker timer. Ask your teacher for permission to carry out your investigation.

Conclusion

What information can you determine using a ticker timer?

3.2 Using a motion sensor

SKILLS LAB

Aim

To become familiar with the operation of a motion sensor and to use it to produce motion graphs.

Risk assessment
3.2 Using a motion sensor

Lab tech notes
3.2 Using a motion sensor

Materials

- Motion sensor
- Dynamics trolley
- Laptop computer

Method

1 Connect the laptop to the motion sensor and open the appropriate software for your motion sensor on the laptop.

2 Position the motion sensor several metres in front of the dynamics trolley and push the trolley towards the sensor. (You may need to attach a cardboard reflector to the front of the trolley to reflect the signal from the motion sensor back to the sensor.) Ensure the trolley does not contact the motion sensor.

Results

Analyse the data on the laptop to produce a position–time graph (and speed–time graph and even an acceleration–time graph, if possible).

Discussion

1 Can you work out what each graph is showing you?

2 How well did the graphs represent the actual motion of the trolley that you witnessed?

3 Design another investigation you could perform with the motion sensor.

4 Evaluate this investigation compared with Investigation 3.2a, in which you used the ticker timer. Which measuring instrument did you prefer and why?

Conclusion

What information do the graphs created by a motion sensor tell you?

3.3 Measuring acceleration by timing or using a motion sensor

CHALLENGE

Design brief

Complete the steps below to measure acceleration.

Risk assessment
3.3 Measuring acceleration by timing or using a motion sensor

Lab tech notes
3.3 Measuring acceleration by timing or using a motion sensor

CAUTION! Never drop objects from high places without looking below to make sure the area is clear. Never drop objects off buildings or bridges.

What you need

- Ball (e.g. tennis ball)
- Stopwatch
- Tape measure
- Motion sensor

What to do

1 Measure how long it takes to drop a ball from one storey in seconds (t).

2 Measure the distance the ball fell in metres (h).

3 For more accuracy, or as a comparison, you could use a motion sensor connected to a computer to measure the acceleration directly.

4 Use the results to determine the acceleration due to gravity in units of m/s^2. The formula that describes this situation is: $h = \frac{1}{2} at^2$

5 Rearrange the formula to make a (acceleration) the subject and substitute your values for h and t. The resulting value for a is the acceleration due to gravity (although it usually has the symbol g), which should be 9.8 m/s^2 near the Earth's surface, although we often round it off to 10 m/s^2 for calculations.
   - How close to 9.8 m/s^2 were your results?
   - Can you account for any differences?

6 *Challenge*: You may like to make several different measurements and plot them as a $h - t^2$ graph on your calculator. If you do a regression to fit the data, the gradient is h/t^2, which is $\frac{1}{2}g$. Double the gradient to get an average value for g.

Figure 1 A ball is required for this investigation.

3.4a Making an accelerometer

CHALLENGE

Design brief

Design an accelerometer.

Risk assessment
3.4a Making an accelerometer

Lab tech notes
3.4a Making an accelerometer

What you need

- Small glass jar and lid
- Paperclip
- Short length of cotton
- Sticky tape

What to do

1 Tie one end of the cotton to the paperclip.

2 Stick the other end of the cotton to the underside of the lid so the paperclip hangs vertically inside the jar without touching the bottom.

3 Fill the jar with water and screw the lid on.

4 Test your accelerometer by pushing it slowly along a table, then speed it up, move it at constant speed and finally slow it down.

5 Take your accelerometer with you in the car, bus or train, and observe the position of the cotton and paperclip when the vehicle:
   - starts moving
   - slows its movement
   - travels at constant speed in a straight line.

Discussion

1 Why does the paperclip resist moving when the jar starts moving?

2 Why does the paperclip keep moving forwards when the jar comes to a rest?

3 What happens to the paperclip when the jar is moving at a constant speed?

4 How do our own bodies tell us we are accelerating, decelerating or travelling around a corner?

3.5a Resultant forces

INVESTIGATION

Aim

To investigate the addition of vectors using three spring balances.

Risk assessment
3.5a Resultant forces

Lab tech notes
3.5a Resultant forces

Materials

- 3 spring balances (0–10 or 0–20 N are best)
- 2 rubber bands
- Graph paper
- Masking tape

Method

1 Test to see that each spring balance reads zero with no force exerted on its hook. (This is known as checking the 'calibration'.) If not, adjust it so it does.

2 Tape a piece of graph paper to the bench, and draw a large dot in the centre of the paper.

3 Tie one rubber band to the centre of the other to create three 'loops' with a knot in the centre.

4 Hook each spring balance onto the loops lying flat on the paper and position the knot so that it stays directly above the dot on the graph paper (Figure 1).

5 Pull on the spring balances in different directions so that the knot stays directly over the dot.

6 Record the force reading on each spring balance, and draw the direction of the force on the graph paper. This can be done by drawing a line directly below the rubber bands.

7 Repeat the investigation twice more using different-sized forces and different directions.

Results

1 Drawing a force diagram: Remove the graph paper and create a force diagram by choosing an appropriate scale (usually 1 cm = 1 N) and drawing the three forces acting from the dot in the correct directions. The forces are drawn as lines with arrowheads. The direction of the arrowhead shows the direction of the force. The length of each line should show the size of each force.

2 Drawing a vector diagram: To convert the force diagram into a vector diagram, leave one of the force arrows in position where it is, then 'slide' the other two force arrows so that all three join head to tail with each other. When all three forces are added, determine the net force by drawing a line from the start to the end and head-to-head and tail-to-tail. This shows the result of the three individual vectors, which should be very small or even non-existent if you did the investigation correctly.

Discussion

1 What is the difference between a force diagram and a vector diagram?

2 What does 'net force' mean?

Conclusion

What is the net force on a stationary object? Explain.

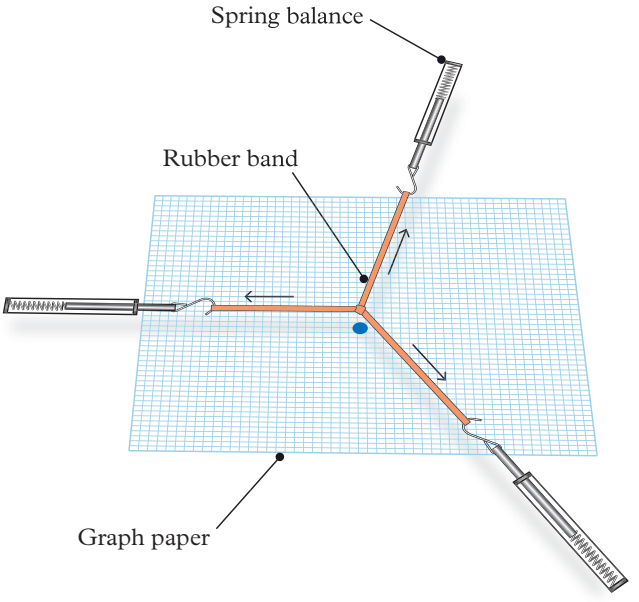


Figure 1 Investigational set-up

3.6 What if forces were changed on Newton's rocket?

INVESTIGATION

Aim

To examine the action and reaction of a balloon rocket.

Risk assessment
3.6 What if forces were changed on Newton's rocket?

Lab tech notes
3.6 What if forces were changed on Newton's rocket?

Materials

- Balloon
- Drinking straw
- Sticky tape
- Fishing line
- Timer
- Measuring tape

Method

1. Thread the fishing line through the straw.
2. Tie the ends of the fishing line to two fixed points across the room.
3. Inflate the balloon and hold it shut. Measure the diameter of the balloon.
4. Use the sticky tape to tape the inflated balloon to the straw.
5. Release the end of the balloon, and measure the distance the balloon travels and the time it takes to come to a complete stop.
6. Reinflate the balloon to the same diameter. Repeat step 5.
7. Determine the average speed of the balloon.

Inquiry

Choose one of the following questions to investigate.

- What if the amount of air in the balloon was increased?
- What if a string with more friction was used?

Answer the following questions with regard to your inquiry question.

- What is the independent variable?
- What is the dependent variable?
- List three variables you would need to control and how you will control them.
- Write a hypothesis for your investigation.
- Use force diagrams to explain the science behind your hypothesis.

Show your teacher your planning for approval.

Results

Record your results in an appropriate table.
Show your teacher your planning for approval.

Discussion

1. Why does the balloon move forwards?
2. Draw a picture of the balloon rocket with all the forces that are acting on it.
3. Describe the action and reaction that occurs in the balloon rocket.
4. How would you expect the average speed to change if the balloon was inflated less? Explain.

Conclusion

Describe how Newton's third law applies to your balloon rocket.

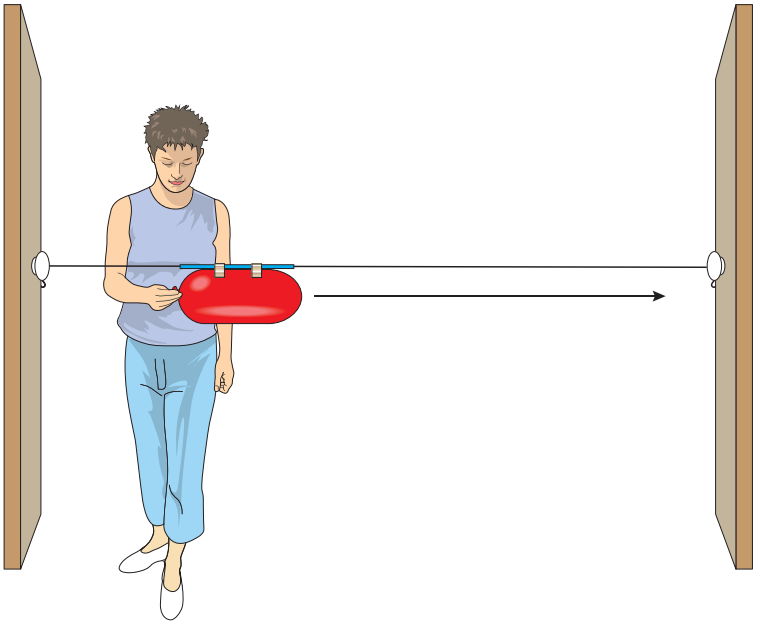


Figure 1 Investigational set-up

4.1 Making series and parallel circuits

SKILLS LAB

Find out how many different ways you can connect two globes in a circuit.

Risk assessment
4.1 Making series and parallel circuits

Lab tech notes
4.1 Making series and parallel circuits

What you need

- 2 × 1.2 V globes and holders
- 1.5 V battery and holder
- 8 connecting wires (with banana plugs or alligator clips)
- Switch
- Ammeter or multimeter

Figure 1 This investigation requires alligator clips.

What to do

1 Construct four circuits, placing the switch so that it controls:
   a both globes, with both either on or off at the same time
   b one globe only, with the other on all the time
   c the other globe only, with the first globe on all the time
   d both globes, with one globe on when the other is off and vice-versa.

   Follow step 2 before you disconnect each circuit.

2 Draw the circuit diagram to show where the switch was placed in each circuit.
   - What effect did the switch have in each case?

3 Connect an ammeter at different places in each circuit and measure the current at each point.
   - What did you find out?

4.2a Using Ohm's law to find resistance

SKILLS LAB

Risk assessment
4.2a Using Ohm's law to find resistance

Lab tech notes
4.2a Using Ohm's law to find resistance

Example

Find the value of a resistor that has a voltage drop of 6 V across it when a current of a 50 mA flows through it.

1 Check the units: 6 V is in volts and so can be used unchanged. 50 mA (milliamps) needs to be converted to amps. The prefix 'milli' means 0.001 (or $\times 10^{-3}$), so 50 mA = 50×0.001 or 0.05 A.

2 Use the Ohm's law triangle to find the correct formula. You want to find resistance so use your fingertip to cover the R – the other two letters show you the formula to use (see Figure 1). The V is over the I, so we use: $R = \frac{V}{I}$.

3 Substitute the numbers for V and I:

$$R = \frac{6}{0.05}$$

4 Do the calculation:

$$\frac{6}{0.05} = 120\ \Omega$$

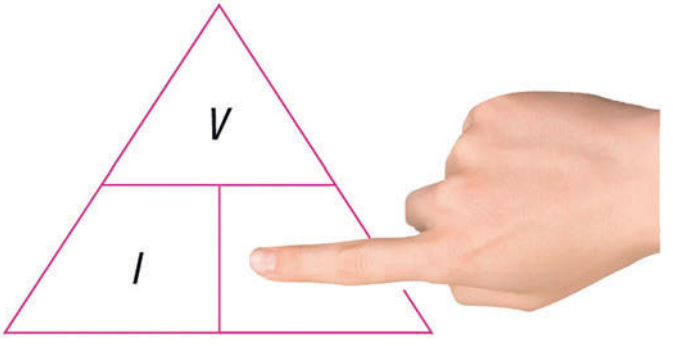


Figure 1 Using Ohm's law triangle

Your turn

1 This law can also be used to work out the voltage or the current. What is the voltage drop across a resistor with a value of 180 Ω and a current of 50 mA? (Remember to cover the V in the Ohm's law triangle to get the correct formula for R and I. If the letters are next to each other, then multiply.)

2 If a 12 V battery is placed in a circuit with a 470 Ω resistor, how much current will flow through the circuit?

3 If the current of a circuit with a 12 V battery is 0.004 A, what is the resistance of the circuit?

4.2b Understanding resistor colour codes

SKILLS LAB

Risk assessment
4.2b Understanding resistor colour codes

Lab tech notes
4.2b Understanding resistor colour codes

Carbon resistors typically have four colour-coded bands on their case. These bands are part of a code that allows you to work out their approximate value and tolerance. The fourth band is the tolerance band, which indicates the accuracy of the resistor. Gold means a 5% accuracy, silver means a 10% accuracy, and no fourth band means a 20% accuracy. The lower the percentage, the more accurate the resistor should be.

To read the three other bands put the tolerance band on the right and start at the other end. The first two bands form a two-digit number according to their colour (see Table 1). The third band tells you how many zeros to put after the number.

Look at the resistor in Figure 1. What does its code mean?

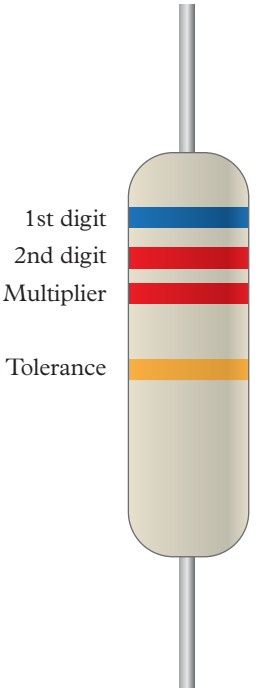


Figure 1 What is the value of this resistor?

1 The tolerance band is gold, so the resistor has 5% accuracy.

2 The first band is blue, so it has a value of 6.

3 The second band is red, so it has a value of 2. The number is 62.

4 The third band is also red, so this means 2 zeros need to be added to the number. The number is now 6200.

5 Resistor values are always coded in ohms, so the value of this resistor is 6200 ohms, or 6.2 kilo-ohms.

Table 1 Resistor colour codes

Colour	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

4.2 Investigating Ohm's law

INVESTIGATION

Aim

To investigate the voltage drop across and the current flow through a resistor, and hence calculate an average value of the resistance.

Risk assessment
4.2 Investigating Ohm's law

Lab tech notes
4.2 Investigating Ohm's law

CAUTION! A power box is connected to mains electricity. There is the possibility of an electric shock. Follow operational and safety instructions. Keep clear of water. Resistors may become hot when the power supply is turned on. Turn off the power box each time a resistor is put in or removed from the circuit.

Materials

- Power supply
- Ammeter
- Voltmeter
- 10 Ω resistor
- 3 other resistors with masking tape over their coloured bands
- Connecting wires

Method

1 Identify the 10 Ω resistor. It should be colour-coded brown, black, black.

2 Connect the circuit as shown in Figure 1. Use the DC terminals of the power supply and start with the dial on 2 V.

3 Switch on the power supply, take the readings on the ammeter and voltmeter, and switch the power off again straight away (so you don't overheat the resistor).

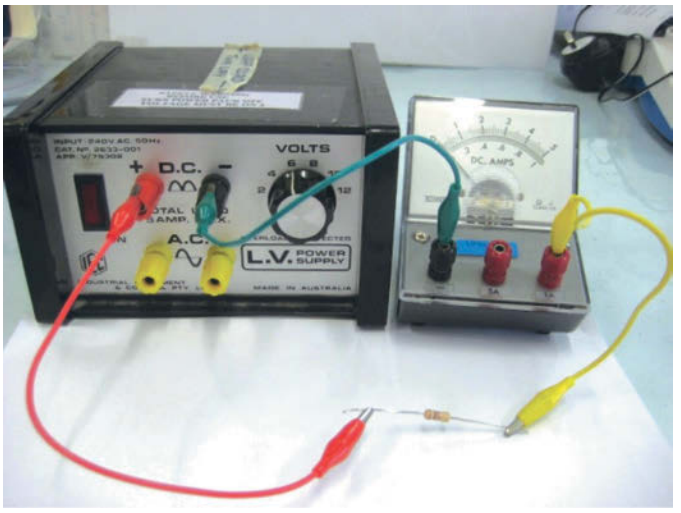


Figure 1 Circuit set-up

4 Change the dial on the power supply to 4 V and repeat step 3. Then change the dial to 6 V and repeat.

Table 1 Results

Resistor	Voltage (V)	Current (mA)	Volts ÷ amps

5 Complete Table 1.

6 Repeat the investigation for the other three resistors, without reading their coloured bands.

7 Complete the results table for each of the three masked resistors and calculate their resistance.

8 Remove the masking tape and determine the resistance values from the coloured bands of the resistors.

Results

Include your results table.

Discussion

1 From your results table, what can you say about the values in the last column?

2 What quantity does the last column calculate?

3 For the three masked resistors, how close were the values you obtained to those marked on their coloured bands?

4 Can you write the difference as a percentage of the average?

5 Which value – the one obtained by reading the coloured bands or the one obtained from your calculations – gives the most accurate measure of a resistor's resistance? Explain your answer.

Conclusion

What do you know about Ohm's law?

5.1 Conservation in action

CHALLENGE

Design brief

Analysis of a simple pendulum shows that it follows a similar pattern to dropping a mass.

Risk assessment
5.1 Conservation in action

Lab tech notes
5.1 Conservation in action

What you need

- Simple pendulum made from a mass on the end of a length of string
- Retort stand

What to do

1 Hang the simple pendulum from the retort stand (Figure 1).

2 Lift up the mass and release it. As it swings, its GPE is converted into KE and back into GPE. The process continues until the pendulum finally comes to rest.

3 Measure how much GPE the pendulum mass had at the start before it was released by measuring its mass and starting height above the bench and using the GPE formula.

4 Allow the pendulum to complete 10 full swings (the release point is swing 0) and stop it at the end of its 10th swing. Hold the weight at the finishing height.

5 Remeasure the finishing height and determine how much energy was 'lost' to air friction each swing (divide by 10 swings).

6 Work out the energy efficiency of the pendulum. Set out your calculations clearly and accurately.

Figure 1 Setting up your apparatus correctly is an important aspect of working scientifically.

5.3 Designing an energy-efficient house

CHALLENGE

Design brief

Design and build two identical houses out of cardboard or wood.

Risk assessment
5.3 Designing an energy-efficient house

Lab tech notes
5.3 Designing an energy-efficient house

Add a feature to one of the houses that will make it more efficient in staying cool. Test your design feature by exposing both houses to an energy source (a strong light) and determine the rate of temperature increase for each house.

Criteria restrictions

- Only one feature may be added to the second house.
- The feature must represent a design feature that is currently available to homeowners.
- The feature must be proportionate in size to the house.

Questioning and predicting

- Which feature will you add?
- What materials will you use?
- Why do you think your added feature will keep the house cool?

Planning and conducting

- How will you measure the temperature of the two houses?
- How long will you expose the houses to the energy source?

Processing and analysing

1 Describe the rate of temperature increase in both houses.

2 How successful was your feature?

3 What were the limitations of your design?

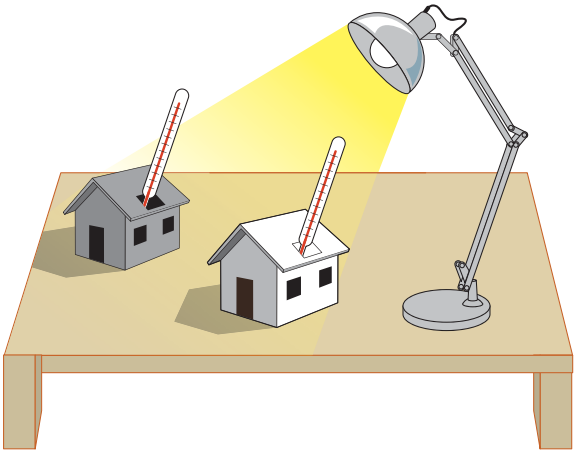


Figure 1 General set-up of investigation

4 Would it be possible to create a large-scale version of your design for a real house?

5 If you were doing this investigation again, how would you modify your device? Explain.

Communicating

Present the various stages of your investigation in a formal investigational report.

6.4a Understanding parallax

CHALLENGE

Design brief

Complete the steps below to understand parallax.

Risk assessment
6.4a Understanding parallax

Lab tech notes
6.4a Understanding parallax

What you need

- Whiteboard
- Whiteboard marker

What to do

1 Position a student in front of the class and approximately 2–4 metres in front of the whiteboard (if possible).

2 Write a series of numbers across the whiteboard at the same height as the student.

3 Ask each member of the class to decide which number is in line with the student.
   - Why do most members of the class see a different alignment of the student and the numbers on the whiteboard?
   - Relate this activity to the night sky. What do the numbers represent? What does the student represent? What do the members of the class represent?
   - How would the results of this demonstration be different if the student stood approximately 30 cm in front of the whiteboard?

6.4b Calculating the distance to the Sun

INVESTIGATION

Aim

To determine a value for the distance from the Earth to the Sun using a pinhole screen and compare this with the known value.

Risk assessment
6.4b Calculating the distance to the Sun

Lab tech notes
6.4b Calculating the distance to the Sun

Materials

- Metre ruler
- Retort stand (about 76 cm in height)
- Clamp
- Coat hanger
- Sticky tape
- Needle or pin
- 2 × A4 sheets of paper
- Calculator
- Sun visible in the sky

Theory

This investigation uses ratios to determine the distance from the Earth to the Sun. If you know the distance from the pinhole to the image of the Sun, the diameter of the Sun's image and the diameter of the Sun, you can calculate the unknown – the distance to the Sun.

You will use the following symbols:

- length from pinhole to Sun's image, L_i
- distance to the Sun, L_S
- diameter of Sun's image, d_i
- diameter of the Sun, d_S

You can write an equation using these four quantities. Try writing this equation or ask your teacher for help. It can be written in either fraction or ratio form.

Method

1. Wrap a sheet of A4 paper around the coat hanger and tape securely into place to form a screen.
2. Make a tiny pin hole in the centre of the screen covering the coat hanger.
3. In the centre of the other sheet of paper, draw two lines approximately 7 mm apart and measure the distance as accurately as possible. It doesn't matter if they are not 7 mm apart, but measure them as carefully as possible and record this value.
4. Tape the A4 paper with the two lines to the top of the base of the retort stand, making sure that the two lines are centred on the base horizontally.
5. Clamp the pinhole screen horizontally so it is facing the screen on the base of the stand and is about 40 cm away from the base.
6. Go outside and point the screen with the pinhole at the Sun. Adjust the position of the pinhole screen along the rod so that the circle of light from the Sun through the pinhole falls exactly between the two lines you drew on the base of the retort stand. The circle of light has to also fill the two lines by just touching both lines.

Figure 1 The Earth and the Sun

Results

1. Measure and record the distance between the two lines on the screen. This is d_i in the equation.
2. Measure and record the distance between the two screens in millimetres. This is L_i in the equation.
3. The accepted value of the diameter of the Sun, d_S, is 1 392 000 km.
4. Use the equation to perform a calculation based on the measurements to determine a value for L_S.

Discussion

1. The correct value for the distance to the Sun is approximately 149 600 000 km. Work out the difference between L_S and this value. Call this value the difference.
2. Divide the difference by the correct value and multiply by 100. This converts it to a percentage and is called the percentage error. Round it off to the nearest whole number.
3. What factors contributed to this error? (Hint: Which measurements were not exact?)

Conclusion

Write a conclusion for this investigation that relates the findings to the aim. Mention the size of the percentage error and comment about how the investigation could have been modified to reduce the errors.

6.6 The expanding universe

CHALLENGE

Design brief

Consider how the universe expands using the following steps.

Risk assessment
6.6 The expanding universe

Lab tech notes
6.6 The expanding universe

What you need

- Balloon
- Permanent marker
- Tape measure

What to do

1 Use the ruler to mark three crosses on the side of the balloon 1 cm apart. Mark the centre cross as the origin (O).

2 Inflate the balloon. Measure the distance of each cross from the origin (O).

Discussion

1 How far has each cross moved?

2 Predict what would happen to the distance between the crosses if you added more air into the balloon.

3 Relate the movement of the crosses to the expansion of the universe.

7.1a Reconstructing Pangaea

CHALLENGE

Design brief

Using a photocopy of a world map, reconstruct Pangaea.

Risk assessment
7.1a Reconstructing Pangaea

Lab tech notes
7.1a Reconstructing Pangaea

What you need

- Photocopy of a map of the world
- Scissors
- Glue

What to do

1 Roughly cut out the continents of the world and fit them back together in the shape of Pangaea.

2 Remember to cut off India from Asia because it was once separated.

3 When you are happy with your supercontinent, glue the pieces into your science book.

4 You may like to add to your supercontinent what you know about the locations of the fossil and glacier evidence.

Discussion

1 Fossil twigs, roots and pollen found in Antarctica are almost identical to those found in Tasmania. Can you provide an explanation for this?

2 Name one other country that may have fossils that are similar to those found in Australia.

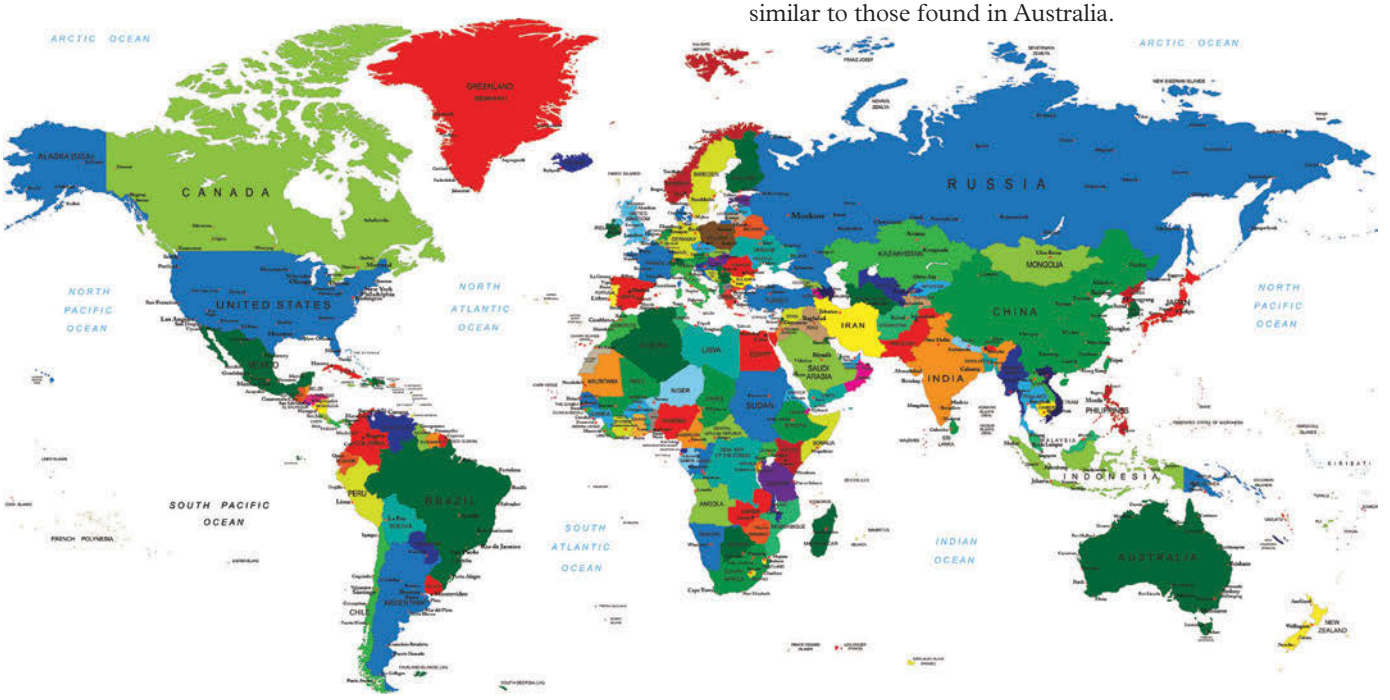


Figure 1 A world map is required for this investigation.

7.3 Chocolate plates

CHALLENGE

Design brief

Create a simulation of tectonic plates.

Risk assessment 7.3 Chocolate plates

Lab tech notes 7.3 Chocolate plates

CAUTION! Do not eat or drink in the laboratory. Allergy alert: don't use chocolate containing nuts.

What you need

- Chocolate bar (such as Mars® Bar or Milky Way®)
- Spatula

What to do

1. Wash your hands before starting this activity.
2. Use a clean spatula to cut the chocolate bar in half lengthways.
3. To illustrate a transform boundary, gently push the 'plates' back together, then slide one half of the chocolate bar forwards and the other backwards. Describe what happens.
4. To illustrate the force of compression associated with mountain building when continental plates collide, push on both sides of the chocolate bar to squeeze it together. What do you notice about the plates now?

Figure 1 Cut the chocolate bar along the length rather than in half as this image shows.

Discussion

1. Was there any vertical movement of the top chocolate crust of the bar when you modelled a transform boundary?
2. Describe what happened to the top chocolate crust of the bar when you modelled a convergent boundary.
3. How would you model a divergent boundary?

7.4 Volcanic bubbles

CHALLENGE

Design brief

Create volcanic bubbles.

Risk assessment 7.4 Volcanic bubbles

Lab tech notes 7.4 Volcanic bubbles

What you need

- Powdered chalk
- Vinegar
- large tray
- beaker
- spatula
- Red food dye
- Bottle of lemonade

What to do

1. Using a spatula mix a small amount of powdered chalk in a beaker with one teaspoon of vinegar and a few drops of food dye. The reaction produces carbon dioxide bubbles, and the food dye makes the froth look like lava.
2. Tiny gas bubbles form as the pressure in a bottle of lemonade is released. As the pressure is released more, bigger bubbles form. This can be seen by placing a bottle of lemonade on a large tray or in a sink and slightly twisting the screw top. The more you twist the lid, and the more pressure that is released, the bigger the bubbles. This is like the cooling of magma inside a volcano.

Figure 1 Gas bubbles formed the holes in this piece of pumice rock.

Discussion

1. What happens to the bubbles in a lemonade bottle when the pressure is released?
2. How is this similar to a volcano?

8.2 Modelling a carbon sink

CHALLENGE

Design brief

This activity may be demonstrated by your teacher.

Risk assessment
8.2 Modelling a carbon sink

Lab tech notes
8.2 Modelling a carbon sink

CAUTION! Dry ice is frozen carbon dioxide (–79°C). Do not touch the dry ice with your fingers or metal objects. Use wooden or plastic tongs. Do not seal dry ice in any container as the gas expands rapidly.

What you need

- Dry ice
- 100 mL water
- Universal indicator
- 200 mL beaker
- Piece of netting
- Watch glass that covers the top of the beaker
- Sticky tape

What to do

1 Place the water in the beaker.

2 Add 5 drops of universal indicator to the water.

3 Place the netting over the top of the beaker and push down the centre slightly. This will provide a pouch to suspend the dry ice above the water. Use sticky tape to hold the netting in place.

4 Place a piece of dry ice in the netting and place the watch glass over the top of the beaker.

5 Observe any colour changes in the water.

Discussion

1 What happened to the solid dry ice?

2 Describe any changes you noticed in the water.

3 What was the final pH of the water?

4 Provide an explanation for the changes you noticed.

5 What is a carbon sink?

6 How could you use this demonstration to explain the consequences of increased carbon dioxide levels in the atmosphere?

8.3 Making a simple barometer

CHALLENGE

Design brief

Explore how a barometer works using the following steps.

Risk assessment
8.3 Making a simple barometer

Lab tech notes
8.3 Making a simple barometer

What you need

- Glass jar
- Rubber balloon
- Rubber band
- Straw
- Sticky tape
- Sheet of thick paper with a scale marked on it

What to do

1 Cut a section from the balloon large enough to cover the opening of the jar.

2 Secure the rubber balloon over the jar with the rubber band.

3 Tape the straw onto the balloon.

4 Place the paper with the scale near the end of the straw and mark on the scale where the straw is.

5 Check the position of the straw on the scale over a few days. Mark each position of the straw (Figure 1).

Discussion

1 What happened to the rubber balloon as the outside air pressure changed?

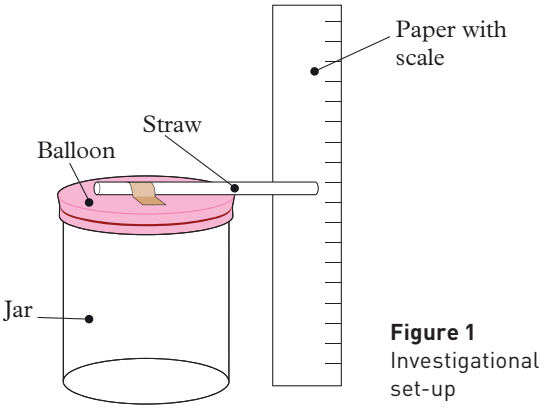


Figure 1 Investigational set-up

2 What happened to the position of the straw against the scale? Why was this?

3 Use the particle model of air to explain why the rubber balloon gets pushed in or out of the jar by the surrounding air.

4 This 'barometer' will also respond to changes in temperature in addition to changes in air pressure. Explain why.

8.3 Making your own clouds

INVESTIGATION

Aim

To simulate the process of condensation.

Risk assessment
8.3 Making your own clouds

Lab tech notes
8.3 Making your own clouds

CAUTION! Wear safety glasses, lab coat and tie long hair back, when using a Bunsen burner. Allow all hot equipment to cool before handling.

Materials

- Ice cubes
- Water
- Bench mat
- Tripod
- 250 mL beaker
- Gauze mat
- Evaporating dish
- Matches
- Bunsen burner
- Safety glasses

Method

1 Set up the apparatus as shown in Figure 1 (except the evaporating dish and ice).

2 Heat the water in the beaker until it boils.

3 Turn the gas off and place an ice-filled evaporating dish on top of the beaker.

4 Carefully observe what happens.

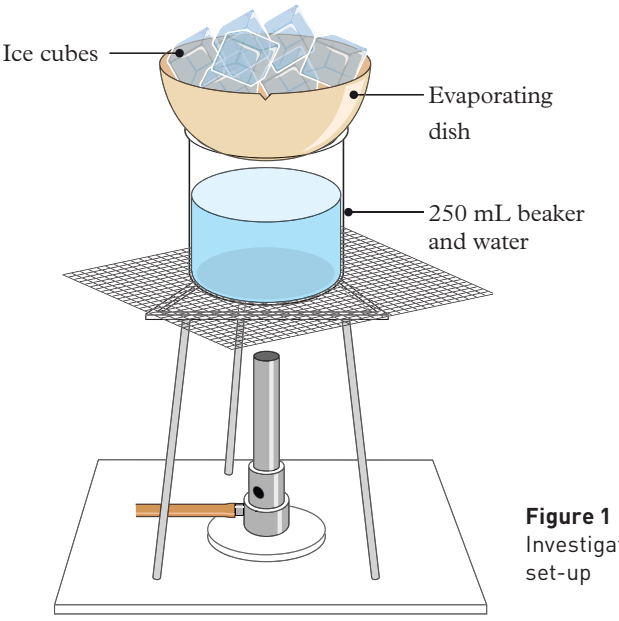


Figure 1 Investigational set-up

Results

Include your observations in an appropriate format.

Discussion

1 What action produced water vapour?

2 What happened to the water vapour?

3 In which of the Earth's spheres would you find water vapour?

4 Why is the condensation of water important to the biosphere?

Conclusion

What do you know about the importance of water condensation in the Earth's spheres?

8.4 Testing phosphorus

INVESTIGATION

Aim

To determine if phosphorus is present in a variety of detergents.

Risk assessment
8.4 Testing phosphorus

Lab tech notes
8.4 Testing phosphorus

CAUTION! If chemicals are used in the phosphorus testing kit, look up the SDS warnings for those chemicals.

Materials

- Variety of detergents
- Phosphorus testing kit
- Test tubes and test-tube rack
- Measuring cylinder

Method

1 Add 9 mL of distilled water to a test tube.

2 Add 1 mL of detergent to the test tube.

3 Follow the instructions of the phosphorus testing kit to determine if there is phosphorus present in the detergent.

4 Repeat steps 1–3 with the remaining detergents.

Results

Record your observations in an appropriate table.

Discussion

1 What detergents contained phosphorus?

2 Why do living organisms need phosphorus?

3 Why are high levels of phosphorus in waterways a problem?

4 Check the labels on the detergents in your home. What phosphorus-containing detergents do you use regularly?

Conclusion

What do you know about the phosphorus cycle?

8.6a What factors affect a greenhouse?

INVESTIGATION

Aim

To determine which surfaces of the Earth absorb energy and radiate it as heat and so are likely to contribute most to the warming of the atmosphere.

Risk assessment
8.6a What factors affect a greenhouse?

Lab tech notes
8.6a What factors affect a greenhouse?

CAUTION! Potting mix may contain pathogenic organisms. Read manufacturers warning labels. Avoid breathing. Wear dust mask and gloves. Perlite is used in gardening. Avoid breathing. Wear dust mask, safety glasses and gloves. May irritate eyes.

Materials

- timer
- 3 cups of dark soil
- 3 cups of white sand or perlite
- White paint and brush or white paper and sticky tape
- Water
- 6 identical clear, empty 600 mL soft-drink bottles with labels removed
- 6 one-hole rubber stoppers with thermometers inserted that fit securely into the bottle top or data-logging equipment using long steel temperature probes with Blu Tack® to secure the probe in place
- 6 plastic containers at least 11.5 cm in diameter at the top (e.g. margarine containers)
- Funnel
- Sunlight or one 150 W floodlight bulb
- Portable reflector lamp
- Stand to support the lamp set-up (retort stand and clamps)

Method

1 Work as a group and label the bottles A, B, C, D, E and F. Paint the upper one-third of the bottles B, D and F white to represent cloud cover. Allow paint to dry. Cover bottle with white paper if paint not available.

2 Use a funnel to fill the base of bottles A and B with dark soil, bottles C and D with white sand or perlite, and bottles E and F with room-temperature water. Ensure that you use the same depth (5–7 cm) in each bottle.

3 Put the thermometers inserted in the rubber stoppers into the bottle tops. Ensure that the bulbs are just above the top of the dirt, water and perlite or sand. If the bulbs are below the base, they may record the heat absorbed directly by the soil or water, which will affect your data. You want to measure the temperature of the air (atmospheric). If using a data-logger temperature probe, secure and seal it into the top of the bottle with Blu Tack®.

4 Record the initial baseline atmospheric temperature of each bottle in a table.

5 If it is a sunny day, take your bottles outside and record the temperatures of each bottle in a table, every 2 minutes for at least 20 minutes. Alternatively, set up the 150 W light source on a stand, facing down. Place the bottles underneath the light source approximately 15 cm away from the lamp. It is important that all bottles receive equal light. Depending on your light source, you may be only able to do two bottles at a time. If this is the case, ensure the two bottles have the same base; for example, dirt.

Results

1 Predict which bottle will get hottest and justify your prediction.

2 Complete a table with your observations.

3 Draw a graph of time (in minutes) versus temperature to record your observations.

Discussion

1 Compare the graphs for the different bottles. Describe the differences. What do these graphs indicate?

2 Which situation produced the lowest temperature? Which situation would lead to the least heating of the atmosphere?

3 Suggest some possible explanations for your results.

4 Explain how this investigation demonstrates the effect of the oceans and dark and light surfaces on air temperature.

5 If the deserts are increasing and ice is melting, exposing dark soil, what effects would you expect these changes to have on atmospheric temperature?

Conclusion

Summarise your key findings from this investigation.

8.6b Melting ice and its effect on sea levels

INVESTIGATION

Aim

To observe the effect of melting sea and sheet ice on global sea levels.

Risk assessment
8.6b Melting ice and its effect on sea levels

Lab tech notes
8.6b Melting ice and its effect on sea levels

PART A: SEA ICE

Sea ice is floating ice, like the ice found in icebergs. Design an investigation that shows the effects of melting sea ice on water level (e.g. an ice cube floating on water).

PART B: SHEET ICE

Sheet ice is ice resting on land. Approximately 98% of Antarctica is covered by sheet ice and the Antarctic ice sheet is one of two polar ice sheets. Design an investigation that shows the effects of a melting ice sheet on water level (e.g. an ice cube resting on clay).

Results

Present your results for each investigation in an appropriate format.

Discussion

1 How did the water level change as the sea ice melted?

2 How did the water level change as the sheet ice melted?

3 Provide an explanation for any differences you observed.

Conclusion

Will melting sea ice or melting sheet ice have the greater effect on sea levels? Why?

8.7 Salt water density

CHALLENGE

Design brief

Consider what density is.

Risk assessment
8.7 Salt water density

Lab tech notes
8.7 Salt water density

What you need

- Salt
- Water
- Measuring spoons
- Food colouring (4 different colours)
- Test tube and test-tube rack
- 4 × 200 mL beakers
- Pipette

What to do

1 Add 150 mL of water to each beaker. Label the beakers 1–4.

2 Add 1 teaspoon of salt to beaker 2 and mix thoroughly.

3 Add 2 teaspoons of salt to beaker 3 and mix thoroughly.

4 Add 3 teaspoons of salt to beaker 4 and mix thoroughly.

5 Add a different food colour to each beaker of salt and water.

6 Use the pipette to add 2 cm of salty water from beaker 4 to the bottom of the test tube.

7 Carefully use the pipette to add 2 cm of the salty water from beaker 3 so that it runs down the sides of the test tube. Be careful not to mix the two solutions.

8 Repeat the previous step with beaker 2 and then beaker 1 so that you achieve a test tube with different coloured layers.

Figure 1 This investigations requires food colouring.

Discussion

1 What is density?

2 Which is denser: the solution in beaker 1 or the solution in beaker 4? Provide evidence from your results to support your answer.

3 Relate your results to the movement of water in ocean currents.

9.2 Testing your senses

CHALLENGE

Design brief

See how your reflexes work by observing your reactions to very warm and cold.

Risk assessment
9.2 Testing your senses

Lab tech notes
9.2 Testing your senses

CAUTION! Knives and scalpels are very sharp. Always cut away from hands.

PART A: TEMPERATURE RECEPTORS

What you need

- Very warm water
- Room-temperature water
- Timer
- Paper Towel
- Ice cubes
- 3 ice-cream containers
- Thermometer

What to do

1. Half-fill one container with cold water and add the ice cubes.
2. Half-fill the second container with room-temperature water.
3. Half-fill the last container with very warm water. Use a thermometer to check the temperature is no hotter than 60 (degrees) Celsius.
4. Place one hand in the ice water and the other in the very warm water for 2 minutes.
5. Remove both hands from the water and place them in the room-temperature water.

Discussion

1. What was the stimulus for the hand in very warm water?
2. What change did the hand detect when it moved from the ice water to the room-temperature water?
3. Is there a set temperature that acts as a stimulus for your hand?
4. Why do scientists use a thermometer rather than their hands to test the temperature of solutions?

PART B: TOUCH RECEPTORS

What you need

- 2 toothpicks
- Ruler
- Plasticine® or playdough
- Blindfold

What to do

1. Work in pairs. One person puts on the blindfold.
2. Place the toothpicks 50 mm apart in the Plasticine®.
3. Using the Plasticine®, gently place the pointed ends of the toothpicks on the blindfolded person's finger. Ask them whether they feel one or two points.
4. If two points are felt, move the toothpicks closer together and repeat step 3.
5. Repeat steps 3 and 4 until the blindfolded person reports 'one point' for the first time.
6. Record your results in a table.
7. Repeat this procedure for the palm of the hand, back of the hand and forearm.

Discussion

1. Are the 'two point' distances the same on different areas of the skin?
2. Which part of the body was best at detecting when two close points are touching it?
3. Which skin areas do you think have more touch receptors? Use your results to support your answer.

Figure 1 This investigation requires Plasticine®.

9.3 Sheep brain dissection

SKILLS LAB

Aim

To explore the structure of a sheep's brain.

Risk assessment
9.3 Sheep brain dissection

Lab tech notes
9.3 Sheep brain dissection

CAUTION! Wear your lab coat, safety glasses and plastic gloves. Be careful with the scalpel because it is likely to be very sharp.

Material

- Sheep's brain
- Dissecting board
- Scalpel
- Newspaper
- Forceps
- Dissecting scissors
- Coloured pins
- Microscope, slide and cover slip (optional)

Method

1 Place newspaper on dissecting board.

2 Examine the outside of the brain. Set the brain down so that the flatter side, with the white spinal cord at one end, rests on the board. Using the different coloured pins, identify the two hemispheres, the four lobes of the brain, the spinal cord, the cerebellum and the cerebrum. Check this with your teacher before continuing.

Figure 1 Step 2 of the method

3 Remove the pins, then the brain over. Identify the medulla and pons.

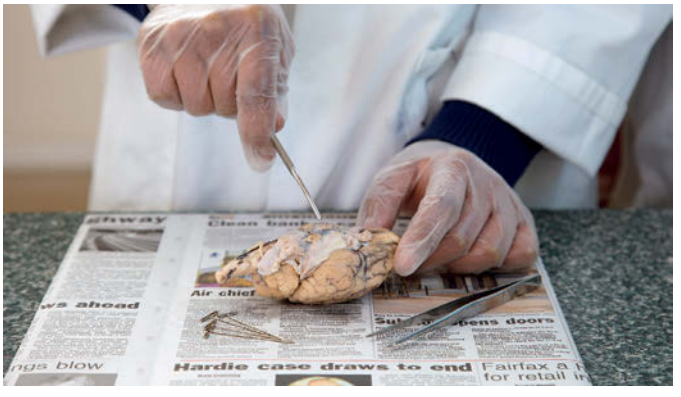


Figure 2 Step 3 of the method

4 Place the brain with the curved top side of the cerebrum facing up. Use a scalpel to slice through the brain along the centre line, starting at the cerebrum and going down through the cerebellum, spinal cord, medulla and pons. Separate the two hemispheres of the brain. Record what you see.

Figure 3 Step 4 of the method

5 Cut one of the hemispheres in half lengthwise. Record what you see.

Figure 4 Step 5 of the method

6 If a microscope is available, slice a very thin section of the cerebrum and put it on a slide, covering it with a drop of water and a cover slip. Draw what you see at two magnifications. Follow the same procedure with a section of the cerebellum, and then compare and contrast the two.

7 Carefully place scalpel and other dissecting tools into a container. Clean up your bench by wrapping the brain and gloves in the newspaper. Wash your hands.

Discussion

1 Was the sheep's brain similar to a human brain in structure? Why do you think this is so?

2 What does the brain feel like? Was it easy to dissect?

9.4 Pipe cleaner neurons

CHALLENGE

Design brief

Build your own neuron out of pipe cleaners.

Risk assessment
9.4 Pipe cleaner neurons

Lab tech notes
9.4 Pipe cleaner neurons

What you need

- 5 different coloured pipe cleaners representing different parts of the neuron (cell body, axon, dendrites, myelin sheath, synaptic terminal)
- A3 or A4 paper
- Sticky tape
- Red felt-tipped pen

What to do

1 Roll a pipe cleaner into a ball to make the cell body.

2 Attach another pipe cleaner to the cell body by pushing it through the ball so that there are two halves sticking out. Twist the two halves together into a single long axon.

3 Push another pipe cleaner through the cell body on the side opposite the axon. This can be shorter than the axon, and you can twist more pipe cleaners to make more dendrites.

4 Wrap a pipe cleaner along the length of the axon to form the myelin sheath.

5 Wrap another pipe cleaner on the end of the axon to make the synaptic terminal.

6 Tape your finished pipe cleaner neuron onto a piece of A3 or A4 paper and label the parts.

7 Mark the path of the nerve impulse, from start to finish, along the neuron.

9.5a How fast is the nervous system?

CHALLENGE

Design brief

Observe how fast the nervous system responses are.

Risk assessment
9.5a How fast is the nervous system?

Lab tech notes
9.5a How fast is the nervous system?

What you need

- Metre ruler
- Blindfold

What to do

1 Work in pairs. One student holds the ruler between their thumb and forefinger so that the ruler hangs with the zero mark at the bottom. The other student needs to wait with their thumb and forefinger at the bottom of the ruler, level with the zero mark.

2 The first student drops the ruler without warning. The other student catches the ruler as fast as they can between their thumb and forefinger.

3 Record the number of centimetres the ruler has dropped by looking at the location of the second student's thumb and forefinger on the ruler (Figure 1).

4 Repeat until you have 10 results for each student.

5 Work out the average reaction distance for each student.

6 Measure the approximate distance the messages must have travelled if they travelled from your eyes to your brain to your fingers.

7 Blindfold one student to try the investigation using touch. Tap the person on the head when you drop the ruler. Does this make a difference to the reaction distance?

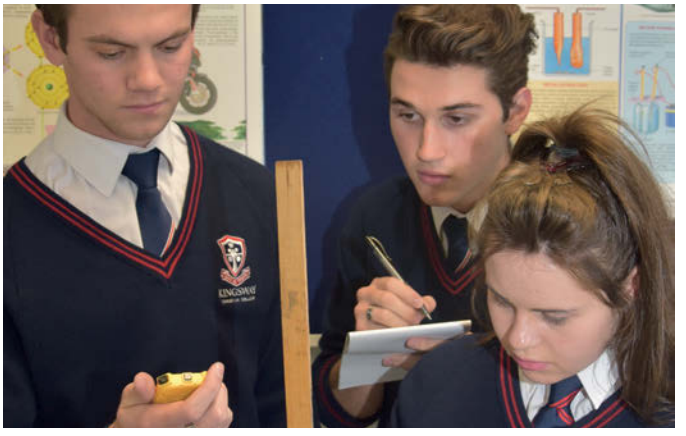


Figure 1 Testing responses

8 Blindfold one student to try the investigation using hearing. Say 'now' when you drop the ruler. Does this make a difference to the reaction distance?

Discussion

1 Which investigation had the fastest results? Why might this be?

2 How could you make sure the results are as accurate as possible?

3 Do you think this is a 'fair test'? Why or why not?

9.6 Glands and organs of the endocrine system

CHALLENGE

Design brief

In pairs, consider the glands and organs of the endocrine system.

Risk assessment
9.6 Glands and organs of the endocrine system

Lab tech notes
9.6 Glands and organs of the endocrine system

What you need

- Large sheet of butcher's paper
- Felt-tipped pen
- Sticky tape

What to do

1 Working in pairs, draw an outline of your partner's body onto the paper.

2 With your partner, draw in the different glands and organs of the endocrine system. Using the information in Table 1 (page 162), annotate each gland with a brief description, in your own words, of what it is responsible for.

3 Use colour coding and arrows to show the path of the hormone(s) produced by each gland to its target organ.

4 Choose one gland or organ to research. Include:
- the hormone it secretes
- what the hormone does
- disorders related to this organ or gland.

9.7 Experiencing homeostasis

INVESTIGATION

Aim

To demonstrate how homeostasis maintains control of the heart rate during and after exercise.

Risk assessment
9.7 Experiencing homeostasis

Lab tech notes
9.7 Experiencing homeostasis

CAUTION! Cease exercise if you have difficulty breathing and tell your teacher.

Materials

- Stopwatch
- Heart rate monitors (optional)

Method

1 While sitting down, find your pulse and count the number of times your heart beats in 15 seconds.

2 Multiply this number by 4 to determine the number of beats every minute.

3 Measure your respiration rate by counting the number of breaths you take in 1 minute.

4 Do step-ups or star jumps for 2 minutes.

5 Measure your heart rate and respiration rate immediately after stopping exercise.

6 Measure your heart rate and respiration rate every 2 minutes for 10 minutes.

Results

1 Record the data in a table.

2 Draw a line graph showing how your heart rate varied after exercise.

3 Draw a line graph showing how your respiration rate varied after exercise.

Discussion

1 What happened to your breathing rate during exercise?

2 Why did your heart rate increase during exercise?

3 Describe what happened to your heart rate during the 10 minutes after exercise.

4 Use homeostasis to explain why your heart rate was different before, during and after exercise.

Conclusion

How does homeostasis ensure your muscles get enough nutrients and remove wastes during exercise?

9.8 Investigating pathogens

CHALLENGE

Design brief

Pathogens are organisms that cause disease.

Risk assessment
9.8 Investigating pathogens

Lab tech notes
9.8 Investigating pathogens

What you need

- A selection of research resources, such as books, medical dictionaries, journals and computers

What to do

1. Working in small teams, brainstorm for 3 minutes and prepare a list of as many different infectious diseases you can think of.
2. You now have 2 minutes to predict what sort of organism causes each of the diseases in your list. Next to each disease, write one of the following words as your prediction: worm, fungus, protozoan, bacterium, virus.
3. Spend a minute discussing how your team can use your resources for the best results. You must use at least two different types of resource.
4. You now have 10 minutes to research the list of diseases to confirm which group of organisms causes the disease.

Discussion

1. How many diseases did you think of? How many of your predictions were correct?
2. What resources did your team use? Which ones were fastest? Find out what resources were the most useful for the other teams.
3. Draw a bar graph showing the number of diseases you listed for each type of organism.
4. Was there an organism that dominated your list? If so, can you think of reasons why you might be more familiar with the causes of some types of disease?

9.8 Investigating germ theory

INVESTIGATION

Aim

To determine what factors affect the growth of airborne microbes.

Risk assessment
9.8 Investigating germ theory

Lab tech notes
9.8 Investigating germ theory

CAUTION! Some microbes are harmful to humans. Wear gloves when collecting samples and observing plates. Never open the incubated plates. Leave sealed.

Materials

- Agar plates
- Various disinfectants
- Timer
- Sticky tape or Parafilm®
- Felt-tipped pen

Method

1. Open the lid of one agar plate and leave it sitting on the bench for 15 minutes.
2. Place the lid on top and seal the agar plate with sticky tape.
3. Leave another agar plate unopened. Seal it with sticky tape.
4. Label each agar plate with the felt-tipped pen.
5. Incubate the agar plates at 35–37°C for approximately 3 days.
6. Wear disposable gloves. Examine the plates for any growth.
7. Collect plates to one place for appropriate disposal. Disinfect benches. Wash hands as you leave the laboratory.

Inquiry

What if the first agar plate was sprayed with a disinfectant before being incubated?

Answer the following questions with regard to your inquiry question.

- What independent variable are you changing from the first agar plate?
- Name three variables you will need to keep the same as the first agar plate.
- How will you determine if the disinfectant was effective?
- Write a hypothesis for your investigation.
- What sort of table will you need to draw to show your results?

Show your teacher your planning for approval.

Results

Record all your results. You could take photos showing the microbe growth on the agar plates.

Discussion

1. Did all the colonies look the same? Why or why not?
2. Why did you leave one agar plate unopened?
3. Do your results support germ theory? Provide evidence from your results to support your answer.
4. Was your hypothesis supported? Provide evidence from your results to support your answer.

Conclusion

Describe the factors that affect the growth of microbes.

9.9 Modelling infection and vaccination

CHALLENGE

Design brief

Model how vaccinations work.

Risk assessment
9.9 Modelling infection and vaccination

Lab tech notes
9.9 Modelling infection and vaccination

CAUTION! Wear safety gloves and safety glasses. Handle sodium hydroxide and hydrochloric acid with care. Consult your teacher for how to safely manage these chemicals.

What you need

- 1 M sodium hydroxide
- 0.1 M hydrochloric acid
- Water
- Phenolphthalein indicator
- Plastic cup
- Pipette (one for each student)

What to do

1 Add half a cup of water to each plastic cup.

2 Place all the cups on one table.

3 All students should turn their back while the teacher adds 2 mL of sodium hydroxide to one cup. This represents a student having an infection.

4 Students should then collect their cups and use the pipettes to exchange 3 mL of water with three other people. This is equivalent to shaking hands. Record who you 'shook hands' with in a table like Table 1.

Table 1 Record of people

Person 1	Person 2	Person 3

5 Add a few drops of phenolphthalein indicator to each cup to determine who caught the disease.

6 Use the information recorded in the table to determine who the original source of the infection was.

7 Repeat steps 1–5, this time choosing whether or not to become vaccinated. This involves adding 2 mL of hydrochloric acid to your cup of water.

8 Repeat this activity, increasing the number of people vaccinated.

Discussion

1 How many people become infected without vaccination?

2 How many people become infected when a few people were vaccinated?

3 Did it make any difference if more people were vaccinated against the disease? Explain why you think this happened.

4 Can you think of any real-life examples of how vaccination can protect vulnerable members of the community?

10.1 Making a biosphere

CHALLENGE

Design brief

Build a biosphere.

Risk assessment
10.1 Making a biosphere

Lab tech notes
10.1 Making a biosphere

What you need

- Pond water containing macro-invertebrates (e.g. water fleas, pond snails)
- Aquatic plants
- Mud or sand from a pond
- Large glass jar with a lid
- Electronic balance

What to do

1 Work in pairs and take turns with observations and note-taking.

2 Take the large glass jar and partly fill it with some mud or sand from a pond and some pond water. Make sure there are some small macro-invertebrates in your pond water.

3 Add some small pieces of aquatic plants to the jar.

4 Seal the jar with an airtight lid and then weigh the jar and contents.

5 Place the jar near a well-lit window but not in direct sunlight or it may warm up too much.

6 Check your biosphere every few days, and write down some observations about what you see happening.

7 Reweigh your jar and contents when you have finished the investigation.

Discussion

1 How did the weight of your jar and contents change over time? Explain what might have caused this change.

2 Plants are important in a biosphere because they make oxygen and sugar from carbon dioxide, water and sunlight. What is this process known as?

3 Animals consume sugar and oxygen to produce carbon dioxide. What is this process known as?

4 Research other homemade biospheres on the internet and suggest some improvements you could make to the design of your investigation.

10.2 What if more seeds were planted in a pot?

INVESTIGATION

Aim

To investigate some factors that affect competition in plants.

Risk assessment
10.2 What if more seeds were planted in a pot?

Lab tech notes
10.2 What if more seeds were planted in a pot?

CAUTION! Potting mix may contain pathogenic organisms. Read manufacturers warning labels. Avoid breathing. Wear dust mask and gloves.

Materials

- Packets of seeds (a variety of vegetables or flowers is needed)
- Small plot (20 × 20 cm) in a garden, divided into thirds, or 3 medium-sized pots containing good-quality potting mix
- Measuring cylinder or graduated jug for watering

Method

1. Prepare the plots (or pots) so the soil is moderately deep and smooth. Label them plot A, B and C.
2. In plot A, plant six seeds of the same type spread evenly apart.
3. Water the soil in all plots (see the inquiry questions below) each day as evenly as possible with the same amount of water.
4. Record the growth of the seeds. If possible, take photographs each week or every few days when the seeds begin to geminate. If the seeds become seedlings (small plants), measure their heights and record the results in a table.

Inquiry

Choose one of the following questions to investigate.

- What if more of the same seeds were planted close together in plot B?
- What if different seeds were planted between the original seeds in plot C?

Answer the following questions in relation to your inquiry question.

- What (independent variable) are you changing from plot A?
- Name three variables you will need to keep the same as plot A.
- How will you measure if the growth of the seedlings was affected?
- Predict which seedlings will grow the best.
- What equipment will you need to complete this investigation?
- Write down the method you will use to complete your investigation.
- What sort of table will you need to draw to show your results?

Show your teacher your planning for approval.

Results

Record all results. You could take photos showing the progress of growth and/or record the average heights of plants of different species and record them in a table.

Discussion

1. What would be your advice to another student who wants to perform the investigation?
2. Was there evidence of competition between the seeds as they germinated? Explain using evidence from your results.
3. Are there other factors that might affect the growth of seeds?
4. Have you previously observed competition between organisms in the natural environment? If so, describe it.

Conclusion

Write a conclusion regarding the factors that affect competition between germinating seeds.

10.5a Inputs and outputs of photosynthesis

INVESTIGATION

Aim

To examine the role of carbon dioxide in photosynthesis.

Risk assessment
10.5a Inputs and outputs of photosynthesis

Lab tech notes
10.5a Inputs and outputs of photosynthesis

CAUTION! Ensure a clean straw is used for each student

Materials

- Bromothymol blue solution
- 4 test tubes with rubber stoppers
- *Elodea canadensis* water plant
- Strong light source
- Clean straws
- Paperclip
- Timer

Method

1. Add 2 drops of bromothymol blue solution to 15 mL of water in all test tubes.
2. Using the straw, gently blow into each test tube. The solutions should change from blue to yellow. This indicates the presence of carbon dioxide from your breath in the water.

3 Label the tests tubes A, B, C and D. Prepare them as shown in Table 1.

Table 1 Set-up of test tubes

Test tube	Set-up
A	Place the paperclip on the end of an *Elodea* plant to weigh it down, and place the plant into the test tube. Place the stopper on the test tube.
B	Place the stopper on the test tube (with no *Elodea*).
C	Place the stopper on the test tube (with no *Elodea*).
D	Place the paperclip on the end of an *Elodea* plant to weigh it down, and place the plant into the test tube. Place the stopper on the test tube.

4 Expose test tubes A and B to sunlight or a bright light for 20 minutes. Record any colour change. Count any bubbles that may have formed on the *Elodea* plants.

5 Place test tubes C and D in a cupboard for 20 minutes. Record any colour changes and count any bubbles.

Results

Record all your observations in a table.

Discussion

1 What caused the bromothymol blue to change from blue to yellow?

2 What would happen to the bromothymol blue if the carbon dioxide was removed from the water?

3 In which test tube would you expect photosynthesis to occur? Explain.

4 In which test tubes would you expect no changes in the colour to occur? Explain.

5 Did your results correlate with your predictions? Use evidence from your results to support your answer.

6 You may have observed bubbles forming around the *Elodea* leaves in test tube A. What gas would you expect this to be?

7 Name one variable that was difficult to control in this investigation. How could you control this better next time?

Conclusion

What are the reactants (inputs) and products (outputs) of photosynthesis?

10.6 Food for thought

CHALLENGE

Design brief

Explore how ecosystems work in small groups

Risk assessment
10.6 Food for thought

Lab tech notes
10.6 Food for thought

What you need

- 2 L bottle of coloured water
- 10 mL and 100 mL measuring cylinders
- Plastic cups (4 for each organism)
- Dropper

What to do

1 Work in groups of five to represent five different parts of the food chain: the Sun, native grass (producer), a cricket (herbivore), a wedge-tailed eaglehawk (top consumer), and a fungus (decomposer).

2 Use the bottle of coloured water to represent the Sun's energy. The total energy available from the Sun is equal to the volume in the bottle (i.e. 2000 mL).

3 Give a cup to each person representing a part of the food chain.

4 Through photosynthesis, the plant receives 3% of the solar energy available to it: 3% of 2000 mL = 60 mL. Measure and pour 60 mL of coloured water into the plant's cup.

5 The herbivore receives 10% of the energy: 10% of 60 mL = 6 mL. Measure out 6 mL from the plant's cup and pour this into the herbivore's cup.

6 The top consumer receives 10% of this energy: 10% of 6 mL = 0.6 mL. Measure out 0.6 mL from the herbivore's cup and pour this into the top consumer's cup.

7 When the top consumer dies, the decomposer will get 10% of its energy: 10% of 0.6 mL = 0.06 mL. This can be represented by adding a single drop into the decomposer's cup.

Discussion

1 Which organism would have been 'most satisfied' by the amount of energy (food) it received? Which would have been least satisfied?

2 Explain what has happened to the 1940 mL of 'energy' from the Sun that did not pass into the plant.

3 How much 'energy' did the herbivore receive? How was 90% of that used by the insect (cricket)?

4 Which consumer in the food chain will have to find the most food to gain enough energy to survive? Explain your answer.

10.7 Natural disasters in Australia

CHALLENGE

Design brief

Conduct research about some of Australia's natural disasters.

Risk assessment
10.7 Natural disasters in Australia

Lab tech notes
10.7 Natural disasters in Australia

What you need

- Large map of Australia
- Colour-coded pins or small cardboard squares (e.g. red for bushfires, blue for floods, brown for droughts)
- Copy of Table 1

What to do

1. Work in small groups to place pins or attach squares of the appropriate colour to the map at the part of the map affected by each natural disaster.
2. If a large area is involved, place a number of pins or squares across the area.

Discussion

1. Were some areas affected by these natural events more than others?
2. Should monsoonal rains have been included in this map? Discuss.
3. Brainstorm some possible effects, both positive and negative, of these events.
4. Does there seem to be any pattern for the alternation of floods and droughts?

Table 1 Some natural disasters in Australia, 1970–2020

Year	Nature of disaster	Location
December 1974	Cyclone Tracy	Darwin, NT
February 1983	Ash Wednesday bushfires	Adelaide Hills, SA
1989	Earthquake	Newcastle, NSW
February 1993	Heatwave	South-eastern Australia
1997	Landslide	Thredbo, NSW
2003	Bushfires	Canberra, ACT
June 2007	Storm and flood	Hunter Valley and central coast, NSW
February 2009	Black Saturday bushfires	Victoria
December 2010–January 2011	Flooding	Queensland and Victoria
February 2011	Cyclone Yasi	Queensland
October 2013	Bushfires	New South Wales
February 2015	Cyclone Lam	Northern Territory
March 2017	Cyclone Debbie	Queensland
December 2019–February 2020	Australian bushfire season	New South Wales, Victoria, Queensland, Western Australia, South Australia, Tasmania, ACT

10.8 Field trip

CHALLENGE

Design brief

Conduct field work to observe a natural ecosystem.

Risk assessment
10.8 Field trip

Lab tech notes
10.8 Field trip

CAUTION! Allergy alert. Do not handle plants you can't identify. Some plants are harmful to humans. Wear gloves if uncertain.

Figure 1 Increased rainfall and open areas allow an undergrowth to develop.

Figure 2 Plants that survive in drier areas have unique adaptations such as thin, needle-like leaves.

Figure 3 The level of acid in the soil can affect the growth of a plant.

The abiotic features of the environment determine the vegetation in an ecosystem.

Choose an ecosystem such as a woodland, grassland or rainforest. After a short study of the vegetation, measure the abiotic factors and make a conclusion about how they determine the type and height of the vegetation. You may need the following materials and equipment:

- Thermometer (for temperature)
- Wet/dry thermometer (for humidity)
- Anemometer (for wind speed)
- Light meter (for light)
- Rod (for measuring soil depth)
- Cobalt chloride paper (for soil moisture)
- Soil pH kit or pH paper

  Note: Dataloggers may be used if preferred.

What to do

1 Observe the plants around you. Describe what you see. You could take photos, draw diagrams or write descriptions.

2 Examine the leaves of the plants. List three of their characteristics and how this feature could give this plant an advantage over other plants.

3 Choose one species of plant. Record its common name, its scientific name and, if possible, the family of plants to which it belongs. Sketch a leaf of this plant.

4 Describe how your chosen plant is adapted to the conditions in the ecosystem.

Table 1 Abiotic factors in an ecosystem

Abiotic factor	Reading
Temperature	
Wind speed	
Humidity	
Light intensity	
Leaf litter depth	
Soil colour	
Soil moisture	
Soil pH	

5 Measure the abiotic factors shown in Table 1 for your chosen ecosystem.

6 For each observation and measurement you made, analyse and evaluate its significance. It might be appropriate to research and analyse the history of the area you are studying.

Discussion

1 What conclusion can you make about the effects of the abiotic factors that you have measured on the vegetation in this ecosystem?

2 Suggest how this environment may be affected by increased human population in the future.

11.2 Modelling the structure of DNA

CHALLENGE

Design brief

To construct a model of DNA that shows the complementary bases arranged in a double helix.

Risk assessment
11.2 Modelling the structure of DNA

Lab tech notes
11.2 Modelling the structure of DNA

What you need

- 4 long pipe cleaners (2 different colours)
- 24 beads (6 different colours)

What to do

1 Choose two pipe cleaners of the same colour.

2 On each pipe cleaner, thread beads of two alternating colours. Leave about 2 cm of space between each bead. This represents the sugar–phosphate backbone of DNA molecules (Figure 1).

3 Cut the remaining two pipe cleaners into 5 cm segments. These will be used to create the paired nitrogen bases A-T and G-C.

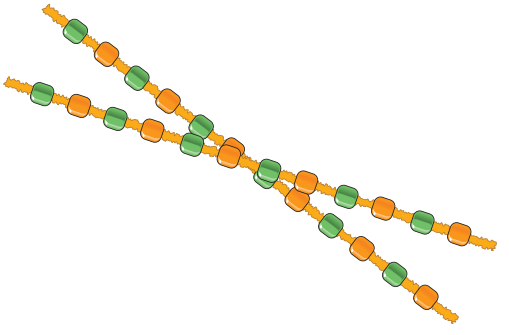


Figure 1 Representation of the sugar–phosphate backbone of DNA

4 Choose two bead colours to represent adenine (A) and thymine (T). Thread these two beads on six of the cut pipe-cleaner strands.

5 The remaining colours represent guanine (G) and cytosine (C). Thread these two beads on the remaining cut pipe-cleaner strands (Figure 2).

6 Attach the short segments of nitrogen bases onto the backbone of the DNA molecule. Make sure each nitrogen base strand is attached next to the same coloured bead (that represents the sugar in the sugar–phosphate backbone). You should have formed a ladder-like structure with the A-T and G-C nitrogen bases as the rungs of the ladder.

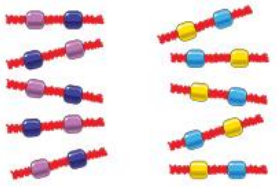


Figure 2 Representation of the paired nitrogen bases A-T and G-C

7 Twist your ladder so that it forms a double-helix structure (Figure 3).

Figure 3 Representation of the double-helix structure of DNA

Discussion

1 What colour beads represented:
   a adenine?
   b thymine?
   c guanine?
   d cytosine?

2 What do the letters 'DNA' stand for?

3 Describe a 'double helix'.

4 Draw a single nucleotide from your model.

11.3 Making protein

SKILLS LAB

A section of a DNA sequence made from a particular gene is shown below:

Risk assessment
11.3 Making protein

Lab tech notes
11.3 Making protein

T A C T T A G A G A T G C T G A C T

1 Write down the complementary sequence of DNA for this part of the gene.

2 If the strand shown is the template strand of the gene, write the RNA sequence that would be made. (Remember to use uracil instead of thymine.)

3 Break the strand into groups of three. Each group is called a codon. Using the genetic code in Figure 1, write down the amino acids that the given sequence codes.

4 How would the protein strand change if the 12th nucleotide in the DNA template strand (guanine) was changed to a thymine?

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met/Start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Figure 1 The entire genetic code was deciphered by 1966, and scientists now understand which amino acid is coded for by each codon. There are three stop codons and one start codon.

11.4 Extracting DNA

INVESTIGATION

Aim

To extract a sample of DNA from peas.

Risk assessment
11.4 Extracting DNA

Lab tech notes
11.4 Extracting DNA

CAUTION! Ethanol is a flammable liquid. Do no use near a flame. Blender has sharp blades. Keep hands clear.

Materials

PART A

- 100 g (½ cup) dried peas soaked overnight in 2 cups of water, or frozen peas (thaw first)
- 200 mL (1 cup) water
- 6 g (1 tsp) table salt
- 20 mL dishwashing liquid
- 1 g (¼ tsp) meat tenderiser
- Blender
- 1 L beaker
- Sieve
- Stirring rod or spoon
- Timer

PART B

- Ice-cold ethanol (stand a sealed bottle containing 200 mL ethanol in a metal bowl of ice water for an hour prior to using)
- Methylene blue stain
- Test tubes and test-tube rack or 50 mL glass vials
- Skewer, glass stirring rod (toothpick for vials)
- Microscope
- Clean microscope slides and cover slips

Method

PART A

1 Dissolve the salt in the water.

2 Combine the peas and salty water in a blender. Mix for 15 seconds to form a lumpy liquid in which the peas are only just broken up. Do not overblend the mixture.

3 Pour the contents through a sieve into the 1 L beaker. Discard the pulp in the sieve.

4 Add the dishwashing liquid and stir the mixture gently to avoid making bubbles. Stir for 8 minutes.

5 Add the meat tenderiser and continue to stir gently for another 2 minutes.

6 This is your prepared DNA source.

PART B

1 Pour 15 mL of the DNA source into a test tube or a 50 mL glass vial. There should be enough of this mix for eight test tubes or vials, which can be shared in the class.

2 Dribble 15 mL of the ice-cold ethanol down the side of the test tube or vial – there should be equal amounts of filtrate and ethanol in the test tube or vial.

3 Leave the test tube or vial for the mixture to separate into layers. This will take at least 10 minutes. The alcohol will eventually settle on top of the watery pea mixture. DNA is less dense than water and should float up into the alcohol layer, leaving the other cellular components behind.

4 When the mixture has separated completely, use a stirring rod to gently twirl and twist the DNA to collect it from the alcohol layer (Figure 1). DNA is white in colour.

5 Put a small amount of the DNA sample onto a glass slide. Gently spread the DNA mixture. Add 1 drop of methylene blue stain to the DNA mixture. Place the cover slip on the edge of the methylene blue and allow it to fall into place. This should eliminate any air bubbles.

6 Look at your sample under ×10 magnification. Once you have focused the microscope, you can then try the higher magnifications using the fine focus knob to focus. You will not see the double-helix strands, but you should see clumps of DNA material that may look like a tangled mass of strands.

Results

Present your results as a labelled diagram, with several short statements or labels explaining your observations.

Discussion

1 Briefly describe the appearance of the DNA under the microscope. Why can you not see the double helix?

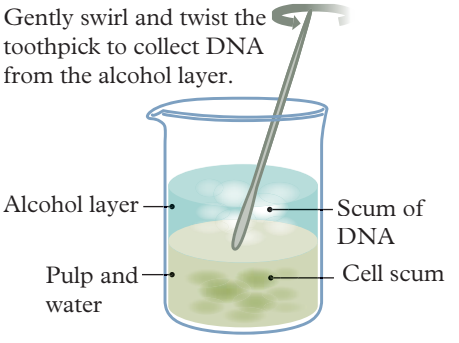


Figure 1 Procedure for collecting DNA from the alcohol layer

2 Do you think human DNA will look the same as the DNA from dried peas?

3 What role does each of the additives (dishwashing detergent, meat tenderiser and alcohol) play?

4 What materials remain in the watery layer?

Conclusion

Summarise the outcomes of this investigation.

11.5 Identifying mutations

SKILLS LAB

Risk assessment
11.5 Identifying mutations

Lab tech notes
11.5 Identifying mutations

First base	Second base: U	Second base: C	Second base: A	Second base: G	Third base
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met/Start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Figure 1 The codon table

1 A normal RNA sequence is given, together with two different genetic mutations.
   - Normal
     AUG ACG CAG AAU UGG GAU CCU ACG
   - Mutation 1
     AUG ACA CAG AAU UGG GAU CCU ACG
   - Mutation 2
     AUG AGC AGA AUU GGG AUC CUA CG

   a Name the type of mutation represented in each case. Explain your answer.

   b Describe the outcome of mutation 1 on protein synthesis. You may wish to consult the codon table in Figure 1.

   c Describe the outcome of mutation 2 on protein synthesis.

2 Genetic Creutzfeldt–Jacob disease (CJD) is caused by an abnormal protein called PrPc. This protein is formed because of a mutation in the *PrPc* gene on chromosome 20 and occurs in DNA base triplet 200 in the gene's sequence (Table 1).

   a What type of mutation is this?

   b Describe the amino acid change that would occur in the PrPc protein.

   c Distinguish between natural and induced mutation.

Table 1 Creutzfeldt-PrPc protein in genes

DNA base triplet number	199	200	201
Normal gene	TGG	CTC	CAA
Mutated gene	TGG	TTC	CAA

11.6 Zazzle genetics

INVESTIGATION

Aim

To demonstrate the role of alleles in determining the phenotype of an individual.

Risk assessment
11.6 Zazzle genetics

Lab tech notes
11.6 Zazzle genetics

CAUTION! Do not eat or drink in the laboratory. This investigation should be done at home or in a canteen/café if the marshmallows will be consumed.

Materials

- A bag containing 6 different coloured counters
- Permanent marker
- Toothpicks
- Pipe cleaners
- Pink and white large marshmallows
- Small marshmallows
- Blue and black felt-tipped pens

Method

1 Choose a counter from the bag. Use the permanent marker to draw an 'A' on one side and an 'a' on the other side. This represents the inheritance of a long antenna (A) or a short antenna (a) from the parent.

2 Flip the counter to determine which allele is passed on to your Zazzle from the father. Write your results in Table 1.

3 Use a second counter to represent two body segments (L) or one body segment (l). Flip the counter to determine which allele is passed on from the father. Write your result in the table.

4 Use three of the remaining counters to represent the following characteristics of the father and write your results in the table.
   - Four eyes (E) or two eyes (e)
   - Straight tail (T) or curly tail (t)
   - One hump (H) or two humps (h)

5 Repeat steps 1–4 for the alleles passed from the mother to your Zazzle.

6 The final counter is used to determine the sex of your Zazzle. The mother has two X chromosomes. This means she can only pass on an X chromosome to your Zazzle baby. Draw an 'X' on one side of the counter and a 'Y' on the other. Flip the counter to determine which chromosome is passed from the father to the child. You have now determined the sex of your Zazzle. A girl will have a pink marshmallow body. A boy will have a white marshmallow body.

7 Determine the phenotype of your Zazzle.

8 Use the materials to construct your Zazzle.

Results

Record your data in Table 1.

Discussion

1 How many chromosomes were present in each of the:
   a mother's somatic cells?
   b father's gametes?
   c baby Zazzle's cells?

2 Write down your baby Zazzle's genotype for each trait.

3 Why does the baby Zazzle have two alleles for each trait?

4 Draw a diagram of your baby Zazzle.

Conclusion

Describe how dominant and recessive traits are inherited.

Table 1 Alleles inherited from the parent

Chromosome	Trait and letter representing it	Allele donated by the father	Allele donated by the mother	Phenotype of the baby Zazzle
1	Antenna (A or a)			
2	Body length (L or l)			
3	Eyes (E or e)			
4	Tail (T or t)			
5	Hump (H or h)			
6	Sex (X or Y)		X	

Figure 1 Baby Zazzles

11.7 Colour-blindness inheritance

INVESTIGATION

Aim

To examine the inheritance of X-linked traits.

Risk assessment
11.7 Colour-blindness inheritance

Lab tech notes
11.7 Colour-blindness inheritance

Materials

- 2 counters
- Permanent marker

Li is colour blind (X^bY) and would like to start a family with Maria. Maria is not colour blind but knows that she is heterozygous (X^BX^b) for the trait as her father is colour blind.

Method

1. On one counter, write X^b on one side and Y on the other.
2. On the second counter, write X^b on one side and X^a on the other.
3. Toss the counters eight times and record the possible genotypes of Li and Maria's children.

Results

Record your data in Table 1.

Discussion

1. How many girls and boys did Li and Maria have?
2. How many children were colour blind? How many children had normal vision?
3. Was colour blindness more common in boys or girls?
4. Can non-colour-blind parents have a colour-blind son? Use a Punnett square to support your answer.
5. Can a non-colour-blind daughter have a colour-blind father? Use a Punnett square to support your answer.
6. Can two colour-blind parents have a non-colour-blind son? Use a Punnett square to support your answer.

Conclusion

How is colour blindness inherited?

Table 1 Possible genotypes

Coin toss	Genotype of child
1	
2	
3	
4	
5	
6	
7	
8	

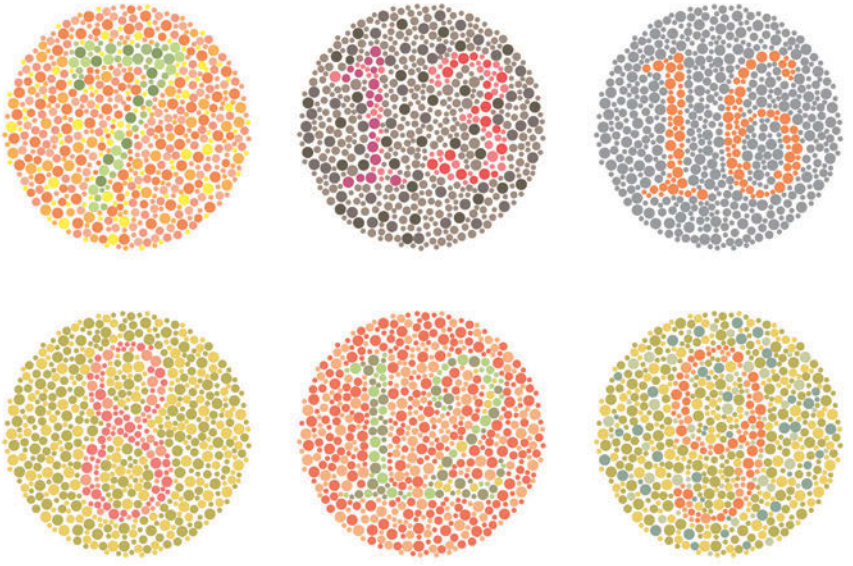


Figure 1 Colour blindness is often tested with the Ishihara test. It affects 1 in 12 men and 1 in 200 women.

11.9 Genetic engineering

CHALLENGE

Design brief

To model how insulin is genetically engineered.

Risk assessment
11.9 Edible genetic engineering

Lab tech notes
11.9 Edible genetic engineering

CAUTION! Do not eat or drink in the laboratory. This investigation should be done at home or in a canteen/café if the lollies will be consumed.

What you need

- 1 packet of lolly snakes
- 1 packet of sour worm lollies
- scissors

What to do

1 Select a single lolly snake from the packet and use a pair of scissors to remove 5 mm from each end of the snake. This will make the ends sticky.

2 Connect the two ends of the snake together to form a loop. You have formed a plasmid of DNA.

3 Obtain one sour worm from the packet. This is your insulin gene that you will insert into the plasmid. Use the scissors to remove 5 mm from each end of the snake. This will make the same type of sticky ends as the plasmid.

4 Open the plasmid so that the sticky ends are exposed. Insert the insulin gene (sour worm) gene into the gap so that the plasmid loop is larger. You have created a recombinant plasmid with DNA from different organisms.

5 Draw a picture of your plasmid and the introduced gene.

6 Describe how you could clone your insulin plasmid in a bacterial cell.

Discussion

1 What is plasmid?

2 Why is insulin needed by some members of the community?

3 Before genetic engineering was possible, pig insulin was often used. Why would genetically engineered human insulin be preferable? (Consider the way the immune system would respond to pig insulin.)

Figure 1 This investigation requires sour worm lollies.

12.2 What if the habitat of bean prey was changed?

INVESTIGATION

Aim

To examine the selection pressures involved in hunting prey.

Risk assessment
12.2 What if the habitat of bean prey was changed?

Lab tech notes
12.2 What if the habitat of bean prey was changed?

Materials

- Paper cups
- Tools: knives, forks, spoons, sticky tape, plastic gloves
- Bean prey: red butted beans (kidney beans), long-toothed yellow beans, panther-toothed black beans, wicked white beans
- Timer

Method

1 Divide the class into five groups. Each group represents a separate tribe.
   - The Knife tribe can only use knives to hunt beans.
   - The Spoon tribe can only use spoons to hunt beans.
   - The Hand tribe are allowed to use their hands to hunt beans.
   - The Sticky-tape tribe can only use sticky tape to hunt beans.
   - The Glove tribe must wear plastic gloves to hunt beans but turn the thumb of their glove inside out so they cannot use their opposable thumb.

2 On a section of grass, spread 20 of each bean type onto the grass.

3 Each tribe has 10 seconds to collect as many beans as they can. Record the data in an appropriate table as shown by Table 1.

4 The two tribes with the least beans become extinct and must sit down.

5 Each bean left in the class will breed. This means the amount of beans remaining on the grass will double. For example, if 6 white beans were collected, then 14 are remaining, and you need to add another 14 white beans to the area. Repeat with the other three colours.

6 Repeat for two further generations so that only one tribe is left.

Inquiry

What if the habitat of bean prey was changed?

Answer the following questions with regard to your inquiry question.

- Write a hypothesis for your inquiry.
- What is the independent variable?
- What is the dependent variable?
- List at least three variables that will need to be controlled. How will you control them?

Show your teacher your planning for approval.

Results

1 Copy and complete Table 1 to record your results for generation 1.

2 Create two more tables for the other two generations.

Discussion

1 Which tribes became extinct first? What was the selection pressure that contributed to their extinction?

2 Why were the bean prey numbers doubled after each generation?

3 Which beans were selected against?

4 Use the mechanism of natural selection to explain the change in bean prey numbers.

5 Suggest a similar example to this investigation that might occur in nature.

Conclusion

Describe how the mechanism of natural selection changes frequency of alleles in a population.

Table 1 Number of beans collected by each tribe

	Knife tribe	Spoon tribe	Hand tribe	Sticky-tape tribe	Glove tribe	Totals
Red-butted beans						
Long-toothed yellow beans						
Panther-toothed black beans						
Wicked white beans						
Totals						

12.3 Divergent and convergent evolution of big beaks and small beaks

INVESTIGATION

Aim

To model divergent and convergent evolution in beak size.

Risk assessment
12.3 Divergent and convergent evolution of big beaks and small beaks

Lab tech notes
12.3 Divergent and convergent evolution of big beaks and small beaks

Materials

- 6 previously prepared bags of food:
  - North Trayland/Season 1 = 4 handfuls popcorn + 20 kidney beans + 50 marbles
  - North Trayland/Season 2 = 1 handful popcorn + 10 kidney beans + 50 marbles
  - North Trayland/Season 3 = 100 marbles
  - South Trayland/Season 1 = 4 handfuls popcorn + 20 kidney beans + 50 marbles
  - South Trayland/Season 2 = 6 handfuls popcorn + 10 kidney beans + 5 marbles
  - South Trayland/Season 3 = 8 handfuls popcorn
- 20 large bulldog clips
- 20 medium-sized bulldog clips
- 20 small bulldog clips
- 30 plastic cups
- 2 large trays
- 6 plastic bags
- Timer

Method

1 Twelve students will represent a population of birds living on an island. Four students should be Giant birds (with a large bulldog clip each). Four students are Midbill birds with the medium-sized bulldog clips. The remaining four students are Babybill birds with the small bulldog clips.

2 A permanent barrier separates the bird population into two groups (North Trayland and South Trayland) with two birds of each type (2 large, 2 medium and 2 small) in each. Place the trays at opposite ends of the classroom.

3 Place the first season's food for each population in the tray. The 12 birds have 25 seconds to collect as much food as possible with their bulldog-clip 'beaks' and place it in their cup 'stomachs'.

4 At the end of the time, calculate how many kilojoules each bird has consumed if popcorn = 2 kilojoules, beans = 5 kilojoules, marbles = 10 kilojoules. Table 1 shows you how many kilojoules each type of bird needs to survive. Record the number of surviving birds in the results tables (Tables 2 and 3).

Table 1 Kilojoules needed by the different birds

Bird	Kilojoules needed to survive	Kilojoules needed to reproduce
Giant	80	160
Midbill	50	100
Babybill	25	50

5 Reproducing birds should choose another student (who is not already a bird) to be their baby (with the same-sized beak).

6 Remove any remaining food from the trays and place back into the plastic bags. Place the food for season 2 in each tray. Repeat steps 3–5.

7 Remove any remaining food from the trays and place the food for season 3 in each tray. Repeat steps 3–5.

8 Clean up any remaining food.

Results

Complete Tables 2 and 3.

Table 2 North Trayland

Bird	Before isolation	Season 1	Season 2	Season 3
Giant	2			
Midbill	2			
Babybill	2			

Table 3 South Trayland

Bird	Before isolation	Season 1	Season 2	Season 3
Giant	2			
Midbill	2			
Babybill	2			

Discussion

1 Describe what happened to the North Trayland population of birds after they were isolated from South Trayland.

2 Describe what happened to the South Trayland population of birds after they were isolated from North Trayland.

Conclusion

Use the terms 'natural selection' and 'selection pressures' to explain the type of evolution that occurred between the two species.

12.6 Who is my cousin?

INVESTIGATION

Aim

To determine the evolutionary relationship between different species.

Risk assessment
12.6 Who is my cousin?

Lab tech notes
12.6 Who is my cousin?

Materials

- DNA sequences
  - Hippo
    AGTCCCCAAAG CAAAGGAGACTATCCT
    TCCTAAGCATAAAGAAAT
    GCCCTTCTCTAAATC
  - Giraffe
    AGTCTCCAAATGA
    AAGGAGACTATGGCTCCTA
    AGCACAAAGAAATGCCCTTCC CTAAATA
  - Rhino
    AGTCCTCCA
    AACTAAGGAGACCATCTTTCCTAA
    GCTCAAAGTTATGCCCTCCCTTAAATC
  - Pig
    AGATTCCAAA GCTAAGGAGACCATTGTT
    CCCAAGCGTAAAGGAATGCCCT
    TCCCTAA ATC
  - Cow
    AGTCCCC AAATGAAAGGAGAC
    TATGGTTCCTAAGCACAAGG AAATGCCC
    TTCCCTAAATA

Method

1 Compare the DNA sequences with each other and determine the number of differences between each pair.

2 Write your results in a results table as shown by Table 1.

Results

Complete Table 1 to show the number of differences in DNA sequence between each animal.

Table 1 Number of differences in DNA sequence

Hippo					
Cow					
Giraffe					
Rhino					
	Pig	Hippo	Cow	Giraffe	

Discussion

1 a Which animal has the least number of differences in DNA sequence when compared to a cow?

b What does this suggest about the evolutionary relationship between these two animals?

2 a Which animal has the greatest number of differences in their DNA sequence when compared to a cow?

b What does this suggest about the evolutionary relationship between these two animals?

3 Use your answers to questions 1 and 2 to complete the phylogenetic tree in Figure 1.

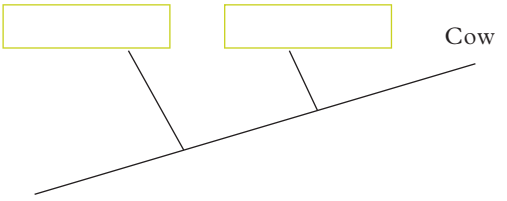


Figure 1 A phylogenetic tree

Conclusion

How do DNA sequences determine the evolutionary relationships between different organisms?

12.7 Selective breeding of dogs

INVESTIGATION

Aim

To examine how selective breeding for chosen characteristics can develop a new breed of dog.

Risk assessment
12.7 Selective breeding of dogs

Lab tech notes
12.7 Selective breeding of dogs

Materials

- Counter
- Permanent marker

Method

1 Imagine you are a scientist who studies small mammals in the bush. You need a dog that will be able to find and retrieve the mammals without causing them unnecessary stress. This will allow you to tag and release the mammals. Table 1 shows a list of possible traits in current breeds of dogs.

Table 1 Possible traits of dogs

Trait	Desired form			
Trainability	High	Moderate	Low	Any
Temperament	Vicious	Friendly	Timid	Any
Bark	Very loud	Moderate	Quiet	Any
Coat colour	Black	Brown	Caramel	Any
Hair length	Long	Moderate	Short	Any
Smell	High ability	Moderate ability	Low ability	Any
Sight	High ability	Moderate ability	Low ability	Any
Hearing	High ability	Moderate ability	Low ability	Any
Speed	Fast	Moderate	Low	Any
Endurance	High	Moderate	Low	Any

2 Identify which two traits are most important for your new breed to inherit.

3 Choose which dogs you need to breed to achieve your desired traits from Table 2.

Table 2 Traits of different dog breeds

Breed	Animo	Bax	Coota	Dallie	Enos	Favious
Trainability	Moderate	Moderate	High	Low	Moderate	High
Temperament	Timid	Timid	Vicious	Timid	Friendly	Vicious
Bark	Moderate	Very loud	Moderate	Quiet	Very loud	Moderate
Coat colour	Black	Brown	Caramel	Caramel	Black	Brown
Hair length	Long	Moderate	Long	Short	Moderate	Long
Smell	High	Moderate	Low	Low	Moderate	High
Sight	Moderate	Moderate	Moderate	High	High	Low
Hearing	High	Moderate	Moderate	High	High	Moderate
Speed	Moderate	Fast	Fast	Fast	Low	Moderate
Endurance	Low	Moderate	High	Moderate	High	Low

4 Choose dogs to be the mother and the father. Write an 'M' for mother on one side of the counter and an 'F' for father on the other side of the counter.

5 Flip the counter for each trait. If it lands with the 'M' side up, then the puppy will inherit the mother's trait. An 'F' indicates that the puppy inherits the father's trait. Write your results in a results table as shown by Table 3.

6 Flip the counter three times for each trait because each pair will have three puppies.

Results

Complete Table 3.

Table 3 Traits of the puppies

Trait	Puppy 1	Puppy 2	Puppy 3
Trainability			
Temperament			
Bark			
Coat colour			
Hair length			
Smell			
Sight			
Hearing			
Speed			
Endurance			

Discussion

1 Were all three puppies identical? Suggest a reason.

2 Which puppy best suited your original needs? Explain your answer.

3 If you were to breed the dogs for another generation, which puppies would you select to be the parents? Explain your answer.

4 Are your puppies a new species? Explain your answer.

Conclusion

Explain how selective breeding can affect the survival of a species.

13.8 Modelling radioactive decay

CHALLENGE

Design brief

To illustrate the idea of exponential decay and half-life; you can use M&M's® to represent the nuclei of atoms.

Risk assessment
13.8 A tasty way to model radioactive decay

Lab tech notes
13.8 A tasty way to model radioactive decay

CAUTION! Do not eat or drink in the laboratory. This investigation should be done at home or in a canteen/café if the M&M's® will be consumed.

What you need

- Pack of M&M's® or counters with M marked on one side of each counter
- A4 plain paper
- Disposable plastic cup

What to do

1 Complete Table 1 to record your results.

2 Count the total number of M&M's® that you have, record this number, and place them in the plastic cup.

3 Shake the cup and tip all the M&M's® onto the paper.

4 Those that have the 'M' facing upwards represent atoms that have decayed. Move these to a 'discard' pile.

5 Count the remaining 'nuclei' and record this number.

6 Place the remaining nuclei back into the cup, shake them and tip them out again.

7 Move the decayed nuclei to the discard pile and count those remaining.

8 Continue until you have three or fewer nuclei.

Table 1 Number of undecayed 'atoms' in each trial

Number of shakes	Number of undecayed 'atoms'			
	0 Start	Trial 1	Trial 2	Trial 3
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Figure 1 This investigation requires M&M's®.

9 Repeat the whole process two more times.

10 Draw a set of axes with the number of atoms remaining (vertical axis) and the number of shakes (horizontal axis). Plot points and draw a line of best fit through the points for each of the three trials.

Discussion

1 The atomic nuclei were represented by M&M's®. What represented the half-life of the decay process?

2 Are the shapes of the three curves similar or different? Comment on your answer.

3 Do you think the overall shape of the curves would be different if you started with more atomic nuclei? Explain your answer.

4 In this activity, could you predict when each individual nucleus would decay? Why is this similar to the behaviour of real radioactive atoms?

5 In this investigation, you would eventually end up with no 'undecayed' M&M's®. Would this be the case with a real radionuclide? Explain your answer.

14.3 Reactivity of metals

INVESTIGATION

Aim

To compare the reactivity of various metals by observing their reaction with hydrochloric acid.

Risk assessment
14.3 Reactivity of metals

Lab tech notes
14.3 Reactivity of metals

CAUTION! Wear protective gloves and safety glasses throughout this investigation.

Materials

- 2 M hydrochloric acid
- Detergent
- 0.5 cm pieces of magnesium, aluminium, iron, zinc and copper
- Steel wool
- Test tubes and test-tube rack
- Ruler
- Timer
- Bench mat
- marker pen

Method

1 Clean the surface of the magnesium with a piece of steel wool.

2 Place the magnesium into a test tube.

3 Add 3 drops of detergent to the test tube.

4 Add 2 cm of hydrochloric acid to the test tube. Set the timer for 5 minutes and record your observations, including the height of the foam produced, in a results table as shown by Table 1.

5 Repeat the process for the remaining metals. Label test tubes.

6 Record your observations over 30 minutes.

7 This equipment can be left set up overnight to observe any further changes.

Table 1 Observations from reacting metals with hydrochloric acid

Metal	Observations	Height of foam (cm)
Magnesium		
Aluminium		
Iron		
Zinc		
Copper		

Results

Complete Table 1.

Discussion

1 Which metal was the most reactive?

2 Which metal was the least reactive?

3 Why were the metals cleaned with steel wool first?

4 Why was detergent added to the test tubes with the hydrochloric acid?

5 What properties would you think the most reactive metal would also exhibit?

6 Is there any link between the reactivity of the metals and where they are located in the periodic table?

Conclusion

What do you know about the reactivity of metals?

Figure 1 This investigation requires safety glasses and protective gloves.

14.4 Identifying patterns in the periodic table

CHALLENGE

Design brief

Discover how to identify patterns in the periodic table.

Risk assessment
14.4 Identifying patterns in the periodic table

Lab tech notes
14.4 Identifying patterns in the periodic table

What you need

- A3 sheet of paper
- Pens
- Highlighter pens

What to do

1 On an A3 sheet of paper, make a copy of the periodic table up to element 20. Leave a gap for the block of transition metals. Ensure that the size of the box for each element will fit the information you will need to insert, as detailed below. (Chlorine has been completed for you as an example.)

2 Use different colours to shade in the metals (blue), the noble gases (purple), hydrogen (red), the non-metals other than the noble gases and hydrogen (green), and the metalloids (grey). Place a suitable key under your periodic table.

3 Identify the elements that will not gain or lose electrons in a reaction because their uncharged atoms are already very stable. Beneath them, write:
   - 'Already a stable structure'
   - 'Does not form an ion'.

4 Identify the elements that will not gain or lose electrons in a reaction, because this would require them to gain or lose more than three electrons. Beneath them, write:
   - 'Needs to gain or lose more than three electrons for a more stable structure'
   - 'Does not form an ion'.

5 Complete the box for each of the other elements listed, except for the metalloids and hydrogen, by stating how many electrons the element needs to gain or lose to achieve a more stable structure, and hence what charge its ion should have, like the example of chlorine. Information for chlorine:
   - Chlorine (Cl)
   - Needs to gain one electron
   - Charge on ion = 1–

Discussion

1 What patterns do you notice in your entries for the alkali metals?

2 What patterns do you notice in your entries for the alkaline earth metals?

Figure 1 This experiment will help you identify patterns in the periodic table.

3 What patterns apply to all the metals listed?

4 What patterns do you notice in your entries for the halogens?

5 What patterns do you notice in your entries for the group 16 elements?

6 What patterns apply to the non-metals, except for hydrogen and the noble gases?

7 In general, what do you expect to happen when a metal atom and a non-metal atom meet? Which groups of non-metals will not react in this way? Discuss.

8 Predict what might happen if:
   a a potassium atom and a fluorine atom meet
   b a calcium atom and an oxygen atom meet.

   You can illustrate your predictions by drawing shell diagrams of the atoms and showing what happens in the reaction.

15.1 Comparing mass before and after a chemical reaction

INVESTIGATION

Aim

To determine if mass is conserved in a chemical reaction.

Risk assessment
15.1 Comparing mass before and after a chemical reaction

Lab tech notes
15.1 Comparing mass before and after a chemical reaction

Materials

- Sodium bicarbonate
- Vinegar
- Balloon
- Balance
- Measuring cylinder
- 2 conical flasks
- Watch glass
- Spatula

Method

PART A

1 Copy the results table for part A (i.e. Table 1) to record your results.

2 Weigh 2.0 g of sodium bicarbonate onto a watch glass.

3 Add 20 mL of vinegar to a flask.

4 Ensure the balance is reading zero. Weigh the vinegar and flask. Record this mass (M_1).

5 Predict whether the mass of the flask and vinegar after the reaction with the sodium bicarbonate will be more than, the same as or less than the initial mass.

6 Add 2.0 g of sodium bicarbonate (M_2) to the flask containing the vinegar and swirl until the bubbling stops.

7 Weigh the flask after the reaction has stopped. Record the final mass (M_3).

PART B

1 Copy the results table for part B (i.e. Table 2) to record your results.

2 Weigh 2.0 g of sodium bicarbonate onto a watch glass.

3 Add 20 mL of vinegar to a flask.

4 Ensure the balance is reading zero. Weigh the vinegar, flask and a balloon. Record this mass (M_1).

5 Predict whether the mass of the flask, vinegar and balloon after the reaction with the sodium bicarbonate will be more than, the same as or less than the initial mass.

Figure 1 Adding sodium bicarbonate to vinegar

6 Add 2.0 g of sodium bicarbonate (M_2) to the flask and quickly stretch the opening of the balloon over the neck of the flask to collect gas.

7 Weigh the flask, with the balloon still attached, after the reaction has stopped. Record the final mass (M_3).

Figure 2 The balloon collecting gas from the reaction.

Results

Copy and complete Tables 1 and 2.

Table 1 Results for part A

Mass of flask and vinegar (M_1)	Mass of sodium bicarbonate (M_2)	Total mass before reaction ($M_1 + M_2$)	Mass after reaction (M_3)

Table 2 Results for part B

Mass of flask, vinegar and balloon (M_1)	Mass of sodium bicarbonate (M_2)	Total mass before reaction ($M_1 + M_2$)	Mass after reaction (M_3)

Discussion

1 Compare the initial and final masses for each part of the investigation.

2 Is this what you expected? Explain why or why not.

3 What gas was produced?

4 What was the purpose of the balloon?

5 How could the design of this investigation be improved?

Conclusion

Do you think that mass was conserved in this chemical reaction?

15.2 Modelling chemical equations

CHALLENGE

Design brief

Create models of chemical equations.

Risk assessment
15.2 Modelling chemical equations

Lab tech notes
15.2 Modelling chemical equations

What you need

- Paper bags
- Model atom kit (or laminated squares labelled oxygen (O) atom, carbon (C) atom, hydrogen (H) atom)
- Felt-tipped pen

Figure 1 This investigation requires brown paper bags.

PART A

What to do

1 Each paper bag represents a molecule. Create a molecule of oxygen (O_2) by placing two oxygen 'atoms' in a paper bag. Write 'O_2' on the bag.

2 Use two paper bags and four model hydrogen atoms to create two molecules of hydrogen (H_2). You have now created the reactants in the chemical reaction:

$$2H_2 + O_2 \rightarrow 2H_2O$$

3 Label the two remaining paper bags 'H_2O'. Take the model atoms out of the reactant bags and place them in the product H_2O bags. Are there enough atoms to fill the H_2O bags?

Discussion

1 Why were there more molecules/bags of hydrogen than oxygen?

2 What would happen if one more molecule of oxygen was added to the reaction? Could it react?

3 How does this model reaction conserve mass?

PART B

What to do

1 Use new bags and the model atoms to create two molecules of methane (CH_4).

2 How many molecules of oxygen (O_2) would you need to turn these methane molecules into carbon dioxide (CO_2) and water (H_2O)?

Discussion

1 How many molecules of oxygen did you need to balance this equation?

2 How many molecules of carbon dioxide and water were you able to create with two methane molecules?

3 Write the word equation for this reaction.

4 Write the balanced chemical equation for this reaction.

15.3 Direct synthesis with a 'pop'

INVESTIGATION

Aim

To produce water by direct synthesis.

Risk assessment
15.3 Direct synthesis with a 'pop'

Lab tech notes
15.3 Direct synthesis with a 'pop'

CAUTION! Wear protective clothing and safety glasses throughout this investigation. Avoid contact with hydrochloric acid.

Materials

- Magnesium ribbon
- Dilute hydrochloric acid (1 M)
- 2 test tubes and test-tube rack
- Rubber stopper
- Wooden splint
- Matches

Method

1 For this reaction, you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1 cm lengths of magnesium ribbon in a test tube and add 10 mL of dilute hydrochloric acid (Figure 1).

Figure 1 Adding hydrochloric acid to magnesium ribbon

2 Place the other test tube (make sure it is dry) upside down over the top of the first test tube so that any hydrogen gas produced enters the second test tube (Figure 2).

Figure 2 Collecting hydrogen gas in a test tube

3 After 15 seconds, place a rubber stopper over the end of the second test tube to trap the hydrogen gas – you now have a test tube of hydrogen gas.

4 Place the sealed test tube containing the hydrogen gas into the test-tube rack.

5 Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.

6 Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1 What evidence was there that water was formed in the reaction?

2 Write a chemical equation for the reaction that occurred, ensuring that no atoms are created or destroyed in the process.

3 Why do you think that heat was required to start the reaction?

4 Apart from synthesis, what other ways could this reaction be classified? (Hint: Think about the energy involved in this reaction.)

Conclusion

What do you know about the direct synthesis of water?

15.4 Testing with pH paper

CHALLENGE

Design brief

Conduct pH tests on everyday items.

Risk assessment
15.4 Testing with pH paper

Lab tech notes
15.4 Testing with pH paper

CAUTION! Acids and bases can be harmful to skin and eyes. Wear safety glasses, lab coat and gloves. Universal indicator is flammable keep clear of flames.

What you need

- pH paper and colour chart or universal indicator and colour chart
- White tile
- Variety of laboratory 0.1M acids and bases
- Vinegar
- Milk
- Toothpaste
- Lemon juice

What to do

1 Tear off about 1 cm of pH paper and place it on the white tile.
2 Place a drop of a laboratory acid on the paper.
3 Compare the colour of the wet spot on the pH paper with the pH colour chart.
4 Repeat for the laboratory bases and the other substances.
5 For each substance, record the pH colour and number, and note whether the substance is an acid, a base or neutral.

Figure 1 This investigation requires a white tile.

6 Dilute some of the substances with water and measure the pH of the diluted solutions with more indicator paper.

Discussion

1 Which was the most acidic solution that you tested (lowest pH)?
2 Which was the most basic solution that you tested (highest pH)?
3 What happens to the pH of an acid when the acid is diluted in water? Is it more or less acidic?
4 Using your answer to question 3, suggest a way of treating a burn caused by acid.

15.4 What if plants were used to create an indicator?

INVESTIGATION

Aim

To make an indicator from red cabbage and demonstrate how it can be used to identify acids and bases.

Risk assessment
15.4 What if plants were used to create an indicator?

Lab tech notes
15.4 What if plants were used to create an indicator?

Red cabbage contains a water-soluble pigment called flavin, which is also found in plums, poppies, grapes and apple skin. Very acidic solutions will turn flavin red, neutral solutions result in a purplish colour, and alkaline solutions appear greenish yellow if flavin is added to them.

CAUTION! Acids and bases can be harmful to skin and eyes. Universal indicator is flammable, keep clear of flames. Blenders have sharp blades keep fingers clear.

Materials

- 2 large leaves from a fresh red cabbage
- 0.1 M sodium hydroxide
- Water
- Stirring rod
- 500 mL beaker
- stick blender
- Strainer
- 0.1 M hydrochloric acid
- Test tubes and test-tube rack

Method

1 To make the indicator:
   a Cut a few red cabbage leaves into smaller pieces and place in the beaker.
   b Cover the cabbage leaves with water and using a stick blender, blend until the water is a deep purple.
   c Strain the liquid discarding the cabbage leaves.
2 To test the indicator:
   a Add a small amount of hydrochloric acid to a test tube and then add a few drops of red cabbage indicator.
   b Record any colour change in a table.
   c Add a small amount of water (neutral solution) to a test tube and then add a few drops of red cabbage indicator.
   d Record any colour change in your table.
   e Add a small amount of sodium hydroxide (basic solution) to a test tube and then add a few drops of red cabbage indicator.
   f Record any colour change in your table.

3 Test a variety of products, such as shampoo, vinegar and baking soda, by adding a few drops of red cabbage indicator solution to them.
4 Record the colour changes and determine which products are acids and which are bases.

Inquiry

What if another plant, flower or fruit was used to create an indicator?

Answer the following questions with regard to your inquiry question.

- What independent variable will you use instead of red cabbage?
- Name three variables you will need to keep the same as the red cabbage method.
- How will you measure if the plant, flower or fruit is an indicator?
- Predict what colour changes you might expect.
- What equipment will you need to complete this investigation?
- Write down the method you will use to complete your investigation.
- What sort of table will you need to draw to show your results?

Show your teacher your planning for approval.

Results

Include your table of observations.

Discussion

1 What colour is the extract from red cabbage?
2 What colour does the extract become in:
   a an acid?
   b a base?
   c water?

Conclusion

What do you know about indicators and how they are produced?

15.5 Neutralisation reactions

INVESTIGATION

Aim

To investigate neutralisation reactions.

Risk assessment
15.5 Neutralisation reactions

Lab tech notes
15.5 Neutralisation reactions

CAUTION! Acids and bases can be harmful to skin and eyes. Wear lab coat, safety glasses and gloves. Universal indicator is flammable keep clear of flames.

Materials

- 1 M hydrochloric acid
- 1 M sodium hydroxide solution
- Universal indicator solution
- Dropping pipettes
- 10 mL measuring cylinder
- 100 mL beaker
- Petri dish
- colour chart

Method

1 Using the measuring cylinder, transfer 5.0 mL of hydrochloric acid into the beaker and then rinse out the measuring cylinder with water.
2 Add 2 drops of universal indicator solution to the acid.
3 Pour 10 mL of the sodium hydroxide solution into the measuring cylinder.
4 Using a dropping pipette, add the sodium hydroxide from the measuring cylinder to the acid in the beaker.
5 Stop adding the sodium hydroxide when the acid has been neutralised. (The indicator will turn green at this point.)
6 Record how much sodium hydroxide you needed to add.
7 Carefully empty and rinse out your glassware. Repeat the whole investigation. Instead of adding universal indicator, use the same amount of sodium hydroxide as recorded in Step 6.
8 Pour the solution into a Petri dish and leave open in a safe place in the laboratory for a few hours. As the solution evaporates, record your observations.

Results

Present your results in a table.

Discussion

1 Why was it essential to rinse the measuring cylinder with water after it was used?
2 Why was the investigation repeated without the indicator?
3 How could you produce the solid salt more quickly in the last step of the method?
4 Should you taste the product of this reaction to check whether salt has been produced? Explain your reasoning.
5 What do you notice about the shape of the salt crystals produced? What can you infer from this about the arrangement of the particles inside the salt crystals?

Conclusion

What have you observed about neutralisation reactions?

15.5 Making sherbet

CHALLENGE

Design brief

Make your own sherbet!

Risk assessment
15.5 Making sherbet

Lab tech notes
15.5 Making sherbet

CAUTION! This challenge should not be completed in a laboratory. Complete this challenge in the cafeteria or at home.

What you need

- 1 tablespoon of icing sugar
- ¼ teaspoon of sodium bicarbonate (baking soda)
- ¼ teaspoon of citric acid
- 1 teaspoon of flavoured jelly crystals
- Small zip-lock sandwich bag

What to do

Perform this investigation in a food preparation area so that the sherbet is safe to eat.

1 Make sure the utensils are clean and dry.

2 Mix all the ingredients in the sandwich bag.

3 Dip a spoon into the mixture and put a small amount on your tongue.

Discussion

1 What happened to the sherbet when it mixed with the saliva in your mouth?

2 What three substances were formed?

3 How did the sherbet feel on your tongue? What differences in tastes did you observe?

4 Do you think that carbonates and bicarbonates should be described as bases? Explain your answer, carrying out research if required.

Figure 1 Sherbet fizzes in a chemical reaction involving saliva.

15.6 What if a metal was protected from an acid?

INVESTIGATION

Aim

To determine what factors protect a metal from acid rain.

Risk assessment
15.6 What if a metal was protected from an acid?

Lab tech notes
15.6 What if a metal was protected from an acid?

CAUTION! Acids and bases can be harmful to skin and eyes. Wear safety glasses, lab coat and gloves.

Materials

- 1 M hydrochloric acid
- Test tubes and test-tube rack
- Small pieces of metals (e.g. aluminium, copper, iron, magnesium, tin and zinc) to fit into test tubes
- Matches
- A variety of materials that could be used as a barrier (such as Vaseline, candle wax, masking tape, sticky tape)
- timer
- disposable gloves

Method

1 Add a small piece of one metal to a test tube and pour in enough acid to cover it.

2 Gently place your gloved thumb over the top of the test tube to allow any gas to accumulate.

3 After about 1 minute, there should be pressure on your thumb. Light a match and bring it to the end of the test tube as you take your thumb away.

4 Observe what happens (e.g. bubbling, metal dissolving, colour change, test tube warming) and record your observations in a table.

5 Repeat steps 1–4 for each metal.

Inquiry

What if a metal was protected from the acid?

Answer the following questions with regard to your inquiry question.

- Choose one metal for your inquiry. Which metal will you use?
- What will you use to prevent the acid and metal reacting?
- How long will you expose your metal to the acid?
- What is your independent variable?
- Name three variables you will need to keep the same as the first method.
- How will you measure if your method of protection is successful?
- Predict what results you might expect.
- What equipment will you need to complete this investigation?
- Write down the method you will use to complete your investigation.

> What sort of table will you need to draw to show your results?

Show your teacher your planning for approval.

Results

Describe your observations. Draw or take pictures of the metal before and after exposure to the acid.

Discussion

1 What observations did you make about how the different metals reacted with the acid?

2 Which metal was the most reactive with the acid?

3 Which metal was the least reactive with the acid?

4 How successful was your method of protection on the metal? Use your observations to support your answer.

5 Compare your results to those achieved by the rest of your class. Which method was the most successful?

6 How could you improve your results if you repeated this investigation?

Conclusion

What do you know about how metals and acid react?

15.7 Oxidation of steel wool

INVESTIGATION

Aim

To examine the oxidation of steel wool.

Risk assessment
15.7 Oxidation of steel wool

Lab tech notes
15.7 Oxidation of steel wool

CAUTION! Vinegar is a weak acid. Wear safety glasses and lab coat.

Materials

- Steel wool that has been soaking in vinegar
- Tape
- Thermometer
- Paper towels
- 2 × 250 mL beakers
- Water
- Stopwatch
- Foam insulation with drawstring that will fit around a beaker (used for sports bottles)
- tongs or forceps

Figure 1 This investigation requires steel wool.

Method

1 Place one beaker into the insulation.

2 Measure the temperature of the:
   a steel wool and vinegar mixture
   b room
   c insulated beaker.

3 Using tongs or forceps remove the steel wool from the vinegar and quickly use the paper towel to squeeze and remove all the vinegar from it.

4 Immediately wrap the steel wool around the thermometer and secure it with the tape.

5 Place the thermometer and steel wool into the insulated beaker and cover the top of the beaker with the insulation.

6 Record the temperature changes of the steel wool every minute for 10 minutes. The original temperature of the steel wool and vinegar mix should be $t = 0$ minutes.

Results

1 Record your observations and temperature measurements in an appropriate table.

2 Draw a graph of your results.

Discussion

1 Describe what happened to the temperature around the steel wool. (Use the term 'exothermic' or 'endothermic' in your answer.)

2 What changes to the steel wool could have caused this change in temperature?

3 What were the reactants in this reaction?

4 What were the products of this reaction?

5 Write a word equation for this reaction.

Conclusion

Use an example to describe oxidation reactions.

15.8 Combustion and candles

CHALLENGE

Design brief

Model combustion reactions using candles.

Risk assessment
15.8 Combustion and candles

Lab tech notes
15.8 Combustion and candles

What you need

- Tealight candle
- Beaker large enough to fit over candle
- Matches
- heat proof mat

What to do

1 On a heat proof mat light the candle with the match.

2 Place the beaker over the candle and observe what happens.

Discussion

1 What was the fuel for the chemical reaction occurring with the candle?

2 Why did the candle go out shortly after it was covered with the beaker?

3 Did you notice any moisture on the inside of the beaker? Where did this water come from?

4 Write a word equation for the combustion of the candle wax.

15.9 Precipitation reactions

INVESTIGATION

Aim

To determine which compounds form precipitates and write equations for the reactions occurring.

Risk assessment
15.9 Precipitation reactions

Lab tech notes
15.9 Precipitation reactions

CAUTION! Wear your lab coat, safety glasses and disposable gloves

Materials

- Plastic document sleeve
- Plastic document sleeve or spotting tile
- Paper towel
- Dropper bottles containing 0.1 M solutions of:
  - Group A: calcium nitrate ($Ca(NO_3)_2$), copper(II) nitrate ($Cu(NO_3)_2$), magnesium nitrate ($Mg(NO_3)_2$), silver nitrate ($AgNO_3$), copper(II) sulfate ($CuSO_4$)
  - Group B: sodium chloride (NaCl), sodium hydroxide (NaOH), sodium sulfate (Na_2SO_4), sodium carbonate (Na_2CO_3)

Table 1 Observations from the reactions

	NaCl	NaOH	Na_2SO_4	Na_2CO_3
$Ca(NO_3)_2$				
$Cu(NO_3)_2$				
$Mg(NO_3)_2$				
$AgNO_3$				
$CuSO_4$				

Method

1 Draw up a large table as shown in Table 1, with group B solutions listed across the first row and group A solutions listed in the first column.

2 Make a second copy of your results table on a piece of A4 paper and place this table into the plastic document sleeve. Place this on the laboratory bench. This now becomes your working area for the investigation and you will add drops of the solutions to the corresponding cells on the results table, which is now protected by the plastic sleeve.

3 Place 1 drop of each of the group A solutions in each cell of the results table in the correct row.

4 Add 1 drop of each of the group B solutions to the drops of the group A solutions in the correct columns.

5 When finished rinse plastic document sleeve under running water. Wipe dry with paper towel.

Results

1 Record whether a precipitate forms, as well as its appearance, on your other copy of the results table.

2 Use Table 1 (page 316) to help you answer the following questions. For each precipitate formed:

a identify the ions that have combined to form the precipitate and write the formula of the ions

b write the formula of the precipitate

c write a word equation for the reaction.

Discussion

1 The sets of compounds tested included a range of anions: NO_3^-, OH^-, CO_3^{2-}, Cl^- and SO_4^{2-}. Of these, which:
   a did not form any precipitates?
   b only formed precipitates with one or two cations?

2 The sets of compounds tested included a range of cations: Na^+, Ag^+, Ca^{2+}, Cu^{2+} and Mg^{2+}. Of these, which:
   a did not form any precipitates?
   b formed precipitates with only one or two anions?

3 Did the precipitation reactions you observed match those predicted from Table 1 on page 316? Discuss why or why not.

4 Write balanced chemical equations for the reactions between:
   a silver nitrate and sodium chloride
   b magnesium nitrate and sodium hydroxide.

5 Why is it important not to touch the tip of the dropper bottles on the top of the solution already on the plastic sleeve?

6 What other factors may affect the outcome of these precipitation reactions?

Conclusion

What do you know about predicting precipitation reactions?

16.1 Energy changes

INVESTIGATION

Aim

To investigate an exothermic and an endothermic process.

This investigation may be carried out using a temperature probe and data-logging equipment instead of a thermometer.

Risk assessment
16.1 Energy changes

Lab tech notes
16.1 Energy changes

CAUTION! Wear your lab coat, safety glasses and plastic gloves. Check the safety data sheets to see how to handle the chemicals in this investigation safely.

Materials

- Sealed bottle containing potassium nitrate (KNO_3) (solid)
- Sealed bottle containing calcium chloride ($CaCl_2$) (solid)
- Measuring cylinder
- Water
- Stirring rod
- Thermometer
- 2 foam cups (or temperature sensor)
- 2 spatulas
- Stopwatch
- Wash bottle
- Residue bottle

Method

1 Prepare a table to record the times and temperatures.

2 Measure 50 mL of water into a foam cup.

3 Measure the temperature of the water and record it.

4 Place three heaped spatulas of calcium chloride into the water and immediately commence stirring and timing.

5 Record the temperature every 15 seconds for 3 minutes.

6 Dispose of the solution into the container provided, and carefully rinse the thermometer with the wash bottle, ensuring the rinse water is also added to the residue bottle. Dispose of the cup as directed by your teacher.

7 Repeat steps 2–6 using potassium nitrate.

Results

Draw a graph of temperature against time and plot your results from the two chemicals on the same graph. Make sure that you label both axes and use the correct units.

Discussion

1 Which reaction was endothermic and which was exothermic?

2 In which reaction did the products have less energy than the reactants?

3 In which reaction did the products have more energy than the reactants?

4 Use the graphs to describe how quickly the temperature rose or fell.

5 Did the temperature reach a steady value after some time? Discuss why you think this.

Conclusion

Suggest how the method used in this investigation could be changed to improve the accuracy of the results.

16.3 Factors affecting reaction rate

INVESTIGATION

Aim

To investigate the rates of a reaction between hydrochloric acid and calcium carbonate.

Risk assessment
16.3 Factors affecting reaction rate

Lab tech notes
16.3 Factors affecting reaction rate

CAUTION! Wear protective gloves, a laboratory coat and safety glasses throughout this investigation. Avoid contact with the acid solutions because they are corrosive. If acid comes into contact with your skin, wash it with water immediately.

Materials

- 30 g small marble chips (calcium carbonate) of similar size
- 20 mL of 0.5 M hydrochloric acid (HCl)
- 20 mL of 1.0 M HCl
- 20 mL of 2.0 M HCl
- Electronic balance
- Stopwatch
- 25 mL measuring cylinder
- 3 × 100 mL conical flasks

Method

1 Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of identical-sized marble chips into the flask.

2 Using a measuring cylinder, add 20 mL of 0.5 M HCl to the conical flask still sitting on the electronic balance. Immediately tare the balance once so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero, as gas is given off.

3 Record in your results table (see Table 1) the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

Inquiry

Choose one of the following questions to investigate.

- What if the marble chips were smaller?
- What if the acid was more concentrated?

Answer the following questions in relation to your inquiry.

- Construct a hypothesis for your investigation.
- What independent variable are you investigating?
- How will you measure your dependent variable?
- Name three variables that you will control. How will you control them?
- Write your method step by step and check it with your teacher.
- Is this investigation safe?
- What personal protective equipment will you need?
- How will you record your results? Will the results be quantitative or qualitative?

Show your teacher your planning for approval.

Results

1 Complete Table 1.

2 Plot a graph of the mass loss by minutes to record your observations.

Discussion

1 Write a balanced chemical equation for the chemical reaction.

2 Describe the relationship between your independent variable and dependent variable as shown by your graph.

3 Is the hypothesis supported by the results?

4 Name two possible sources of error in your investigation. How could you improve the quality of the evidence that was obtained in the investigation?

Conclusion

Write a conclusion of your investigation that includes a general statement that summarises the evidence that supports your hypothesis.

Table 1 Results

	Independent variable (time)								
Dependent variable (mass loss)	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min

16.4 Using a catalyst

INVESTIGATION

Aim

To investigate the effect of adding a catalyst to a reaction.
The reaction used in this investigation is the decomposition of hydrogen peroxide:
$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

Risk assessment
16.4 Using a catalyst

Lab tech notes
16.4 Using a catalyst

CAUTION! Wear protective gloves, a laboratory coat and safety glasses throughout this investigation. Avoid contact with hydrogen peroxide.

Materials

- Hydrogen peroxide (H_2O_2) solution (10 mL)
- Manganese dioxide (MnO_2) powder
- Test tubes and test-tube rack
- Spatula

Method

1 Place 5 mL of hydrogen peroxide solution into two separate test tubes.

2 Allow one of the tubes to stand; add a small amount of manganese dioxide to the other test tube using a spatula.

3 Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1 Was there any evidence of reaction in the test tube in which manganese dioxide was not added?

2 Would you say that the manganese dioxide acted as a catalyst in this reaction? Justify your answer.

Conclusion

What do you know about how catalysts affect the rate of a reaction?

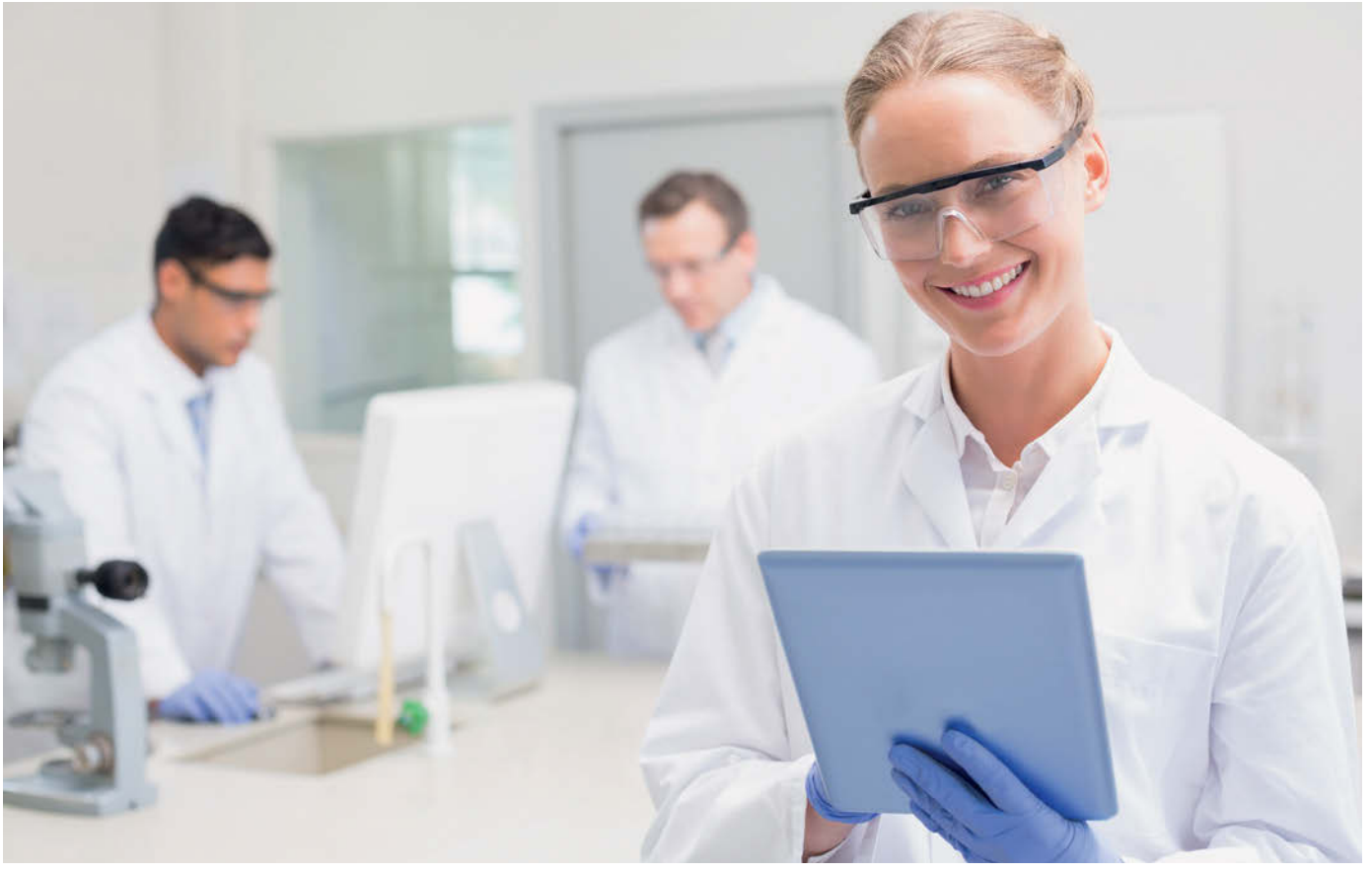


Figure 1 This investigation requires a lab coat, gloves and safety glasses.

GLOSSARY

A

abiotic
all the non-living components of an ecosystem; for example, light, temperature and water

absolute dating
a method that uses the amount of radioactivity remaining in the rock surrounding the fossil to determine its age

absolute magnitude scale
a scale for measuring the brightness of objects from the same distance; used to compare the actual brightness of different stars

absorption spectrum
a spectrum with lines missing from the pattern; the opposite of an emission spectrum because the element has absorbed its characteristic light wavelengths and removed them from the spectrum

acceleration
rate of change of velocity; rate of change of speed if the motion is in a constant direction

acceleration due to gravity
the acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8$ or 10 m/s^2

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

adenine
a nucleotide of DNA or RNA; complementary to thymine in DNA and uracil in RNA

aerobic respiration
chemical reaction that transfers energy to cells

alkali
a base that dissolves in water

alkali metals
the group of elements found in group 1 of the periodic table

alkaline earth metals
the group of elements found in group 2 of the periodic table

alkaline solution
a solution that contains a base

allele
a version of a gene. Each person inherits one allele from each parent

allopatric speciation
speciation caused by physical separation of populations

alpha
a radioactive particle containing two protons and two neutrons; can be stopped by a piece of paper

ammeter
a device that measures the current travelling through a particular point in an electric circuit

ampere
unit of electric current; 1 ampere is equal to 1 coulomb of charge passing a given point in one second

amplitude
the distance a particle moves from its position of rest

analogous structure
a structure that is found across organisms and performs the same function but is structurally different

angle of incidence
the angle between the incident ray and the normal (the line drawn at right angles to a reflective surface)

angle of reflection
the angle between the reflected ray and the normal (the line drawn at right angles to a reflective surface)

angle of refraction
the angle between the refracted ray and the normal (the line drawn at right angles to a refractive surface)

anion
a negative ion that results from an atom gaining electrons

antibiotics
a medicine used in the treatment of bacterial infections

antibody
a specific molecule produced by B cells that binds to a pathogen

apparent magnitude scale
a scale for measuring the brightness of an object when viewed from the Earth

artificial selection
when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

atmosphere
layer of gases that surrounds Earth and other planets

atom
the basic unit of a chemical element

atomic number
the number of protons of an atom

atomic theory
the theory that all matter is made up of atoms

autonomic nervous system
the part of the nervous system that controls involuntary actions such as heartbeat, breathing and digestion

autosome
a chromosome that does not determine the sex of an organism

axon
the part of a neuron (nerve cell) that carries the electrical message away from the cell body to the synapse

B

B cell
an immune system cell that produces antibodies in response to pathogens

behavioural isolation
when a species displays different behaviours, for example reproductive rituals

beta
a radioactive particle (high-speed electron or positron) with little mass; can be stopped by aluminium or tin foil

Big Bang theory
the theory that the universe began from a hot, dense state at some time in the past, from when it has continued to expand and will continue to do so into the future

binary fission
form of asexual reproduction used by bacteria

biodegradable
an object or a substance that can be broken down by bacteria, fungi and other living organisms

biogeography
the study of the geographical distribution of animals and plants

biological control
releasing a living organism (a parasite or consumer) into an ecosystem in order to control a population

biotic
all the living organisms in an ecosystem

biosphere
the intersection between the atmosphere, hydrosphere and lithosphere, where all living things are found

bivalent chromosome
a chromosome that has duplicated, consisting of two sister chromatids joined at a centromere

black dwarf
a remnant formed when a white dwarf star cools and gradually fades away

black hole
a region in space of infinite density where gravity is so large that nothing can escape from it, including light itself

blue shift
apparent decrease in wavelength with a corresponding increase in frequency

Bohr model of the atom
a way to represent the electrons of an atom in a series of shells around the atomic nucleus

brain
the primary organ of the central nervous system consisting of soft nervous tissue and contained in the skull of vertebrates

C

capture–recapture
a method of estimating the number of organisms in an ecosystem by capturing, marking and releasing organisms

carbon farming
the process of growing plants that are not harvested for firewood, building or any other purpose

carbon sink
any feature of the environment that absorbs and/or stores carbon

carbon tax
a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme
the process of allocating a set limit of carbon credits to businesses that can then be traded

carrier
a person who is heterozygous and therefore has one recessive allele that is not expressed in their phenotype

catalyst
a substance that increases the rate of a reaction but is not used up in the reaction

cation
a positive ion that results from an atom losing electrons

cell body (soma)
the main part of a cell that contains the nucleus/genetic material

cellular respiration
see aerobic respiration

central nervous system
the brain and spinal cord

chemical bond
an attraction between atoms or ions that allows for the formation of chemical compounds

chlorophyll
a molecule (enzyme) found in chloroplasts that is used to speed up photosynthesis

chromatid
one half of a duplicated chromosome

circuit diagram
a diagrammatic way to represent an electric circuit

claim
a statement that asserts that something is the case, without necessarily providing proof

climate
weather conditions at a particular place over a long period of time based on the collection and analysis of large amounts of data

coal washing
the process of 'cleaning' coal with water and chemicals to remove sulfur and other impurities before it is burned at a coal power plant

codon
sequence of 3 nitrogen bases in RNA

coefficient
tells us how many of each compound is either needed or produced in a chemical reaction

collision theory
a theory that states that particles involved in a chemical reaction must collide in order to react

combustion
an exothermic reaction between a fuel and oxygen that produces heat, carbon dioxide and water

commensalism
a relationship between two organisms from different species, in which one organism benefits and the other organism is not affected

community
different populations living in the same place at the same time

competition
a relationship between organisms using the same limited resources in an ecosystem

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand. Adenine pairs with thymine, and cytosine pairs with guanine

compression
a part of a sound wave where air particles are forced close together

concave mirror
a mirror in which the centre goes in, and it converges the incident rays

conduction
transfer of thermal energy involving direct contact with no movement of material

continental crust
thick part of the Earth's crust which forms the basis of the large land masses

continental drift
the continual movement of the continents over time

continental shelf
underwater cliffs between the beach and the ocean

convection
the transfer of heat energy through particles

convection currents
the movement of energy from one place to another

converge
when rays of light move towards a single point

convergent boundary
the boundary between two tectonic plates that are moving together

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

converging
moving together

convex mirror
a mirror in which the centre sticks out, and it diverges the incident rays

core
the centre of the Earth

Coriolis effect
the influence of the Earth's rotation on the direction of air or water movement

corrosion
the gradual destruction of materials by a chemical reaction with their environment

cosmic microwave background radiation
form of electromagnetic radiation in the microwave spectrum left over from the formation of the universe; evidence of the Big Bang theory

critical angle
the angle of incidence when the refracted angle is 90°

crust
lithosphere; the outer layer of the Earth

cytosine
a nucleotide of DNA or RNA; complementary to guanine

D

deceleration
slowing down; also known as negative acceleration

deciduous
a type of plant that loses its leaves during the cooler months, to conserve energy when there is less sunlight; annual shedding of leaves

decomposers
organisms, such as bacteria and fungi, that feed on other dead organisms

decomposition
a reaction where a compound breaks down into two or more elements

dendrite
the part of a neuron (nerve cell) that receives the message and sends it to the cell body

denitrifying bacteria
bacteria that convert nitrates in soil to free atmospheric nitrogen

deoxyribonucleic acid (DNA)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

dependent variable
the variable being tested in an experiment

derived units
units of measurement that are calculated from the international system of units; for example, volume (cm^3) and area (cm^2)

diploid
a nucleus that contains two complete sets of chromosomes

displacement
a vector quantity that measures the change in position of an object and its direction over a certain period of time

distance
how far an object has travelled in a set time

diverge (light)
when rays of light move away from each other

diverge (speciation)
two species can experience different selection pressures, and gradually become more different; may lead to the two species becoming reproductively isolated

divergent boundary
the boundary between two tectonic plates that are moving apart

diverging
moving apart

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

Doppler effect
the apparent change in wavelength (or frequency) when the source of the waves or the observer is moving; responsible for the red shift of distant stars

E

ecosystem
a number of communities together with the surrounding non-living factors

ectotherm
an animal that is unable to regulate its own body temperature

elastic potential energy
the energy possessed by stretched or compressed objects

electric circuit
a closed pathway that conducts electrons in the form of electrical energy

electric current
the rate of motion carried from one part of a conductor to another

electromagnetic spectrum
a range of electromagnetic waves with different wavelengths and energies

electron
a negatively charged subatomic particle that moves in the space around an atomic nucleus

electron shell
the area of space around a nucleus where a specific electron may be found

electronic configuration
the distribution of electrons of an atom or molecule in atomic or molecular orbitals

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

endocrine system
a collection of glands that make and release hormones

endotherm
an animal that regulates its own body temperature

endothermic reaction
a chemical reaction that absorbs energy in the form of heat

energy efficiency
a measure of how much input energy is transformed, rather than lost (via sound or heat)

enhanced greenhouse effect
the additional effect that humans are having on the natural greenhouse effect due to the burning and release of fossil fuels

enzyme
a catalyst that is used in living cells

epicormic bud
a small growth beneath the bark of a plant that allows regeneration after a fire

epidemic
a widespread outbreak of an infectious disease that is typically isolated to a specific region

epigenetics
the study of how gene expression is influenced by the environment

eutrophication
a process whereby excessive levels of phosphorus in waterways lead to the excess growth of algae and bacteria and an increased consumption of oxygen, suffocating fish and other aquatic animals

evaporation
the process of liquid water gaining thermal energy and changing into gas

evolution
the permanent change in the frequency of alleles in a population due to natural selection

evolutionary relationship
a relationship that is based on distant common ancestry

exothermic reaction
a chemical reaction that releases energy in the form of heat or light

F

fault
a fracture in rock where the tectonic plates have moved

feedback mechanism
a feedback loop where the system responds to a particular stimulus; can be positive or negative

fight, flight or freeze
a stress response that helps an organism to react to perceived threats

filter
a transparent material that allows some wavelengths of light to pass through

focal length
the distance from the middle of the lens to the focus

focus
the point where rays of light cross

force
a push or pull that acts on an object as a result of interacting with another object; a vector quantity

fossil
the remains or traces of an organism that once existed

fossilisation
the process of an organism becoming a fossil

frequency
the number of waves that pass a point every second; measured in hertz

fuel
a substance that undergoes a chemical reaction to produce a large amount of energy at a fast but controllable rate

fuse
a wire of high resistance; it will melt if too much current flows through the circuit

G

galaxy (galaxies)
a system of billions of stars, gas and dust that is held together by gravity

galvanising
to coat iron or steel in a layer of zinc for protection

gamete
a sex cell containing half the number of chromosomes of other body cells

gamma
high-energy electromagnetic rays released as a part of radioactive decay; can be stopped by lead

gene
a specific sequence of DNA that codes for a particular trait, usually a protein

gene pool
all the genes or alleles in the entire population

gene probe
short sections of nucleotides known to be complementary to the genetic sequence of interest

genetic code
the sequence of nucleotides found in DNA that is inherited from parents

genetic mutation
a permanent change in the sequence of nucleotides in DNA

genetic screening
the testing of a cross section of individuals to determine whether they have a particular trait or disease

genetic testing
the testing of an individual to determine whether they have a particular trait or disease

genotype
the combination of alleles for a particular trait

geographic isolation
the isolation of populations based on geography, for example, mountains and rivers

geosequestration
the capture and storage of carbon underground

germ theory
the current accepted theory that explains that pathogens cause infectious diseases

gravitational potential energy
the energy possessed by objects raised to a height in a gravitational field

gravity
a force that attracts mass towards mass; for example, mass towards the centre of the Earth

group
a vertical list of elements found in the periodic table that have characteristics in common

guanine
a nucleotide of DNA or RNA; complementary to cytosine

H

half-life
the time it takes for half the nuclei of a radioisotope to decay

halogens
the group of elements found in group 17 of the periodic table

haploid
a nucleus that contains one complete set of chromosomes; usually found in a gamete

hertz
the unit used to measure frequency

Hertzsprung–Russell diagram
graph displaying star data with spectral class or star temperature on the x-axis and absolute magnitude on the y-axis

heterozygous
having two different alleles for a particular trait; a carrier for the recessive trait

hibernation
an extended period of inactivity, typically in response to colder conditions

homeostasis
the process by which the body detects and responds to stimuli to ensure a stable internal state is maintained

homologous structure
a structure that is found across organisms and has a similar pattern but different function

homozygous
having two identical alleles for a particular trait

horizontal transfer
the transfer of genetic material (usually containing antibiotic resistance) between different bacteria

hormone
a chemical messenger that travels through blood vessels to target cells

human immunodeficiency virus (HIV)
a virus that infects white blood cells inhibiting the third line of defence which if untreated leads to AIDS

hydrocarbon
a compound of hydrogen and carbon

hydrosphere
collection of all the Earth's water

hydrostatic equilibrium
this refers to a condition where the forces become balanced resulting in some form of stability

hydrotropism
the growth or turning of plant roots towards or away from moisture

hypothesis
a proposed explanation for phenomena that can be tested

I

immune
able to fight an infection as a result of prior exposure

immune system
a system of organs and structures that protect an organism against disease

independent variable
the variable that is deliberately changed or tested during an experiment

indicator
a substance that changes colour in the presence of an acid or a base

inertia
the tendency of an object to resist changes in its motion while either at rest or in constant motion

inhibition
competition that occurs when an organism stops the growth or development of another organism by producing a chemical; the slowing of a process

inoculation
the introduction of a pathogen, usually weakened, into a host

interneuron
a nerve cell that links sensory and motor neurons; also known as a connector neuron

ion
a charged atom that results from an unequal number of electrons and protons

isobar
a line drawn on a weather map that joins places of equal air pressure

isolation
the division of a population into two groups

isotope
an atom that has more or less neutrons in its nucleus

K

karyotype
the arrangement of a complete set of chromosomes in pairs of decreasing size

kinetic energy
the energy possessed by moving objects

Kyoto Protocol
an international treaty which commits parties of the United Nations to reduce greenhouse gas emissions

L

law of conservation of energy
a scientific law that states the total energy in a system is always constant and cannot be created or destroyed

lens
a curved piece of transparent material

light-year
the distance that light travels in 1 year

lignotuber
a small growth in the root of a plant that allows regeneration after a fire

lithosphere
outermost rocky layer of the Earth, consisting of the mantle and crust

litmus paper
a paper containing an indicator that turns red when exposed to an acid and blue when exposed to a base

living fossil
an existing species of ancient lineage that has remained unchanged in form for a very long time

logbook
a book used to record all information relating to experiments or investigations

longitudinal wave
a type of (sound) wave where the particles move in the direction of travel of the wave

luminosity
the actual brightness of a star; see absolute magnitude scale

M

magnetometer
an instrument that measures changes in the Earth's magnetic field

magnitude
the size or extent of something

mantle
the layer of molten rock located beneath the Earth's crust

mass number
the number that represents the total number of protons and neutrons in the centre of an atom

matter
physical substance made of atoms

mean
the average of a set of data

mechanical isolation
when two mates are physically incompatible

median
the middle data in a set that has been ordered by increasing value

medium
a substance or material through which light can move

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

metal oxide
a molecule containing a metal and oxygen

metalloids
a small collection of elements that have a mixture of characteristics of metals and non-metals

metals
a collection of elements found on the left-hand side and centre of the periodic table that are malleable, lustrous, ductile and highly conducting

microwaves
a part of the electromagnetic spectrum

mid-ocean ridge
a series of underwater mountains that form as a result of tectonic plates moving apart and allowing magma to rise to the surface

migrate
the movement of an animal from one region to another, typically in response to changing seasons

Milky Way
a barred spiral galaxy that contains our solar system

mode
the most frequently occurring data in a set

motor neuron
a nerve cell that carries a message from the central nervous system to a muscle cell

mutagen
a chemical or physical agent that causes a change in DNA

mutation
a permanent change in a sequence of DNA

mutualism
a relationship between two organisms of different species in which both organisms benefit

myelin sheath
a fatty layer that covers the axon of a nerve cell

N

natural active immunity
immunity that is gained from having been exposed naturally to a particular pathogen

natural selection
the process by which individuals with favourable traits are 'selected' by nature

nebula (nebulae)
a cloud of gas and dust in space; a star nursery

negative feedback mechanism
a regulatory loop in which the stimulus causes a response that acts in the opposite direction to whatever is being regulated

net force
the vector sum of all the forces acting on an object; also known as resultant force

neurotransmitter
a chemical messenger that moves across the synapse between the axon of one neuron and the dendrite of another neuron

neutral
(pH 7) neither an acid nor a base; for example, water

neutralisation reaction
a reaction between an acid and a base that produces water and a salt

neutron
a neutral (no charge) subatomic particle in the nucleus of an atom

neutron star
a small, highly dense star, made mostly of neutrons

Newton's first law
Newton's first law of motion states that an object will remain at rest and will not change its speed or direction, unless it is acted upon by an outside, unbalanced force; also known as the law of inertia

Newton's second law
Newton's second law of motion describes how the mass of an object affects the way it moves when acted upon by one or more forces. It is often expressed as $F = ma$ (F = total force on the object; m = mass of the object; a = acceleration)

Newton's third law
Newton's third law states that for every action force, there is an equal and opposite reaction force

nitrogen cycle
nitrogen moves through living and non-living things by changing forms

nitrogen-fixing bacteria
bacteria that convert nitrogen from the atmosphere into various nitrogen compounds

noble gases
a collection of gaseous elements found in group 18 of the periodic table

non-metals
a collection of elements that are found on the right-hand side of the periodic table

non-specific immune response
a general response that acts to stop any pathogen that has gained entry to the body

normal
an imaginary line that is drawn at right angles to the surface of a reflective or refractive material

nova
a star showing a sudden large increase in brightness and then slowly fading away to its original state in a few months or years

nuclear fusion
a high-energy reaction in which two lighter atomic nuclei fuse to form a heavier nucleus

nucleotide
the building block of DNA consisting of a deoxyribose sugar, phosphate and nitrogen base

nucleus
(chemistry) the centre of an atom that contains protons (positive) and neutrons (no charge)

O

ocean trench
a deep ditch under the ocean along a tectonic plate boundary

Ohm's law
a law stating that electric current is proportional to voltage and inversely proportional to resistance

opaque
a substance that does not allow light to pass through

optic fibre
a thin fibre of glass or plastic that carries information and/or data in the form of light

outlier
a value that is outside the normal range of all other results

ovum
the female gamete of animals and some plants

P

pandemic
a widespread outbreak of an infectious disease that is spread across multiple global regions

parallax error
an error that occurs when the reader's eye is not placed directly opposite a mark

parallel
the positioning of loads (e.g. lights) in an electric circuit so that they are connected to the battery separately; they are in parallel to each other

parasitism
a relationship in which one organism (parasite) benefits and the other organism (host) is harmed

pathogen
an infectious-disease-causing agent

pedigree
a diagram showing the inheritance pattern of a particular trait

pentadactyl limb
a limb with five digits

peptide hormone
a hormone made from proteins

period
a horizontal list of elements found in the periodic table

periodic table
a table that places elements in order of their atomic number and groups them according to similar properties

peripheral nervous system
all the neurons (nerve cells) that function outside the brain and spinal cord

permafrost
ground that has been frozen since the last ice age; stores carbon

pH scale
a scale that represents the acidity or basicity of a solution; pH < 7 indicates an acid; pH > 7 indicates a base; pH 7 indicates a neutral solution

phagocyte
an immune system cell that surrounds, absorbs and destroys pathogens

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

photolysis
the breakdown of a chemical substance by light, one example being the breakdown of water into oxygen and hydrogen

photosynthesis
the process in plants in which glucose is produced from water and carbon dioxide

phototropism
the process where a plant's cells in the dark expand to bend the plant towards a light source; the growth or turning of a plant towards or away from light

planetary nebula
a glowing shell of gas formed when stars die

plate tectonics
the theory that the surface of the Earth is divided into a series of plates that are continually moving

polymers
giant molecules made from the joining of many smaller molecules

population
a group of the same species living in the same place at the same time

potential difference
voltage; the difference in the electrical potential energy carried by charged particles at different points in a circuit

precipitate
an insoluble compound formed in a precipitation reaction

precipitation
the process in which water vapour in the upper atmosphere becomes liquid water in the form of rain, snow or sleet and falls to the ground

precipitation reaction
a reaction where two soluble ionic solutions mix to form an insoluble substance as a product

primary colours of light
the three colours of light (red, blue and green) that can be mixed to create white light

principle of independent assortment
the inheritance of one set of factors from one parent is separate from the inheritance of other factors

principle of segregation
pairs of gene variants are separated into reproductive cells

product
the substances formed by a chemical reaction

proton
a positively charged subatomic particle in the nucleus of an atom

Punnett square
a diagram that is used to predict the outcome of breeding organisms

Q

quadrat
a randomly selected square plot used to estimate the number of organisms in an ecosystem

R

radiation
the transfer of energy through waves

radioactive decay
the conversion of a radioactive isotope into its stable form, releasing energy in the form of radiation

radionuclide
a radioactive isotope

rarefaction
a part of a sound wave where air particles are forced apart

reactant
the substances present at the start of a reaction and that undergo change during a chemical reaction

reaction rate
how fast or slow a reaction proceeds

reading error
an error that occurs when markings on a scale are not read correctly

receptor
a structure that detects a stimulus or change in the normal functioning of the body

recessive trait
a characteristic that results from the inheritance of two identical alleles

red giant
a large, bright star with a cool surface that forms when a star like our Sun runs out of hydrogen fuel

red shift
apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

reflex
an involuntary movement in response to a stimulus

refracted ray
a ray of light that has bent as a result of light speeding up or slowing down

refraction
the bending of light as a result of light speeding up or slowing down

refractive index
a measure of the bending of light as it passes from one medium to another

relative atomic mass
the average mass of an element that includes the mass and prevalence of its different isotopes

reliable
a test, research or experiment that consistently achieves the same results

resistance
a measure of how difficult it is for the charged particles in an electric circuit to move

resistor
a device that has opposition to an electric current

ribonucleic acid (RNA)
a complementary copy of DNA that is able to carry the genetic message from the nucleus to the cytoplasm

Richter scale
a scale used to express the magnitude of an earthquake, based on recordings of a seismometer

rift valley
a deep valley that forms as a result of tectonic plates moving apart

risk assessment
undertaken by scientists before conducting research and recognises any hazards and how to manage these safely

rounding off
reducing the number of significant figures by increasing or decreasing to the nearest significant figure; for example, 7.6 cm is rounded up to 8 cm, 7.2 cm is rounded down to 7 cm

S

Safety Data Sheet (SDS)
a document that anticipates, recognises and controls any chemical safety hazards in an experiment

salts
formed in a reaction between an acid and a base; a substance that contains a metal cation and a non-metal anion

sample size
the number of subjects being tested or used in an experiment

scalar quantity
quantity that has magnitude (size)

sea-floor spreading
a theory that the middle of the ocean is spreading apart, forming new oceanic crust

secondary colours of light
the colours of light (magenta, cyan and yellow) that result from the mixing of two primary colours of light

seismic surveys
a method for gaining information about the layers of the Earth where sound waves are sent into the Earth, and the time it takes for them to return is recorded

seismometer
a device that responds to ground motions

selection pressure
environmental factors that affect an organism's ability to survive

selective breeding
the breeding of individuals with desirable traits

sensory neuron
a nerve cell that carries a message from a receptor to the central nervous system

series
the positioning of loads (e.g. lights) side by side in an electric circuit so that the electrical energy passes through one load at a time

sex chromosome
a chromosome that determines the sex of an organism

shell diagram
a diagram that shows the arrangement of electrons and electron shells in an atom

short circuit
when electrical current flows along a different path from the one that was intended

SI system
international system of units based on the metric system; for example, kilogram, metre, kilometre

significant figures
the number of digits that contribute to the overall value of a number

singularity
a point at which a function takes an infinite value, for example, in space-time when matter is infinitely dense, such as the centre of a black hole

solar system
the eight planets, and their moons, that orbit the Sun, including gas or dust

somatic nervous system
the part of the nervous system that controls the muscles that are attached to the skeletal system

sonar
the recoding of how long it takes a sound wave to reflect or echo back to its starting point after it hits an object; it is used to detect the location of things, for example, a submarine

speciation
the process that results in the creation of a new species

speed
the distance travelled per unit of time

speed of sound
the speed that a sound wave travels through a medium at a certain temperature

sperm
the male gamete of animals

spinal cord
the cylindrical bundle of nerve fibres and associated tissue which is enclosed in the vertebrae

star
an object in space that is made of hydrogen and helium, and which is luminous in the sky

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions

stem cell
a cell that can produce a number of different types of cells. Adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce multiple types of cells

steroid hormone
a hormone secreted by the adrenal glands and ovaries (females) and testes (males). They are produced from cholesterol

stimulus
any information that the body receives that causes the body to respond

stomata
small pores (openings) on a leaf surface used in the control of water and gas movement

subduction
the movement of one tectonic plate under another tectonic plate

supernova
an explosive death of a star

survival of the fittest
individuals with favourable traits are more likely to survive and pass on these traits

symbiosis
a close physical relationship that occurs over a long time between two members of different species

sympatric speciation
speciation caused by reproductive separation of populations that maintain physical contact

synapse
a small gap between two neurons that must be crossed by neurotransmitters

synaptic terminal
a bulb at the end of the axon of a neuron which stores and releases neurotransmitter molecules to stimulate the following neuron

synthesis
the combination of two or more substances to form one compound

T

T cell
an immune system cell that recognises and kills pathogens

target cell
a cell that has a receptor that matches a specific hormone

tectonic plate
a large layer of solid rock that covers part of the surface of Earth; movement of tectonic plates can cause earthquakes

telescope
an optical device that is used to make distant objects appear closer, through the use of specifically arranged lenses and light

temporal isolation
when different populations reproduce at different times

Thomson plum pudding model
an early model of an atom that suggested that the positively charged nucleus had negatively charged electrons scattered through it (like a plum pudding)

thymine
a nucleotide of DNA; complementary to adenine

total internal reflection
when a light ray passes from a more dense material at a large angle, it can be reflected back into the dense medium

transcription
the formation of complementary RNA from DNA

transform
to change form; tectonic plates transform when they slide past each other

transform boundary
the boundary between two tectonic plates that are sliding past each other

transition metals
the elements found in groups 3–12 of the periodic table

transitional fossil
a fossil or an organism that shows the intermediate state between an ancestral form and that of its descendants; also known as a 'missing link'

translation
the formation of a protein from RNA; occurs on a ribosome

translucent
a substance that allows light through, but it diffuses so that objects cannot be seen clearly

transmit
to allow light to pass through

transpiration
the process of water evaporating from plants

transverse wave
a type of wave where the vibrations are at right angles to the direction of the wave

tsunami
a series of large waves that result from an underwater earthquake

U

universal indicator
a solution that is used to determine the pH (amount of acid or base) of a solution

universe
the collection of everything in existence; including solar systems, galaxies and stars

V

vaccination
an injection of an inactive or artificial pathogen that results in the individual becoming immune to the disease

valence shell
the outermost electron shell in an atom that contains electrons

valid
a test, research or experiment that correctly tests what it was designed to test

variable
anything that can change the outcome or result of an experiment

variation
differences that exist between individuals

vector
an agent (often a bacteria or virus) used to deliver a trans-gene

vector quantity
quantity that has size and direction (e.g. velocity, displacement)

velocity
the vector quantity that measures speed in a particular direction

vestigial structure
a structure in an organism that no longer has an apparent purpose

virtual focus
the point from which the rays of light seem to come

virtual image
an image that appears in a mirror; it cannot be captured on a screen

visible spectrum
the variety of colours or wavelengths of light that can be seen by the human eye

voltage
potential difference; the difference in the electrical potential energy carried by charged particles at different points in a circuit

W

water vapour
a gaseous form of water

wavelength
the distance between two crests or troughs of a wave

weather
a snapshot of what the air and conditions are like in any one place on the Earth at any one time

white blood cell
an immune system cell that destroys pathogens

white dwarf
a small, hot star that forms when a star like our Sun runs completely out of fuel and slowly fades and cools

wind
the sideways movement of air as a result of lower density warm air rising through the atmosphere

Z

zero error
an error that occurs when an instrument has not been adjusted to zero before the measurement was taken

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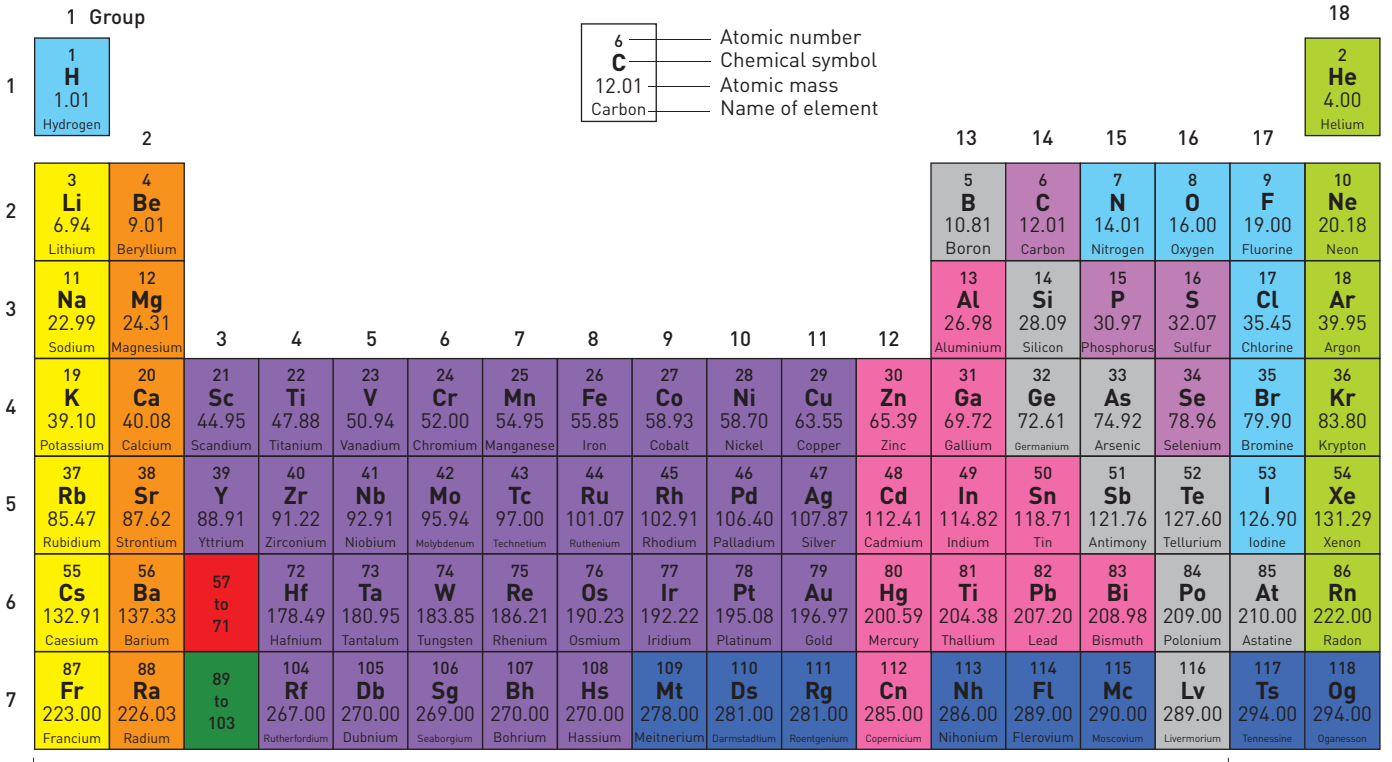
NOTES

PERIODIC TABLE



A volcanologist wearing a heat suit watching an eruption of ash, vapours and glowing lava (i.e. molten rock) from Mount Etna.

Lava can range in temperature from 475°C to 1150°C and changes colour from glowing red to white as it becomes hotter. The suit is designed to protect the scientist from this heat. Other dangers on the slopes of a volcano include poisonous gases, like hydrogen sulphide, and lava bombs (i.e. chunks of molten rock ejected by the volcano).

Mount Etna stands 3323 metres tall on the Italian island of Sicily. It is the largest active volcano in Europe.

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