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VICTORIAN CURRICULUM VERSION 2.0

Third Edition

OXFORD SCIENCE
Victorian Curriculum

10

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VICTORIAN
CURRICULUM
VERSION
2.0

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Contents

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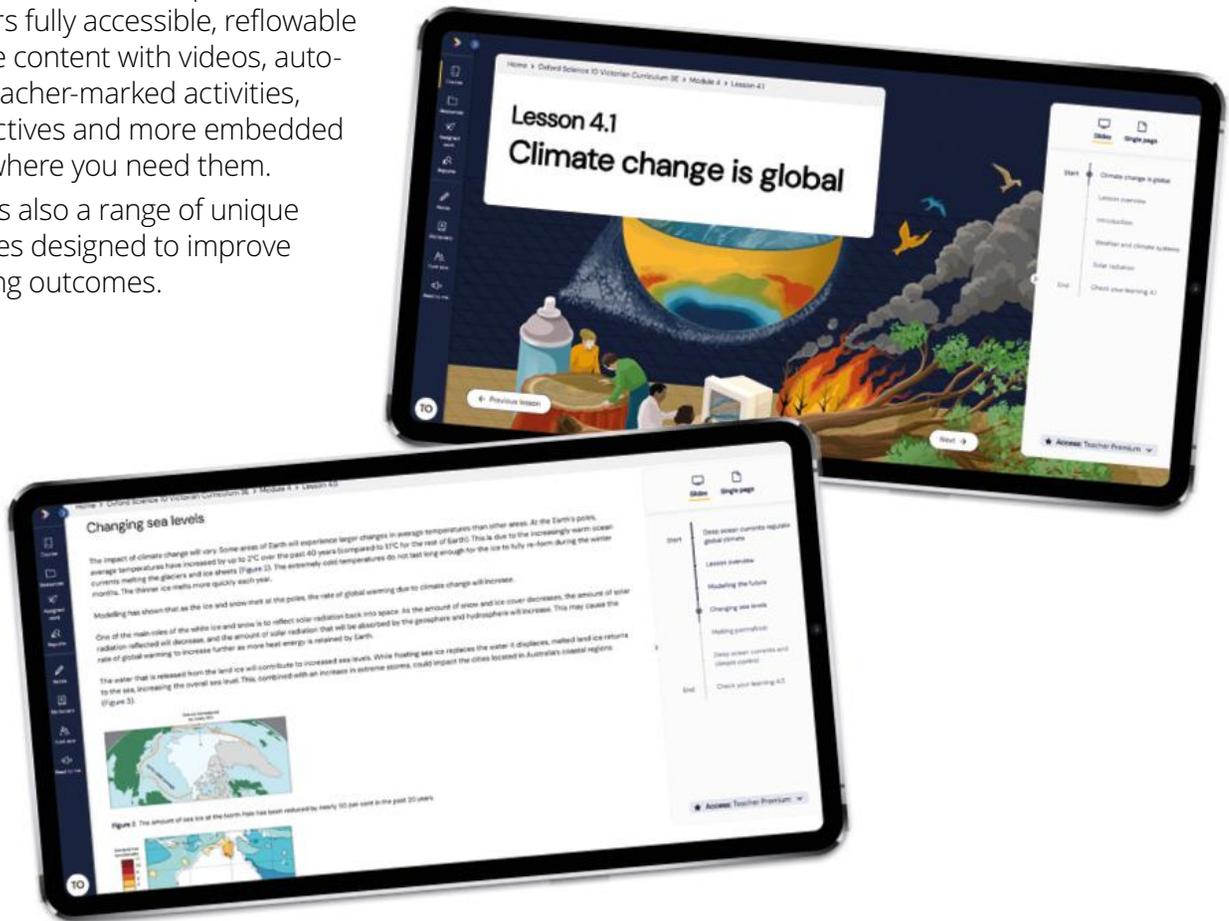
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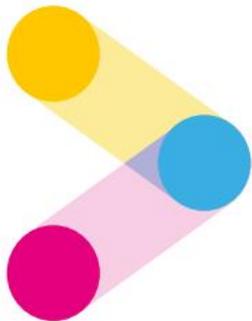
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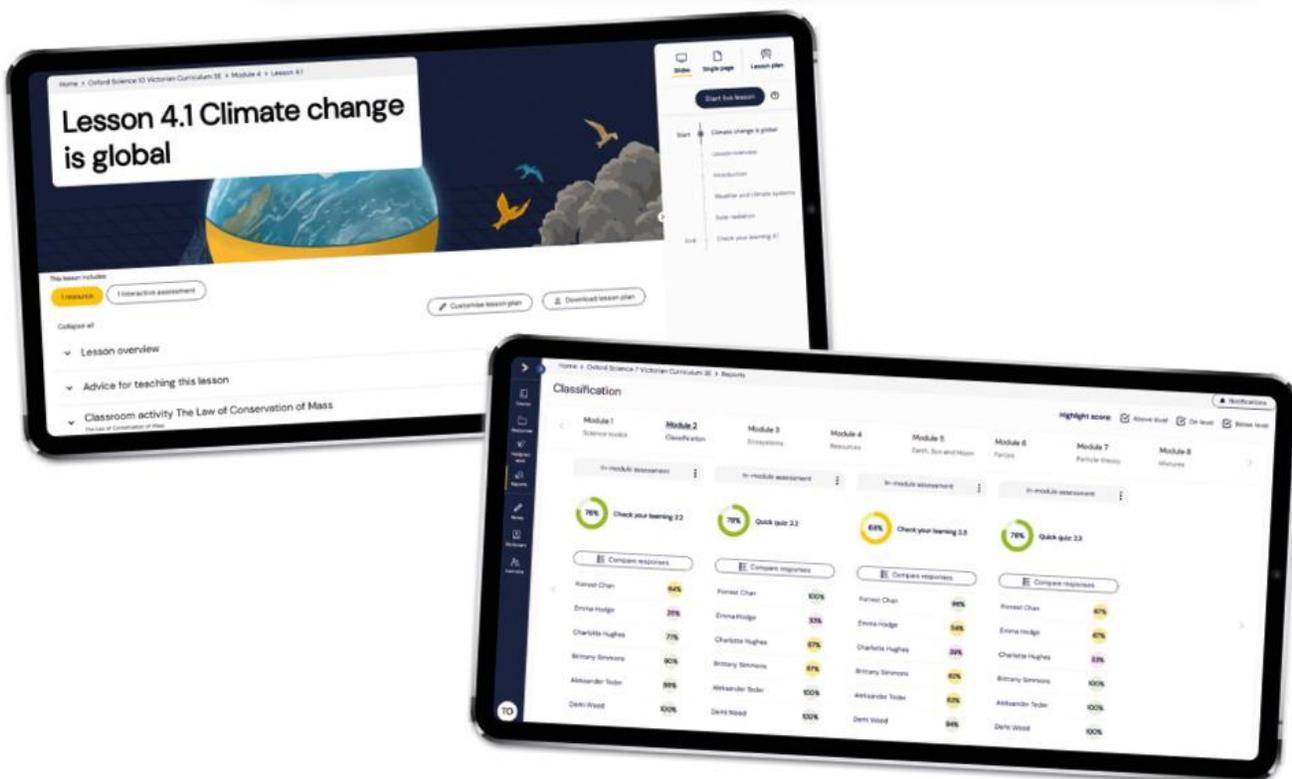
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Module

1

Science toolkit

Overview

Scientists must ensure that their investigations follow the scientific method so that their methodology is reliable and the results accurate and valid. This allows other scientists to repeat the investigation and obtain the same results to verify hypotheses and conclusions. The scientific methodology also helps scientists identify risks they could experience during an investigation and how they are mitigated.

To verify their data, scientists keep a logbook which includes dates, data, changes made and any errors they need to account for. This ensures that scientists take any outlier data into account when completing calculations, as well as identifying the effect of errors on their results. The data can then be analysed for any trends which help prove or disprove the hypothesis and support their conclusion. Most scientists will communicate their findings as a scientific report; however, a scientific poster is a concise way to communicate key information.

This Science toolkit includes all the content you need to learn as part of the Science Inquiry sub-strand of the Victorian Curriculum Version 2.0. You will be building on the skills covered in Years 7 and 8, while learning new aspects of the scientific method and how to communicate your findings.

Lessons in this module

Lesson 1.1

Scientists value the knowledge and skills of Aboriginal and Torres Strait Islander Peoples

Key ideas

→ Aboriginal and Torres Strait Islander Peoples have developed sophisticated science skills that enabled them to survive and thrive some of the most challenging environments in the world for tens of thousands of years.

→ Indigenous science sees everything as connected – the land, water, plants, animals and people are all part of one big system that remains in balance.

→ The scientific knowledge and skills of Aboriginal and Torres Strait Islander Peoples is now recognised and valued by Western scientists.

Learning intentions and success criteria

Australia is home to many Aboriginal and Torres Strait Islander Peoples

Australia is home to over 250 different Aboriginal and Torres Strait Islander Peoples, each with their own culture, customs, language, laws and knowledge systems.

Aboriginal and Torres Strait Islander Peoples – also known as First Nations Peoples – have lived in Australia and the islands of the Torres Strait for at least 65,000 years, making them the oldest surviving cultures in the world. Aboriginal and Torres Strait Islander cultures in Australia are incredibly rich and diverse. Although these groups are different and distinct, they share a deep connection to **Country**.

Country a term used by Aboriginal and Torres Strait Islander Peoples to describe the connections between land, water, sky, animals, plants, people, stories, songs, cultural practices and spiritual beliefs that make up a traditional area

The scientific knowledge and skills of Aboriginal and Torres Strait Islander Peoples developed as part of their connection to Country over tens of thousands of years. They cover a wide range of areas, such as:

- detailed local knowledge of weather patterns, seasons and tides (Figure 1)
- knowledge of the stars and astronomy
- bush food, medicine and healing
- detailed knowledge of natural resources and how to manage them sustainably
- the physics required to design, make and use a variety of tools.

The knowledge and traditions of Aboriginal and Torres Strait Islander Peoples suffered significantly after the English colonised Australia from 1788. Over many decades, government policies have had a devastating impact on Aboriginal and Torres Strait Islander Peoples. These policies have directly (and indirectly) removed people from their traditional lands, broken families up and prevented culture, knowledge, skills and language from being passed down from generation to generation. This includes passing down scientific knowledge and skills.

Despite the negative impacts of colonisation, the cultures, languages, beliefs, knowledge and skills of Aboriginal and Torres Strait Islander Peoples have survived and are still practised today. In fact, this knowledge is gaining recognition for its scientific rigour and relevance to modern-day challenges such as climate change and sustainability.

December

January

Kangaroo-apple season

November

Buathgurru
Grasses season

- Unpredictable warm weather, often with thunder.
- Days are long and nights are short.
- Fruits appear on kangaroo-apple bushes.

- Weather is warm and it rains a lot.
- Grasses flower.

Biderap
Dry season

February

- Hot and dry.
- Female common brown butterflies fly.

October

Poorneet
Tadpole season

- Weather gets warmer but rain continues.
- Lots of tadpoles appear.
- Days are the same length as the nights.

Iuk
Eel season

March

- Hot winds stop and weather cools down.
- Eels are fat and ready to catch.
- Days are the same length as the nights.

September

- Coldest days, longest nights and most rainfall of the year.
- Wombats come out to graze in the sun.
- Soft tree ferns are eaten when no fruits are available.

April

- Cold weather comes to an end.
- Orchids flower.
- Koalas begin mating.

Gulinga
Orchid season

August

Waring
Wombat season

May

July

June

Figure 1 The Wurundjeri people of the Kulin Nation in Victoria identify seven seasons in their calendar. These seasons are marked by changes in the weather, the life cycles of plants and animals, and the position of the stars in the sky at night.

Indigenous science

Aboriginal and Torres Strait Islander Peoples have developed sophisticated science skills that enabled them to survive and thrive some of the most challenging environments in the world for tens of thousands of years.

Over this time, Aboriginal and Torres Strait Islander Peoples created sophisticated systems for closely observing Country, identifying the similarities and differences between the individual parts and how they work together to create a balance. This approach to close observation, grouping and classification to identify patterns and balance has been passed down through storytelling that often models the consequences if balance is not maintained. Today, this body of knowledge and skills is referred to as **Indigenous science**.

While **Western science** often relies on comparative testing, it is recognised that the Indigenous approach to science – observation, classification, identification and modelling – is a unique way to approach the investigation of the natural world that is place-specific, producing knowledge that is tailored to a particular environment.

Indigenous science a system of knowledge developed by Aboriginal and Torres Strait Islander Peoples over tens of thousands of years that combines careful observation and testing of the natural world with cultural understanding to explain how things work and are connected in nature

Western science a system of knowledge based on careful observation, measurement, testing and experimentation (known as the scientific method) to develop and test hypotheses to explain how things work

The scientific knowledge and skills of Aboriginal and Torres Strait Islander Peoples is now recognised and valued by Western scientists. It is integral to current conversations and collaborations around some of the biggest scientific questions of today, such as sustainability, management of natural resources, food security and climate change.

Examples of Indigenous science

Aboriginal and Torres Strait Islander Peoples developed advanced scientific knowledge and skills that were integral to survival, cultural practices and management of the environment.

Astronomy

Aboriginal and Torres Strait Islander Peoples have a rich tradition of using the stars for navigation, timekeeping and cultural storytelling. Today, there are many Aboriginal and Torres Strait Islander Peoples who are sharing their knowledge with the wider community including Krystal de Napoli and Karlie Noon.

- **Navigation**: The stars, moon and constellations are used to navigate large distances across land and sea. For example, Torres Strait Islander Peoples use star maps for navigation at sea.
- **Seasonal calendars**: Many Aboriginal and Torres Strait Islander Peoples developed complex seasonal calendars based on the appearance of certain stars or constellations. For example, the Wardaman people of the Northern Territory associate the appearance of a star cluster known as the "Seven sisters" with the start of the wet season.
- **Predicting events**: Knowledge of lunar cycles and eclipses is used to predict environmental changes, such as tides and animal migrations.

Ecology and land management

Aboriginal and Torres Strait Islander Peoples developed sophisticated land and water management practices that have sustained ecosystems for thousands of years. Today there are Aboriginal and Torres Strait Islander Peoples who keep this traditional knowledge alive and collaborate with communities to teach traditional practices, including Victor Steffensen (Figure 2).

- **Cultural burning**: Aboriginal and Torres Strait Islander Peoples use controlled burning to manage landscapes, promote new growth and encourage biodiversity (Figure 3). This practice (also known as "cool burning" and "fire-stick farming") has shaped Australia's ecosystems.
- **Using resources sustainably**: Knowledge of plant and animal life cycles has ensured sustainable harvesting. For example, certain plants are only harvested at specific times to allow time for them to regrow.
- **Water management**: In dry regions, Aboriginal and Torres Strait Islander Peoples have developed techniques to locate and manage water sources, such as digging soakage wells or using natural indicators (e.g. bird behaviour) to find water.

Figure 2 Victor Steffensen, a Tagalaka man, is deeply committed to teaching cultural burning practices, through workshops and initiatives like the Firesticks Alliance. He shares this knowledge with both Indigenous and non-Indigenous communities, emphasising the importance of understanding the land's needs and fostering a healthier relationship with nature.

Medicine

Aboriginal and Torres Strait Islander Peoples have an extensive knowledge of medicinal plants and healing practices, developed through observation and testing.

- **Plant-based medicines**: Plants like eucalyptus, tea tree and kangaroo apple are used for their antiseptic, anti-inflammatory and healing properties (Figure 4). For example, eucalyptus leaves are used to treat respiratory conditions. Aboriginal and Torres Strait Islander Peoples also understood the dosage and preparation of medicinal plants, such as boiling, crushing and infusing, to maximise their effectiveness.
- **Healing practices**: "Ngangkari" (traditional healers) of the Ngaanyatjarra, Pitjantjatjara and Yankunytjatjara lands (in the remote western desert of Central Australia) combined physical treatments with spiritual healing to set broken bones and care for wounds.

Figure 3 Cultural burning in Kakadu National Park

Figure 4 Tea tree (*Melaleuca)* leaves and seeds are used for their antiseptic, anti-inflammatory and healing properties.

Engineering

Aboriginal and Torres Strait Islander Peoples developed tools, structures and technologies suited to their environments.

- **Tools and weapons**: Boomerangs, spears and spear-throwers were designed using principles of aerodynamics and physics. Boomerangs, for example, were crafted to return to the thrower or travel long distances, depending on their purpose (Figure 5).
- **Fish traps and aquaculture**: The Gunditjmara people of Victoria created traps and dug channels to catch and farm eels at Budj Bim Cultural Landscape – a UNESCO World Heritage site near Warrnambool in western Victoria (Figure 6).
- **Housing and shelter**: Structures like bark huts, stone houses and windbreaks were designed for insulation, ventilation and protection from the elements, reflecting an understanding of materials science and environmental conditions.

Figure 5 The Luritja and Pertame Peoples in Central Australia design and craft boomerangs, spears and spear-throwers.

Figure 6 The Gunditjmara people of Victoria dug these channels to catch and farm eels. These channels are at least 6,600 years old.

David Unaipon

The Australian $50 note features David Unaipon (Figure 7A), born in 1872 on the Lower Murray in South Australia, who was a member of the Ngarrindjeri people and is recognised for his contributions to science and technology and improving the lives of Aboriginal Australians.

Between 1909 and 1944, Unaipon submitted 19 provisional patents for his inventions; he could not afford to patent all of them. His inventions included a modified hand piece used in sheep shearing (Figure 7B), a centrifugal motor, a multi-radial wheel and a mechanical propulsion device (helicopter).

Even into old age, he worked to unlock the secrets of perpetual motion.
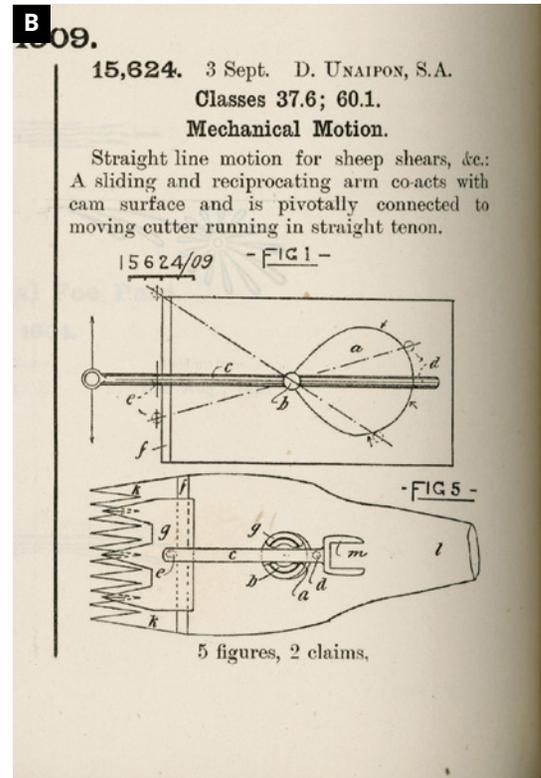
Figure 7 (A) David Unaipon features on the $50 bank note. (B) David Unaipon's patent for the modified hand piece used in sheep shearing.

Agriculture

Aboriginal and Torres Strait Islander Peoples practiced sustainable agriculture and developed methods to store and preserve food.

- **Cultivation**: Evidence suggests that some Aboriginal Peoples in Victoria and New South Wales cultivated yams, grains and other plants. Grinding stones that date back 30,000 years indicate the processing of seeds and grains.
- **Food preparation**: Techniques like roasting, crushing and soaking were used to treat certain plants, such as cycads, so that toxins were removed, making them safe to eat (Figure 8).

Figure 8 Aboriginal Peoples across Far North Queensland observed that the seeds and stems of cycad plants could be poisonous. They planned and conducted tests to discover ways to make them safe to eat.

- **Food preparation and preservation**: Smoking, drying and fermentation were used to preserve meat, fish and plants. For example, Torres Strait Islander Peoples preserved fish and dugong meat for long-term storage.
- **Seasonal harvesting**: Knowledge of seasonal cycles ensured that food resources were harvested sustainably, preventing overuse.

Different approaches, similar goals

Indigenous science and Western science both aim to understand the natural world, but they can use different paths to get there. Indigenous science sees everything as connected – the land, water, plants, animals and people are all part of one big system that remains in balance. Western science, on the other hand, has often broken things down into smaller parts to study them separately in controlled experiments before reconstructing the whole. Table 1 shows some of the different approaches taken by Indigenous and Western science to achieve similar goals and outcomes.

Table 1 A comparison of Indigenous science and Western Science

Indigenous science	Western science
• Science is passed down orally through stories, songs and direct teaching. • Knowledge is integrated with cultural and spiritual systems. • Everything is viewed as interconnected and part of one system. • Methods are specific to local environments and contexts. • Knowledge is developed and modelled in local environments by the whole community over generations. • Its focus is on understanding specific places and ecosystems in detail.	• Science is written down in formal documents, papers and textbooks. • Knowledge is considered separate from cultural and spiritual systems. • Focus is on breaking things down into separate parts to study them (e.g. fields such as Biology, Chemistry and Physics). • Methods used are standardised so that they can be repeated anywhere. • Knowledge is often developed by specialist experts in laboratories. • It usually aims to find universal laws (rules that apply everywhere).

Check your learning 1.1

Check your learning 1.1

Retrieve

1 **Define** Indigenous science.
2 **Identify** one way in which Indigenous science is similar to Western science and one way in which it is different.

Comprehend

3 **Describe** why it is important to refer to Aboriginal and Torres Strait Islander Peoples as "Peoples" and not "people".
4 **Describe** one example of Aboriginal and Torres Strait Islander Peoples observing the world.
5 **Describe** one example of an experiment that Aboriginal and Torres Strait Islander Peoples may have conducted thousands of years ago.

6 **Explain** why it is important to communicate the results of an experiment to produce clean water or identify plants that are safe to eat.

Apply

7 **Identify** the Aboriginal and Torres Strait Islander nations in your local area. Carry out some research to investigate one or two examples of scientific knowledge and skills used by one or more of these groups.
8 **Compare** and **contrast** two differences between Indigenous science and Western science. In your answer, **use** specific examples from both knowledge systems to support your comparison.

Lesson 1.2
Scientists follow the scientific method

Key ideas

→ The scientific method is a framework that helps scientists figure out how things work by asking questions and testing ideas. It is an essential tool to guide scientific inquiry and research that is valid and reliable.

→ There are five stages to the scientific method.

→ Pseudoscience is a term used to describe theories, beliefs or claims that seem scientific but aren't backed by any real evidence or results from experiments.

Introducing the scientific method

Being a scientist means that you need to use the scientific method. The scientific method is a framework that helps scientists figure out how things work by asking questions and testing ideas. It is an essential tool to guide scientific inquiry and research that is valid and reliable.

At each stage of scientific inquiry, the scientific method outlines what a scientist must do in order to ensure their findings can be trusted. It also helps scientists evaluate and test the claims and findings made by other scientists. This is known as "peer review", and helps to ensure all scientific findings are **valid**.

There are five stages to the scientific method (Table 1). In this module, you will develop the science inquiry skills needed at each stage of the scientific method. These skills will ensure you can investigate ideas, solve problems, draw valid conclusions and develop evidence-based arguments.

valid when the design of the experiment will produce a result that answers the scientific question

inference a conclusion based on evidence and reasoning

hypothesis a proposed explanation for a prediction that can be tested

Table 1 The five stages of the scientific method

Stages of the scientific method	What happens at each stage	Lessons in this module
Stage 1: Questioning and predicting	A curious scientist has questions about the world. Observations lead to asking questions, making **inferences** and forming **hypotheses** to be tested.	• Lesson 1.3 Scientists form hypotheses that can be tested (page 15)
Stage 2: Planning and conducting	There are many different ways to test a hypothesis. They could use information or data that already exists, design a controlled experiment or complete field work to generate their own data. This approach allows them to collect and organise reliable information that can be trusted by everyone in the community. When conducting an investigation, appropriate safety precautions must be taken, risk assessments completed and specialised equipment selected so precise and accurate data can be collected.	• Lesson 1.4 Scientists plan and conduct investigations (page 18) • Lesson 1.5 Scientists always take safety precautions (page 23) • Lesson 1.6 Scientists use specialised equipment (page 29)

Stages of the scientific method	What happens at each stage	Lessons in this module
Stage 3: Processing, modelling and analysing	Data collected and any changes made should be recorded in a logbook. Patterns in the data might provide evidence that the hypothesis is supported, so scientists need to process and analyse the data so they can create models that can be tested further. Once the data has been collected, it must be checked to make sure it tells the full story of what has happened. Scientists look for patterns and trends that might show a predictable relationship to support the hypothesis.	• Lesson 1.7 Scientists use tables, graphs and models to record and process data (page 33) • Lesson 1.8 Scientists keep a logbook (page 41) • Lesson 1.9 Scientists analyse trends in data (page 45)
Stage 4: Evaluating	Once the data has been processed and analysed, scientists need to compare the new information with the hypothesis or other experiments. Does it answer the original question? Does the information tell the same story as other scientific investigations? Can it be used to explain the original observations? This process is different to processing and analysing data. Evaluating the science means that scientists must consider the accuracy and importance of their work. Scientific investigations can only be used to make decisions or design solutions to problems if they can be trusted.	• Lesson 1.10 Scientists evaluate conclusions (page 50)
Stage 5: Communicating	The work of scientists is only important if people know about it. Consider the safety features of a car. Seatbelts, airbags and braking systems are only included in cars today because scientists communicated the results of their scientific process to car manufacturers and the public. Scientists must be able to explain what they do to many different audiences. Good science communication explains a complex scientific idea in simple language that everyone can understand. This allows science to influence environmental, social and economic change.	• Lesson 1.11 Scientists communicate their findings (page 57) • Lesson 1.12 Command terms identify the tasks in a question (page 63)

As shown in Figure 1, the scientific method is often presented as a cycle because the results from one scientific inquiry can lead to new questions, prompting further investigation and greater understanding of the scientific explanations. This means scientists often loop back to earlier stages of the process to refine understanding and continue their research. Most of the time, science inquiry is not a linear progression where you simply follow steps once and reach a final result.

1.2
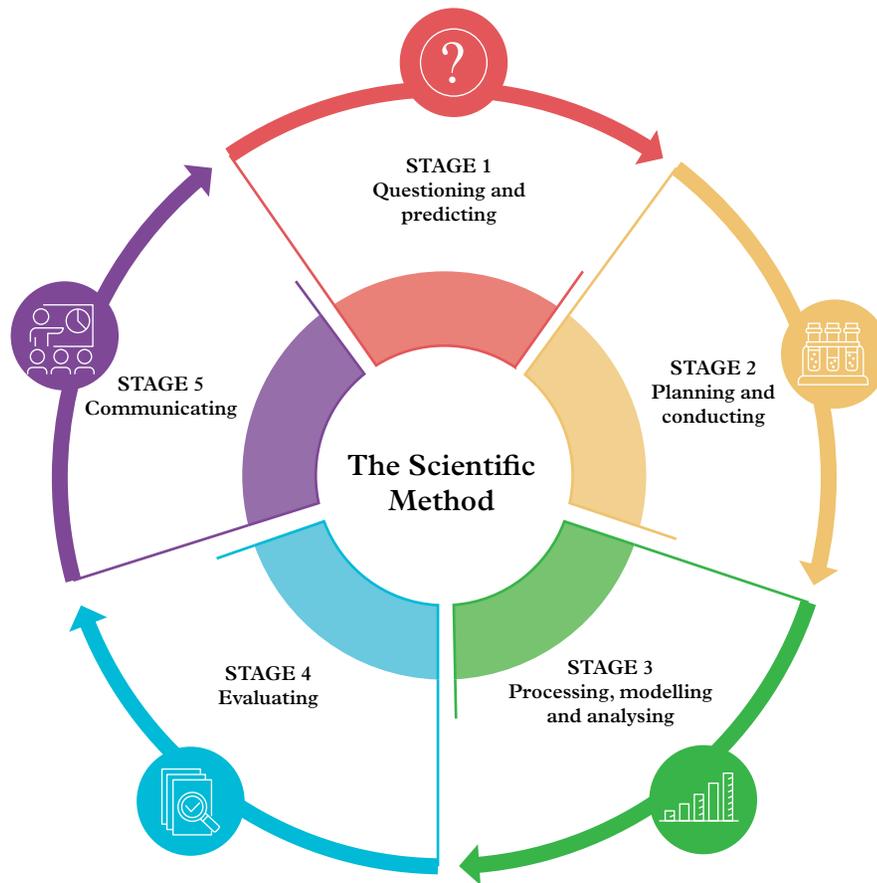
Figure 1 The scientific method

Why the scientific method is important

The scientific method is important for several reasons.

It helps us tell the difference between claims that have reliable evidence and claims that have no evidence. Instead of guessing or believing rumours, scientists use the scientific method to test a claim. For example, if someone says "Eating carrots helps you see in the dark", rather than just believing them, we can use the scientific method to check if this claim has evidence to support it.

It allows other people to check our work. When scientists do experiments, they write down exactly how they did everything. This means other scientists can try the same experiment to see if they get the same results. It's like a very detailed recipe – anyone can follow it, and they should get similar results.

It teaches us to be curious and think critically. Instead of just accepting what we're told, the scientific method encourages us to ask questions, look for evidence, and come to our own conclusions based on careful observation and testing.

Pseudoscience

pseudoscience
a claim that has not been tested using the scientific method

Pseudoscience is a term used to describe theories, beliefs or claims that seem scientific but aren't backed by any real evidence or results from experiments (Table 2). The word "pseudo" (pronounced *SYOO-doh*) comes from an Ancient Greek word that means "false".

Table 2 Common pseudosciences

Type of pseudoscience	Description
Astrology	The belief that the positions of stars and planets at the time of your birth determine your personality and future. While astronomy is a real science that studies planets and stars in the universe, astrology makes predictions without any scientific evidence.
Crystal healing	The belief that different crystals have healing powers. Crystals are beautiful minerals that are studied by geologists, but there is no scientific evidence that they can cure illnesses or are beneficial to our health.
Flat Earth idea	The belief that Earth is flat rather than spherical. This contradicts centuries of scientific observations, satellite imagery and physics.

Unlike real science, pseudoscience doesn't follow the scientific method. This means it doesn't involve carefully collecting evidence and testing ideas over and over. One example of a popular pseudoscience is astrology (Figure 2).

Figure 2 Although many people enjoy reading their stars, astrology is a pseudoscience.

Check your learning 1.2

Check your learning 1.2

Retrieve

1. **Identify** the five stages of the scientific method.
2. **Define** the term "pseudoscience" and give one example of a pseudoscience.

Comprehend

3. **Explain** why it is so important for scientists to follow the scientific method.

4. **Describe** one idea or invention that has changed in your lifetime due to science.

Analyse

5. **Compare** (the differences between) these two stages in the scientific method: "Processing, analysing and modelling" and "Evaluating".

◀ **Apply**

6 It is often said that science is never "finished". **Evaluate** this statement (by providing examples of science that are never finished and deciding if this statement is true).

7 Look carefully at Figure 3.

  a **Propose** a possible question about the local environment that a Wurundjeri scientist may have investigated.

  b **Describe** the investigation that the scientist may have completed to answer their question.
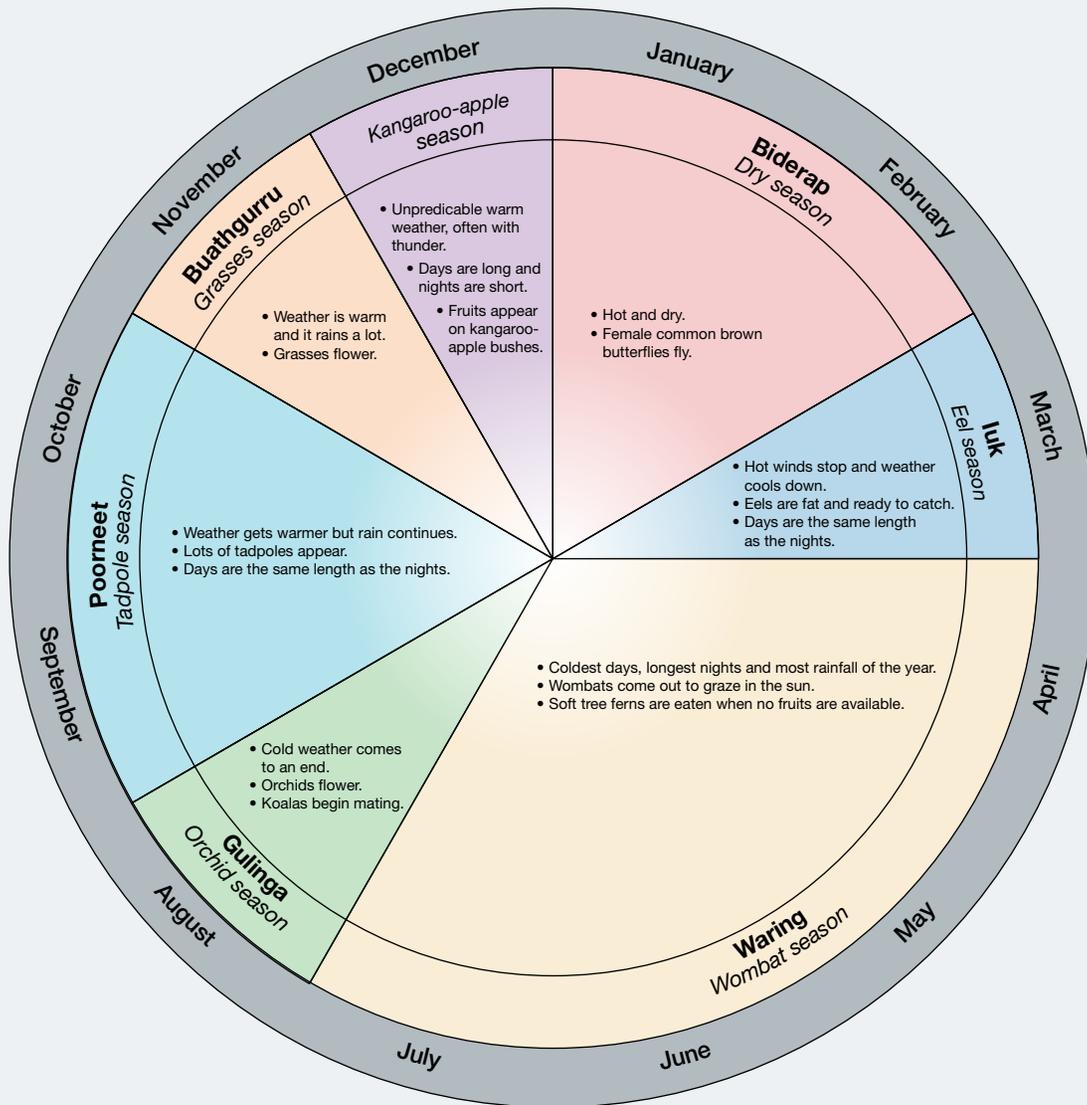
Figure 3 Repeated observations and analysis of patterns by the Wurundjeri people in Victoria identified the different seasons in their environments.

8 Research the prediction of your star sign for the next day or week. **Evaluate** the truth of this prediction (by identifying how many star signs there are, describing the number anvd ages of people in the world that would be affected by this star sign and deciding if this prediction could be true for all these people).

Lesson 1.3
Scientists form hypotheses that can be tested

Key ideas

→ There are variables that must be considered when trying to answer a question and formulate a hypothesis. This includes independent, dependent and controlled variables.

→ A **prediction** is a specific statement about **what** you expect to observe when you try to answer your question.

→ A **hypothesis** is a proposed scientific explanation for a question. It should try to explain **why** something happens based on previous observations, research or your reading on the topic. It is often written as an "If… then…because…" statement.

Learning intentions and success criteria

The best way to learn is by observing

Following the scientific method means that all scientists follow the same general set of rules and processes when conducting inquiries and research. This helps to ensure that all scientific research and findings are based on careful testing and reliable evidence.

Stage 1 of the scientific method involves making observations, making inferences and asking questions (Figure 1).

STAGE 1
Questioning and predicting
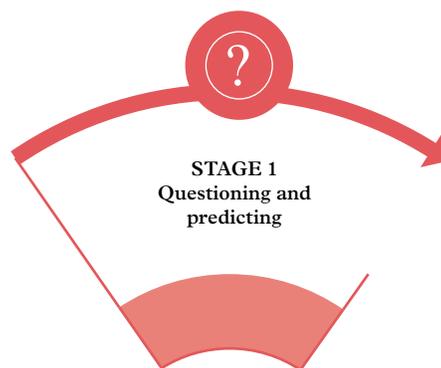
Figure 1 Stage 1 of the scientific method is **Questioning and predicting**.

Questions lead to hypotheses

All scientific investigations start by asking a question. Questions can be big, such as "How did the universe start?", or they can be small, such as "What will happen if acid is mixed with metal?".

For instance, the broad question "How does climate change affect ecosystems?" can be divided into smaller, testable questions:

• What is the current temperature trend in specific regions?
• How are plant growth patterns changing over time?
• What changes are occurring in animal migration patterns?

Breaking questions down into measurable parts is essential. Scientists do this by operationalising their questions, which means designing them in a way that specifies what will be tested or measured. For example, instead of asking, "What happens if plants get more water?" a scientist might ask, "What happens if I water plants with 200 mL of water daily compared to 50 mL?"

Now that you know how scientists observe and ask questions, we will learn about how they make predictions and form hypotheses.

1.3

Understanding the role of variables

Once a scientist has made an observation and decided on the inquiry question they want to investigate, it is time to make predictions and form a hypothesis to test. Before planning an experiment, they need to think about all of the things that might affect the result. These are known as **variables**. When a variable is changed, the results of the experiment might change.

variable something that can affect the outcome or results of an experiment

Types of variables

Variables can be independent, dependent or controlled (Table 1).

- An **independent** variable is the one thing you choose to change in your experiment. They are called "independent" because they don't depend on anything else in an experiment or situation – they stand on their own.
- A **dependent** variable is the thing you measure at the end of an experiment. They are called "dependent" because the results "depend" on the independent variable.
- **Controlled** variables are all the other factors that must be kept the same throughout your experiment. They are called "controlled" because you control them during the entire experiment.

Table 1 Different types of variables in an experiment

Experiment scenario	Type of variable
To test the growth rate of tomato plants, you choose three identical plants and change the amount of sunlight each one receives every day.	The number of hours of sunlight each plant receives every day is the **independent** variable.
After two weeks, the height of the plants are different.	The height of the tomato plants is the **dependent** variable.
Any factors that aren't related to the amount of sunlight the plants are receiving must be the same for all plants. This includes the: • amount of water they receive • type of soil they are planted in • room temperature • levels of fertiliser in the soil • size of the pots.	These are all **controlled** variables.

prediction an outcome that is expected based on prior knowledge or observation

Once the question is testable, the scientist can predict the outcome of the test and state the reason for their **prediction**. A hypothesis can then be developed and tested in the investigation. It is written as a statement that is based on the scientist's prior knowledge and reasoning. The easiest hypothesis to use is an "If... then... because…" statement. For example:

"If more yeast suspension is added to 2 mL hydrogen peroxide, then more gas will be produced because more yeast suspension increases the rate of reaction."

This hypothesis includes the variables to test (assuming all other variables are controlled):

- independent variable – amount of yeast suspension used
- measured dependent variable – volume of gas produced
- the reasoning behind the prediction – scientific knowledge about rates of reaction.

Hypotheses like this can guide investigations and help scientists focus on gathering the correct data to draw conclusions.

Check your learning 1.3

Check your learning 1.3

Retrieve

1 **Define** the term "hypothesis".
2 **Identify** the name given to the variable that is being tested (and is therefore changed on purpose).
3 **Identify** the two variables contained in a hypothesis.

Comprehend

4 **Explain** why most variables need to be controlled.
5 **Explain** the difference between a hypothesis and a prediction.

Analyse

6 Justin decided to conduct an experiment to find out whether cats prefer fish wet food or chicken wet food. He gave one cat a bowl of fish wet food and the other cat a bowl of chicken wet food and then left them alone. When he returned an hour later, the bowl of chicken wet food was gone and there was a small amount of fish wet food left. Justin concluded that cats preferred chicken wet food to fish wet food.

a **Explain** why you agree or disagree with Justin's conclusion.
b **Explain** whether Justin conducted a reasonable experiment. (Did he control all other variables? Would he have seen the same results if he repeated the experiment? Was the experiment fair?)
c **Identify** two variables that should have been controlled. **Explain** how these variables could have affected the results.
d **Describe** two ways Justin could improve his experiment so that his results were more reliable.

Apply

7 **Create** a hypothesis for an investigation that looks at the stopping distances of cars in different conditions.
8 List some variables you would control if you were investigating the energy efficiency of a bouncing tennis ball.

Lesson 1.4
Scientists plan and conduct investigations

Key ideas

→ The type of data being collected will determine what investigation method is used.

→ When planning and conducting an investigation, it must be reproducible by others.

→ Ethics considers "Should we?" when determining whether an investigation should be carried out on people, animals or the environment.

→ When conducting field work, scientists must seek permission from the land owner or organisation to access the land.

→ If research is being conducted at culturally significant sites, appropriate protocol must be followed to access the site, not damage any sacred objects, and limit access to people who have permission to be there.

→ The results obtained from investigations must be reliable, as this indicates the investigation method is sound.

A goal without a plan is just a wish

Stage 2 of the scientific method involves **planning** scientific investigations and **conducting** experiments (Figure 1).

In this lesson, you will learn about the ways in which scientists plan and conduct experiments so that:

- they are reproducible
- the equipment and technologies chosen will collect accurate and reliable data
- the results are reliable
- any risks are recognised and managed
- they consider any ethical issues
- they follow necessary protocols (especially when accessing Aboriginal and Torres Strait Islander Peoples' cultural sites and artefacts on Country).

STAGE 2
Planning and conducting
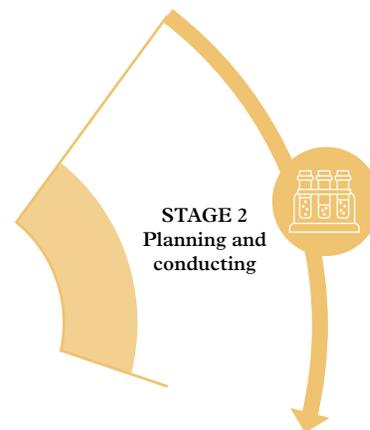
Figure 1 Stage 2 of the scientific method is **Planning and conducting**.

The aim of an investigation

The aim of an investigation is to explore a scientific question, test a hypothesis, or solve a problem by collecting and analysing data. It helps scientists understand how or why something happens by conducting experiments in a controlled and systematic way. Investigations can confirm existing knowledge, discover new information, or provide evidence to support or refute a hypothesis.

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1.4

For example, if you are investigating how the concentration of an acid affects the rate of a chemical reaction, the purpose of your investigation could be: "To determine how changing the concentration of hydrochloric acid affects the rate at which it reacts with magnesium ribbon". This clear purpose guides the experiment by focusing on what you aim to learn and what variables to measure, such as the time it takes for the magnesium to dissolve.

Investigation methods

To collect reliable data, the best investigation method must be selected as some are more suited to collecting certain types of data.

Field work

Scientists collect data directly from natural environments, rather than in a laboratory. Data collected from field work can include quantitative measurements such as temperature or population numbers, as well as qualitative observations, such as habitat conditions and the behaviour of organisms (Figure 2).

Figure 2 In the field, scientists are able to collect more accurate data from the environment.

Laboratory experimentation

Within a laboratory setting, controlled investigations can be conducted to explore hypotheses and manipulate variables. Data collected from these investigations include quantitative measurements including reaction times, change in temperatures or energy outputs, as well as qualitative observations such as colour changes or smell.

Figure 3 Investigations completed in a laboratory allow for precise control and replication of findings.

Investigations must be reproducible

Once the hypothesis has been written, it's time to plan how to carry out the experiment.

An experiment must be a **reproducible** test to ensure accurate and reliable results. A reproducible test is one in which only one variable is changed at a time, and all other conditions are controlled. This means the test can be reproduced and should achieve the same results. This helps scientists trust the effect of the variable being tested.

For example, if you are testing how sunlight affects plant growth, you should keep the type of plant, the amount of water, and the soil the same for all the plants, and only change the amount of sunlight each plant receives (Figure 4). By doing this, you can be confident that any differences in plant growth are due to the amount of sunlight and not other factors.

This approach helps scientists make valid conclusions and advances our understanding of the world.

reproducible
when the experiment can be repeated by another scientist in another laboratory

1.4

Figure 4 If you are testing how sunlight affects plant growth, you should control all other variables like water, soil, temperature and pot size.

Ethics

ethics a set of principles that provide guidance to determine what is morally right and wrong

Ethics are a set of principles that provide a way to think when making decisions. Sometimes when you make a decision, you use the rules that are written down, such as the school rules or the laws of the government. At other times, you use rules that are not written down. Some rules are set according to what is normal to the people around you. For example, the unwritten rules in your science classroom may be different to the rules in a physical education class. When playing sport, it might be normal to yell to a team member, whereas yelling in a science classroom is not normal. Neither of these rules are written down; however, everyone in the class will know them and behave accordingly. The expectation that you should behave according to the values of those around you is called the **cultural norm**.

cultural norm the expectation that you should behave according to the values of the people around you

Ethical approaches

When answering the question "Should we?", scientists can use a variety of ethical approaches. Two of the most common approaches are consequentialist ethics and deontological ethics.

Consequentialist ethics

The consequentialist approach to ethics considers the consequences of an action in order to decide whether an action is good or bad. This approach can also be described as "the end justifies the means".

If this approach was used by Alfred Nobel, a Swedish chemist, engineer and inventor, he might have considered that his dynamite invention (patented in 1867) was bad, because it had been used to kill many people, and that the science should therefore not have been investigated. Alternatively, if the consequence was setting up the Nobel Prize that led to increased recognition of science and scientists, and the promotion of peace, then the overall action could be considered good.

Deontological ethics

In contrast, the deontological approach to ethics considers each action taken according to a set of rules or duties. If an individual did the "right thing" at the time, then ethically it is "good", regardless of the outcome.

Using this approach, Alfred Nobel did the ethically right thing because he wanted to stop people becoming hurt by unstable nitroglycerine. The consequences of this decision are not as important when using this approach.

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                    ┌─────────────────────────┐
                    │    Ethical approaches    │
                    └─────────────────────────┘
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Consequentialism	Deontological
'the end justifies the means'	*'doing the right thing regardless of consequences'*

Are the consequences good or bad?	Are the actions involved good or bad?
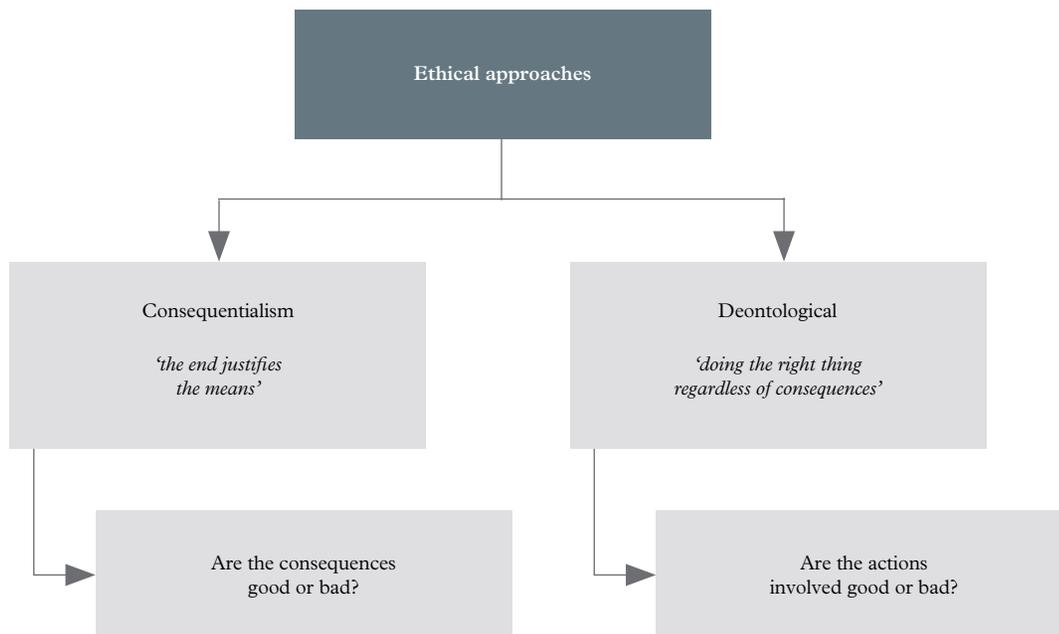
Figure 5 A consequentialist approach to ethics considers the consequences. A deontological approach considers duties and rules.

Ethical issues must be considered

Ethical issues in science are the questions and decisions that scientists face about what is right or wrong when doing research. These issues involve making choices that could affect the wellbeing of people, animals or the environment.

When planning and conducting an inquiry, a simple way for a scientist to consider ethical issues is by asking "Should we?" rather than just "Can we?". For example:

- Should we test new medicines on animals?
- Could this research harm anyone?
- Do the potential benefits of this research outweigh the risks?
- Should we share this discovery if it could be used in harmful ways?
- Are we being completely honest about our results?

These questions don't always have clear right or wrong answers. This is why it is important to discuss and think about them carefully before, during and after scientific research is conducted.

Figure 6 There are many ethical issues related to animal testing, including whether animals should have more legal rights and how to balance the wellbeing of animals against the benefits of developing safe medicines for humans and other animals.

1.4

Protocols must be followed

When planning and conducting scientific research in the field (i.e. outside the laboratory), it is important that scientists do their research and seek permission from the person or organisation that owns the land they will be using to conduct their research. This could be a private landholder; a company that holds a lease to the land; or a local, state or federal government organisation.

When conducting research on culturally significant sites in Australia, key protocols need to be followed. These include:

- requesting and receiving consent from the Traditional Owners of the land on which the research is being done
- respecting cultural sensitivities and engaging with Elders and community leaders to ensure these are understood
- not disturbing sacred objects
- limiting access to the site to people who have permission to be there
- ensuring the Traditional Owners understand the aims, methods and possible impacts (both positive and negative) of the research
- ensuring data is shared appropriately with the community.

Hamersley Gorge (Figure 7) is located in the Pilbara region of Western Australia. There are many sacred sites in the Pilbara region including nearby Juukan Gorge. In 2020, mining company Rio Tinto legally destroyed a 46,000-year-old cave in the Juukan Gorge to expand one of its iron ore mines, despite its cultural significance to Traditional Owners. The event led to global outrage, a parliamentary inquiry, and changes to Western Australian cultural heritage laws.

Figure 7 When conducting scientific research on sites in Australia that are culturally significant, it is essential that scientists seek permission and follow all protocols carefully.

Results must be reliable

reliable consistency of a measurement, test or experiment

It is extremely important that the results of an experiment are **reliable**. Reliable results are those that are consistent and can be trusted because they are repeatable under the same conditions.

If you do an experiment once, following your plan exactly, you will probably get a set of results you think are accurate and reliable. But what if you try the experiment again the next day and the results are different? You would probably ask:

- Did I do things in a different order?
- Did the conditions change? (For example, hotter or cooler weather.)
- Did I use different materials? (For example, a different brand of vinegar or a slightly different variety of plant.)

Repeating the experiment until you get the same results at least three times helps to ensure your results are reliable. Another way to ensure your results are reliable is to ask someone else to perform the same experiment multiple times to confirm that they get the same results. This consistency is crucial for making sure your findings are precise and trustworthy.

Check your learning 1.4

Check your learning 1.4

Retrieve

1 **Explain** what it means for an investigation to be "reproducible".

2 **Define** what ethics means.

Comprehend

3 List some advantages and disadvantages of field work and laboratory experimentation.

4 **Explain** why results must be reliable when planning and conducting an investigation.

5 **Explain** why scientists must seek permission before conducting field research on private or culturally significant land. Support your answer with two examples from the text.

Analyse

6 **Analyse** the events that resulted from the destruction of Juukan Gorge by Rio Tinto in 2020. You will need to conduct some additional research online for this. In your response, **identify** three specific protocols that were not followed by Rio Tinto.

Apply

7 **Examine** one ethical issue of your own choice that scientists might face when conducting medical research. In your response, consider both the potential benefits and risks of the issue.

Lesson 1.5
Scientists always take safety precautions

Key ideas

→ When working in the laboratory, is important to follow all safety rules to keep yourself and others safe.

→ All risks must be recognised and managed when conducting investigations.

→ Safety data sheets are used to communicate information about how to handle and store the substance, as well as first aid information in the event of an accident.

→ Pictograms are symbols used to communicate the specific type of hazard the substance presents.

→ A risk assessment is created before beginning an investigation. It helps identify risks and describes how to prevent and mitigate them if they occur.

→ When working with chemicals, they must be safely disposed and not poured down the sink, as they can be toxic for the environment.

Learning intentions and success criteria

1.5

Safety in the laboratory

A science laboratory is not like a normal classroom. When completing investigations in the laboratory, all laboratory rules must be followed and you must work in a safe manner and understand what to do in an emergency. Before starting your investigation, any protective equipment must be put on including safety glasses, lab coat and gloves. When setting up your work bench, ensure there is sufficient space for you to work. As you perform your procedure, you must keep in mind any safety risks identified on your risk assessment as well as storing equipment and any chemicals in a safe manner on your bench to minimise chemical spills and equipment damage and breakage. Most safety is common sense – common sense can prevent many dangerous situations.

In the laboratory, do:
- wear a lab coat for practical work
- keep your workbooks and paper away from heating equipment, chemicals and flames
- tie back long hair whenever you do an experiment
- wear safety glasses while mixing or heating substances
- tell your teacher immediately if you cut or burn yourself, break any glassware or spill chemicals
- wash your hands after an investigation
- listen to and follow the teacher's instructions
- wear gloves when your teacher instructs you to.

In the laboratory, don't:
- run or push others or behave roughly
- eat anything or 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 directly; 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.

Risks – anticipate, recognise and eliminate

risk exposure to danger

Scientists work with many hazardous materials when completing experiments. As a result, they need to be aware of **risks** – anything that might affect their health or safety in the laboratory. The laboratory is a safe place, as long as hazards are anticipated, recognised, and eliminated or controlled.

Risks must be recognised and managed

When planning and conducting scientific experiments, managing risks is crucial for everyone's safety. Before starting any experiment, scientists need to identify what could go wrong (e.g. harmful chemical reactions, dangerous equipment or toxic materials).

They must put safety measures in place to prevent accidents and minimise harm. This includes:
- using protective equipment (e.g. goggles, gloves and lab coats)

- carefully following safety instructions and warnings for chemicals (and other dangerous materials)
- working in well-ventilated areas
- knowing emergency procedures (including proper disposal of hazardous materials).

It is also important to consider risks not only to the people doing the experiment, but to others nearby (e.g. animals involved in research) and the environment. For example, if an experiment requires strong acids, the scientists need safety materials and equipment nearby and must know how to safely clean up spills.

A well-planned experiment includes thinking ahead about safety. Missing one small thing could lead to an accident. The goal is to get good scientific results while keeping everyone and everything safe.

Safety data sheets

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 should be used during an experiment (Figure 1).

safety data sheet (SDS) a document that details health and safety information about a material, including safe handling and its properties

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.

Physical and chemical properties of the substance
Everyone in a laboratory should be able to easily identify the chemical. The SDS should include the colour, smell, pH, flammability, solubility, melting and boiling points of the chemical.

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.

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. This section provides information about how to safely handle and store the substance to minimise the risks.

Contact details of the manufacturer

Hazard level of the chemical
All chemicals should contain labels relating to their particular dangers. This may include flammability, corrosive ability, toxicity and ability to cause long-term damage, such as cancers. The risks can be shown using descriptions or the symbols shown in Figure 4.

What to do in the case of a spill
This includes first aid measures, any antidotes, symptoms that might result from exposure and if personal protective equipment (PPE) is recommended for the aiders. Advice may be needed on how to cover drains to prevent the chemical making its way into ground water.

Protective measures
Information on the eye and face protection needed, the type of gloves or skin protection required and the possible need for masks.

SAFETY DATA SHEET
Sodium Chloride: Hazardous chemical

Section 1 - Identification

MSDS name:	Sodium Chloride
Synonyms:	Common salt; Halite; Rock salt; Saline; Salt; Sea salt; Table salt.
Company identification:	Chemical company

Section 2 - Hazard(s) 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 - Composition and information on ingredients

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 4 - 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 5 - 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.

Section 6 - 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 7 - 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 8 - Exposure controls and 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.

Figure 1 Example of a safety data sheet (SDS) from a manufacturer or certified provider

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1.5

Safety data sheets can contain a lot of information, including the type of protective equipment that must be worn (Figure 2 and Figure 3) and the specific hazards of chemicals (Figure 4). An SDS can also include:

- 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 the safety of individuals and the environment.
- How to transport the chemical. 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. The hazards identified in the Safety Data Sheet are often used by industries to create safety signs which they display around the work environment.

Figure 2 The hazards identified in safety data sheets (SDSs) are displayed by many industries, including the mining industry.

Figure 3 Emergency workers in sealed positive-pressure protective suits communicating with each other

Figure 4 Pictograms such as these are often seen on the labels of chemicals to communicate specific hazards.

Writing a risk assessment

Including a **risk assessment** is a crucial part of any scientific investigation. It helps the person conducting the experiment to identify potential risks and plan how to prevent or manage them if they occur.

A risk assessment table provides a summary of possible hazards and outlines safety precautions, making the investigation safer and more organised. Important details to include in a risk assessment table are the mass of solids, the volume and concentration of solutions, and any equipment used, as these factors can significantly impact the safety and risks associated with the experiment. An example of a risk assessment table is shown in Table 1.

risk assessment
the process of identifying and evaluating potential risks, including how they can be mitigated and what to do if there is exposure to the risk

Table 1 A risk assessment table for an experiment involving a reaction between a magnesium ribbon and hydrochloric acid

Chemical	Risk	Precaution	Management
200 mL of 1M HCl	HCl is corrosive and can cause chemical burns.	Wear goggles and gloves to protect the eyes and skin.	If contact occurs, rinse immediately with plenty of water. Seek medical help if necessary.
Mg ribbon	When reacted with HCl, heat and hydrogen gas is produced.	Use a small amount of magnesium ribbon and control the rate of the reaction.	Conduct the experiment in a well-ventilated area. If the reaction is still too vigorous, dilute the acid.
Hydrogen gas produced by the reaction	Hydrogen gas is flammable.	Perform the experiment away from open flames or sparks.	In the case of a fire, use a fire extinguisher to handle any ignition of gas.

Your teacher should provide you with a template to create your risk assessment, or you may have access to programs that will create your risk assessment for you, such as RiskAssess.

Safety in the field

When scientists work in the field (i.e. conduct research and practical work in the natural environment), they need to take important safety measures to protect themselves and their research.

This includes wearing appropriate protective clothing and equipment specific to the location they are working in – for example, closed-toe shoes, long pants or weather-appropriate clothing to guard against hazards like sharp rocks, thorny plants or extreme temperatures (Figure 5).

Scientists working in the field should carry first aid kits, satellite phones and special equipment like GPS trackers in case of emergencies. They should also work in pairs or teams whenever possible rather than on their own.

It is crucial to research potential dangers in advance, such as dangerous local wildlife, extreme weather conditions or terrain challenges, and plan accordingly.

Taking these precautions helps ensure that scientists can focus on their research without putting themselves at risk.

Experiments conducted in a laboratory are easier to control than those conducted in the field because external factors like weather conditions and natural disasters don't influence the results.

Figure 5 Volcanologists are scientists who study volcanoes. When they are out in the field, they wear heat-resistant silver suits to protect themselves against heat, ash and molten rock.

1.5

Safe disposal of chemicals and other materials

Safely disposing of chemicals is just as important as safely using them. Not everything can be poured down the sink. Some schools have acid-neutralising traps in the drains that allow diluted acids to be disposed of in this way. Other chemicals can react with the acid traps or can be toxic for the environment. As a result, these chemicals must be collected at the end of the class and disposed of appropriately by your teacher. These chemicals include **corrosive** liquids, grease and oils, biohazardous wastes and toxic solids. Table 2 lists the safe disposal techniques for various materials.

corrosive
a substance that can damage or destroy other materials

Table 2 Examples of how various materials can be disposed of safely

Material	Examples	What to do with it
Biohazardous waste	Animal cells and tissue	Solids should be collected by your teacher. Deactivate liquid with bleach (1 part bleach to 9 parts water) for 30 minutes before pouring down the drain.
Grease and oils	Vegetable oils Machinery oil	Collect in a bottle and place in regular rubbish. Dispose of as hazardous chemical waste.
Corrosive liquids	Weak acids Strong acids or alkalis	Pour down the drain. Neutralise the acid or alkali and pour down the drain.
Solids	Play dough	Place in regular rubbish.
Hydrogen peroxide	> 8%	Dilute before pouring down the drain.

Check your learning 1.5

Check your learning 1.5

Retrieve

1 **Describe** what a risk is.
2 **Explain** what information is found on a safety data sheet.
3 **Explain** the purpose of a risk assessment.
4 **Identify** five things you should do to stay safe in the laboratory.
5 **Identify** the three safety symbols shown in Figure 6. Describe the meaning of each symbol.

Comprehend

6 **Explain** why you should not mix chemicals that have not been described in the method.
7 **Explain** why it is dangerous to drink from laboratory glassware.

Analyse

8 A student has created a risk assessment for an investigation related to the effect of salt concentration on the boiling point of water (Table 3) but has not completed all aspects of it. **Analyse** this risk assessment and **identify** the information that is missing.

Figure 6 Three safety symbols

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1.5

Table 3 Risk assessment for an upcoming investigation

Equipment	Risk	Precaution	Management
Bunsen burner	Burn, fire hazard	Keep area around the Bunsen burner clear and allow equipment to cool before handling	
Thermometer (alcohol)	Cuts, slipping		Alert your teacher and clean up the spill immediately. If there is broken class, use a brush and dustpan.
Beaker		Inspect the beaker for cracks or chips before use and handle carefully when taking it off the Bunsen burner.	Alert your teacher and clean up immediately using a brush and dustpan.

Apply

9 In an investigation, some equipment you will be using includes distilled water, hydrochloric acid, beakers and a Bunsen burner. **Describe** the risks, precautions and management that should be taken with each piece of equipment.

Lesson 1.6
Scientists use specialised equipment

Key ideas

→ When conducing investigations, select suitable materials, equipment and technologies that will provide accurate and precise results.

→ In an investigation, multiple trials are conducted to ensure the method is reliable and the data is accurate and precise.

→ Errors in an investigation can affect the outcome, so you must be aware of how systematic errors can occur.

Learning intentions and success criteria

Materials and technologies

Selecting suitable materials and technologies is a critical aspect of successfully conducting scientific investigations. It is important that when choosing tools and materials that they are safe, reliable and appropriate for the task.

When completing an investigation involving chemistry, the correct chemicals at the appropriate concentration must be used, as well as technology such as digital probes to record temperature or pH more accurately (Figure 1).

In physics, motion sensors or electrical circuit kits are used to measure variables including speed or resistance with precision, while in biology, sensors that monitor environmental conditions all day would provide more accurate conditions.

1.6
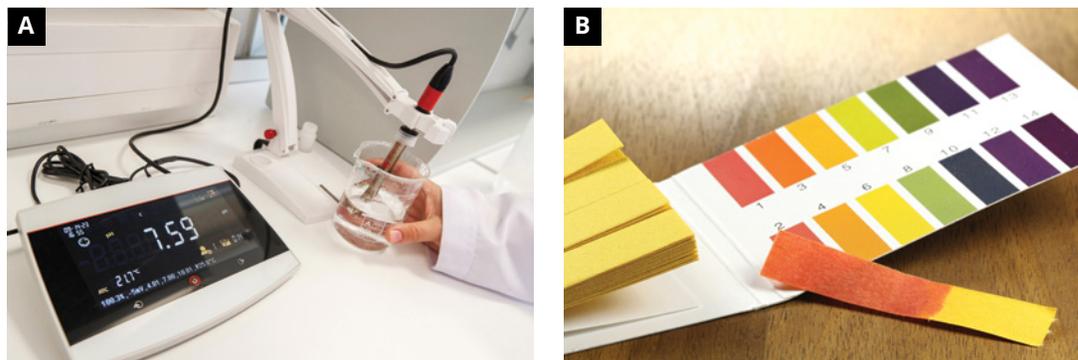
Figure 1 (A) A pH meter is able to accurately determine the pH of a solution. (B) Universal indicator only provides an approximate pH value based on the colour of the paper.

Scientific equipment

equipment
items used in the laboratory to conduct experiments

experiment an investigation used to test a hypothesis, solve a problem or find an answer to a question

results the measurements and observations made in an experiment; often presented in a table or graph

Equipment is the term used to describe the beakers, Bunsen burners, conical flasks, retort stands and other items used by scientists to conduct **experiments** (Figure 2). Using the correct equipment ensures accurate and precise **results** and the safety of scientists.

Beaker	Measuring cylinder	Bunsen burner	Filter funnel
Conical flask	Tripod stand	Test tube	Stirring rod
Retort stand with boss head and clamp	Gauze mat	Evaporating dish	Watch glass	Thermometer
	Test-tube holder	Test-tube rack	Metal tongs	Spatula

Figure 2 Types of equipment used in the laboratory

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1.6

Repeating trials

Repeating trials is a crucial step for ensuring accuracy, precision and reliability in the results and the method as it allows you to identify and reduce errors.

Reliable

A reliable science investigation is dependent on the ability to repeat the investigation with the same scientist and same materials (**repeatable**) or with another scientist in another laboratory (**reproducible**) and achieve the same results. For an experiment to be reliable, all the variables that can affect the dependent variable must be identified and controlled for.

Reliable data means the experiment has been repeated numerous times and the mean calculated for the results. This ensures that the results were not due to errors.

Accuracy

Following the planned procedure during an experiment is crucial to obtaining reliable and **accurate** results. When you follow the steps exactly as written, it ensures consistency and reduces the chance of errors, and helps maintain focus on the relevant variables. By using the correct equipment and ensuring careful measurements, you can observe the effect of the independent variable on the dependent variable while keeping the controlled variables constant.

This approach not only minimises errors but also ensures that other students conducting the same experiment can achieve similar results, making the investigation repeatable and scientifically valid. This will likely produce results that can be confidently analysed to draw meaningful conclusions.

repeatable when an experiment can be repeated by the same scientist using the same materials

reproducible when the experiment can be repeated by another scientist in another laboratory

accurate how carefully, correctly and consistently data have been measured or processed; in science, how close a measured value is to the true value

Precision

Precision refers to how consistent your measurements are, even if they aren't accurate. Precision reflects the reliability of your experimental procedure and the quality of the equipment or method you use for measurement.

Imagine you are trying to calculate the value of gravity (where $g = 9.8$ m/s^2) by dropping an object from a height and measuring the time it takes to fall.

- If you calculate values like 4.7, 12.5, 5.3 and 9.2, the results are neither accurate nor precise. This indicates significant errors in your method and/or data collection, as the values are far from 9.8 m/s^2 and inconsistent with each other.
- If you calculate values like 8.7, 9.5, 8.2 and 10.7, the results are accurate but not precise. While they are generally close to 9.8 m/s^2, they vary significantly and lack consistency, indicating errors in your data collection.
- If you calculate values like 12.2, 12.9, 11.9 and 12.4, the results are precise but not accurate. Although the measurements are consistent, they are far from the true value of 9.8 m/s^2. This indicates an error in your method.
- If you calculate values like 9.7, 9.4, 9.9 and 9.6, the results are both precise and accurate. These measurements are consistently close to 9.8 m/s^2, showing a reliable and accurate method.

Figure 3 The reliability of your scientific method will affect the accuracy and precision of the data collected.

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1.6

Errors

There are many different variables that can affect the outcome of an experiment. Something as simple as measuring the mass of an object on scales can change if someone breathes on the scales, or if a person generates a small breeze by walking past quickly. These small unpredictable variations in measurements are called **random errors**. Random errors can be reduced if the measurements or experiments are repeated.

random error when an unpredictable variation in measurement occurs, resulting in an outlier result

systematic error a repetitive error that is not removed by repeating the experiment

Another error that can occur is a **systematic error**. These errors occur when there is an error in the equipment that is used (such as scales that constantly measure the wrong mass) or in the way the experiment is completed.

Repeating the experiment will not remove these errors. Instead, checking the accuracy of the scales with a known weight (Figure 4) or carefully checking that there are no other variables in the method that will affect the outcome will minimise these errors.

Figure 4 Checking the accuracy of scales will minimise errors in data.

Check your learning 1.6

Check your learning 1.6

Retrieve

1 **Explain** the difference between accuracy and precision.
2 **Describe** how repeating trials improves the results and method.
3 **Explain** the difference between a random error and systematic error.

Comprehend

4 **Explain** the advantage of using digital equipment over their analogue counterparts.
5 **Justify** when you would use a beaker or measuring cylinder for a volume of liquid.

Analyse

6 An investigation is conducted on the conservation of mass in a chemical reaction using the following method:
  a Measure 5 g of baking soda and place it in a sealed plastic bag.
  b Measure 100 g of vinegar and add it to a separate container.
  c Carefully pour the vinegar into the plastic bag with the baking soda and quickly seal the bag to prevent any gas from escaping.
  d Observe the reaction and measure the total mass of the sealed bag and its contents before and after the reaction.
  e Record the mass measurements and any observations.
    Analyse the method used in this investigation to determine its reliability, and the precision and accuracy of the data collected.

Apply

7 From an experiment you have previously completed, **identify** a random error and systematic error that could have occurred.

Lesson 1.7
Scientists use tables, graphs and models to record and process data

Key ideas

→ Scientists need to collect data and present it in an organised manner.

→ Tables and graphs allow scientists to identify patterns in their results.

→ Tables should have a heading, column headings with units of measurement and data in each column.

→ Different graphs should be used depending on the type of data (discrete or continuous) being displayed.

→ Keys help scientists interpret or identify information in scientific diagrams, maps and data.

→ Models are representations that help explain scientific concepts or can be used to test explanations.

→ Mathematical relationships show connections between variables and pieces of data, and express them as numbers or equations.

→ The data presented in some graphs can be extrapolated or interpolated to make predictions.

→ If using data from secondary sources, you need to check they are reliable sources.

Learning intentions and success criteria

Without data, you're just another person with an opinion

Stage 3 of the scientific method involves processing, modelling and analysing data generated during a scientific inquiry (Figure 1). This can be done using:

- data tables
- graphs
- keys
- models
- formulas.

STAGE 3
Processing, modelling and analysing
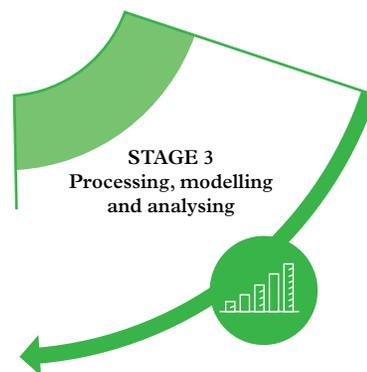
Figure 1 Stage 3 of the scientific method is **Processing, modelling and analysing**.

Representations to organise data

Once data has been collected from an investigation, how to effectively organise and represent the data is crucial for interpreting and communicating scientific findings. Representations such as keys, tables, graphs, models and diagrams allow us to visualise patterns, trends and relationships within data sets. These tools not only help in making sense of complex information but also in presenting it clearly to others.

1.7

Data tables

During the investigation, you will be collecting and recording qualitative and quantitative data into your logbook (Lesson 1.8 Scientists keep a logbook (page 41)) for later analysis. This is essential for drawing valid conclusions and evaluating the outcomes of the investigation.

For example, you may be required to collect data at regular intervals using consistent units of measurement, such as temperature every minute or height every day. To be accurate in this data collection and to minimise errors, measurements should be double-checked before being recorded and the data should be presented in a clear and structured manner, such as a table, including units (Table 1). Qualitative data can also be recorded in a table or as a list in your logbook.

There are four steps for constructing a table:

1 Use a ruler to draw a table with the correct number of columns.
2 Write a table heading that describes the content of the table, such as "The change in water temperature over time".
3 Give each column a heading that includes the units (what the numbers in the column mean), such as "Temperature (°C)". The variable being changed (independent variable) goes in the first column, and the variable being measured (dependent variable) goes in the columns to the right.
4 Add your data in the correct columns.

A spreadsheet can also be used to create a table.

Table 1 Data presented in a table is easier to read and analyse.

Time (minutes)	Temperature (°C)	Observations
0	15	6 ice-cubes in the beaker with water.
1	18	
2	25	
3	32	3 of the ice-cubes have melted and the remaining 3 are now half their original size.
4	40	
5	49	
6	56	The Bunsen Burner went out. Had to relight it.
7	58	
8	63	Small bubbles appearing in the solution. All the ice-cubes have melted.

Graphs

There are two main types of data that are recorded and graphed by scientists so they can be analysed efficiently.

categorical data
information that can be divided into groups or categories

numerical data
information in the form of numbers

discrete data
information that can only take on specific and distinct values, such as whole numbers

- **Categorical data** is a collection of information that can be divided into named groups (e.g. colours, types of animals, types of vehicles).
- **Numerical data** is a collection of information that can be represented as numbers (e.g. temperature, wind speed, height).
  Numerical data can be divided into two smaller groups.
- **Discrete data** is data that can only take a specific and separate value. It is usually counted in whole numbers that cannot be broken down into smaller parts. For example:
  – the number of students in a class
  – the number of votes in an election.

Discrete data is often represented in a column graph.

- **Continuous data** is data that can take any value within a range. It can be divided into smaller parts. It is measured, not counted. For example:
  - measuring the speed and acceleration of a runner over the course of a 100 m sprint
  - measuring the rate at which water is poured into a glass
  - measuring temperature and wind speed over the course of a day.

Continuous data should always be represented in a line or scatter graph.

continuous data
information that can be any value, including decimals and fractions that are measured

Table 2 Summary of the data type and how it can be represented

Type of data	Description	Representations
Discrete data	distinct, separate values like the number of students in a class	bar graphs, tables or pie charts
Continuous data	values within a range, such as height or temperature	line graphs or histograms (to show fluctuations over time or a range of values)
Qualitative data	description of characteristics like colour or texture	categorical tables or bar chart
Quantitative data	numerical values like weight or time	line graphs, scatter plots or histograms (to allow for precise measurement and analysis)

Choosing the appropriate representation for each data type allows for clearer interpretation of patterns, trends and relationships.

Line graphs

Line graphs are used when both the independent variable and the dependent variable are continuous data (Figure 2). This includes changes in variables such as temperature, speed or population growth over time. Patterns are more easily observed as well as the relationship between the independent and dependent variable.

line graphs
individual data points that are connected and that change over time
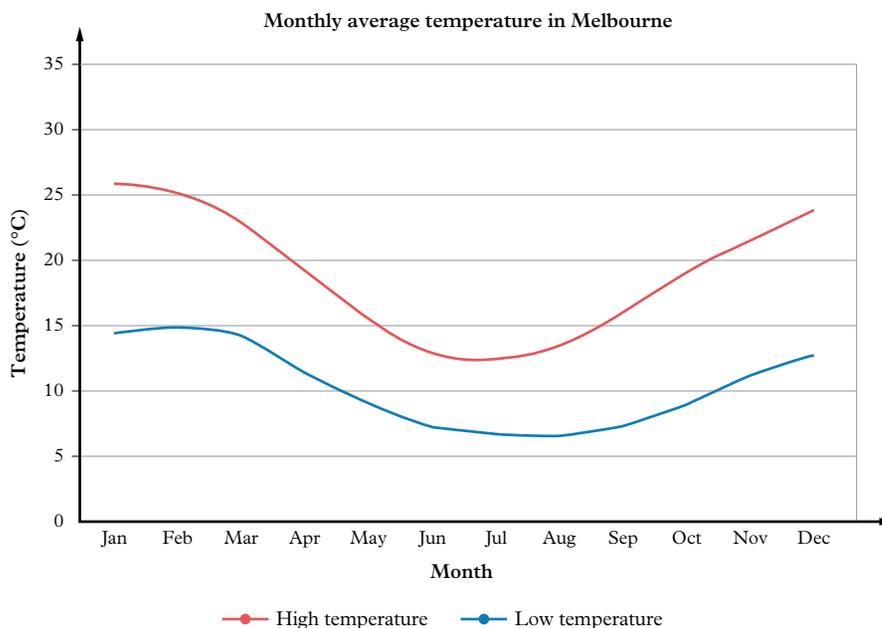
Figure 2 A line graph plots continuous data. In this graph, two data sets are included and are represented by different colours to make it easier to interpret.

1.7

Column graphs

column graph
vertical bars used to compare data

In a **column graph**, the height of each column represents a value that you have measured. This type of graph is good for showing discrete data.

Imagine that a scientist is recording the number of insects at different locations. In this experiment, the independent variable (the variable that is changed) is the location, and the dependent variable (the variable that is measured) is the number of insects.

Scatter plots

scatter plot a type of graph that displays the relationship between two sets of numerical data

line of best fit a straight line that goes through the middle of all the scatter points to minimise the distance between the line and the scatter points

Scatter plots are used when both the independent variable and the dependent variable are continuous and may not be connected by a line. Occasionally, a **line of best fit** can be used to show the trend or direction of the relationship. A line of best fit is a straight line drawn through a group of data points, and it can show the positive or negative relationship (correlation) between two variables (Figure 4).

Imagine that a scientist is investigating how temperature changes over time. In this experiment, the independent variable (the variable that is changed) is time, and the dependent variable (the variable that is measured) is temperature.

Number of insects caught at different locations

Figure 3 An example of a column graph
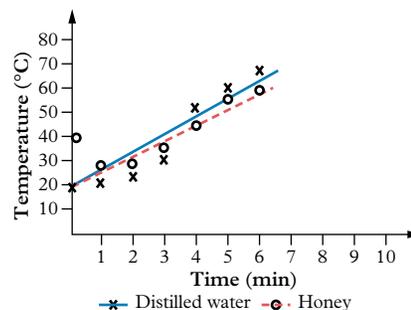
Figure 4 An example of a scatter plot

Keys

A key is a guide that helps a scientist to interpret or identify information in scientific diagrams, maps and data. Examples include:

- a legend on a graph to explain what different coloured lines represent
- a colour key on a weather map to indicate temperature ranges
- a symbol key on a geological map to indicate different types of rock
- a dichotomous key to identify plants or animals based on their characteristics (Figure 5).

Models

Models are representations of systems, structures or processes, and are often used when the actual system is too large, too small or too complex to study directly. Models can be physical (like a model of the solar system), mathematical (such as a formula) or conceptual (like a flow chart). Models help us understand how things work by simplifying complex ideas into something easier to study and experiment with. They include:

- a physical model of the solar system
- a diagram showing how the water cycle works
- a computer simulation of weather patterns or ozone levels (Figure 6)
- a mathematical model predicting population growth
- a scale model showing the relative sizes of different atoms.

Models are not just used for communication. Some models (such as physical or computer models) can be used to test hypotheses about how a system might behave differently if a variable is changed.

DICHOTOMOUS KEY

VERTEBRATE

FUR → **MAMMAL**

NO FUR

FEATHERS → **BIRD**

NO FEATHERS

DRY SKIN → **REPTILE**

MOIST SKIN

SCALES → **FISH**

NO SCALES → **AMPHIBIAN**
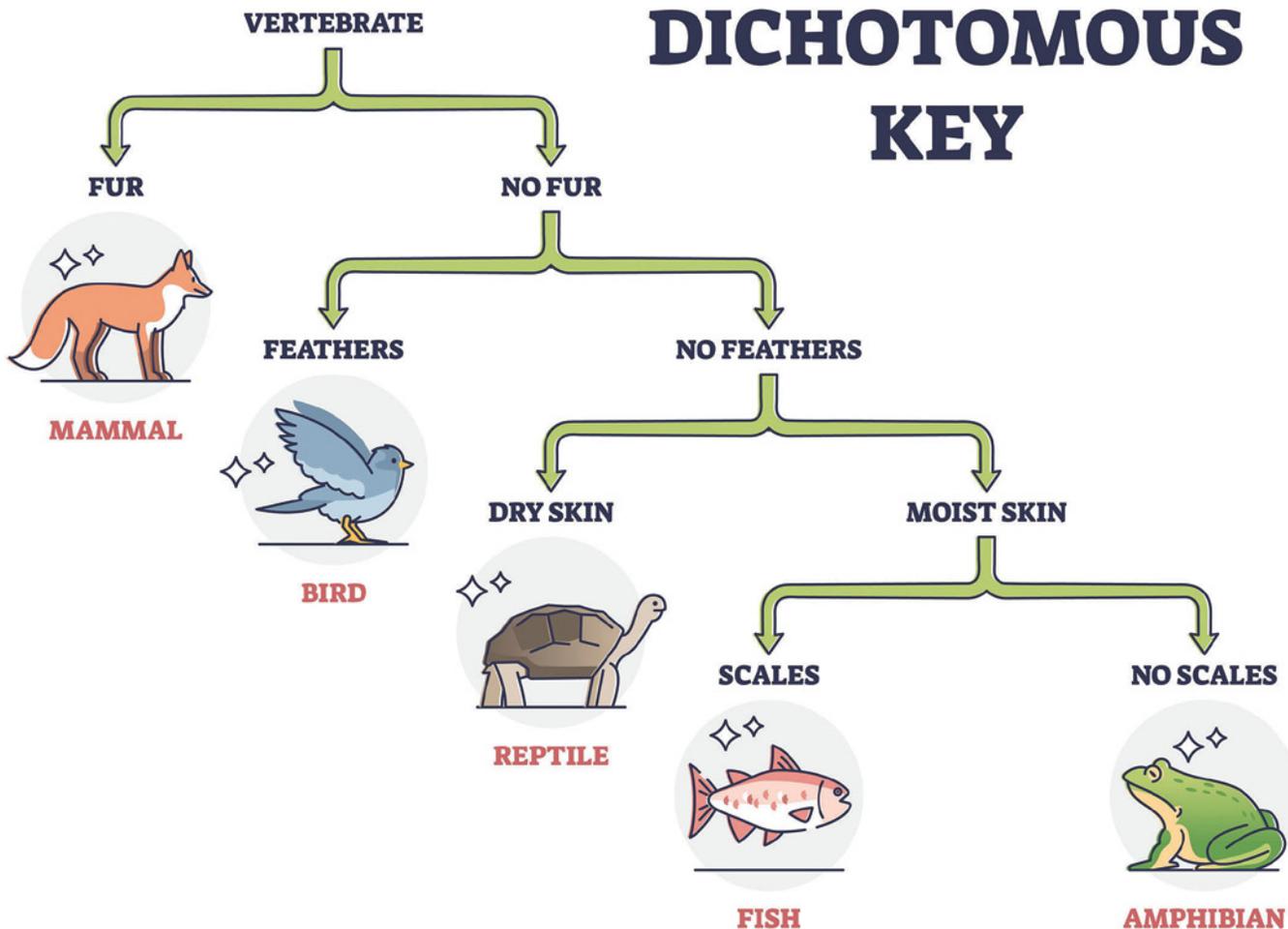
Figure 5 A dichotomous key can be used to identify animals based on their characteristics.

1974
1984
1994
2004
2014
2024
2034
2044
2054
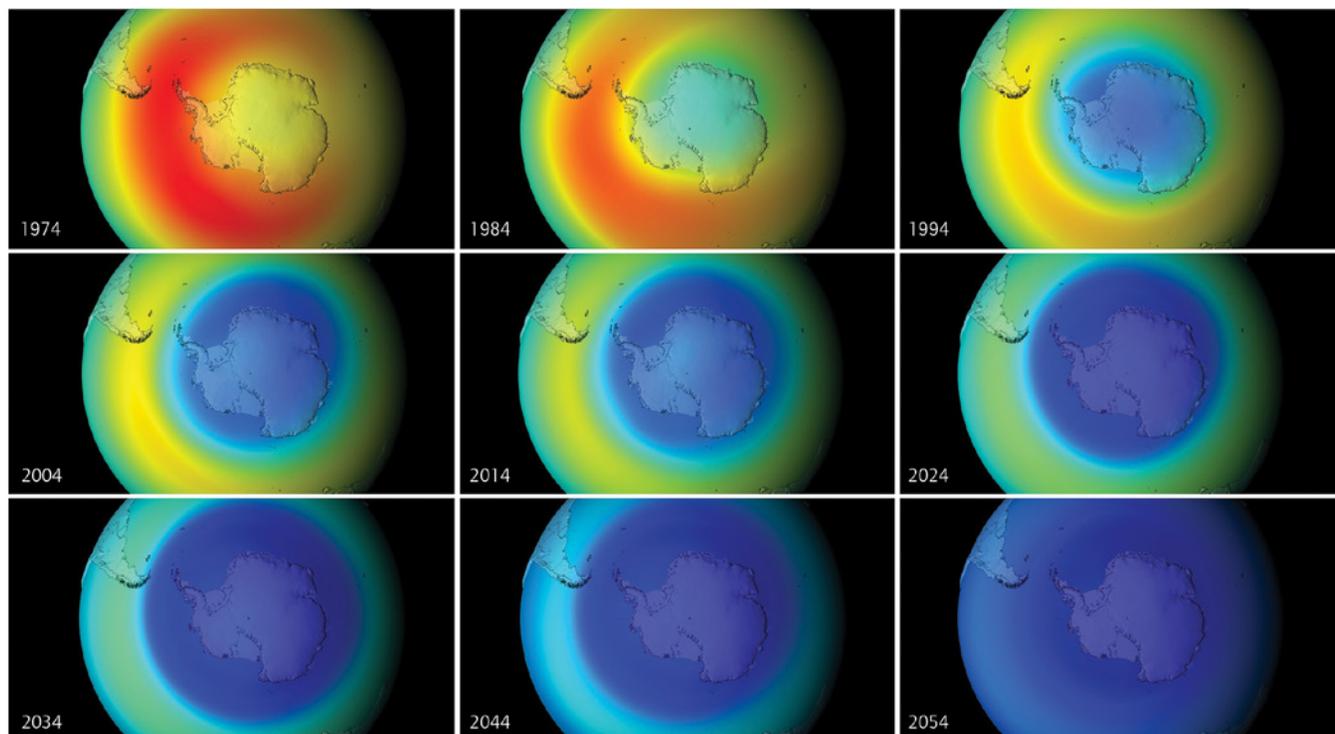
Figure 6 Computer modelling can make predictions about the future, such as Antarctic ozone levels.

Mathematical formulas

Mathematical formulas show connections between independent variables and dependent variables and express them as numbers or equations. Examples include:

- distance travelled = walking speed × time spent walking
- graphing the relationship between the amounts of water given to plants and their growth
- temperature changes throughout a day
- how the weight of a bag changes as you add more items
- finding patterns in measurements (e.g. analysing daily rainfall over a month).

Mathematical relationships can sometimes be used to predict how things may change in the future.

Extrapolating graphs

Graphs can be used to show data that has been collected, but it can also be used to analyse data and to make conclusions. When drawing a graph, it is important to:

- label each axis (with units)
- scale the axis so that it uses the space available
- consider if the line should pass through the origin (0, 0)
- plot the graph and draw the line of best fit
- identify and explain any outliers.

Extrapolation occurs when data are estimated outside the known values. Extrapolating a graph occurs when a line is drawn to estimate values beyond the available data. This can introduce errors to the data, because there is no data collected to support the conclusions that have been made (Figure 7).

extrapolation
estimating unknown values from trends in known data
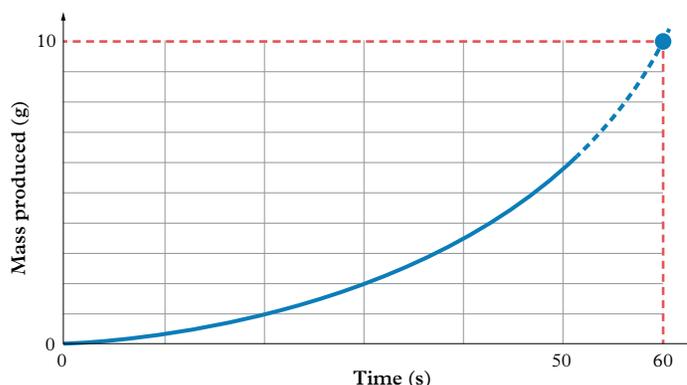
Figure 7 The data were only collected for 50 seconds. Extrapolating the data to 60 seconds can introduce errors.

Interpolation and making predictions

interpolation
determining a value from existing values

While extrapolation involves estimating values outside the known data, **interpolation** is the process of estimating values within the range of the data you have already collected. Interpolation is often considered more reliable than extrapolation because it is based on data points that are within the observed range. To interpolate, you simply use the existing data points on a graph to estimate unknown values between them. For example, if you have data for the mass of an object at 2 g and 5 g, you can interpolate to predict the volume at 2.5 g by drawing a line between the two points and reading the value (Figure 8).

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1.7

Both extrapolation and interpolation allow us to make predictions based on trends shown in graphs. However, extrapolation should be done cautiously, as it involves estimating data outside the known range, which can lead to less accurate results. Interpolation, on the other hand, uses existing data points and is generally more reliable for making predictions within the known range. It's important to always consider the reliability of the predictions and whether additional data could improve the accuracy of your results.
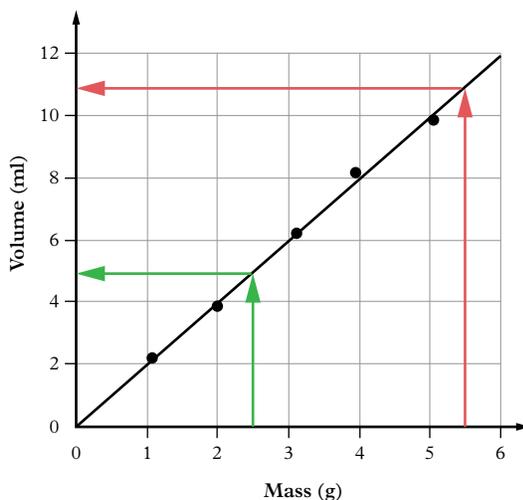
Figure 8 Interpolation uses existing data points to estimate unknown values and is more accurate than extrapolation.

Secondary sources

A reliable secondary source is one that provides accurate, well-researched and credible information derived from primary sources. These sources interpret, analyse and synthesise data and information, offering insights that help deepen an understanding of the research topic. Reliable secondary sources are typically created by experts, are peer-reviewed and are published in reputable scientific journals.

Check your learning 1.7

Check your learning 1.7

Retrieve

1 **Identify** the two types of numerical data that scientists collect.

2 **Identify** which variable (independent or dependent) is located on the *x*-axis of a graph.

3 **Describe** the type of graph that would be used to show the number of birds found in a particular area each month.

4 **Describe** the main purpose of using data tables.

5 **Identify** the difference between categorical data and numerical data.

6 **Define** what extrapolation and interpolation means.

Comprehend

7 **Classify** the following as discrete or continuous data.

   a Student's favourite colour

   b Height of the members in your family

   c The number of books on a shelf

   d The mass of eggs

   e Amount of liquid in a bottle

8 **Select** the best graph that could be created for the data from the following scenarios.

   a Students conduct an investigation to measure the temperature of water as it is heated over a period of 10 minutes.

   b Students measure the height of plants after 4 weeks of using different types of fertilisers.

   c Students count the number of M&Ms of each colour in a bag.

   d Students measure their reaction time to different stimulis (e.g. visual, auditory).

   e Students measure the pH levels of various solutions (e.g. vinegar, soap, water).

Analyse

9 Students conducted an experiment to measure the growth of bacteria in a petri dish over a period of 10 days. They recorded the number of bacterial colonies each day and created a table with their data (Table 3).

   a Plot the data on a graph with the number of bacterial colonies on the *y*-axis and the day on the *x*-axis.

1.7

◀ **b** **Use** the model to predict the number of bacterial colonies on day 12.

c **Use** the graph and model to estimate the number of bacterial colonies on day 7.5.

d **Explain** how the model helps in understanding the growth pattern of bacteria.

e How reliable and accurate do you think the data collected is? What factors could affect the precision of the measurements?

f How does the model help in understanding the growth pattern of bacteria? Are there any limitations to the model?

g **Compare** the growth rate of bacterial colonies between the first 5 days and the last 5 days. What differences do you observe?

h **Interpret** the significance of the steepest part of the graph. What does it tell you about the bacterial growth during that period?

i **Calculate** the average daily increase in the number of bacterial colonies over the 10-day period.

Table 3 The number of bacterial colonies over 10 days

Day	Number of bacterial colonies
1	5
2	12
3	20
4	35
5	50
6	70
7	95
8	120
9	150
10	180

Apply

10 The speed of a car was recorded at regular intervals along a straight stretch of road and the following graph created (Figure 9).

a **Determine** the speed of the car at 2.5 seconds.

b **Justify** if the speed determined in part a is reasonable. HINT: to convert m/s into km/s, multiply your answer by 3.6.

c **Explain** if this is an example of interpolation or extrapolation.

d **Determine** the speed of at car at 12 seconds.

e **Justify** if the speed determined in part d is reasonable. HINT: to convert m/s into km/s, multiply your answer by 3.6.

f **Explain** if this is an example of interpolation or extrapolation.
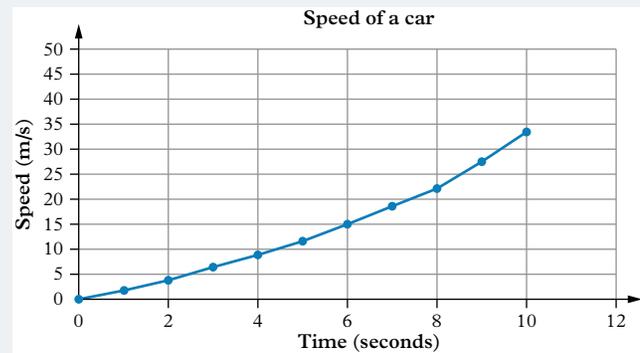
Figure 9 The graph for the speed of a car over time

Lesson 1.8
Scientists keep a logbook

Key ideas

→ A logbook is used by scientists in the laboratory and in the field to record the details and results gathered during experiments and research.

→ A logbook provides evidence of the planning, changes and results of an experiment.

Learning intentions and success criteria

A logbook is used to record essential data and observations

There are many different types of science and even more types of science investigations. Some investigations last a few minutes, while others can last many years.

An example of a long investigation is an ecologist recording how the population numbers of dolphins in Port Phillip Bay change over a decade (i.e. 10 years).

All investigations rely on the scientists collecting and recording data and observations in an electronic or physical **logbook**. Logbooks contain all of the information that will eventually be used to write a formal report (i.e. a written report used to communicate the results of an experiment with other scientists).

logbook a detailed recording of observations and data from a scientific investigation

Figure 1 Logbooks contain important data and observations from experiments conducted in the laboratory or in the field.

1.8

Title of the experiment

The date on which the experiment was conducted

Aim and prediction for the experiment

Marshmallow slingshots   **1 February 2026**

Aim

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

Prediction

If the rubber bands are pulled back twice as much, then the marshmallow will move twice as far.

Method

Refer to page 169 of Oxford Science 8. Please note: instead of rubber bands, 1 cm wide elastic was tied around the base of the chairs for Experiment 1.5.

The method used or the page number of the method. Record any changes to the method.

Measurements

Record any measurements you made to the maximum number of digits provided by the equipment. (You can round them off later. If you don't record them then you cannot get them back later.)

Distance marshmallow has moved

Distance elastic pulled back	Attempt 1	Attempt 2	Attempt 3	Average
1 cm	20 cm 3 mm	23.4 c	19.9 cm	21.1 cm
2 cm				
3 cm				

Show all calculations (even when adding simple numbers).

```
 20.3
 23.4
+19.9          63.6 ÷ 3 = 21.2 cm
 63.6
```

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.

Include any ideas, explanations, diagrams, graphs, sketches or mistakes that happened. Write everything down even if it seems unimportant. You may not remember it weeks or even months later.

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.

Do not rewrite any entries. Try to keep it as neat as you can but it is not a formal report. It is more important that you record your data and observations. If you make a mistake, put a single line through it. Do not white it out, as it may be useful again later.

Include a conclusion or reflection for each experiment to make sure you understood what happened and why.

You may need to write up a formal report for your experiment. If you have completed your logbook well, you will find all the details of the report easily available.

Glue or staple in any photocopies to prevent them falling out.

Figure 2 A sample logbook entry

Creating a logbook

There are some basic rules for creating and using a logbook.

1   Use a bound notebook (Figure 1) or an electronic device that is backed up regularly. Loose papers become lost, and electronic devices can fail. Whether you're using a physical or electronic logbook, ensure that the way you record and store data in your logbook is safe and reliable.

2   Logbooks can be lost, so label your logbook with your name, email address, school and teacher's name. Labelling the logbook with your contact details (and those of your school and teacher) ensures that it will find its way back to you.

3   The second page of the logbook should contain a table of contents (Table 1). Each page should be numbered to help you find the relevant experiments.

4   Always date every entry.

5   Each page should contain the title of the experiment.

Figure 2 shows a sample logbook entry.

Table 1 A table of contents should be included at the start of your logbook.

Unit/subject	Experiment title	Page number
Chemistry	Rates of reactions	2
Biology	Peripheral vision	5
Physics	Newton's first law	10

Check your learning 1.8

Check your learning 1.8

Retrieve

1   **State** the purpose of an experimental logbook.

2   A student made a mistake on a page then ripped that page out of their logbook. **Recall** why this would be the wrong thing to do.

Comprehend

3   **Explain** why an electronic logbook should be backed up regularly.

Analyse

4   **Infer** why it is important to make sure the writing in your logbook is legible (able to be read).

5   **Infer** one reason why it is important to include the date of the experiment in the logbook.

6   **Infer** why you should reflect on each experiment before starting the next experiment.

Apply

7   Use the following logbook entry (Figure 3) to answer the following questions.

   a   **Evaluate** the logbook entry and **identify** which pieces of information are missing.

   b   **Discuss** why each piece of information is necessary for a complete and accurate record of the investigation.

Effect of light intensity on the rate of photosynthesis. 15 March 2025

Aim

To determine how different light intensities affect the rate of photosynthesis in aquatic plants.

Materials

- Aquatic plants (Elodea)
- Beakers
- Water
- Light source (lamp)
- Light meter
- Stopwatch

Method

1. Place the aquatic plant in a beaker filled with water.
2. Position the light source at a fixed distance from the beaker.
3. Measure the light intensity using the light meter.
4. Record the number of oxygen bubbles produced by the plant in 5 minutes.
5. Repeat the experiment with different light intensities.

Results

- Light intensity: 100 lux, Oxygen bubbles: 5
- Light intensity: 200 lux, Oxygen bubbles: 10
- Light intensity: 300 lux, Oxygen bubbles: 15

Conclusion

The rate of photosynthesis increases with light intensity.

Figure 3 Logbook entry

Lesson 1.9
Scientists analyse trends in data

Key ideas

→ Describing trends in graphs will help determine the relationship between variables.

→ Measures of centre can be used to analyse a data set.

→ To determine the validity and reliability of data, the investigation must have measured the intended variable and the data must be consistent across trials.

→ A conclusion must be included, identifying whether the hypothesis was supported or refuted using evidence.

→ Sources of uncertainty should be considered.

Learning intentions and success criteria

Describing relationships between variables

In science, we often look for relationships between different variables. For example, if you're measuring how the height of a plant changes with the amount of sunlight it gets, the amount of sunlight is the independent variable, and the plant's height is the dependent variable. In this case, you are looking for a relationship between the amount of sunlight and the growth of the plant. Sometimes the relationship might be clear, like when more sunlight leads to taller plants. At other times, the relationship might be more complex or less obvious, and you will need to collect more data or look for other factors that could be influencing the result.

Analysing numerical data

There are many different ways to use mathematics to represent data. The measures of centre of a dataset can be found in a number of ways (outlined in Table 1). Worked example 1.9A shows how to find the measures of centre of a data set.

Table 1 Ways to determine the measures of centre for a data set

Measure	Description
Mean	• The expected or average value of a data set • It is calculated by the formula: $$\text{mean} = \frac{\text{sum of all values}}{\text{number of values}}$$
Median	• The middle value of the data • It is calculated by placing all the values in order from lowest to highest and then selecting the value in the middle.
Mode	• The most common value in the set of data • It is calculated by tallying how many times each number appears. The number that appears most often is the mode.

mean the average of a data set

median the middle value for data arranged from smallest to largest

mode the value that appears the most in a data set

1.9

<div style="border:1px solid #ccc">

Worked example 1.9A Calculating mean, median and mode

A car travelled 100 m in the following times:

278 seconds, 167 seconds, 180 seconds, 208 seconds, 3 minutes

Calculate the:

1 mean

2 median

3 mode.

Solution

1 Mean: To calculate the mean, all values must be in the same unit (seconds).

The data should therefore be: 278 seconds, 167 seconds, 180 seconds, 208 seconds, 180 seconds.

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

$$= \frac{278 + 167 + 180 + 208 + 180}{5}$$

$$= \frac{1{,}013}{5}$$

$$= 202.6 \text{ seconds}$$

As all values have three significant figures, the answer should also have three significant figures. 202.6 seconds should be rounded up to 203 seconds.

Therefore, the mean is 203 seconds.

2 Median: To calculate the median, all the values must be placed in increasing order.

167 seconds, 180 seconds, 180 seconds, 208 seconds, 278 seconds

The median value is the middle number, which is 180 seconds.

3 Mode: The mode is the most common number in the data set.

The mode value is 180 seconds.

</div>

Interpreting graphs

Line graphs are the most common graphs that are drawn in scientific reports. These graphs are used to show the relationship between the independent variable and the dependent variable. The shape of the graph gives a hint of how the two variables are related (Figure 1).
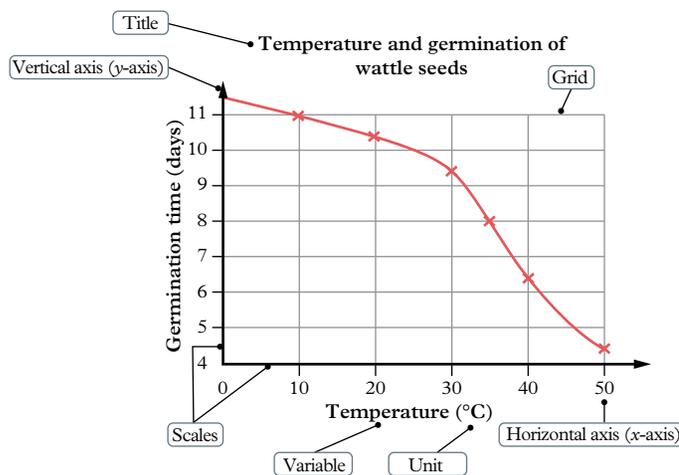
Figure 1 A line graph of germination time of wattle seeds versus temperature

When the line is horizontal, it means the dependent variable is not affected by the independent variable (Figure 2).

If the line is sloped down, the dependent variable decreases as the independent variable increases. This is called an **inversely proportional relationship** (Figure 3).

Occasionally a graph is curved. These types of graphs should be divided into sections. Section A (between 1 and 4 of Figure 4) shows a directly proportional relationship. Section B (between 4 and 7 of Figure 4) shows an inversely proportional relationship.

inversely proportional relationship when one quantity decreases the other quantity increases, or vice versa
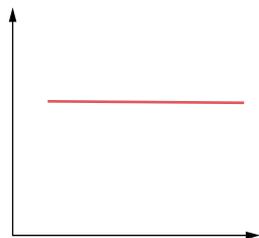
Figure 2 A horizontal line on a graph means the dependent variable is not affected by the independent variable.
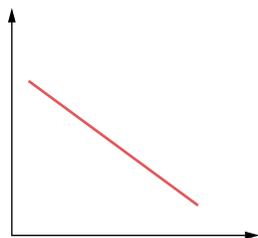
Figure 3 An inversely proportional relationship
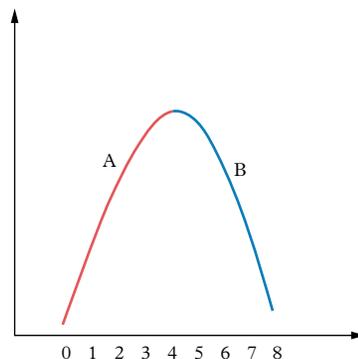
Figure 4 A curved graph is divided into sections that show different relationships.

Describing patterns and trends in data

When analysing data, one of the most important things we do is look for patterns and trends. **Patterns** are regular or repeated arrangements of data points, and **trends** refer to the overall direction or movement of data over time.

For example, if you're looking at how the temperature changes throughout the day, you might notice a pattern where the temperature rises in the morning and falls in the evening. A trend might be that the temperature generally increases over a week during the summer (Figure 5).

Recognising patterns and trends helps us understand how things are changing and predict what might happen next. However, it's also important to look for inconsistencies in the data – these are points that don't fit the general pattern. For instance, if the temperature suddenly drops during the afternoon when the trend suggests it should continue rising, that could be an inconsistency (or an outlier) that needs further investigation.

pattern a repeated sequence or arrangement of numbers or data points

trend represents the overall direction of the data points
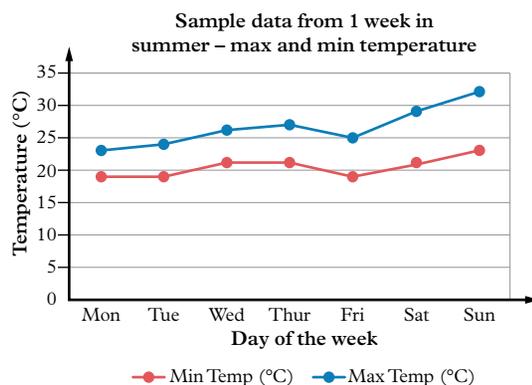
Figure 5 The minimum and maximum temperatures for 1 week in summer

Assessing the validity and reliability of first-hand data

To assess the validity of data, you must consider whether the experiment accurately measures the intended variable and whether external factors were controlled. To assess the reliability of data, check if the data is consistent across multiple trials and if the methods used are precise and repeatable.

Examples of valid and invalid data

- **Valid data**: In an experiment to measure the effect of light intensity on photosynthesis, valid data would show a clear relationship between light intensity and the rate of photosynthesis, with controlled variables such as temperature and carbon dioxide levels kept constant.
- **Invalid data**: If the same experiment is conducted but the temperature fluctuates significantly, the data may show changes in photosynthesis rates that are actually due to temperature variations rather than light intensity. This data would be invalid because it does not accurately measure the intended variable.

Examples of reliable and unreliable data

- **Reliable data example**: When measuring the speed of a chemical reaction at different temperatures, reliable data would show consistent reaction speeds when the experiment is repeated under the same conditions. For example, if you measure the reaction speed at 25°C multiple times and get similar results each time, the data is reliable.
- **Unreliable data example**: If the same reaction speed experiment is conducted but the measurements vary widely each time due to inconsistent timing methods or fluctuating temperatures, the data would be unreliable. This inconsistency makes it difficult to draw accurate conclusions.

Outliers

outlier a data point that differs significantly from the main group of data

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. An outlier is a value that is outside the normal range of all other results. For example, an outlier may be observed in the data when measuring the height of seedlings after 3 weeks of growth (Table 2).

From the table, it is clear to see that seedling 5 is the outlier as it is outside the normal range when compared to the other results. The mean height of all the seedlings is 3.4 cm. If seedling 5 was excluded, the mean height would be 3.9 cm. This shows how one outlier can affect the results. In this case, the outlier has decreased the mean and so it is not representative of the growth of the seedlings.

Table 2 An outlier can affect the measures of centre. In this case, the mean is lower if seedling 5, the outlier, is included in the calculation.

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

Sources of uncertainty

Recognising sources of uncertainty and considering alternative explanations are essential for a thorough analysis of the data. This involves acknowledging limitations in the data and exploring other factors that could affect the results.

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1.9

Sources of uncertainty in an investigation can include:

- **Measurement errors**: These can occur due to inaccuracies in the instruments used or human error during data collection. For example, if a thermometer is not calibrated correctly, the temperature readings might be inaccurate.
- **Sample variability**: Differences in the samples used for experiments can introduce uncertainty. For instance, if studying plant growth, variations in soil quality or water availability among different samples can affect the results.
- **External influences**: Uncontrolled external factors, such as changes in weather conditions or environmental disturbances, can impact the data. For example, unexpected rainfall during an outdoor experiment can alter the results.

Drawing conclusions

After completing an investigation, you should draw a **conclusion** that aligns with the data and observations collected, ensuring the conclusion is based on accurate and reliable evidence. Here you will explain whether your hypothesis was supported or refuted (using data to support your findings) as well as highlighting the significance of the results.

conclusion a statement that "answers" the aim of an experiment

For example, if testing if more salt will be soluble in warmer water, a conclusion could be:

"The experiment investigating the effect of temperature on the solubility of salt in water demonstrated a clear relationship between these two variables. As the temperature increased, the amount of salt that dissolved in the water also increased. This observation is consistent with the scientific concept that higher temperatures enhance the solubility of substances. The data collected supports the hypothesis that temperature positively affects the solubility of salt in water."

Check your learning 1.9

Check your learning 1.9

Retrieve

1 **Define** the following terms in the context of data:
   a pattern
   b trend.

Comprehend

2 **Describe** the factors that contribute to the validity of an experiment.
3 **Explain** what reliable data is.
4 **Describe** what it means if data is valid.

Analyse

5 Look at the following set of data showing the temperature at different times during the day:
   a 8 am: 20°C
   b 12 pm: 25°C
   c 2 pm: 30°C
   d 5 pm: 22°C
   e 7 pm: 18°C
   Describe the trend you notice in the temperature data. **Identify** any inconsistencies, and **explain** what could cause them.

6 Below is data from an experiment measuring the growth of plants in two different soil types:
   – Soil A: Plant 1: 15 cm, Plant 2: 14 cm, Plant 3: 16 cm
   – Soil B: Plant 1: 10 cm, Plant 2: 12 cm, Plant 3: 11 cm
   a **Describe** the relationship between soil type and plant growth based on this data.
   b **Explain** if the data is reliable and justify your reasoning.

1.9

7 **Use** the following data from an investigation about how different temperatures affected the activity of an enzyme to answer the following questions.

a **Create** a graph for Table 3.

b Examine the graph to identify any potential outliers. **Explain** why these data points might be considered outliers.

c **Interpret** the overall trend of the graph. How does temperature affect enzyme activity?

d **Discuss** the possible reasons for the decrease in enzyme activity at higher temperatures.

Table 3 How different temperatures affected the activity of an enzyme

Temperature (°C)	Reaction rate (units/min)
10	2
20	5
30	8
40	12
50	15
60	14
70	9
80	3

Apply

8 **Describe** the relationship between the independent variable and dependent variable in Figure 6.
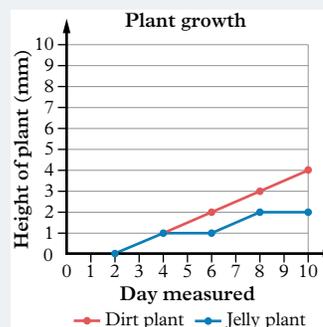
Figure 6 Height of plant versus day measured

9 For the following scenarios, **identify** sources of uncertainty.

a Students are measuring the speed of a toy car as it travels down a ramp.

b Students are testing the strength of bridges made from different materials and designs.

c Students are measuring their reaction times to a visual stimulus using a stopwatch.

Lesson 1.10
Scientists evaluate conclusions

Key ideas

→ To solve a problem, there are different approaches that can be used.

→ Bias can affect all aspects of a scientific investigation and can skew the outcome.

→ Do not take information from secondary sources as true until you check who wrote it, where it has been published and if it's current.

→ Possible alternative explanations for the observed results should be considered.

→ The quality of the data can be improved by repeating trials, having your work peer reviewed, using calibrated digital equipment, analysing sources of error, evaluating the data and improving data recording.

Learning intentions and success criteria

Take a step back and evaluate

Stage 4 of the scientific method involves evaluating the conclusion from the data and findings generated during a scientific inquiry (Figure 1). Scientists do this by:

- evaluating how the problem was solved
- evaluating the validity of information
- suggesting alternative explanations.
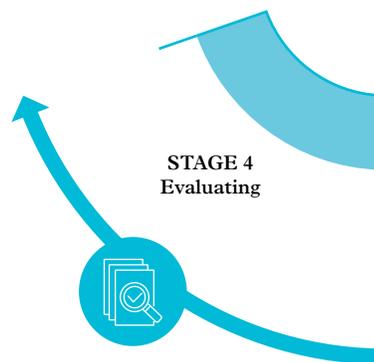
STAGE 4
Evaluating

Figure 1 Stage 4 of the scientific method is **Evaluating**.

Approaches used to solve problems

There are various approaches that can be used to solve different problems. Here you need to compare different methods and determine which is most effective based on evidence and scientific principles, while understanding the strengths and limitations of each approach.

These approaches include:

- laboratory experiments
- field work
- modelling and simulations
- comparative analysis
- writing a pros and cons list
- conducting a SWOT analysis
- creating cause-and-effect diagrams.

The strengths and limitations of each approach can be seen in Table 1.

Table 1 A summary of the strengths and limitations of the approaches used to solve problems

Approach	Strength	Limitation
Laboratory experiments	Easy to isolate variables and control the conditions; can produce precise, repeatable results	• Lack real-world context as conditions in the laboratory are not mimicked in natural environments • Can be expensive and time-consuming
Field work	Provides real-world data and makes results more applicable to actual situations	• Cannot control conditions that can introduce variability and challenges in isolating factors • Can be resource intensive and time consuming
Modelling and simulations	Useful for predicting outcomes, testing complex scenarios and analysing patterns without the need for experiments	• Relies on the accuracy of the model and the data used
Comparative analysis	Evidence-based decision-making that identifies similarities, differences and trends in data or case studies	• Requires high-quality, reliable data
Pros and cons list	Simple to use and organises thoughts to evaluate options to make an informed decision	• May rely too much on subjective judgement rather than objective evidence • May oversimplify complex problems
SWOT analysis (Figure 2)	Identifies strengths, weaknesses, opportunities and threats	• May not deeply analyse causes of weaknesses or threats • How factors are categorised can be subjective
Cause-and-effect diagram (Figure 3)	Maps out underlying causes of problems and explores potential solutions	• Can be time consuming to create • May oversimplify interconnected issues

Figure 2 A SWOT analysis grid
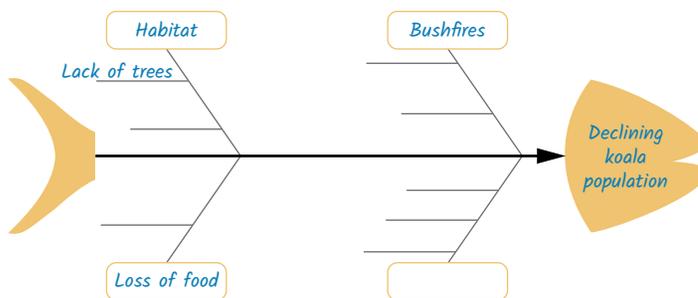
Figure 3 A cause-and-effect diagram

Validity of primary and secondary sources

When analysing the validity of information from primary and secondary sources, it is important to critically evaluate several key aspects to determine its credibility and reliability.

Social media is full of big claims and headlines quoting the latest scientific claim. These claims cannot be trusted unless they pass the validity and credibility tests. There are a number of things to look for before the claim is even read.

Bias

bias discrimination against ideas, against people or in the collection and interpretation of information

If a person is biased, it means they have already made a decision about a person or outcome. In science, **bias** can cause an observer to only notice the information that they expect to occur and to avoid or refuse to acknowledge data that is unexpected. Because biased observations only tell one side of a story, it can sometimes cause inaccurate data and leave a false impression. There are many ways bias can affect a scientific investigation.

Confirmation bias

confirmation bias when a scientist selects a method that will support the outcome they want

When a researcher has a hypothesis that they are certain is correct, they may shape their investigation so that the data supports the hypothesis. This is known as **confirmation bias**; it involves favouring information that "confirms" a hypothesis.

Sampling bias

sampling bias a bias where a group of test subjects do not represent the larger sample group

Sampling bias occurs when an experiment tests a small group of subjects (either people or objects) that do not represent the larger group (Figure 4). This has been seen most recently during pre-election surveys where people are asked who they will vote for via landline phone surveys in city regions. These surveys often miss people who are not home during the day or who do not have a landline phone because they only use their mobile phone. This means the predictions of who will win an election may be biased because the sample only represents people who own landline phones.

Channelling bias

When scientists want to test the effectiveness of a new drug, they will carefully select a large group of people and divide them into two smaller groups.
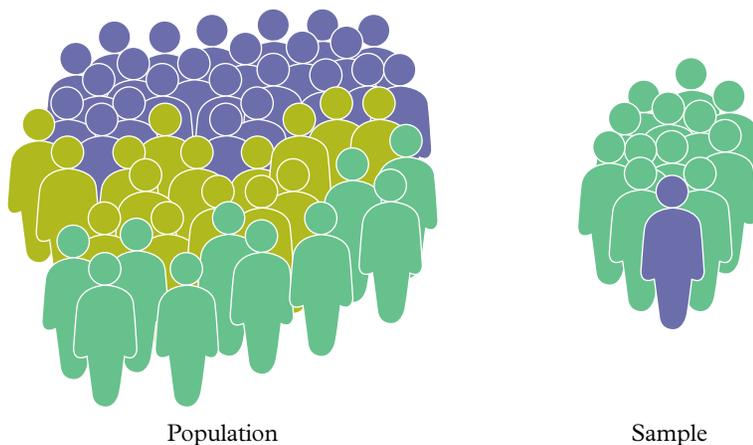
Population   Sample

Figure 4 Sampling bias exists when the population of the sample doesn't reflect the actual population.

When selecting which person will be placed into each group, it is tempting for the scientist to place or "channel" the people most affected by a condition into the group that will receive the treatment and the people who are least affected into the non-treatment group. But this can affect the outcome of the trial.

Instead, the two groups should be **randomised** (randomly assigned to a group), and both groups should appear to receive the same treatment. This can be done by giving both groups a pill to take at the same time each day. One group will have the new drug in the pill, while the control group will be given a placebo.

A **placebo** is a substance or treatment that is designed to have no effect, for example, a sugar pill. Some people can be so convinced that the treatment will work that a placebo will make them feel better. In one experiment, a group of patients with osteoarthritis of the knee underwent a placebo operation instead of receiving the real procedure. These patients reported feeling less pain as a result of the fake procedure. When participants do not know if they are receiving the real treatment or a placebo, it is called a randomised **blind study**.

Although a blind study is useful, the doctors treating the participants might also behave differently towards a patient if they know the patient is receiving treatment or a placebo. To avoid this, sometimes the treating doctors are not told which treatment the patient is being given. In these tests, only the scientists know the outcome and can decode which group received the treatment. When there are two layers of people who do not know who received the treatment until it is over, this is called a randomised **double-blind study**.

Who is the author?

It is always worth checking who wrote the article before reading their claims. Is the author qualified in that field? During the COVID-19 pandemic, there were many "doctors" claiming to know about vaccines and the spread of viruses, but many of these people were not qualified in infection, epidemiology or even medicine. It is always worth asking "What are the author's qualifications?".

Why was the article written?

Some big headlines are written by companies that want you to buy their product. Cosmetic companies will make claims that their skin cream will make you look younger, while car companies will claim that their oil will make your car run more smoothly. They may write an article or claim that quotes scientific data that make their product look the best, and often ignore data that disagree with their claim. Always consider why the article was written and if it is biased to a particular view.

randomised when people or objects are selected at random

placebo a substance or treatment that is designed to have no effect

blind study when the participants do not know if they are receiving the treatment or a placebo

double-blind study when neither the participants nor the treating doctors know if they are receiving the treatment or a placebo

Is it current?

A current claim does not just mean the most recently written article. While the date on the article of claim is important, it is worth checking if the data match other available data.
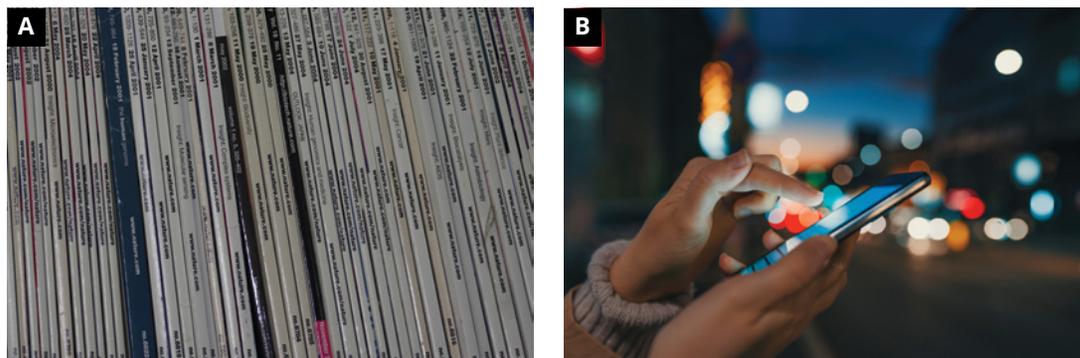
Figure 5 (A) Peer-reviewed articles in science journals are a valid secondary source because they have been checked by other scientists. (B) Posts and articles on social media are not always a valid source because they have not been checked for credibility and posts can often be sponsored by companies with their own agendas.

It is easy for a group of non-scientists to write an article each week with a new claim, but it is important to check if the data are able to be reproduced by other scientists. Does it fit with current research, or is it from the same group of people using the single set of data?

Is the publisher reputable?

Social media has a wide mix of trustworthy as well as untrustworthy publishers. This also happens with some online "scientific" journals. There are some websites that claim to be scientific journals, but they are "pay to publish" sites. These websites will publish any article that is written as long as the authors pay the company. In 2005, MIT students used a computer to generate random science and jargon words in a science paper. They then submitted the paper to a variety of science sites around the world. Some sites published the fake science paper. A good publisher will always peer review a paper before publishing. This means that the paper will be checked by other scientists who have been trained in the area.

Alternative explanations

Considering alternative explanations involves exploring other factors that could potentially explain the observed results. This helps to ensure that the conclusions drawn are not biased.

For example, if an investigation looked at the effects of air pollution on respiratory health, you should also consider other factors that could influence respiratory health, such as allergens, weather conditions and lifestyle factors. These alternative explanations help in understanding that air pollution is not the sole factor affecting respiratory health.

Improving the quality of data

The quality of the data collected from investigations or fieldwork has an impact on the conclusions that can be drawn. To improve the quality of the data, a number of things can be done, including:

- Repeating trials – Completing multiple trials for an investigation ensures results are accurate and precise. Only completing one trial means you would not be able to identify any errors if they occurred.

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- Using digital equipment – Digital equipment such as temperature probes and motion sensors, reduce measurement errors and produce more accurate results, as long as they are calibrated and maintained (Figure 6).
- Aanlysing sources of error – Identifying systematic and random errors will help refine your method so these errors can be reduced.
- Peer review – Have a peer review your data and method for any inaccuracies or inconsistencies.
- Evaluation – Critically analyse your data for any patterns, outliers and inconsistencies.
- Improving data recording - All data and observations should be immediately recorded to avoid errors due to memory or miscommunication. The way the data recorded is also important, such as using a table, so it is clear what has been collected and when.
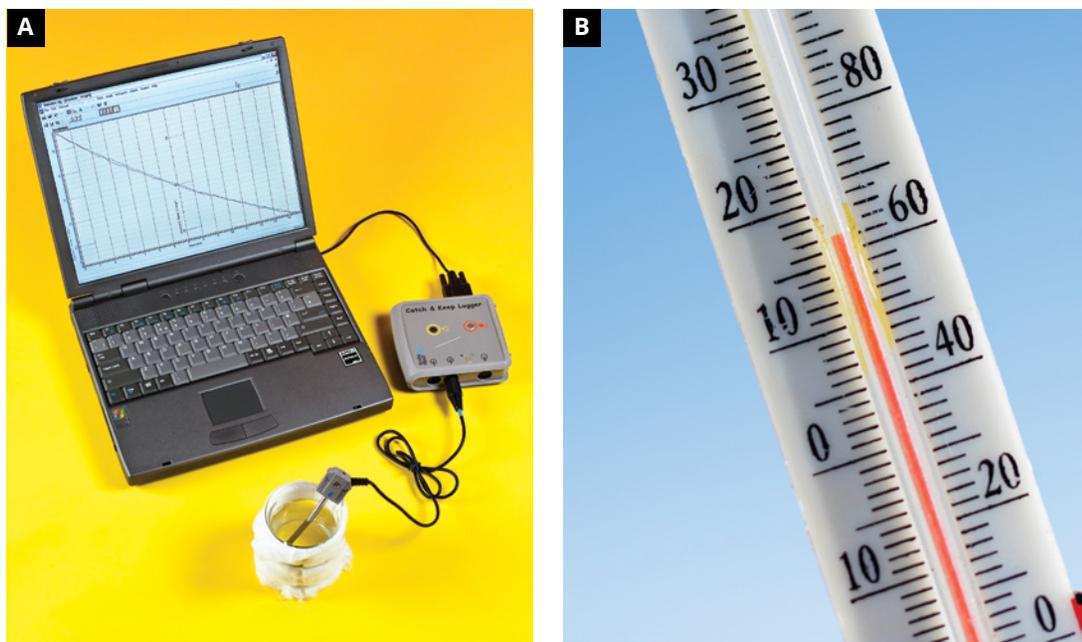
Figure 6 (A) Temperature data collected from a data logger will be more accurate than taking a reading from (B) an analogue thermometer, due to errors that will occur when trying to read the markings.

Check your learning 1.10

Check your learning 1.10

Retrieve

1 **Explain** how bias can affect an outcome.
2 **Identify** three ways the quality of data could be improved.
3 **Identify** three things to look for when evaluating the validity of primary and secondary resources.
4 **Describe** why there are various approaches used to solve problems.

Comprehend

5 **Describe** how not calibrating scales at the start of an experiment could affect the results of the experiment.
6 For each scenario, **determine** what approach would be best to solve the problems.
    a You are investigating the effect of different fertilisers on plant growth.

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1.10

b You are studying the biodiversity of a local wetland.

c You are comparing the health outcomes of two different diets.

d Your school is planning to implement a new recycling program.

7 Recall two places where you would find reliable research. **Explain** why these sources are reliable.

8 **Explain** how data can be used to draw evidence-based conclusions.

Analyse

9 **Contrast** what is meant by the terms "current" and "recent" in scientific publishing.

10 **Identify** a source of secondary data from social media. **Judge** the validity of the claim made in the information using methods described.

11 Below is data from an experiment measuring the growth of plants in two different soil types:
  – Soil A: Plant 1: 15 cm, Plant 2: 14 cm, Plant 3: 16 cm
  – Soil B: Plant 1: 10 cm, Plant 2: 12 cm, Plant 3: 11 cm

  Scientists concluded that: "Plants grown in Soil A exhibit greater growth compared to those grown in Soil B. The average height of plants in Soil A is 15 cm, while the average height of plants in Soil B is 11 cm. This suggests that Soil A may have more favourable conditions for plant growth, such as better nutrient content or soil structure."

  Given the information provided, write an alternative conclusion that uses the data provided and considers other possible factors influencing plant growth.

Apply

12 A scientist tested how the amount of light in a glasshouse affected the growth of wheat plants. When they analysed their results, they stated that their findings could not be applied to plants growing outside the glasshouse. **Discuss** why the scientist put a limit on how the findings of their investigation could be applied.

13 **Identify** which of the following doctors could be trusted to comment on vaccines. **Justify** your decision (by describing the qualifications of each type of doctor and comparing these to the type of information needed on vaccines).
  – A person with a PhD in English literature
  – Veterinarian
  – Epidemiologist

14 You are part of a research team investigating the impact of urban development on local water quality. Your team needs to determine the best approach to study this issue and how to present your findings.

  a **Create** a method for conducting a laboratory experiment to test water samples from various locations within the urban area. Include steps for sample collection, testing procedures and data recording.

  b **Discuss** the advantages and disadvantages of using field work to collect water samples directly from different sites within the urban area. Consider factors such as accessibility, environmental conditions and data accuracy.

  c **Evaluate** the effectiveness of using computer modelling and simulations to predict future changes in water quality based on current urban development trends. What are the strengths and limitations of this approach?

  d **Justify** your choice of using comparative analysis to study the differences in water quality between urban and rural areas. **Explain** why this method is suitable for your research and how it can help identify key trends.

  e **Predict** the potential outcomes of implementing a new urban development policy aimed at improving water quality. Use a SWOT analysis to identify the strengths, weaknesses, opportunities and threats associated with this policy.

15 **Create** a fishbone diagram to identify and organise the possible causes of water pollution in the urban area. Include categories such as human activities, industrial processes and natural factors.

Lesson 1.11
Scientists communicate their findings

Key ideas

→ The results and findings of a scientific investigation are communicated using a scientific report or scientific poster.

→ When presenting a scientific argument, you must provide evidence to support your argument, using correct scientific language and terminology.

→ A scientific report should include all common sections and headings to clearly communicate the purpose, hypothesis, method and results and the data analysis that supports the conclusion.

→ A scientific poster is similar to a report, except it is more concise due to space limitations.

Learning intentions and success criteria

Communication is key

Stage 5 of the scientific method is communicating the data and findings generated during a scientific inquiry (Figure 1). This includes asking another scientist to check if they are correct. This process of **peer review** means the second scientist:

• evaluates the methods to identify assumptions, errors and improvements
• evaluates the results to identify outliers and anomalies
• evaluates the patterns or trends that were identified.

STAGE 5
Communicating

peer review
a process in which experts evaluate the findings of a report before it is published
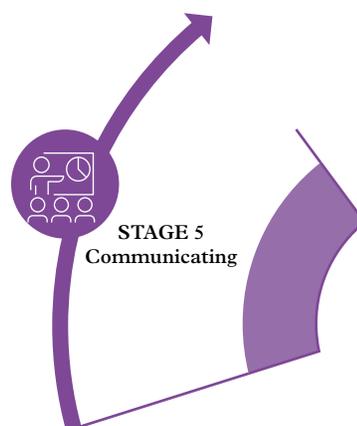
Figure 1 Stage 5 of the scientific method is **Communicating**.

Introduction

Like all forms of communication, the way we communicate in science depends on the audience. If the audience does not know the key words or concepts that you are discussing, you will need to use simple diagrams, models and language so they understand what you are trying to say. For example, two physicists may say, "Potential energy was added to the rubber band", whereas a teacher may say, "The rubber band was stretched".

How to present a scientific argument

To present an effective scientific argument, you must use evidence to support your argument, correct scientific language and terminology. However, this will depend on your audience and the purpose of your investigation. This will ensure that your argument will be relevant and can be understood by others in the specific community you're addressing.

1.11

Evidence

For example, if you are arguing that climate change is affecting local weather patterns, you should present data on temperature changes, precipitation levels and extreme weather events. By using evidence, you can demonstrate the validity of your arguments and persuade the audience to your point of view.

Scientific language and terminology

Using correct scientific language and terminology is essential for precision and clarity. Scientific terms have specific meanings that convey complex concepts accurately. For example, when discussing chemical reactions, you would use terms like "reactants", "products" and "catalysts". This ensures that your arguments are understood by others in the scientific community.

When communicating with non-specialist audiences, explain technical terms when necessary and avoid complex scientific terminology.

Writing scientifically

Writing scientifically is different to writing an English essay. For example, read the next two paragraphs:

> **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 one rose and water was placed above a Bunsen burner to heat the water. When the water reached its boiling point, some of the water evaporated, producing steam. The heat from the steam caused the rose to wilt.

The descriptive sentence tells us all what 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 scientifically and that you do not include information irrelevant to the research.

Writing a scientific report

Scientists write reports so that their investigation and results can be reviewed by their science-trained colleagues or peers. As both the writer and reader are science trained, these reports will contain many terms that have particular meanings. For example, the word "significant" can mean "important" when used by a person in the street. But to a scientist, the word "significant" means that a result is "not due to chance". This means that the words in a scientific report need to be carefully chosen. Clear and detailed writing ensures that others can replicate the experiment and verify the results.

All scientific reports have common sections and headings. Table 1 explains each section that you will need to include in your scientific reports.

Table 1 Sections of a scientific report

Section	Description
Title	• A statement that includes the independent variable and the dependent variable.
Abstract	• Presented on its own page at the start of a report. • 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.)
Introduction	• A summary of any previous experiments that you have completed. • A description of the key concepts being examined and how they are related to your hypothesis.
Aim	• A statement of what you are trying to achieve in the experiment.
Hypothesis	• A prediction of how the independent variable will affect the dependent variable and the reason that supports the outcome. • "If … <how the independent variable will change> … then … <how the dependent variable will change> … because … <reason for the change>".
Method	• A list of the materials, containing the concentrations and brands, should be included in the method. • The method should contain step-by-step instructions or a brief description (in past tense) that would enable someone to repeat the experiment. • Safety advice or a risk assessment should be included. • Relevant labelled diagrams should be included where necessary.
Results	• The data should be presented in a table, graph or diagram. • A written summary of the results (stating facts without conclusions) should also be included.

Discussion	• This section should analyse the results by:
	  – describing the relevant science concepts that occurred in the results
	  – drawing conclusions from the results
	  – comparing the conclusions to the hypothesis
	  – describing how the results could apply in the real world.

Conclusion	• The conclusion should answer the aim of the experiment by:
	  – comparing the conclusions to the aim
	  – describing the limitations of the experiment (by describing situations where these results would not apply)
	  – describing another investigation that could be conducted to confirm or extend the conclusions.

References	• Any sources that you used to research the scientific concepts or definitions should be included here. • There are different ways to write a reference. Check which style is preferred by your school. • Most scientific communications use APA Style (American Psychological Association Style). For example: Silvester, H. (2023). *Oxford Science 10 Australian Curriculum* (2nd ed.). Oxford University Press.

1.11

When writing reports, scientists also avoid using the first person ("I", "we", "me", "you", "us", etc.). All science should be **unbiased** and **objective**.

unbiased impartial and free from preconceived ideas

objective uninfluenced by personal opinions and interests

Scientific reports and papers are written in the third person so that it is clear that the communication is objective, rather than being based on the opinions or beliefs of individuals.

Scientists usually use past tense when they write a report because they are describing something they have already completed. If results were described in present tense (the now) or future tense (the later on), then the reader or listener would not be sure if the experiment was finished.

Some examples showing the differences between scientific language and common language are given in Table 2.

Table 2 Examples showing differences between scientific language and common language

Scientific language	Common language
The equipment was set up.	I set up the equipment.
The mass of the beaker was measured.	We weighed the beaker on the scales.
The beakers were heated to 50 degrees Celsius. (Past tense)	Heat the beakers to 50 degrees Celsius. (Present or future instruction)
The two trolleys were pulled apart. (Past tense)	Pull the two trolleys apart. (Present or future instruction)
The metal was malleable.	The metal could be bent into any shape.
At 6:15 am a single magpie sitting on a protruding tree branch called loudly for 30 seconds.	I think it was a magpie that sang the warbling song that woke me up in the morning.
The mass of the sodium bicarbonate was identified as a possible random error.	We could have improved the experiment if we were more organised and measured the amount of bicarb properly.

Creating a scientific poster

Another way to communicate your findings is to create a scientific poster (Figure 2). It contains all the components you would find in a scientific report but is a concise summary of an investigation, communicating the research process, findings and conclusion in an effective manner. Your teacher should be able to provide you with a digital or paper copy of a scientific poster template for you to work with.

The boiling point of water
Student name:

Abstract

This investigation explores the effect of varying amounts of salt on the boiling point of water. By comparing the boiling points of plain water and salt solutions with different concentrations, we aim to understand how salt influences the boiling point. Our findings indicate that increasing salt concentration raises the boiling point of water.

Materials

- 4× 250 mL beakers
- Distilled water
- 100 mL measuring cylinder
- Bunsen burner
- Thermometer
- Stopwatch
- Electronic balance
- Spatula
- Gauze mat
- Tripod
- Salt

Introduction

The boiling point of water is a fundamental physical property that can be altered by the presence of impurities. Understanding how salt affects the boiling point is essential for applications in cooking, chemistry and industrial processes. This study focuses on the impact of different salt concentrations on the boiling point of water, using plain water as the control.

Aim

To determine if the concentration of salt affects the boiling point of water

Hypothesis

If the concentration of salt in the water increases, then the boiling point will increase because more energy is required to reach the boiling point due to the salt ions.

Method

1. 100 mL of distilled water was measured into a measuring cylinder and poured it into a beaker.
2. The Bunsen burner, gauze mat and tripod were set up.
3. The thermometer was placed in the water and the initial temperature recorded.
4. The beaker was placed on the tripod, the Bunsen burner lighted and the stopwatch started.
5. Once the water started boiling, the temperature and time taken was recorded.
6. A clean beaker was placed on the electronic balance and 1 g of salt added. In the remaining two beakers, 5 g and 10 g of salt were added respectively.
7. 100 mL of distilled water was added to the measuring cylinder and added to each beaker with salt.
8. Each salt solution was tested by placing it on the tripod, recording the initial temperature and lighting the Bunsen burner.
9. Once the water was boiling, the solutions temperature was recorded and the time taken.

Figure 1: Equipment setup

Results

Boiling points of solutions

Temperature (°C) — y-axis: 96, 98, 100, 102, 104, 106
Solution — x-axis: Distilled water, 1% salt solution, 5% salt solution, 10% salt solution

Conclusion

The investigation confirms that the presence of salt significantly affects the boiling point of water, supporting the hypothesis. Higher salt concentrations lead to an increase in the boiling point and affect the time taken to reach it.

Some other alternative explanations for the results include other impurities in the water and uneven heat distribution from the Bunsen burner, affecting the boiling point readings.

References

Silvester, H. (2023). *Oxford Science 10 Australian Curriculum* (2nd ed.). Oxford University Press

Figure 2 A sample scientific poster

1.11

Check your learning 1.11

⊡ **Check your learning 1.11**

Retrieve

1 **Identify** what should be included in the discussion section of a scientific report.

2 Outline the correct order for the following items in a scientific report.
   a Discussion
   b Method
   c Results
   d Abstract
   e Introduction
   f Conclusion
   g Aim

3 **Explain** the difference between a scientific report and scientific poster.

Comprehend

4 **Explain** why a conclusion is written at the end of an experiment or investigation.

5 **Explain** why personal pronouns are not used in scientific reports.

6 **Explain** why it is important that scientists prepare scientific reports.

7 **Explain** why using a common format for all scientific reports might make it easier for scientists to communicate with one another.

8 Rewrite the following statements using scientific communication.
   a I measured the speed of a skateboard.
   b The acid made lots of bubbles appear on the side of the metal.
   c When I put my hand in the water, it felt very cold. I think it was 15 degrees.

Analyse

9 **Compare** the information that is written in the results and discussion sections.

10 You are investigating the impact of different types of water filtration systems on the removal of contaminants from urban water sources. You have collected data on the effectiveness of three different filtration systems: System A, System B and System C.

Data:
- System A: Removes 85% of contaminants, costs $200, lasts 2 years.
- System B: Removes 90% of contaminants, costs $300, lasts 3 years.
- System C: Removes 80% of contaminants, costs $150, lasts 1 year.

Analyse the data provided to communicate scientific ideas and information for the purpose of recommending the best water filtration system for urban use. Construct evidence-based arguments and use appropriate scientific language, conventions and representations to answer the following questions:
   a **Classify** the filtration systems based on their effectiveness, cost and lifespan.
   b **Compare** and **contrast** the advantages and disadvantages of each filtration system.
   c **Distinguish** between the short-term and long-term benefits of each system.
   d **Interpret** the data to determine which system offers the best balance of cost-effectiveness and contaminant removal.
   e **Calculate** the annual cost of each filtration system and use this information to support your recommendation.

Apply

11 You are part of a team tasked with investigating the spread of a new infectious disease in your local urban area. The following data has been collected (Table 3).

Table 3 Data collected from the spread of a new infectious disease

Infection rates	Age distribution of cases	Hospitalisation rates	Recovery rates
Week 1: 50 cases **Week 2:** 120 cases **Week 3:** 200 cases **Week 4:** 350 cases	**0–10 years:** 30 cases **11–20 years:** 70 cases **21–30 years:** 100 cases **31–40 years:** 150 cases **41–50 years:** 200 cases **51+ years:** 170 cases	**Week 1:** 10% **Week 2:** 15% **Week 3:** 20% **Week 4:** 25%	**Week 1:** 30% **Week 2:** 40% **Week 3:** 50% **Week 4:** 60%

Present a scientific argument, providing a clear and concise summary to the city council of your findings. **Use** appropriate scientific language and conventions, including evidence-based arguments and visual aids such as graphs, charts and diagrams to convince the council of the importance of your solution. Some things to consider include:

- your proposed measures to control the spread of the infectious disease
- the potential impact of your proposed measures on public health and the community
- the feasibility of your proposed measures, taking into account factors such as cost, resources and community acceptance
- the long-term outcomes of implementing your proposed measures
- use of scientific language and conventions to explain how your proposed measures will reduce the spread of the disease over time.

Lesson 1.12
Command terms identify the tasks in a question

Key ideas

→ Command terms are instructive words that require specific types of mental processes to perform set tasks.

→ Command terms can be grouped into categories based on the level of cognition required to perform the task.

Learning intentions and success criteria

Command terms

Command terms are instructive words that require specific types of mental processing or "**cognition**" to perform set tasks. For example, the word "explain" is a command term because it requires you to first recall what you understand about something and then reframe that understanding into clearer succinct terms. Command terms are often used in questions, which means you will encounter a variety of different command terms in school as you learn new information and undertake assessments.

command term a "doing word" that requires you to perform a specific thinking task

cognition mental processes that are involved in acquiring, storing, manipulating and retrieving information

Familiarising yourself with different command terms and the tasks and thinking processes behind them can help you determine how to best respond to a question. An understanding of command terms can be the difference between achieving partial or full marks on an important exam or assessment question (Figure 1).

Some command terms require multiple or more complex cognitive processes than others. For example, if you were asked to **name** the two fruits in Figure 2, you may instantly recall "apple" and "orange". However, if you were asked to **compare** the two fruits, you would also need to consider the two fruits and identify at least one similarity and one difference between them. In this sense, "compare" involves more cognitive processes than "name".

Table 1 lists common command terms and their associated tasks. It also shows four categories of thinking processes that can be used to group command terms: retrieve, comprehend, analyse and apply.

"Retrieve" questions come before "apply" questions. This is because retrieve questions ask you to perform a simpler cognitive task – remembering – than apply questions. An apply question requires you not only to recall information but also to interpret that information and determine how it can be used in a specific situation. Performing questions in order of simpler cognitive processes to more complex cognitive processes can support the way you acquire and understand new information.

Figure 1 Familiarising yourself with different command terms can help you answer questions and improve your learning.
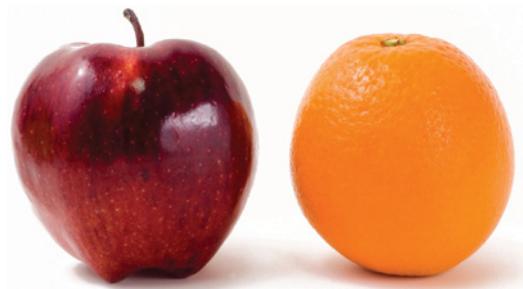
Figure 2 Two healthy fruits

Table 1 Common command terms and their tasks

Command term	Task	Category
Define	give the meaning of a word	**Retrieve** – Recall information from permanent memory.
Identify	recognise and state a distinguishing factor or feature	
Name	provide the correct term or noun	
Recall	present remembered ideas, facts or experiences	
Use	operate or put into effect	
Select	pick out	
Describe	give an account of a situation, event, pattern or process, or of the characteristics or features of something	**Comprehend** – Activate and transfer knowledge from your permanent memory to your working memory.
Explain	make an idea or situation plain or clear by describing it in more detail or revealing relevant facts	
Summarise	give a brief statement of a general theme or major point/s; present ideas and information in fewer words and in sequence	

Command term	Task	Category
Calculate	determine or find (e.g. a number, answer) by using mathematical processes	**Analyse** – Use your reasoning to go beyond what was directly taught.
Categorise	place in or assign to a particular class or group	
Classify	arrange, distribute or order in classes or categories according to shared qualities or characteristics	
Compare	display recognition of similarities and differences and recognise the significance of these similarities and differences	
Contrast	give an account of the differences between two or more items or situations	
Distinguish	recognise as distinct or different; note points of difference between	
Interpret	use knowledge and understanding to recognise trends and draw conclusions from given information	
Create	reorganise or put elements together into a new pattern or structure	**Apply** – Use your knowledge in specific situations.
Discuss	examine by argument; sift the considerations for and against; talk or write about a topic	
Evaluate	examine and determine the merit, value or significance of something	
Elaborate	investigate, inspect or scrutinise	
Justify	give reasons or evidence to support an answer, response or conclusion	
Predict	give an expected result of an upcoming action or event	

Check your learning 1.12

Check your learning 1.12

Retrieve

1 **Define** the term "command term".

2 **Identify** the command term that requires you to "use knowledge and understanding to recognise trends and draw conclusions from given information" and **identify** the category of thinking process this verb belongs to.

Comprehend

3 **Explain** in your own words what is required to correctly answer:
   a a "discuss" question
   b a "calculate" question
   c a "predict" question.

Analyse

4 **Compare** the terms "categorise" and "classify".

Apply

5 After conducting an experiment on how temperature affects the plant growth of corn and beet plants, a student was asked: "Identify which plant would be more suitable to grow in a hot environment. Justify your answer". Their response was: "The corn would be more suitable to grow in a hot environment". **Evaluate** whether the student has correctly answered the question.

Lesson 1.13
Review: Science toolkit

Summary

Lesson 1.1 Scientists value the knowledge and skills of Aboriginal and Torres Strait Islander Peoples

- Aboriginal and Torres Strait Islander Peoples have developed sophisticated science skills that enabled them to survive and thrive some of the most challenging environments in the world for tens of thousands of years.
- Indigenous science sees everything as connected – the land, water, plants, animals and people are all part of one big system that remains in balance.
- The scientific knowledge and skills of Aboriginal and Torres Strait Islander Peoples is now recognised and valued by Western scientists.

Lesson 1.2 Scientists follow the scientific method

- The scientific method is a framework that helps scientists figure out how things work by asking questions and testing ideas. It is an essential tool to guide scientific inquiry and research that is valid and reliable.
- There are five stages to the scientific method.
- Pseudoscience is a term used to describe theories, beliefs or claims that seem scientific but aren't backed by any real evidence or results from experiments.

Lesson 1.3 Scientists form hypotheses that can be tested

- There are variables that must be considered when trying to answer a question and formulate a hypothesis. This includes independent, dependent and controlled variables.
- A **prediction** is a specific statement about **what** you expect to observe when you try to answer your question.
- A **hypothesis** is a proposed scientific explanation for a question. It should try to explain **why** something happens based on previous observations, research or your reading on the topic. It is often written as an "If... then...because..." statement.

Lesson 1.4 Scientists plan and conduct investigations

- The type of data being collected will determine what investigation method is used.
- When planning and conducting an investigation, it must be reproducible by others.
- Ethics considers "Should we?" when determining whether an investigation should be carried out on people, animals or the environment.
- When conducting field work, scientists must seek permission from the land owner or organisation to access the land.
- If research is being conducted at culturally significant sites, appropriate protocol must be followed to access the site, not damage any sacred objects, and limit access to people who have permission to be there.
- The results obtained from investigations must be reliable, as this indicates the investigation method is sound.

Lesson 1.5 Scientists always take safety precautions

- When working in the laboratory, is important to follow all safety rules to keep yourself and others safe.
- All risks must be recognised and managed when conducting investigations.
- Safety data sheets are used to communicate information about how to handle and store the substance, as well as first aid information in the event of an accident.
- Pictograms are symbols used to communicate the specific type of hazard the substance presents.
- A risk assessment is created before beginning an investigation. It helps identify risks and describes how to prevent and mitigate them if they occur.
- When working with chemicals, they must be safely disposed and not poured down the sink, as they can be toxic for the environment.

Lesson 1.6 Scientists use specialised equipment

- When conducing investigations, select suitable materials, equipment and technologies that will provide accurate and precise results.

- In an investigation, multiple trials are conducted to ensure the method is reliable and the data is accurate and precise.
- Errors in an investigation can affect the outcome, so you must be aware of how systematic errors can occur.

Lesson 1.7 Scientists use tables, graphs and models to record and process data

- Scientists need to collect data and present it in an organised manner.
- Tables and graphs allow scientists to identify patterns in their results.
- Tables should have a heading, column headings with units of measurement and data in each column.
- Different graphs should be used depending on the type of data (discrete or continuous) being displayed.
- Keys help scientists interpret or identify information in scientific diagrams, maps and data.
- Models are representations that help explain scientific concepts or can be used to test explanations.
- Mathematical relationships show connections between variables and pieces of data, and express them as numbers or equations.
- The data presented in some graphs can be extrapolated or interpolated to make predictions.
- If using data from secondary sources, you need to check they are reliable sources.

Lesson 1.8 Scientists keep a logbook

- A logbook is used by scientists in the laboratory and in the field to record the details and results gathered during experiments and research.
- A logbook provides evidence of the planning, changes and results of an experiment.

Lesson 1.9 Scientists analyse trends in data

- Describing trends in graphs will help determine the relationship between variables.
- Measures of centre can be used to analyse a data set.
- To determine the validity and reliability of data, the investigation must have measured the intended variable and the data must be consistent across trials.

- A conclusion must be included, identifying whether the hypothesis was supported or refuted using evidence.
- Sources of uncertainty should be considered.

Lesson 1.10 Scientists evaluate conclusions

- To solve a problem, there are different approaches that can be used.
- Bias can affect all aspects of a scientific investigation and can skew the outcome.
- Do not take information from secondary sources as true until you check who wrote it, where it has been published and if it's current.
- Possible alternative explanations for the observed results should be considered.
- The quality of the data can be improved by repeating trials, having your work peer reviewed, using calibrated digital equipment, analysing sources of error, evaluating the data and improving data recording.

Lesson 1.11 Scientists communicate their findings

- The results and findings of a scientific investigation are communicated using a scientific report or scientific poster.
- When presenting a scientific argument, you must provide evidence to support your argument, using correct scientific language and terminology.
- A scientific report should include all common sections and headings to clearly communicate the purpose, hypothesis, method and results and the data analysis that supports the conclusion.
- A scientific poster is similar to a report, except it is more concise due to space limitations.

Lesson 1.12 Command terms identify the tasks in a question

- Command terms are instructive words that require specific types of mental processes to perform set tasks.
- Command terms can be grouped into categories based on the level of cognition required to perform the task.

Review questions 1.13

Review questions: Module 1

Retrieve

1 **Identify** the most appropriate definition of "independent variable".
   - A The variable that is measured
   - B The variable that is controlled
   - C The variable that is deliberately changed by the scientist
   - D The variable that is measured at the end of the experiment

2 **Identify** which of the following statements is correct.
   - A Correlation means causation.
   - B Data are described in the method section of a scientific report.
   - C Data are analysed in the results section of a scientific report.
   - D A safety data sheet should include the protective equipment to be used for a chemical.

3 **Identify** which of the following scientists could be trusted to make a claim on the growth rate of plants.
   - A General practitioner in medicine (GP)
   - B Chiropractor
   - C Person with a masters of Botany
   - D Person with a PhD in epidemiology

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

5 **Define** the term "variable".

6 **Identify** why consumer scientists are interested in what can be observed and tested, rather than in the slogans and claims of manufacturers.

7 A student conducts an experiment where they measure the amount of mass produced over time. They collect data for up to 50 seconds and then create the graph in Figure 1. **Recall** the term that describes what they have done with their graph.
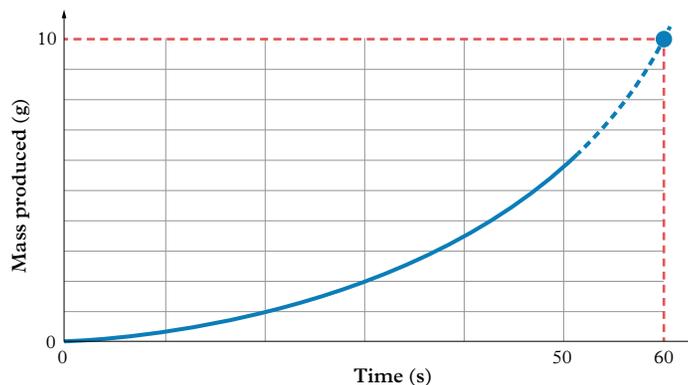
Figure 1 A graph created by a student

8 **Identify** three types of information that should be included on a safety data sheet.

9 **Identify** the most accurate way to measure each of the following in your school science laboratory.
   - a Time
   - b Mass
   - c Length

10 **Define** the following terms.
   - a Valid
   - b Reproducible
   - c Accuracy

Comprehend

11 **Describe** how scientists find out about the safety risks involved in an experiment they are planning.

12 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.

13 **Explain** why beakers are not used to measure volumes.

14 **Explain** why every experiment should have a large sample size.

15 **Explain** why it is important that scientific papers are peer reviewed.

Analyse

16 **Define** and **contrast** independent, controlled and dependent variables.

17 **Contrast** the four categories of command terms and **identify** an example of a command term and its task for each category.

18 A student has written a report using information they read in an article posted on social media by an influencer. **Consider** whether the student has used a valid secondary source.

19 **Calculate** the range of the following measured lengths if two pieces of wood (5.2 ± 0.1 cm and 2.3 ± 0.1 cm) were added together.

20 A student used a measuring cylinder to measure two volumes: 15 mL and 18 mL. The uncertainty for both measurements was 0.2 mL. **Calculate** the final volume and uncertainty if the two liquids were combined.

Apply

21 A consumer scientist wanted to test the effect of a lotion for treating acne. They first tested the lotion on a group of 20 teenagers, all aged 15, but then they decided to conduct more tests. So they then tested 100 more teenagers, all aged 15.

    a **Determine** whether this is an example of experimental repetition or increasing the sample size.

    b **Decide** which result (using 20 teenagers or 120 teenagers) is likely to lead to the most reliable conclusion. **Justify** your answer (by comparing the reliability of the test of 20 teenagers to that of 120 teenagers and deciding which is more reliable).

22 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. **Describe** how the scientist might test a fabric for durability in a valid way. **Discuss** why this is important.

Figure 2 How might a scientist test the durability of different denims?

23 A make-up manufacturer claims that their brand of tinted lip gloss will stay on for at least 6 hours, even during eating and drinking. **Create** an experiment based on the scientific method to test this claim. **State** your hypothesis, and then **identify** the variables you will be considering. **Describe** the measurements you will take and how you will ensure that they are accurate.

    a **Predict** the results you would expect to obtain if your stated hypothesis was correct.

    b **Evaluate** the accuracy of the results that you may measure and suggest what further investigation you could undertake to improve the reliability of your conclusions.

    c Assuming you found that the manufacturer's claim was correct, **create** a scientifically accurate slogan or advertisement for the lipstick based on your findings.

Figure 3 What results would be expected for the hypothesis from question 23?

24 You are investigating the effect of different exercise routines on heart rate recovery times. You have collected the following data on recovery times (in minutes) for two different exercise routines, Routine A and Routine B.

Data:
- Routine A: 5, 6, 7, 8, 5, 6, 7, 8, 5, 50
- Routine B: 10, 12, 11, 13, 12, 11, 10, 12, 11, 13

a **Calculate** the mean (average) recovery time for Routine A and Routine B.

b **Calculate** the median recovery time for Routine A and Routine B.

c **Identify** the mode (most frequent value) of recovery times in Routine A and Routine B.

d **Identify** any outliers in the data for Routine A and Routine B.

e **Explain** how these outliers affect the mean, median and mode.

f **Discuss** the implications of the outliers on the overall analysis of heart rate recovery times for different exercise routines.

Social and ethical thinking

25 Two phrases commonly used in advertising are "Scientists have proved …" and "Recommended by scientists". These are often accompanied by pictures of named scientists who are paid to appear in the advertisement. **Discuss** the ethical implications of using these phrases or pictures of scientists, by completing the following.

a **Describe** why the company may choose to use the phrases or a picture of a scientist.

b **Describe** how a person viewing the advertisement might be affected by the use of the phrases or pictures.

c **Describe** how a person would be affected if the phrases/pictures were not used.

d **Evaluate** whether using the phrases/pictures disadvantage the person viewing the advertisement.

e **Decide** whether the phrases/pictures of scientists should be allowed in advertising.

Critical and creative thinking

26 One source of information for consumers is *Choice* magazine. The magazine reports the results of testing of a variety of brands of consumer products.

a If a consumer scientist was reading a report on the safety of children's pyjamas, **describe** the evidence they might look for to see if the report was fair and objective.

b If the scientist concludes that the report is reliable, **propose** how the public might be convinced to read the report before purchasing children's pyjamas.

Research

27 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your findings in a format of your choosing.

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.
- **Describe** the scientific tests that are performed to check that the claims are correct and that the results that have been obtained are valid.
- After researching and comparing a range of evidence, **evaluate** whether we should drink bottled water in Australia or use tap water.

- **Describe** any limitations of your conclusions (for example, does it depend on where you live?).

Figure 4 Why do people drink bottled water?

Mobile phone safety

Research is continuing into the safety of mobile phones, although most people in the Western world have one or use one. You are an advisor to the minister of communications and technology.

- Produce a report, of at least 10 points, detailing research that has taken place into mobile phone safety.
- Make sure you assess the validity of these secondary sources.
- Include the outcomes or conclusions reached in these studies.

Figure 5 People of all ages use mobile phones.

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.

- **Describe** the reliability of each of the sources that you use by identifying the source, the reason for the article and the validity of the data used.
- **Define** the term "opposing evidence".
- **Identify** whether the warnings are based on anecdotal evidence or scientific evidence.
- **Discuss** whether anecdotal evidence can be of value to scientists.

Figure 6 Are artificial colourings and flavourings in foods bad for us?

Module

2

Genetics

Overview

Genetic inheritance explains how characteristics are passed down from parents to offspring through DNA, chromosomes, genes and alleles. DNA is organised into chromosomes, which contain genes that control what each organism looks like and sometimes even how they behave.

Sexual reproduction allows the types of genes that determine each characteristic to become mixed, allowing all offspring to be different. Mendel's laws of inheritance help predict how these characteristics are inherited.

Genetic disorders like sickle cell anaemia or cystic fibrosis are caused by changes in the DNA, and these can be inherited. Understanding genetics helps us to explain how diseases develop and how characteristics are passed down from parents to offspring.

Lessons in this module

Lesson 2.1
Science as a human endeavour: Scientists review the research of other scientists

Key ideas

→ Gregor Mendel's experiments with peas was able to demonstrate that genetic information was passed from parents to offspring.

→ Watson and Crick were able to use the research from Linus Pauling, Erwin Chargaff and Rosalind Franklin to discover the structure of DNA.

→ Advances in technology now allows the use of computer modelling to generate large data sets and compare them to experimental results.

Learning intentions and success criteria

Introduction

Scientific understanding is constantly being reviewed and refined. Sometimes scientists collaborate and sometimes scientific teams "compete" to make discoveries first. The scientific understanding of genes and DNA is no exception.

Gregor Mendel

Gregor Mendel was an Austrian monk and scientist (Figure 1). He is known as the "father of genetics" because he was the first person to make accurate conclusions about how genetic information is passed from parents to offspring. Mendel loved experimenting with peas – and he did many experiments in his garden.

Before Mendel (in the early 1800s), it was thought that children inherited a mixture of characteristics from both their parents, resulting in a mixture of looks, in the same way that mixing red and yellow paint produces orange paint. It was thought that you could not separate the pure red or yellow forms again. Mendel discovered that the different "factors" could be separated again.

Mendel observed the inheritance of different characteristics in pea plants, such as seed colour, pod shape and height
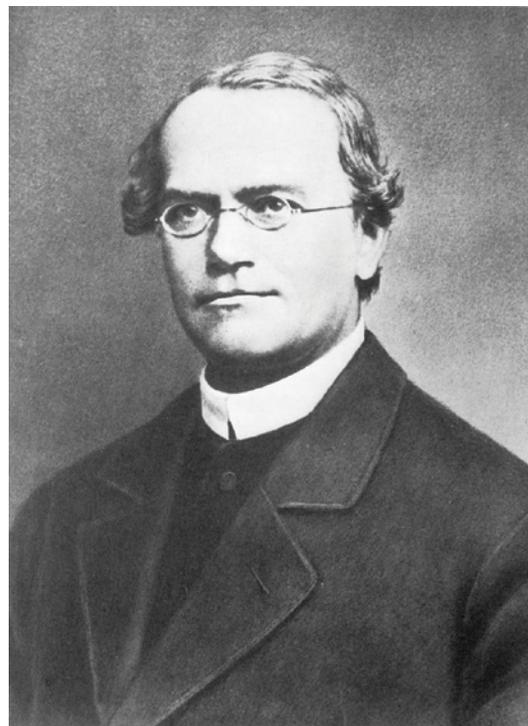
Figure 1 Gregor Johann Mendel, 1822–1884, is known as the father of genetics.

(Figure 2). From his observations he accurately concluded that "factors" (now called **genes**) existed in pairs, one from each parent. Genes control the characteristics of the cells, and therefore the characteristics of each person.

The importance of Mendel's research was not realised at the time, even by Mendel himself. When he sent his research to Charles Darwin (responsible for the theory of evolution), the letter remained unopened until after Darwin's death. It wasn't until the early 1900s when three other scientists repeated Mendel's experiments that he was given credit for the two key principles of genetics: segregation and independent assortment.

Principle of segregation

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.

Principle of independent assortment

gene basic unit of genetic material passed on from parents to offspring

Seed shape	Spherical	Wrinkled
Seed colour	Yellow	Green
Flower colour	Purple	White
Pod shape	Inflated	Constricted
Pod colour	Green	Yellow
Flower position	Axial	Terminal
Stem height	Tall	Short

Figure 2 The seven traits, or characteristics, of pea plants studied by Mendel

The inheritance of one set of factors from one parent is independent from the inheritance of other factors. So, just because you inherit one factor (e.g. blue eyes) from your mother, that does not mean you inherit all other factors from her (e.g. her blonde hair and small nose). Factors are usually inherited independently from each other.

For almost 70 years after Mendel's death, the identity and chemical structure of these factors remained unknown. Today we know the factors as genes made up of DNA.

Watson and Crick's double helix discovery

James Watson was a young chemist from the United States who went to the University of Cambridge, in the United Kingdom. There he met Francis Crick, an English physicist (Figure 3). Watson and Crick were theoretical scientists. This meant they did not complete any experiments themselves. Instead, they used the experimental results from other scientists (Linus Pauling, Erwin Chargaff and Rosalind Franklin) to develop their own models and theories.

Figure 3 James Watson and Francis Crick with their DNA model

DNA (deoxyribonucleic acid) 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

They worked as a team to unravel the secret of the structure of **DNA (deoxyribonucleic acid)**, which they identified as a double helix (two-stranded spiral) in 1953.

Rosalind Franklin

Rosalind Franklin had wanted to study science since the age of 15 and eventually earned her doctorate in physical chemistry at the University of Cambridge in 1945 (Figure 4).

In 1951, she 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 part of the DNA project, no one had worked on it for months. When Wilkins returned, he misunderstood her role, treating her as a technical assistant. His mistake was not surprising given 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.

Between 1951 and 1953, Franklin was able to improve the quality of the photographs she took of DNA crystals. While she was out of the laboratory, Wilkins showed Watson photograph 51, one of Franklin's best crystallographic images of DNA (Figure 5). When Watson saw the picture, he was able to imagine the structure of DNA that he and Crick had been working on. They quickly completed their model and published the result in the journal *Nature*. Franklin's work appeared as a supporting article in the same issue of the journal.

Figure 4 Rosalind Franklin
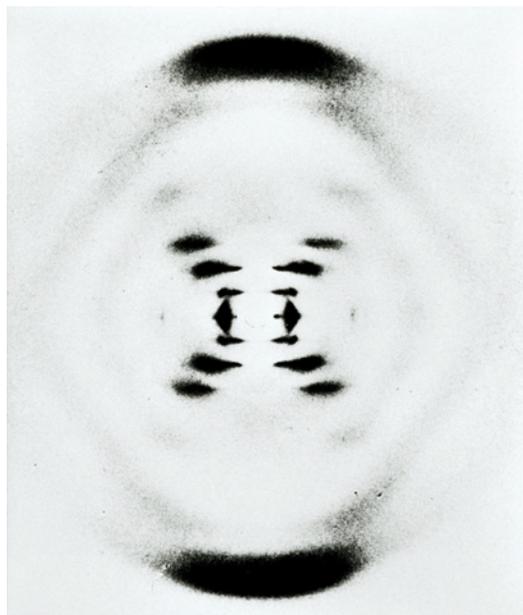
Figure 5 Photograph 51: the X-ray crystallography image of DNA taken by Rosalind Franklin

Big data

The early experiments such as those of Mendel, Watson, Crick and Franklin took most of their lives to develop the ideas, gather enough data and analyse the results. Today, computer modelling can generate large data sets and compare them to experimental results. The Human Genome Project was developed in multiple laboratories over 13 years at a cost of more than 2 billion dollars. Today, the same process that identifies all of a person's genetic material can be done in 24 hours for a few hundred dollars. This data contains approximately 3 billion data points and would take a scientist decades to read.

Data is changing the way scientists complete experiments. Instead of painstakingly breeding and growing individual pea plants, scientists can now identify the genetic code and use a fast computer to model all the possible breeding options and predict the possible results. This means that computers are not only modelling but also generating hypotheses.

If Mendel was a scientist today, he would not have been restricted to choosing only seven characteristics of his pea plants (height, pod shape, seed shape, pea colour, etc). Instead, he would have entered all the pea plant data and used machine learning to select the key characteristics to study.

🔲 Test your skills and capabilities

Acknowledging the work of others

Plagiarism involves presenting someone else's ideas or work as your own. It can be as obvious as directly copying, or it can include taking their ideas and using them in a very similar manner. In the art or fashion industries, it could be copying the style of a painting or dress. In the science world, it can involve using someone else's results without acknowledging their contribution. If a student or a person employed at a university is found to have committed plagiarism, they can be expelled or sacked.

Wilkins showed Franklin's results to Watson and Crick without her knowledge. Watson and Crick then used her photo to create and publish their DNA model without acknowledging Franklin's contribution.

Evaluate one of the following ethical issues that arises from this discovery by:
- describing the ethical approach you are using (e.g. consequentialist or deontological)
- describing the issue from the point of view of Franklin
- describing the issue from the point of view of Wilkins, Watson and Crick
- deciding which view has greater importance.

1 Should Wilkins have shown Watson and Crick photograph 51?
2 Franklin was considered a brilliant scientist and a kind-hearted woman; however, she is also described as short-tempered and stubborn. Some of her fellow scientists (including Wilkins) found her difficult to work with. If Franklin had been given a choice, should she have shared her results with other scientists?
3 Should all scientists share their results with each other? If so, how should the work be acknowledged? Provide reasoning to justify your answer.

Skills builder: Evaluating data and information

4 Research Mendel's work. **Evaluate** 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?)

DNA consists of a sugar–phosphate backbone and complementary nitrogen bases

Key ideas

→ Genes are made of a chemical called deoxyribonucleic acid (DNA).

→ The DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds.

→ DNA has a double-helix shape.

Your DNA blueprint

DNA is like a blueprint, or set of plans, for every structure and function in an organism. It contains a code unique to each individual that can be passed from parents to children, generation after generation, with little or no change. Every cell in your body (except red blood cells) contains the same identical DNA molecules. The DNA in your body is 99.9 per cent identical to the person next to you. It is only very small differences in the code that give your hair, eyes and skin their unique colour and texture. Understanding of the structure of DNA allows us to explain the similarities and differences that exist between and within species.

Structure of a nucleotide

nucleotide
a subunit of a nucleic acid

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 parts:

- 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)
- thymine (T).

These four nitrogen bases are what defines the four different nucleotides (or "beads") that make up the DNA.
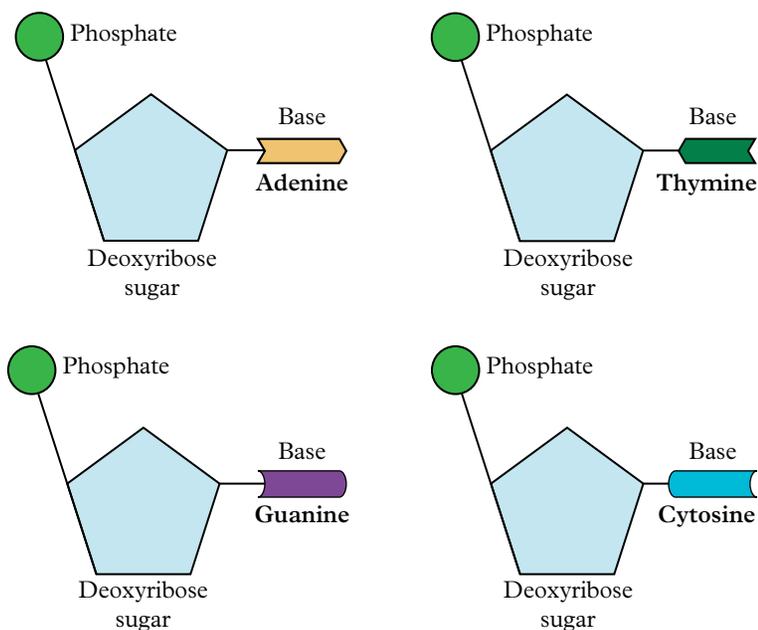
Figure 1 Nucleotides: the building blocks or subunits of DNA

Structure of a polynucleotide chain

When nucleotides (or "beads") join together, they form a long polynucleotide chain called a nucleic acid. DNA is a nucleic acid.

The nucleotide "beads" in the long nucleic chain are joined together by their sugar and phosphate groups. The sugar of one nucleotide is joined to the phosphate of the next nucleotide with a strong covalent bond. This forms a sugar–phosphate backbone, like the sides of a ladder (Figure 2).
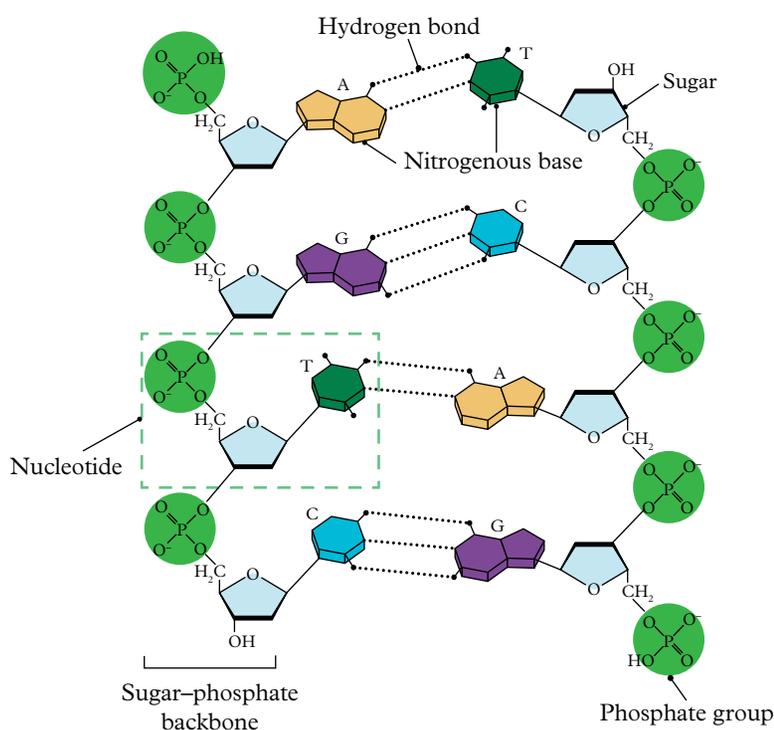
Figure 2 Nucleic acids such as DNA are made up of a chain of nucleotides joined together through a sugar–phosphate backbone.

2.2

Double helix

The sugar–phosphate backbone of one nucleic acid chain is attracted to a second nucleic acid chain, creating a ladder-like structure.

The "rungs" of the ladder are made up of **hydrogen bonds** (relatively weak bonds) between the nitrogen bases. A large nitrogen base (adenine or guanine) is always bonded to a small nitrogen 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) (Figure 3). These base pairs (G-C and A-T) are called **complementary bases** or complementary base pairs. This means that one nucleic acid strand will be complementary to the other strand.

The two nucleic acid strands then wind into a double helix – the twisted ladder (Figure 4).

DNA molecules have two vital properties.

- DNA can make copies of itself: if two strands unwind, each strand can be used to make a new DNA molecule.
- DNA can carry information: the order of bases along a strand is a code for making proteins.

hydrogen bond a type of weak chemical bond between two groups of atoms; the bond between two nitrogen bases in the DNA helix

complementary base a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand; adenine pairs with thymine, cytosine pairs with guanine
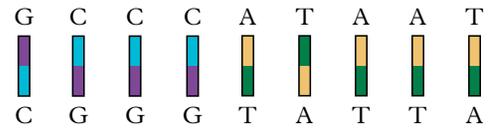
Figure 3 DNA bases always pair as guanine with cytosine and thymine with adenine.
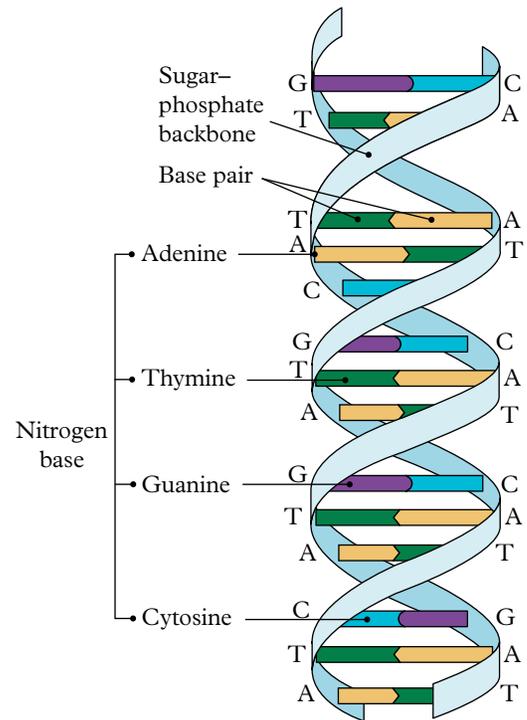
Figure 4 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules and the rungs are pairs of nitrogen bases.

Check your learning 2.2

Check your learning 2.2

Retrieve

1 **Define** the term "nucleotide".

Comprehend

2 **Explain** how nucleotides join together to form polynucleotides.

3 **Explain** how two polynucleotides can twist helically around each other to form a double helix of DNA.

4 **Describe** the part of the DNA molecule that varies. **Identify** the part that remains constant.

5 **Describe** how the order of the bases on one polynucleotide chain determines the order of the bases on the other chain.

Analyse

6 **Identify** the complementary DNA sequence to GTTAGCCAGT.

Apply

7 David recorded the following answer as the complementary DNA sequence for question **6**: TGACCGATTG.

Discuss why David's answer is incorrect. **Identify** where he has gone wrong.

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2.2

Biology

Skills builder: Planning investigations

8 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?)

Lesson 2.3
Experiment: Extracting DNA

Caution

- Ethanol is flammable – do not use near ignition sources. Minimise vapours.
- Wear safety glasses, a lab coat and gloves.
- Keep hands, clothing and hair away from the sharp blades of the blender.

Aim

To extract a sample of DNA from peas

Materials

Part A

- 100 g dried peas soaked overnight in 2 cups of water, or frozen peas (thaw first)
- 200 mL water
- 6 g table salt
- 20 mL dishwashing liquid
- 1 g meat tenderiser
- Measuring cylinder
- 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 (liquid)
- Test tubes and test-tube rack or 50 mL beakers
- Skewer or 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 beaker. There should be enough of this mix for eight test tubes or beakers, which can be shared in the class.

2 Dribble 15 mL of ice-cold ethanol down the side of the test tube or beaker – there should be equal amounts of filtrate and ethanol in the test tube or beaker.

3 Leave the test tube or beaker to allow 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.

Gently swirl and twist the stirring rod to collect DNA from the alcohol layer.

Alcohol layer

Scum of DNA

Pulp and water

Cell scum
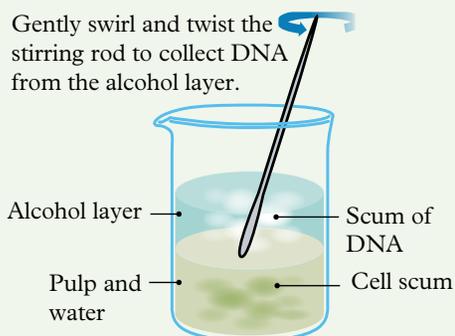
Figure 1 Procedure for collecting DNA from the alcohol layer

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

Construct a flow chart of the method by drawing a labelled diagram of each step.

Draw a labelled diagram of the microscope's view, with several short statements explaining your observations.

Discussion

1 Briefly **describe** the appearance of the DNA under the microscope. Explain why you cannot see the double helix.

2 **Compare** the DNA of the peas with human DNA.

3 **Describe** the role of each of the additives (dishwashing detergent, meat tenderiser and alcohol) in isolating the DNA from the cells.

4 **Identify** and **describe** the materials that would remain in the watery layer of the pea mixture.

Conclusion

Describe the function of DNA in peas.

Lesson 2.4
Challenge: Modelling the structure of DNA

Aim

To construct a model of DNA that shows the complementary bases arranged in a double helix

What you need:

- 4 long pipe cleaners (2 different colours)
- 24 beads (6 different colours: colour 1 = phosphate; colour 2 = sugar; colour 3 = adenine; colour 4 = thymine; colour 5 = cytosine; colour 6 = guanine)

What to do:

1   Choose two pipe cleaners of the same colour.
2   On each pipe cleaner, thread beads with alternating phosphate beads and sugar beads (i.e. colour 1, colour 2, colour 1, colour 2, etc.). Leave about 2 cm of space between each bead. This represents the sugar–phosphate backbone of DNA molecules (Figure 1).
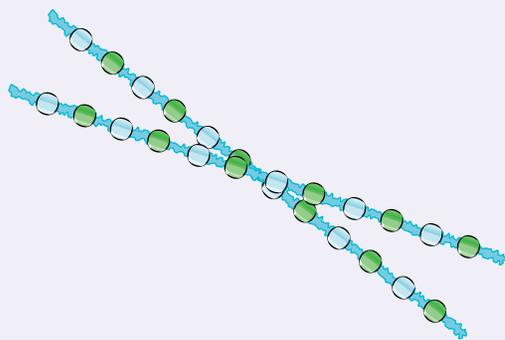
Figure 1 Representation of the sugar–phosphate backbone of DNA molecules

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.
4   Choose the two bead colours that represent the adenine and thymine nitrogen bases. Thread one of each bead onto half of the cut pipe cleaner strands.

5   The remaining bead colours represent guanine and cytosine. Thread these two beads onto each of the remaining cut pipe-cleaner strands (Figure 2).
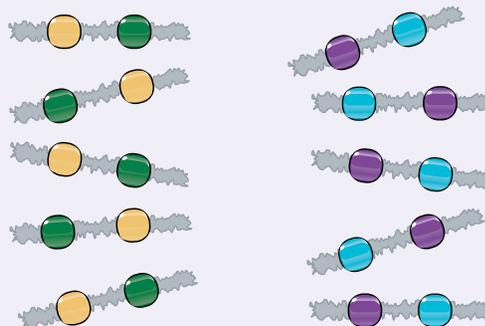
Figure 2 Representation of paired nitrogen bases A-T and G-C

6   Lie the two sugar–phosphate backbones down so that they are parallel. The colour 1 beads (phosphate) should be opposite the colour 2 beads (sugar) on the other strand.
7   Attach the short pipe cleaner segments with the nitrogen bases onto the backbone of the DNA molecule. Make sure each nitrogen base strand is attached next to a sugar (colour 2) bead. You should have formed a ladder-like structure with the A-T and G-C nitrogen bases as the rungs of the ladder.
8   Twist your ladder so that it forms a double helix structure (Figure 3).
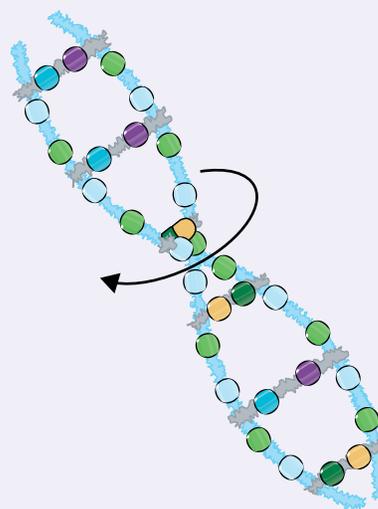
Figure 3 Representation of the DNA double helix structure

Questions

1 **Identify** the bead colour that represents the nitrogen bases:
   a   adenine
   b   thymine
   c   guanine
   d   cytosine.

2 **Explain** what is meant by the term "sugar–phosphate backbone".

3 **Identify** what the letters DNA represent.

4 **Describe** a "double helix".

5 **Identify** the base that is complementary to:
   a   adenine
   b   guanine.

6 **Identify** the type of bond that holds the nitrogen bases A-T or G-C together.

Lesson 2.5
Chromosomes carry genetic information in the form of genes

Key ideas

→ Each cell in your body (except red blood cells) contains 46 chromosomes.

→ Chromosomes can be arranged from largest to smallest to form a karyotype.

→ Females have two X chromosomes; males have an X and a Y chromosome.

→ Genes are sections of DNA that have a function. DNA cannot leave the nucleus of a cell.

Learning intentions and success criteria

Chromosomes and genes

chromosome the form of DNA that is tightly wound around proteins before replication

Inside the nucleus of a cell are the chromosomes. **Chromosomes** are made up of DNA molecules tightly wound around proteins.

There are 46 chromosomes in a human nucleus: 23 of them come from the mother and 23 from the father. Along the length of each chromosome, in specific positions, are the genes.

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).

karyotype a way of representing a complete set of chromosomes, arranged in pairs, in order of decreasing size
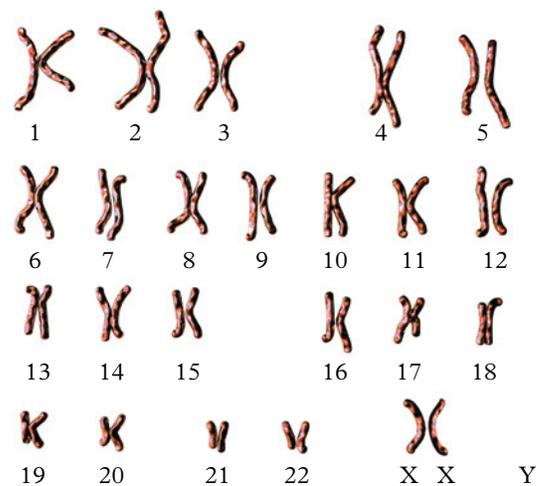
Figure 1 Pairs of chromosomes are often referred to by numbers according to their size – the largest pair is number 1. The last two chromosomes determine the sex of an individual. Human females have two X chromosomes, and males have one X and one Y chromosome. This karyotype is from a female (XX).

How we relate chromosomes to DNA

DNA is found inside a cell's nucleus, and looks a little like a pile of wool. By the time a cell is ready to divide, the DNA has copied itself and the chromosomes can clearly be seen under a microscope.

A simple equation to understand the relationship between DNA and chromosomes is:

A single chromosome = a molecule of DNA (a DNA helix)

Chromosomes may be a single helix or a pair of joined strands (a duplicated chromosome). The two joined strands are identical to each other. They form during DNA replication so that two identical copies are produced. Each strand of a duplicated chromosome is called a **chromatid**. The two chromatids are joined at a location called the centromere (Figure 3). This is where fibres can attach to pull the two chromatids apart when a cell divides (Lesson 2.8 Challenge: Cell division in action (page 93) and Lesson 2.10 Challenge: Modelling meiosis (page 97)).

If the DNA in a single chromosome was 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 m long! The DNA fits inside the cell because the DNA molecules are 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.

chromatid one side of the X-shaped chromosome that contains a double helix of DNA
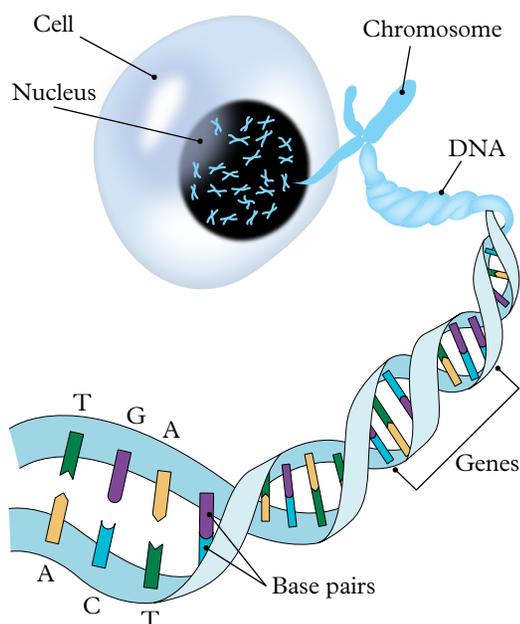
Figure 2 The relationship between DNA and chromosomes
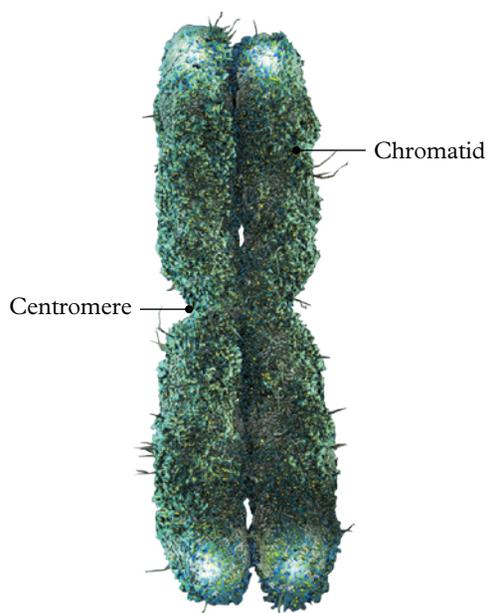
Figure 3 An X-shaped chromosome is made up of sister chromatids joined at the centromere.

Figure 4 The relationship between DNA and genes

How we relate genes to DNA

DNA in chromosomes consists of sections, and each section is a gene (Figure 4). Some genes have 250 nucleotide "beads", whereas other genes have over 2 million nucleotide "beads". The order of the nucleotides (with the nitrogen bases A, T, G or C) in each gene contains information for one characteristic or trait. For example, a gene may have information for making the pigment melanin, which gives our 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 sentence with a lot of words (genes) made up of alphabet letters (nucleotides).

2.5

Figure 5 The sequence of bases on DNA is the coding system for life. The sequence of bases shown here comes from the DNA in adenovirus types 5 and 2. These viruses cause a range of illnesses, including colds, sore throats and diarrhoea.

Check your learning 2.5

Check your learning 2.5

Retrieve

1 **Identify** the number of chromosomes in each of your cells.
2 **Define** the term "karyotype".
3 **State** the names of the nitrogen bases that are represented by the letters A, T, G and C.
4 **Identify** the nitrogen bases that are complementary to A, T, G and C.

Comprehend

5 **Describe** how DNA is like a string of beads.

Analyse

6 **Compare** DNA, chromosomes and genes.

Apply

7 This topic compared the structure of chromosomes, genes and nucleotides to sentences, words and letters. **Evaluate** this comparison (by comparing the similarities and differences between each group of terms and deciding if there are more similarities than differences).

Skills builder: Communicating

8 Part of a base sequence on one polynucleotide strand on DNA reads ACTGGCATTCAG.
   a Write the complementary 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?)

Lesson 2.6
DNA holds the code for building proteins

Key ideas

→ Transcription is the process of copying genetic information from DNA into mRNA.

→ Translation is the process of decoding mRNA to form a protein.

Learning intentions and success criteria

Genetic code

One major feature of DNA is its ability to replicate itself; another feature is its ability to carry the genetic coding system for making proteins. The order of the nucleotides on the DNA strands is the **genetic code** for an organism.

The genetic code has the instructions to make a protein (Figure 1). 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.

genetic code the sequence of nucleotides in DNA, inherited from parent organisms

2.6

DNA molecule

Gene 1

DNA strand
(template)

Transcription

mRNA

Translation

Protein

Codon

Amino acid
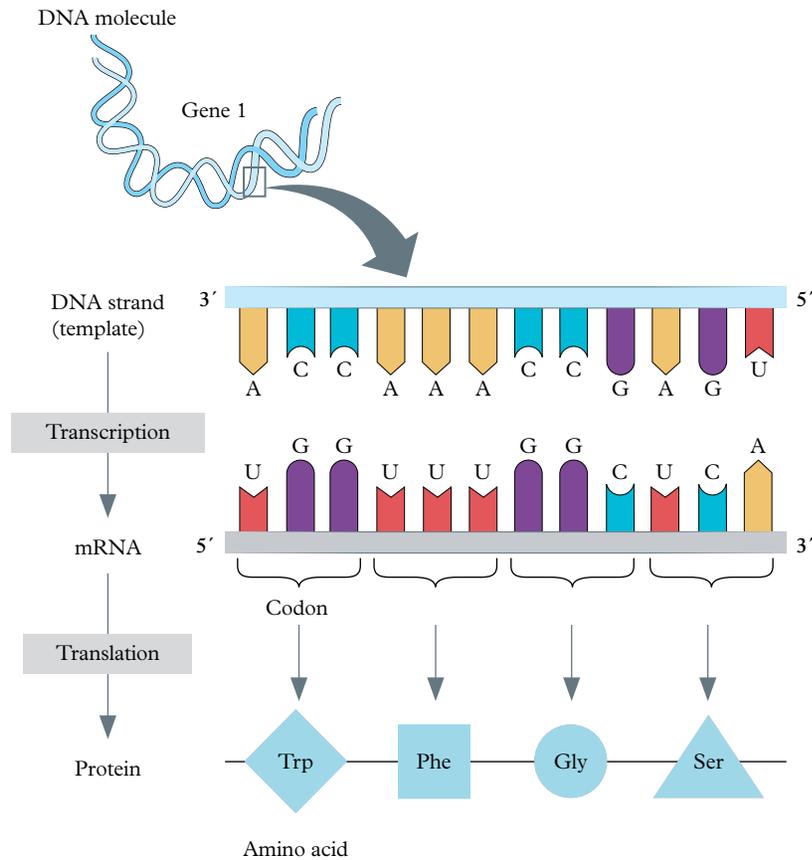
Figure 1 Protein synthesis. A complementary strand of mRNA is made (G-C and A-U). The mRNA leaves the nucleus and is used to form a protein. (Trp = tryptophan; Phe = phenylalanine; Gly = glycine; Ser = serine)

How genes make protein

To make protein, the DNA molecule unwinds and one strand acts as a pattern or template to form a molecule of messenger RNA (mRNA, messenger ribonucleic acid; Figure 2). This is sometimes called the central dogma of biology.

RNA

RNA contains a ribose sugar, unlike DNA which has a deoxygenated ribose sugar. The nitrogen bases of RNA are adenine, cytosine, guanine and uracil (not thymine). Messenger RNA (mRNA) plays a key role in protein synthesis. mRNA acts like a photocopy of the original DNA blueprint.

Transcription

The process of making an mRNA copy from a DNA strand is called **transcription**. Transcription takes place in the nucleus and involves a number of stages.

1 DNA is "unzipped", unwinding the two strands.

transcription the process of copying the DNA that makes up a gene to messenger RNA

RNA
(single-stranded)

Base

Ribose sugar

Phosphate group
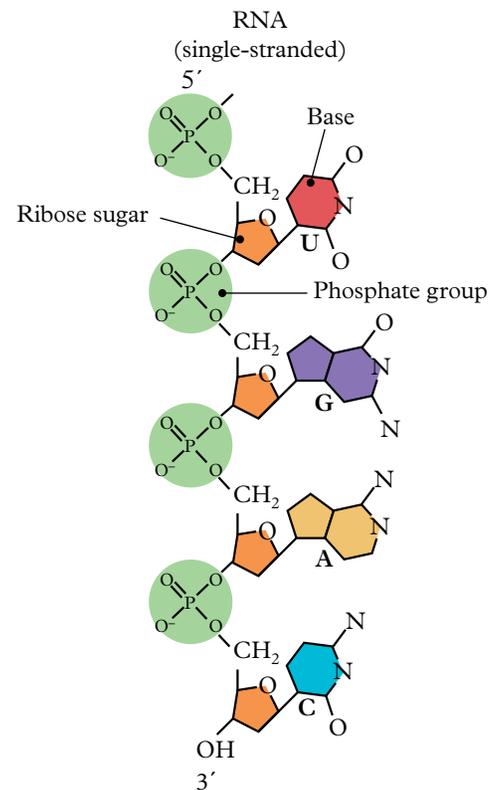
Figure 2 The structure of RNA

2   An enzyme called RNA polymerase moves along the exposed gene on the DNA strand. As it goes, it joins together free RNA nucleotides (C, G, A, U), which form the strand of mRNA. The mRNA nucleotides are complementary to the DNA nucleotides.

3   The RNA polymerase detaches once the mRNA strand is complete. The two DNA strands re-join.

Translation

The next process of forming a protein from RNA is called **translation**.

Unlike DNA, mRNA can leave the nucleus and attach to a ribosome in the cytoplasm. The mRNA now "tells" the ribosome the order in which to connect the amino acids that will make up a protein.

The nitrogen bases on the mRNA are read in groups of three called **codons**. Each codon corresponds to a single amino acid.

Amino acids are brought to the ribosome by another type of RNA called transfer RNA, or tRNA. The amino acids join in a chain according to the order specified by the sequence of codons in the mRNA. Eventually the amino acids form a long chain, which becomes the final protein (Figure 3).

translation the formation of a protein from RNA; occurs on a ribosome

codon a group of three nucleotides on mRNA
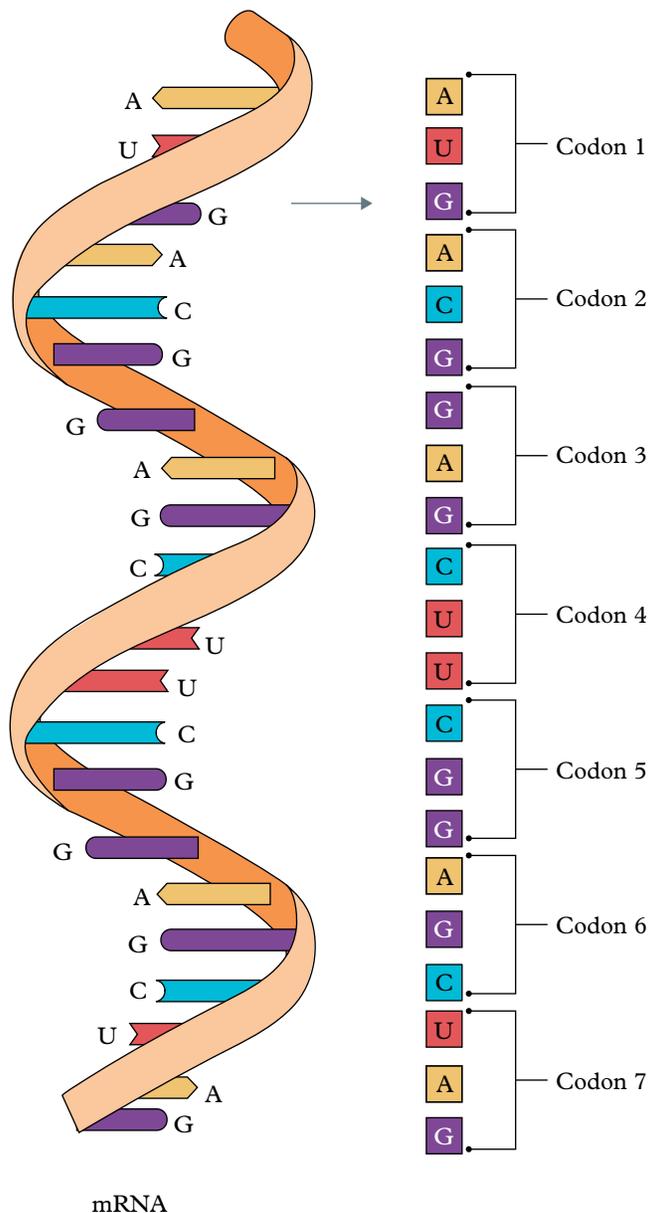
Figure 3 Each codon codes for a specific amino acid. Proteins are made up of long chains of amino acids.

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2.6

Check your learning 2.6

Comprehend

1 **Describe** the process of translation in your own words.

2 **Explain** the role that mRNA plays in the conversion of DNA information into protein.

Analyse

3 **Compare** the features of DNA and RNA. (You may like to draw a Venn diagram for this task.)

4 **Contrast** transcription and translation.

5 **Identify** the mRNA sequence for the template DNA sequence GTTAGCCAGT. (Remember to pair uracil with adenine.)

Apply

6 The human body can make 10 of the 20 amino acids that it needs to survive. **Discuss** why it is important to eat a balanced diet that includes protein.

Lesson 2.7
Mitosis reproduces a nucleus

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Most of the cells in your body are somatic cells (all except sperm and egg cells).

→ Somatic cells are diploid, which means they carry two sets of genetic material – one from the mother and one from the father.

→ Mitosis is the division of the genetic material to produce two genetically identical nuclei.

Mitosis reproduces a nucleus

somatic cells the body cells except gametes (egg and sperm)

mitosis the process of cell division that results in genetically identical daughter cells; allows growth and repair

cytokinesis the splitting of a replicating cell into two cells

diploid containing two complete sets of chromosomes

Every organism needs to grow and repair damage throughout its lifetime. This means cells need to reproduce. **Somatic cells** are all the cells in the body except for the egg and sperm cells (which are called gametes). When somatic cells reproduce, they undergo a process called **mitosis**.

Mitosis is a part of cell division where one parent nuclei divides to form two genetically identical daughter nuclei. Once the nuclei have divided, the rest of the cell will divide into two in a process called **cytokinesis**. In humans, this means the parent cells have 46 chromosomes and the daughter cells each have 46 chromosomes or 23 pairs of chromosomes. Each set of 23 chromosomes comes from a parent (23 from the mother and 23 from the father). When a cell has two complete sets of chromosomes, they are described as **diploid**.

Cell division is essential for an organism to grow or to repair damage. In humans, intestine cells replace themselves every 4 days, skin cells every 3 weeks and bones every 7 to 10 years. This means the body is constantly undergoing mitosis and cytokinesis.

Most of the time, cells are not dividing and are in the phase called **interphase** (Figure 1 and Figure 2). During this phase, the cells do everyday processes such as making proteins. Cells will only start mitosis when new cells are needed. Before mitosis begins, the cell must make new copies of DNA.
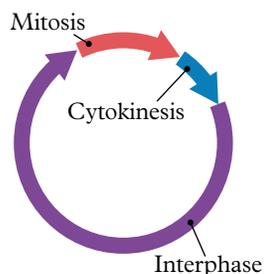
Figure 1 The cell cycle; cells spend most of their life in interphase, when normal cell functioning occurs.

interphase
a phase of cell life where normal functioning occurs

Interphase
The normal life of the cell

Early prophase

1 Prophase
- Chromosomes appear
- Nuclear membrane disappears
- Spindle forms

Late prophase

5 Cytokinesis
Cytoplasm divides; two daughter cells are produced

2 Metaphase
Chromosomes line up in a single line across the centre of the cell with spindle fibres attached to the centromere

4 Telophase
Nuclear membranes re-form

3 Anaphase
- Each pair of chromatids separates at the centromere
- Each chromatid (now called a chromosome) moves to the opposite pole

Figure 2 Interphase and the phases of mitosis and cytokinesis

This doubles the single chromosomes to duplicated chromosomes, connected at the centromere. When the cell undergoes mitosis, the duplicated chromosomes separate and each of the daughter cells will receive a genetically identical copy of each chromosome.

Cancer: Mitosis out of control

The rate of mitosis in a cell needs to be carefully controlled. Cells do not survive indefinitely in an organism. The death of a cell is carefully programmed into a cell's DNA. All cells are constantly checking to make sure that everything is running normally.

If any errors occur, then the cell will undergo programmed cell death, called **apoptosis**. This checking for errors is especially important during mitosis. Before the cell enters prophase or telophase, the DNA is carefully checked to make sure there are two complete sets of unaltered chromosomes.

apoptosis
programmed cell death

Sometimes the DNA of a cell can become damaged. This may be due to radiation, viruses or chemicals called mutagens. If this damage is not detected, then the cell may start undergoing continual cycles of mitosis without apoptosis. This is one of the key characteristics of cancer cells.

2.7

a	b	c	d	e
Interphase	Metaphase	Anaphase	Telophase	Cytokinesis

Figure 3 These mitotic cells have been stained with a fluorescent stain to show the separation of DNA.

a The cell is at the end of interphase – the DNA has been replicated. During prophase, the nuclear membrane breaks down and the red spindle fibres bind to the centromere.

b The (blue) chromosomes line up along the middle of the cell during metaphase.

c Anaphase occurs when the spindles contract, separating the two chromatids at the centromere and pulling them to the end of the cell.

d During telophase, the nuclear membrane re-forms around the two sets of DNA.

e Cytokinesis occurs when the cell membrane divides in two.

Figure 4 Stages of mitosis

Check your learning 2.7

Check your learning 2.7

Retrieve

1   **Recall** the phase where most cells spend most of their time.

Comprehend

2   **Explain** why cells need to undergo mitosis.

3   **Describe** what happens in each phase of mitosis.

Analyse

4   A cell that is about to undergo mitosis must double its amount of DNA. **Consider** why this needs to occur.

5   **Contrast** mitosis and cytokinesis.

6   **Identify** each of the stages of mitosis that is happening in Figure 4.

Apply

7   **Develop** a story of a chromosome as it undergoes mitotic division. **Describe** how it replicates, remains attached at the centromere until anaphase, and says its final goodbye during cytokinesis.

8   Use your understanding of mitosis to **evaluate** the following claim: "Interphase has nothing to do with mitosis."

Lesson 2.8
Challenge: Cell division in action

Aim

To identify cells undergoing different stages of mitosis

What you need:

- Prepared microscope slide (or slides) showing tissue that is in the process of growth and development
- Light microscope
  Alternatively, you could prepare your own slides from the growing root tips of a plant, such as garlic or spring onion.

What to do:

1   View a slide under the microscope at the greatest magnification possible.

2   In your field of view, identify the cells that are in interphase and those that are undergoing the phases of mitosis (prophase, metaphase, anaphase and telophase).

3   Sketch at least four cells undergoing different stages of cell division. Remember the conventions for drawing biological images under the microscope. Clearly label all the components within the cell that you can identify correctly.

Questions

1 **Explain** why DNA can be difficult to see under the microscope during interphase.
2 **Describe** an advantage of DNA being tightly wound around a protein during mitosis.
3 **Describe** the possible consequences for a cell if errors occur during the process of DNA replication that occurs during interphase.
4 **Describe** an advantage of cellular mitosis for an organism.
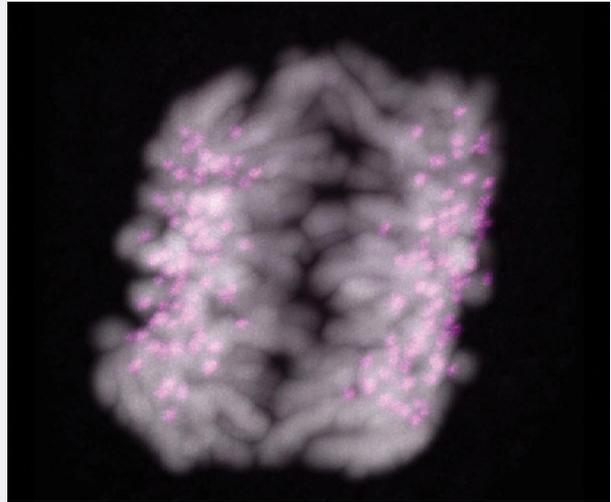
Figure 1 These human chromosomes are in one of the phases of mitosis.

Lesson 2.9
Meiosis forms gamete cells

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ A gamete is a sex cell (egg or sperm) that has half the genetic material of the parent cell.

→ Meiosis is the process of cell division that produces haploid gametes.

→ Two haploid gametes combine to produce the first diploid cell of a new organism.

Meiosis produces gametes

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 a sperm and the female gamete is an ovum. In flowering plants, the male gamete is contained in a pollen grain and the female gamete is located in the flower's ovary. The male and female gametes of a species join to form the first cell of the new offspring.

Gametes differ from all other body cells because they contain half the number of chromosomes of somatic cells – they are **haploid**.

gamete a haploid cell that combines with that of the opposite sex as part of sexual reproduction

haploid containing one complete set of chromosomes in each cell; an example is gametes

Most somatic cells in your body contain 46 chromosomes arranged in pairs (two sets of 23 chromosomes, or $2n$). They are diploid. Gametes (egg and sperm) only have a single set of chromosomes. In humans, this means that gametes have 23 chromosomes (n) (Figure 1). When the egg and sperm combine at fertilisation, a diploid somatic cell is produced (Figure 3) – one set of 23 chromosomes comes from the mother and one set of 23 chromosomes comes from the father.

46 chromosomes in a diploid body cell

23 chromosomes in a haploid gamete
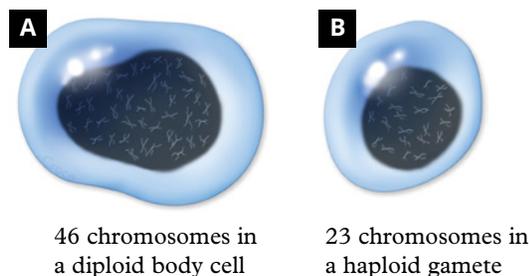
Figure 1 (A) A diploid body cell; and (B) a haploid gamete
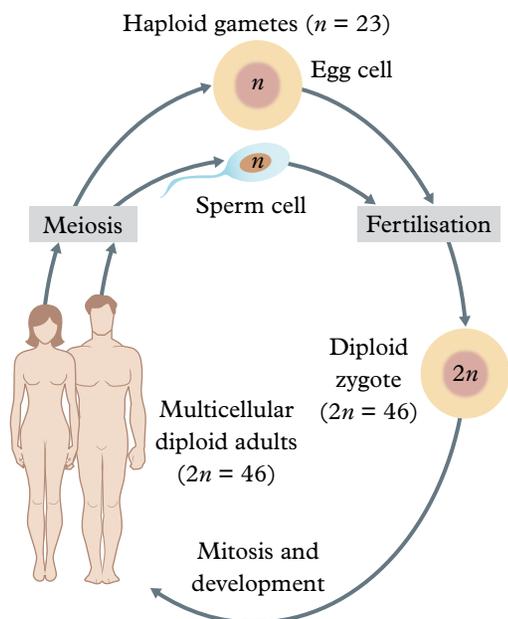
Figure 2 The human life cycle, involving mitosis and meiosis
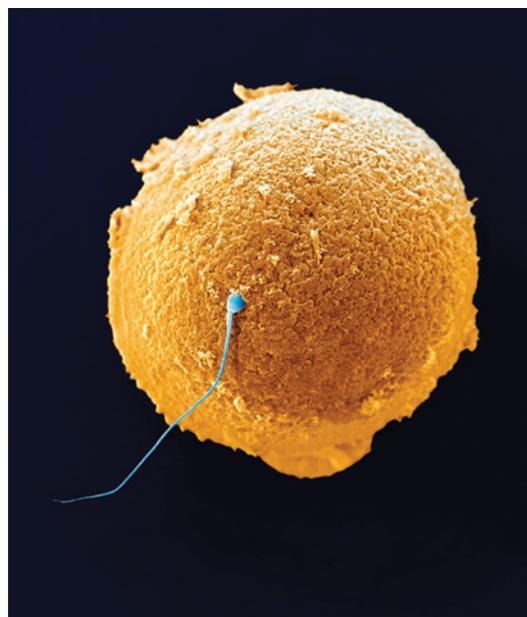
Figure 3 When a haploid sperm cell (n) fertilises a haploid egg cell (n), a diploid somatic cell ($2n$) is formed.

This means that every cell in a child has a mixture of both parents' genetic material (half from the mother and half from the father). In this way, all children are similar, but not identical, to their parents. Each child is also different from their sisters or brothers as the formation of the gametes results in different combinations or variations of chromosomes.

Meiosis is the type of cell division that occurs when gametes are being made from their parent cells. It is sometimes called reduction division and occurs in two stages, known as meiosis I and meiosis II (Figure 4). Before meiosis can occur, the single chromosomes must copy the DNA to form duplicated chromosomes. Once this occurs, the first stage of meiosis can begin.

Fertilisation occurs when the gamete from the mother combines with the gamete of the father. In humans, the egg contains one copy of each of the mother's chromosomes (22 and an X chromosome) and the sperm contains one copy of each of the father's chromosomes (22 and either an X chromosome or a Y chromosome). Each of the mother's egg cells will contain a different combination of chromosomes. This happens because the mother has two copies of each chromosome (one from her mother and one from her father). The random nature of which copy of each chromosome is contained in which egg cell means that there is variation between all the children in a family.

meiosis the process that results in the formation of gametes with half the genetic material of the parent cell

2.9

Prophase I
- Diploid cell ready to undergo meiosis
- Nuclear membrane will disappear

Metaphase I
- Chromosomes line up in pairs across the centre of the cell

Meiosis I

Anaphase I
- One chromosome from each pair is pulled to opposite ends of the cell by the spindle

Two daughter cells (haploid with bivalent chromosomes)

Telophase I
- Nuclear membrane re-forms and the resulting two daughter cells are haploid

Each daughter cell now undergoes a mitotic-like division (meiosis II) to produce four daughter cells (gametes), each with a single set of chromosomes

Meiosis II

Four daughter cells (haploid with single-stranded chromosomes)

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 diploid again so that the zygote can grow (by mitosis) into an embryo.

Check your learning 2.9

Check your learning 2.9

Comprehend

1　We all started from a single cell, a zygote, which then grew into an embryo. **Explain** how meiosis and mitosis allow the formation of a zygote and its growth into an embryo.

2　**Explain** why the offspring of sexually reproducing organisms are not identical to their parents.

3　**Explain** why it is essential that the number of chromosomes is halved during meiosis.

Analyse

4　**Compare** a haploid cell and a diploid cell.

5　Prepare a table **comparing** mitosis and meiosis.

6　Interphase is the "normal" life stage of the cell – the phase between one mitotic division and the next. Interphase also occurs before meiotic divisions. **Identify** the number of chromosomes present at each phase of meiosis shown in Figure 4.

7　The chromosomes in Figure 5 are separating at the centromere. **Identify** the phase of meiosis that the cell is undergoing.
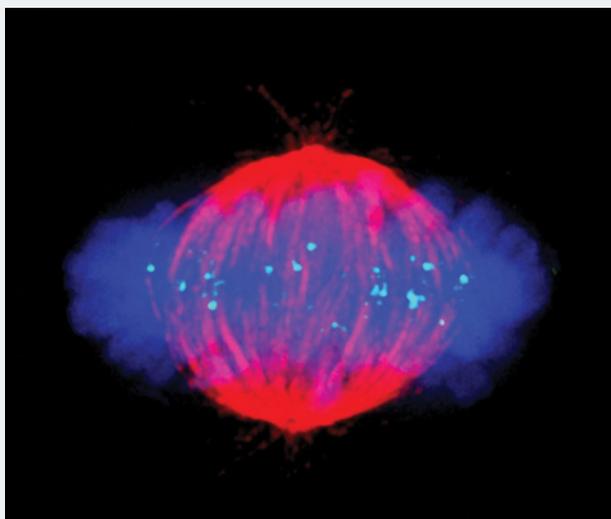
Figure 5 Each stage of meiosis includes prophase, metaphase, anaphase and telophase.

Skills 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?)

Lesson 2.10
Challenge: Modelling meiosis

Aim

To model the stages of meiosis

What you need:

• Pipe cleaners
• Sticky tape
• Felt-tipped pens
• A4 sheet of paper

What to do:

1   Draw the outer membrane of a cell on the sheet of paper.

2   Cut a pipe cleaner in half and place both halves in the centre of the cell. These represent two single chromosomes in a cell starting meiosis.

3   Cut a second pipe cleaner in half and twist each half around the centre (centromere) of the first duplicated chromosomes.

4   Place the two chromosomes in the centre of your cell. Identify the phase of meiosis that this represents.

5   Move each chromosome to opposite ends of your cell, keeping the twisted centromeres intact. Identify the phase of meiosis that this represents.

6   Turn the paper over and draw two cells half the size of the original cell.

7   Place one chromosome in the centre of each cell. Identify the phase of meiosis that this represents.

8   Untwist the two pipe cleaners and move them to the opposite ends of each cell. Identify the phase of meiosis that this represents.

9   Draw a line down the centre of each cell. Identify the phase of meiosis that this represents.

10 Draw a labelled picture of each stage that you demonstrated with the pipe cleaners. Include:
  – the phase name
  – labels for the nuclear membrane, centromeres and single/duplicated chromosomes
  – a description of what is happening at each stage.

Questions

1 **Contrast** the number of chromosomes in a cell before and after it undergoes meiosis.
2 **Define** the following terms.
  a Haploid
  b Diploid
  c Gamete

3 **Explain** why gametes need to be haploid.
4 **Explain** the process of meiosis.
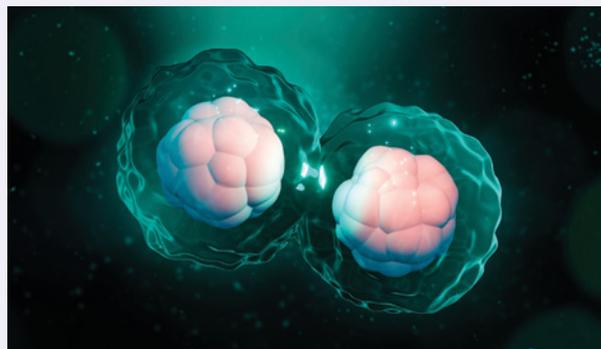
Figure 1 Can you identify this stage of meiosis?

Lesson 2.11
Alleles can produce dominant or recessive traits

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Genes can have different versions (alleles) at the same location of a chromosome.

→ The unique combination of alleles for a gene inherited from parents is called the genotype of the organism.

→ Homozygous individuals have two identical alleles; heterozygous individuals have two different alleles.

→ A dominant trait only needs a single allele present to appear in the phenotype.

→ Recessive traits need two copies of the allele to appear in the phenotype.

→ A person who is heterozygous for a recessive trait is said to be a carrier for the trait.

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. Each version of a gene (e.g. for eye colour) at the same position (or loci) of a chromosome is called an **allele**.

If a person has two identical alleles for a trait or characteristic, they are said to be pure-bred or **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** or a hybrid for the trait (Figure 1).

If someone is heterozygous for eye colour, then the colour of their eyes is determined by which version 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 identical copies (homozygous) 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 often 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/pure-bred (BB) or heterozygous/hybrid (Bb) for the trait. A brown-eyed individual who is heterozygous for the trait is sometimes called a **carrier** for the blue eye trait. They have one 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**.

Figure 1 A heterozygous pair of chromosomes

allele a version of a gene; a person inherits two alleles for each gene, one coming from each parent

homozygous having two identical alleles for a particular trait

heterozygous having two different alleles for a particular trait; a carrier for a 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 is only expressed in the phenotype when two identical alleles are inherited

carrier a person who has the allele for a recessive trait that does not show in their phenotype

genotype the combination of alleles for a particular trait

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 the stem, 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 get enough food when you are growing, then you will not reach your full height.

phenotype the physical characteristics that result from an interaction between the genotype and the environment

2.11

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. This shows the possible genotypes the children could inherit. From the genotypes, the possible phenotypes of the children can be predicted. Worked example 2.11A shows how to use a Punnett square to predict the possible genotypes and phenotypes of offspring.

Punnett square
a diagram used to predict the outcome of breeding organisms

Parents' phenotype	Homozygous non-tongue-roller	×	Heterozygous tongue-roller
Parents' genotype	rr	×	Rr
Parents' gametes	r r	×	R r

F$_1$ genotype (offspring)

Punnett square

	Father's alleles	
	R	**r**
Mother's alleles **r**	Rr	rr
r	Rr	rr

F$_1$ phenotype   50% tongue-rollers
50% non-tongue-rollers
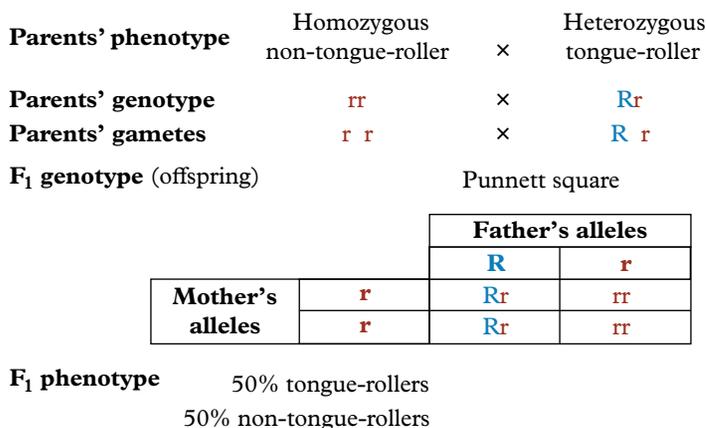
Figure 2 The ability to roll your tongue is inherited.

Worked example 2.11A Using Punnett squares

A man who is heterozygous for brown hair has a child with a woman who has the recessive trait of red hair. Calculate the probability of the child having red hair.

Solution

First the symbols for hair colour need to be selected.

Red hair is a recessive trait = h (lower-case letter)

The letter chosen for the dominant trait must be a capital letter (same gene, different allele).

Brown hair = H

Father (heterozygous) = Hh

Mother has the recessive trait (homozygous) = hh

Then a Punnett square can be constructed.

	Father's alleles	
	H	**h**
Mother's alleles **h**	Hh	hh
h	Hh	hh

The children's possible genotypes are 2 Hh : 2 hh.

The children's possible phenotypes are 2 brown hair : 2 red hair.

Therefore, the child has an equal (50 per cent) chance of having red hair.

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2.11

Biology

Check your learning 2.11

Check your learning 2.11

Retrieve

1 **Define** the term "carrier".

Analyse

2 Dimples (D) is dominant to no dimples (d). **Identify** the genotypes for individuals who:
   a are homozygous for dimples
   b are heterozygous for dimples
   c have no dimples.

3 The trait for blue eyes is recessive to the trait for brown eyes.
   a **Calculate** the chances of two blue-eyed parents having a brown-eyed child.
   b **Calculate** the chances of two brown-eyed parents having a blue-eyed child.

Apply

4 If the children of a right-handed man and a left-handed woman are all right-handed, **identify** whether left-handedness is a dominant or recessive trait. **Justify** your answer (by defining dominant and recessive traits, describing an example of each type of inheritance, and deciding which type of inheritance is most likely).

5 Hemochromatosis is an autosomal recessive trait that causes the body to absorb too much iron from its food. **Explain** how a child could inherit this trait when neither parent has the trait.

Lesson 2.12
Experiment: Zazzle genetics

Caution

Do not eat or drink in the laboratory.

Aim

To demonstrate the role of alleles in determining the phenotype of an individual

Materials

- A bag containing 6 different coloured counters
- Permanent marker
- Toothpicks
- Pipe cleaners
- Large pink and white marshmallows
- Small marshmallows
- Blue and black felt-tipped pens

Figure 1 Zazzles

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 once. The letter that is showing on the upper side represents the allele that is passed on to your baby 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 to 4 to determine the alleles passed from the mother to your baby 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. To determine which sex chromosome is passed from the father to your baby Zazzle, draw an "X" on one side of the counter and a "Y" on the other. Flip the counter. You have now determined the sex of your Zazzle. A girl (XX) will have a pink marshmallow body. A boy (XY) will have a white marshmallow body.

7 Determine the phenotype of your Zazzle.

8 Use the materials to construct your Zazzle.

Results

Copy and complete Table 1.

Table 1 Alleles inherited from the parent

Chromosome	Trait and letter representing it	Allele donated by father	Allele donated by the mother	Phenotype of 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	

Discussion

1 **Identify** whether this activity is a case study, modelling/simulation, quantitative analysis or a controlled experiment. **Justify** your reasoning (by identifying the key characteristics of the activity and comparing these with the definition of the term you chose).

2 **Identify** the number of chromosomes present in each of the:
   a mother's somatic (non-gamete) cells
   b father's gametes
   c baby Zazzle's cells.

3 **Identify** your baby Zazzle's genotype for each trait.

4 **Identify** the dominant trait for each of the Zazzle genes.

5 **Explain** why the baby Zazzle has two alleles for each trait.

6 **Compare** the definitions of phenotype and genotype.

7 Draw a diagram or take a photo of your baby Zazzle.

Conclusion

Describe how dominant traits and recessive traits are inherited.

Lesson 2.13
Alleles for blood group traits co-dominate

Key ideas

→ The gene for blood type can make protein enzymes that make sugar molecules (A or B) on the surface of a red blood cell.

→ The allele symbols for this gene can be expressed together.

→ Other genes can produce the Rhesus protein.

Blood types

Some genotypes are more complex and involve more alleles. This is the case when determining your blood group. When stating your blood group, two components are usually referred to – a letter grouping (ABO) and whether you are Rhesus positive or negative. Rhesus protein molecules are present on the surface of the red blood cells of 80 per cent of people. These people are said to be Rhesus positive. If the Rhesus molecule is not present, these people are said to be Rhesus negative.

There are four other types of blood groupings. Table 1 shows the proportion of Australians who fall into each of these four groups.

People who have blood group A have red blood cells that display a special sugar molecule A on the surface of their red blood cells. People who are blood group B display sugar molecule B on their red blood cells. Group AB people display both molecules A and B, and people in blood group O have neither sugar molecule. The gene for each of these traits produces an enzyme (a protein) that makes the specific red blood cell sugar molecule (Figure 1).

It is important to know your blood group because mixing different types of blood can cause clots to form that block blood vessels. A person who is transfused with the wrong type of blood can die.

ABO blood grouping is determined by a different gene from Rhesus grouping, so the inheritance of each component must be investigated separately. Three alleles determine the ABO blood group (Table 2). Depending on which of these three alleles you inherit from your parents, your blood group may be different from that of your parents or your siblings.

The I^A and I^B alleles are described as **co-dominant**. The symbol for a co-dominant trait is given the symbol of a capital letter with a superscript. Co-dominant traits are expressed equally together, rather than one being dominant over the other. This means a person with the genotype I^AI^B will make the enzymes for sugar A and sugar B. This will give a person the
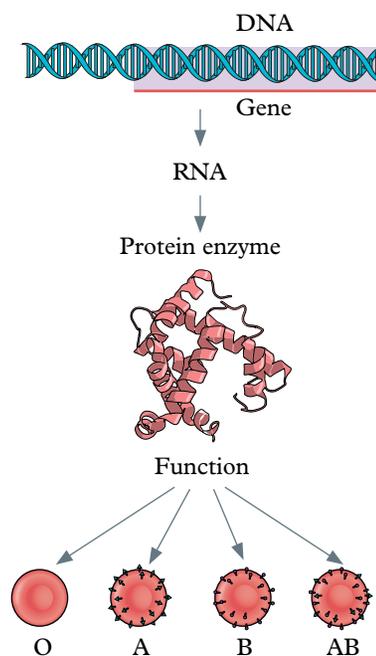
Figure 1 Genes for blood type produce an enzyme that makes a sugar (A or B) on the surface of a red blood cell.

co-dominant two different alleles that can both appear in the phenotype at the same time; both can appear with a single allele

2.13

blood type AB. However, both of these alleles are completely dominant over the recessive trait of the O blood type (i). This means a person with the genotype I^Ai or I^AI^A will make sugar molecule A and therefore have blood type A. A person with the genotype I^Bi or I^BI^B will make sugar molecule B and have blood type B. Worked example 2.13A shows how to use a Punnett square to predict the inheritance of co-dominant traits.

Table 1 Blood groupings in Australia

Blood group (phenotype)	Frequency in Australian population (%)	Frequency in Australian population of Rhesus positive (%)	Frequency in Australian population of Rhesus negative (%)
O	49	40	9
A	38	31	7
B	10	8	2
AB	3	2	1

Table 2 Blood group alleles

Trait	Allele symbol	Function
Dominant trait	I^A	Produces an enzyme that forms an A sugar on red blood cells.
Dominant trait	I^B	Produces an enzyme that forms a B sugar on red blood cells.
Recessive trait	i	Results in a non-functioning enzyme. No specific sugar on the surface of red blood cells.

Worked example 2.13A Using Punnett squares for co-dominant traits

A couple, Greg (blood group A) and Ellie (blood group B), decide to have a child. If both their individual mothers were blood group O, calculate the possibility of their child being blood type O.

Solution

First calculate the phenotype and then the genotype of each parent (Figure 2).

Greg's blood group is A. This means there are two possibilities for his genotype: I^AI^A or I^Ai.

If Greg's mother was blood group O, then Greg could have only inherited the alleles for the recessive trait (i) from his mother and so he must be heterozygous (I^Ai).

By applying the same process to Ellie, it can be determined that she is I^Bi.

This information can be used to construct a Punnett square, as shown in Figure 2.

	Greg	Ellie
Parents' phenotype	Blood type A	× Blood type B
Parents' genotype	I^Ai	× I^Bi
Parents' gametes	I^Ai	× I^Bi
F$_1$ genotype (offspring)	Punnett square	

		Ellie's alleles	
		I^B	i
Greg's alleles	I^A	I^AI^B	I^Ai
	i	I^Bi	ii
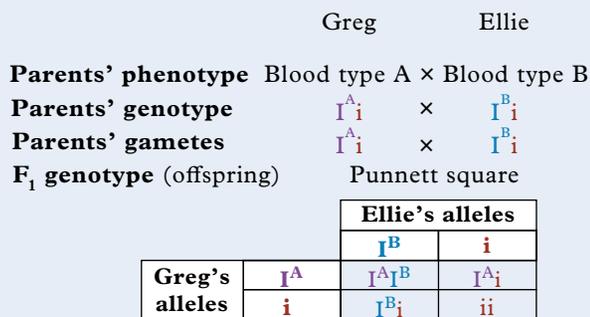
Figure 2 A Punnett square showing the inheritance of genes for the ABO blood type

The four possibilities for the ABO blood group for Greg and Ellie's child are:

Genotypic ratio: 1 I^AI^B : 1 I^Ai : 1 I^Bi : 1 ii

Phenotypic ratio: 1 AB : 1 A : 1 B : 1 O

This means that Greg and Ellie's child has a 1 in 4 (25%) chance of being blood type O.

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2.13

Biology

Check your learning 2.13

Check your learning 2.13

Retrieve

1 From Table 1, **identify** the blood group in Australia that is the:

   a most common

   b least common.

Comprehend

2 Complete Table 3 to **summarise** the possible genotypes that combine to produce each blood group phenotype and the sugars displayed.

Table 3 The genotype and AB sugars found in different blood types

Blood group (phenotype)	Possible genotypes	Sugars displayed on a red blood cell
O		
A		
B		
AB		

Analyse

3 **Consider** two parents who are both blood group O. **Identify** the blood groups their children could have.

4 Vinda is homozygous for blood group A. Julie is heterozygous for blood group B. Use a Punnett square to **calculate** the possible genotype(s) and blood group(s) for a child of Vinda and Julie.

5 **Construct** an appropriate graph to present the type of data presented in Table 1.

   a **Analyse** the data in the graph and **describe** any pattern you identify in terms of independent and dependent variables.

   b Does the pattern you identified in part **a** represent correlation or causation? **Justify** your response.

Lesson 2.14
Experiment: Blood typing experiment

Caution

Wear safety glasses, a lab coat and gloves when working with chemicals.

Aim

To determine the inheritance of blood groups

Materials

- Anti-A solution ($2\,M$ hydrochloric acid solution)
- Anti-B solution ($2\,M$ sulfuric acid solution)
- Sample blood O (deionised/distilled water)
- Sample blood A ($0.1\,M$ silver nitrate solution)
- Sample blood B ($0.1\,M$ barium nitrate solution)
- Sample blood AB (a $50:50$ mix of $0.1\,M$ silver nitrate and $0.1\,M$ barium nitrate solution)
- Spotting tiles

- 6 pipettes, one for each solution
- 6 toothpicks
- Unknown sample of blood

Method

1 Place two drops of sample blood O in the first wells of two rows of your spotting tile (Figure 1).
2 Using a fresh pipette, place two drops of sample blood A in the second wells of your spotting tile.
3 Repeat for the remaining blood samples.
4 Add a drop of anti-A solution to each of the wells in the first row of your tile.
5 Add a drop of anti-B solution to each of the wells in the second row of your tile.
6 Use a different toothpick to carefully mix each well.
7 If the red blood cells react with the anti-A or anti-B, it will form small clumps in the well. Record your observations ("+" for clumps; "–" for no clumps) in Table 1.
8 Test the unknown sample of blood to determine the blood type.
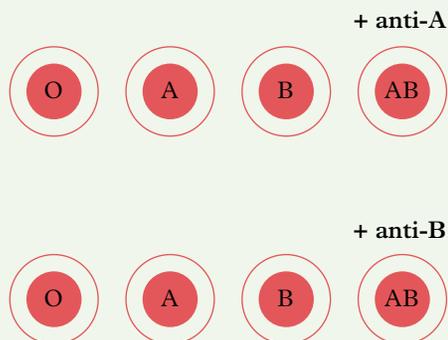
+ anti-A

+ anti-B

Figure 1 Where to place blood samples on the spotting tile

Results

Copy and complete Table 1.

Table 1 Results from the blood typing experiment

	Sample blood O	Sample blood A	Sample blood B	Sample blood AB
Anti-A				
Anti-B				

Discussion

1 **Define** the term "co-dominance".
2 **Identify** the possible genotype, or genotypes, of the following phenotypes.
   a Person with blood group A
   b Person with blood group B
   c Person with blood group AB
   d Person with blood group O
3 **Justify** the blood type that was obtained from the unknown sample of blood.
4 **Identify** the alleles that a person with type AB blood could pass on to their children.
5 **Identify** whether a person with blood group AB could have a child with blood group O. Justify your answer (by identifying the genotype of a person with blood type AB, identifying the genotype of a person with blood type O, describing how a parent passes on an allele to a child, and deciding whether an AB parent could have an O child).
6 A girl with blood group O claimed that she must have been adopted, because her mother's blood group is A and her father's blood group is B. **Outline** how you would explain to her that it is possible to be blood type O with type A and type B parents.

Conclusion

Describe how blood group is inherited.

Lesson 2.15
Alleles on the sex chromosomes produce sex-linked traits

Key ideas

→ The four patterns of inheritance are autosomal dominant, autosomal recessive, X-linked dominant and X-linked recessive.

→ Sex chromosomes are chromosomes that determine the sex of an organism.

→ Human females have two X chromosomes and human males have an X and a Y chromosome.

→ Fathers pass an X chromosome to each daughter and a Y chromosome to each son; mothers pass one X chromosome to each of their children.

→ Autosomes are non-sex chromosomes.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Sex chromosomes

Humans have 22 pairs of chromosomes that are not sex chromosomes, called **autosomes**. The twenty-third pair of chromosomes are the chromosomes that determine the sex of the offspring (**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. Females have two X chromosomes and therefore are more likely to have a copy of the effective working allele.

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 types (Table 1):

- autosomal dominant
- autosomal recessive
- X-linked dominant
- X-linked recessive.

autosome
a chromosome that does not determine the sex of an organism

sex chromosome
a chromosome that determines the sex of an organism

Figure 1 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.

Figure 2 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes in humans. In rats, spontaneous high blood pressure is linked to the Y chromosome, so only male rats experience spontaneous high blood pressure.

Figure 3 A male gets his X chromosome from his mother and his Y chromosome from his father. A female gets one of her X chromosomes from her mother and the other X chromosome from her father.

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. it 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. it 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). • Daughters of an affected father will all be carriers. • A carrier mother has a 50% chance of passing the trait on to each son.

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.

When the gene is defective, the colour receptors do not function properly and the person cannot distinguish red from green (Figure 4). Approximately 8 per cent of males and less than 1 per cent of females have red–green colour blindness. It is very rare for a female to have two defective alleles, but not as rare for them to be "carriers" (heterozygous) of the defective allele.

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. It is possible to treat this disease today because the clotting factors can be produced from donated blood or made in the laboratory. These clotting factors are given by injection.
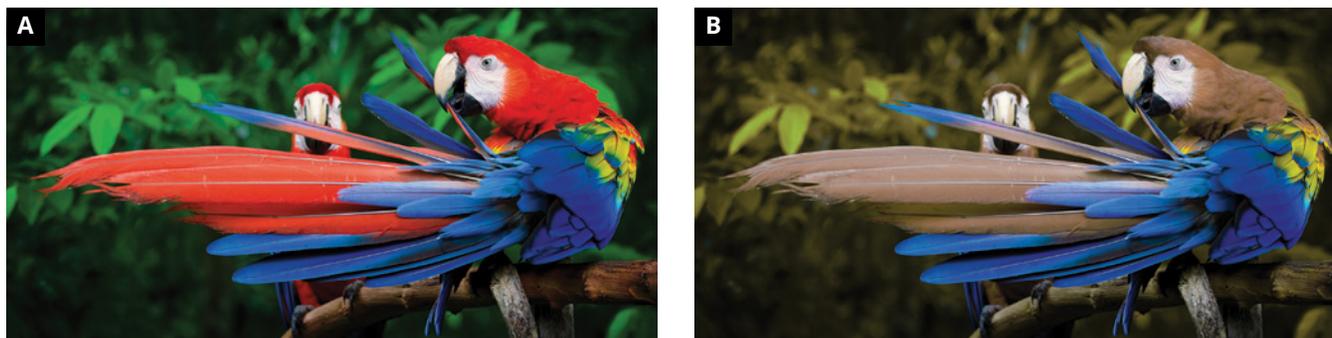
Figure 4 A person with colour blindness will have a very different view of the world. (A) A person with normal vision can see all the colours of these parrots. (B) A person with colour blindness cannot see the red and green feathers.

In the past, there was no treatment for haemophilia. Queen Victoria, Queen 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 their only X chromosome with the "defective" allele from her, 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 (Figure 5).

Alexei's disease caused great stress to the family. Alexandra even consulted the monk Rasputin to pray over him, but there was no reliable treatment for haemophilia in the early twentieth century.

Figure 5 Queen Victoria's granddaughter Alexandra, her husband, Nicholas II (the last Tsar of Russia), and their son, Alexei, who suffered from 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. For haemophilia, we can use X^H and X^h to represent the normal allele and the allele for haemophilia, respectively (Figure 6).

2.15

Key: H = normal allele and h = allele for haemophilia

Queen Victoria $X^H X^h$ × $X^H Y$ Albert

↓

Carrier daughter $X^H X^h$ × $X^H Y$ Her husband

↓

Alexandra $X^H X^h$ × $X^H Y$ Nicholas II
(carrier granddaughter)   (last Tsar of Russia)

↓

Alexei $X^h Y$
(haemophiliac son)
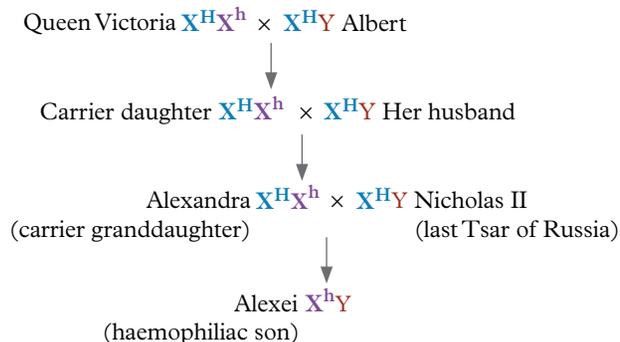
Figure 6 Genotypes in the family tree of Queen Victoria leading to Alexei

Check your learning 2.15

Check your learning 2.15

For the following questions, assume that the sex-linked gene is X-linked and recessive.

Comprehend

1 **Explain** why a defect in a sex-linked gene affects males more than females.

Analyse

2 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. **Calculate** the genotypes for this family.

3 The girl from the family in question **2** married a normal-sighted man and had a son who was colour-blind. **Calculate** the genotypes for this family.

4 The colour-blind son from the family in question **3** married a normal-sighted woman and had a son with normal sight and a colour-blind daughter. **Calculate** their genotypes.

5 **Calculate** the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia.

6 If a man has a mutated gene on his Y chromosome, **identify** which grandparent he inherited it from.

Apply

7 **Describe** who will be affected by a Y-linked gene. **Justify** your answer (by describing the sex chromosomes of males and females, and describing who would be affected by a gene on the Y chromosome).

8 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 **justify** your answer.

    b **Identify** the coat colour of the offspring of a tortoiseshell cat and a black cat.

Figure 7 A tortoiseshell cat

Lesson 2.16
Experiment: Colour-blindness inheritance

Aim

To examine the inheritance of X-linked traits

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 "Xb" on one side and "Y" on the other.
2   On the second counter, write "Xb" on one side and "XB" on the other.
3   Toss the counters eight times and record the possible genotypes of Li and Maria's children in Table 1.

Results

Copy and complete Table 1.

Table 1 Possible genotypes of Li and Maria's children

Coin toss	Genotype of child
1	
2	
3	
4	
5	
6	
7	
8	

Discussion

1   Identify the number of girls and boys that Li and Maria had in your experiment.
2   Identify the number of children who were colour blind. Identify the number of children who had normal vision.
3   Contrast the number of girls and boys who had colour blindness.
4   Evaluate whether non-colour-blind parents can have a colour-blind son (by using a Punnett square to support your answer).
5   Evaluate whether a non-colour-blind daughter can have a colour-blind father.
6   Evaluate whether two colour-blind parents can have a non-colour-blind son.
7   Many parents think that if they have three daughters first, they are more likely to then give birth to a boy. Evaluate this idea (by describing how the sex of offspring is determined, describing the law of segregation, and describing the probability of inheriting an X or Y chromosome in each generation).

Conclusion

Explain how colour blindness is inherited.
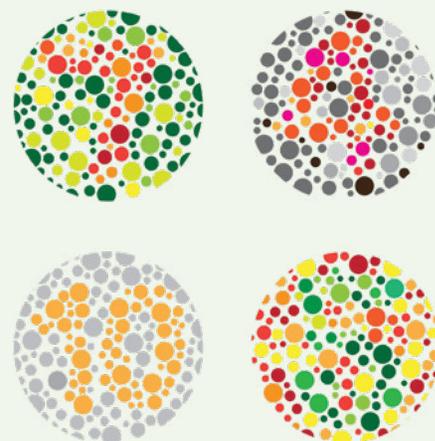
Figure 1 The Ishihara colour test uses coloured dots to identify whether a person is colour blind. The dots in each of these pictures are arranged to represent a number.

Lesson 2.17
Inheritance of traits can be shown on pedigrees

Key ideas

→ Pedigrees are a visual way to show the inheritance pattern of a trait.

→ Circles represent females and squares represent males.

→ Shaded symbols represent individuals who express the trait.

→ Recessive traits may skip a generation.

→ Once a dominant trait disappears from a family line, it will not reappear.

Kinship systems

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.

They can provide an indication of potential recessive traits that may affect your health if you inherited two copies of the alleles (one from each parent). Understanding the way recessive traits can accumulate if small groups intermarry is the basis of many European laws that forbid the marriage of siblings (brother and sister).

Aboriginal and Torres and Strait Islander Peoples in Australia have demonstrated an understanding of traits and inheritance without the use of the advanced technologies that are now available to geneticists. Despite living thousands of kilometres away from Gregor Mendel, Aboriginal and Torres and Strait Islander Peoples had observed how some recessive traits and illnesses could be inherited in the children of related parents.

This resulted in the development of kinship systems that can be used to identify relatives in the mother's or father's line. Across mainland Australia, a "skin name" can identify relatedness and roles in society. It can also determine who is and who is not allowed to marry.

Pedigree construction and analysis

pedigree a chart showing the phenotypes for an individual and their ancestors, usually over several generations; also known as a family tree diagram

Inheritance of characteristics is today often traced through families using family tree diagrams or **pedigrees**. There are specific symbols used in constructing pedigrees (Figure 1).

- Males are represented by squares and females by circles.
- A marriage or de facto relationship 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.

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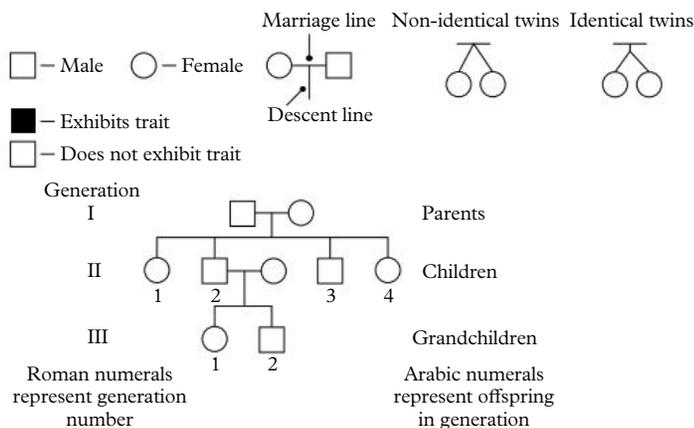
Figure 1 Some symbols used in family tree diagrams

When analysing a pedigree to determine whether a trait is dominant or recessive, the following rules apply.

- If neither parent has a characteristic and some of their offspring have it, then the characteristic is recessive (i.e. both parents are carrying the allele for the recessive trait but it is not shown in their phenotype).
- If both parents have a characteristic and some of their children do not have it, then the characteristic is dominant (i.e. both parents are heterozygous).
- If both parents have a characteristic and it is recessive, then all of their children will have that characteristic because only recessive alleles could be inherited by offspring. If both parents have a characteristic and none of their children have it, then the characteristic is dominant because it would require two heterozygous parents to produce offspring that do not inherit the characteristic.

In 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 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.
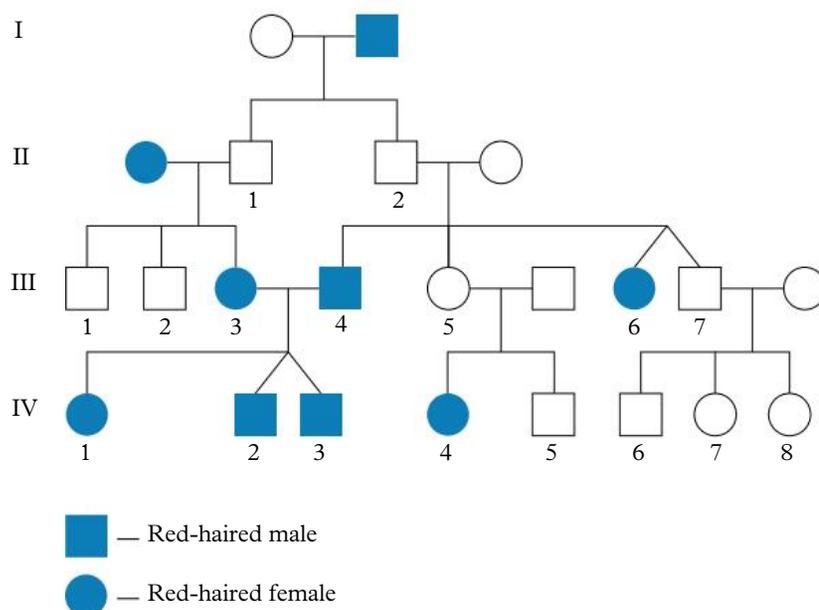
Figure 2 A pedigree for red hair
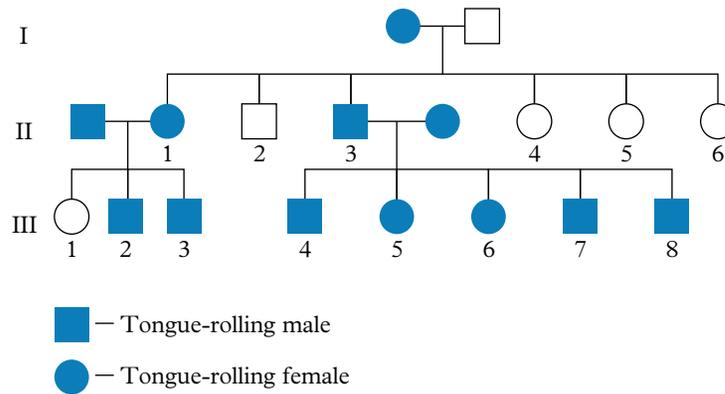
Figure 3 A pedigree for tongue rolling

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a disease. There is a series of questions you should ask when determining the inheritance pattern from a pedigree.

1 Are more males than females affected by the trait?

YES, go to 2. 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/some of her sons?

YES – Sex-linked recessive.

5 Do affected children have unaffected parents?

YES – Autosomal recessive.

Dwarfism

achondroplasia
a genetic (inherited) disorder of bone growth resulting in abnormally short stature and short limbs

Achondroplasia is the most common form of dwarfism (Figure 4) and is inherited as an autosomal dominant trait (although spontaneous mutations can also arise with no prior family history). The gene is located on chromosome 4, and it controls the production of a protein that responds to a growth factor hormone. If this gene is not functioning (affected allele), a person will not produce the protein. This means they will not be able to respond to the growth factor and will have a short stature. People with achondroplasia have normal intelligence and lead independent and productive lives, despite their medical problems.

Figure 4 Achondroplasia is the most common form of dwarfism.

Because the trait is dominant, people affected by achondroplasia have at least one affected parent (Figure 5). If one parent is affected, there is a 50 per cent chance of the children being affected.
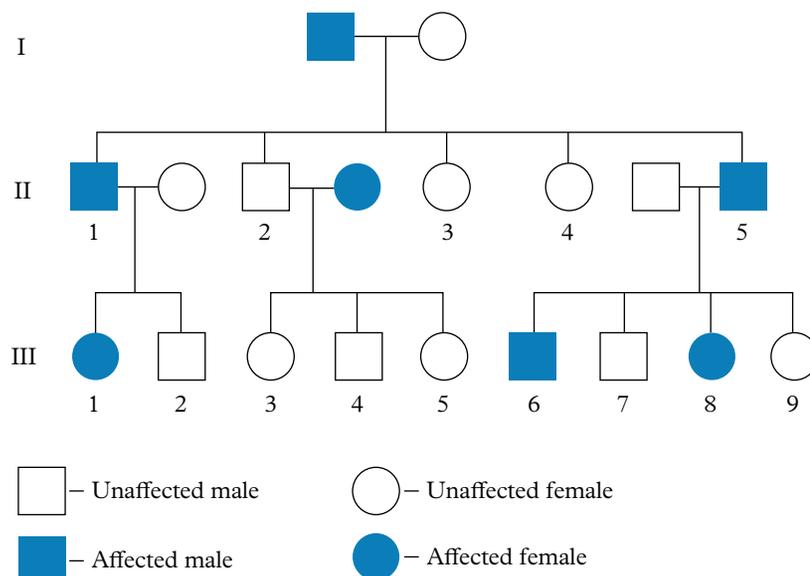
Figure 5 The pedigree chart of a family affected by achondroplasia – some of the children are unaffected.

Check your learning 2.17

Check your learning 2.17

Comprehend

1 **Represent** the following with a pedigree symbol.

   a A female with a trait

   b A male without a trait

   c Non-identical male and female twins without a trait

Apply

2 Some people have ear lobes that hang free and some people's ear lobes are attached. Natalie has attached ear lobes, but both Natalie's parents and her brother, Daniel, have free-hanging ear lobes as shown in the pedigree (Figure 6).

   a **Identify** whether the characteristic of free-hanging ear lobes is a dominant trait or a recessive trait. **Justify** your answer (by describing each of the rules that apply to the pedigree).

   b Use suitable symbols to **represent** the alleles for the ear lobe gene, and then **determine** the genotypes of:

      i Natalie

      ii Natalie's parents.

   c **Identify** the possible genotypes for Daniel.
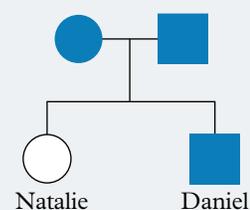
Figure 6 A pedigree showing inheritance of ear lobes

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 7.

   a Use this pedigree and suitable symbols to **demonstrate** the genotype of individuals I1, I2 and II5. **Determine** the genotype of individual A.

   b **Identify** one carrier in the pedigree shown in Figure 7.
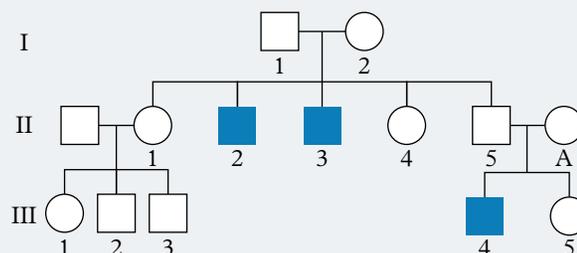
Figure 7 A pedigree showing the inheritance of an X-linked disease

◀ **4** Evaluate Figure 8.

   a In this family pedigree, **identify** the characteristic indicated by shading as dominant or recessive. **Justify** your answer.

   b If R represents the allele for the dominant trait and r represents the allele for the recessive trait, **determine** the genotypes of individuals 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.
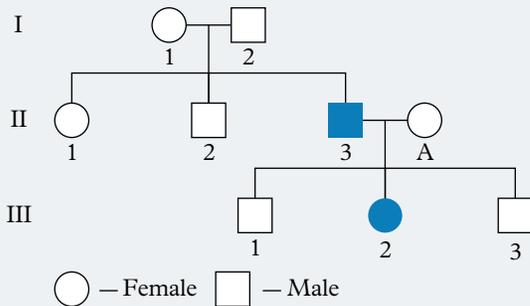
Figure 8 A pedigree indicating the inheritance of a trait

5 The pedigree in Figure 9 shows the inheritance of two genetic disorders (vision defects and limb defects) in the same family.

   a **Identify** the allele responsible for the vision defect as dominant or recessive. **Justify** your answer.

   b **Identify** the allele responsible for the limb defect as dominant or recessive. **Justify** your answer.
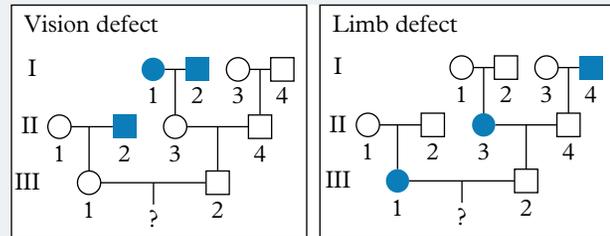
Figure 9 Pedigrees for the inheritance of vision defects and limb defects

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Lesson 2.18
Mutations are changes in the DNA sequence

Key ideas

→ Mutagens such as chemicals, UV light and cigarette smoke can cause permanent changes in the sequence of nucleotides that make up DNA.

→ Genetic mutations can involve substituting one nucleotide for another, or deleting or adding a nucleotide.

→ Chromosomal mutations result from the centromere failing to separate (non-disjunction) during meiosis.

Learning intentions and success criteria

Mutations and mutagens

mutation a permanent change in the sequence or amount of DNA

A **mutation** is a change in the sequence or amount of the genetic material (DNA) that can be passed on to daughter cells. 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).

If the change is in a single gene, then it is called a genetic mutation; if it affects most of a chromosome, it is called a chromosomal mutation.

Before a new cell can be produced, the three billion nucleotides need to be copied. Although the aim of copying the DNA is to keep the order of nucleotides the same, occasional errors can occur. The order of nucleotide nitrogen bases in the DNA is critical – a tiny change in the sequence changes the order of amino acids in the protein being made, which, in turn, may affect how the protein functions. 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.

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 thymines that are close together on a DNA polynucleotide chain to bind together, forming "thymine dimers". This causes problems during DNA replication G A C T T G G A T C Bond

Figure 1 The effect of mutagens

A single nucleotide mutation many thousands of years ago prevented the production of brown pigment in eyes. As a result, blue eyes developed in humans. The mutation gave humans a new allele. However, some mutations are deadly, because they cause a cell to rapidly reproduce and never die (cancer).

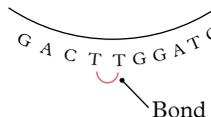Natural mutations occur at a continuous low rate. However, environmental factors called **mutagens** can increase the frequency of mutations. Mutagens include chemicals, radiation and ultraviolet (UV) light (Figure 1).

mutagen a chemical or physical agent that causes a change in genetic material such as DNA

Genetic mutations

There are two types of single nucleotide (point) mutation:
- substitution mutations
- frameshift mutations.

A **substitution mutation** occurs when one nucleotide base substitutes for another. As the genetic code is read in groups of three (called triplets), this may or may not have an effect on the final protein (Figure 2).

substitution mutation a form of mutation where one nucleotide is substituted for another; may or may not result in a deformed protein

A T H E C A T A T E T H E R A T A N D R A N F A R

B T H E C A (R) A T E T H E R A T A N D R A N F A R
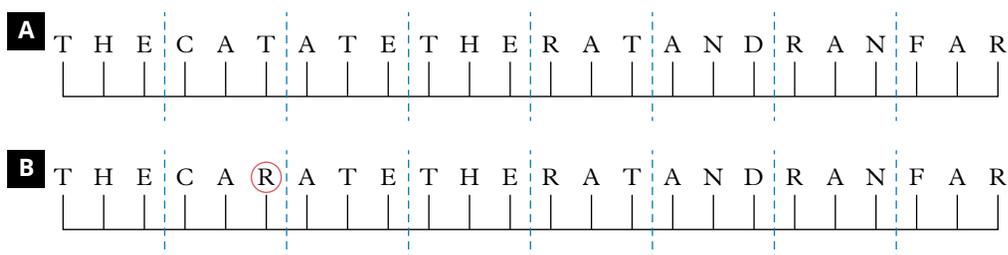
Figure 2 (A) The original DNA sequence. (B) The DNA sequence with the substitution where the sixth letter, T, was substituted by R. In DNA it might be a G substituted for A. This small change will be passed on to the RNA but may not affect the order of amino acids in a protein.

Sickle cell anaemia is an example of a substitution mutation that does affect the final protein (Figure 3). The gene that makes part of the haemoglobin molecule, which carries oxygen around the body, substitutes 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 the protein haemoglobin that is produced is sticky and deformed, which doesn't carry oxygen as effectively. People with sickle cell anaemia can feel tired, and the sticky haemoglobin deforms the red blood cells, making them a sickle shape. The unusually shaped red blood cells can become "stuck" in the smaller blood vessels causing pain to the person.

Normal DNA sequence

Valine – Histidine – Leucine – Threonine – Proline – Glutamic acid – Glutamic acid – Lysine

A section of the β-chain on normal haemoglobin

Normal red cells

Mutated DNA sequence

Point mutation

Result of point mutation

Valine – Histidine – Leucine – Threonine – Proline – Valine – Glutamic acid – Lysine

A section of the β-chain on sickle cell haemoglobin

Sickle cells

Figure 3 Haemoglobin and sickle cell anaemia – an example of the effects of a point mutation

A deletion or an addition can have a large impact on how the genetic code (groups of three nucleotides) is read. Adding or removing one letter shuffles all the groups of three nucleotides (Figure 4).

These are both **frameshift mutations** because the group-of-three reading frame has been shifted along the DNA strand.

Frameshift mutations have more damaging effects than substitution mutations because they change the entire reading frame of the DNA and RNA, producing a very 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 be useful. Frameshift mutations will always cause a damaged protein.

frameshift mutation a type of mutation in which a nucleotide is added or deleted, causing a shift in the reading frame of codons; usually results in a deformed protein
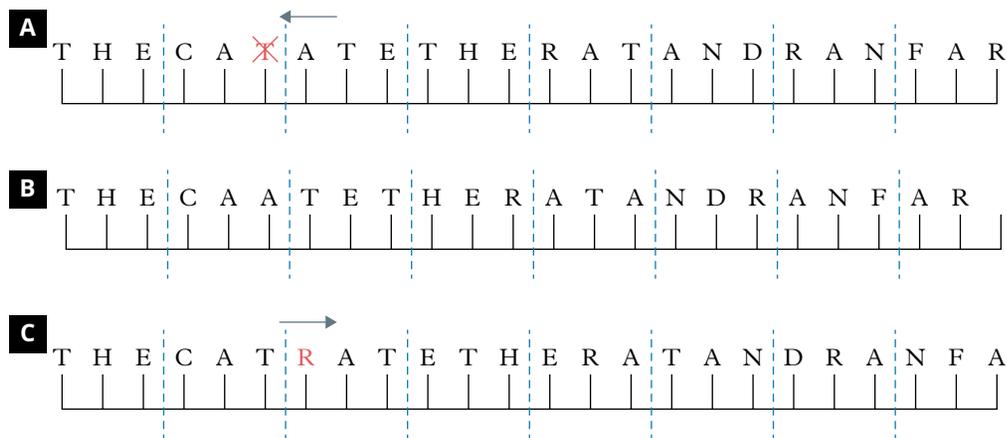
Figure 4 (A) A deletion of the sixth letter, T, in the example sentence results in the sequence shifting to the left. (B) The new DNA sequence after the T is deleted. (C) The addition of an extra R at the seventh letter results in the rest of the DNA sequence being shifted to the right.

Mutations involving chromosome number

This type of mutation is usually the result of **non-disjunction** – the failure of a chromosome pair to separate at the centromere in meiosis. In such cases, one of the daughter cells (gametes) will have too many chromosomes and the other will have too few chromosomes (Figure 5). If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

non-disjunction the failure of one or more chromosomes to separate during meiosis; can result in an abnormal number of chromosomes in the daughter cells
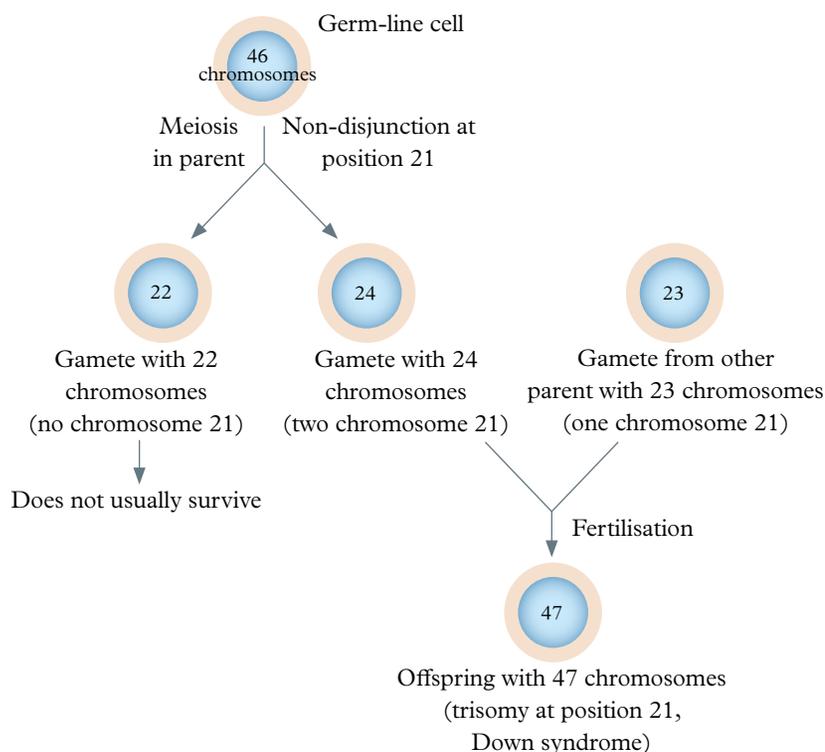
Figure 5 Changes in chromosome numbers due to non-disjunction

Down syndrome is the result of non-disjunction in chromosome pair 21 during the formation of the gametes in one parent. A person with Down syndrome has three copies (trisomy) of chromosome 21 (Figure 6 and Figure 7).

2.18
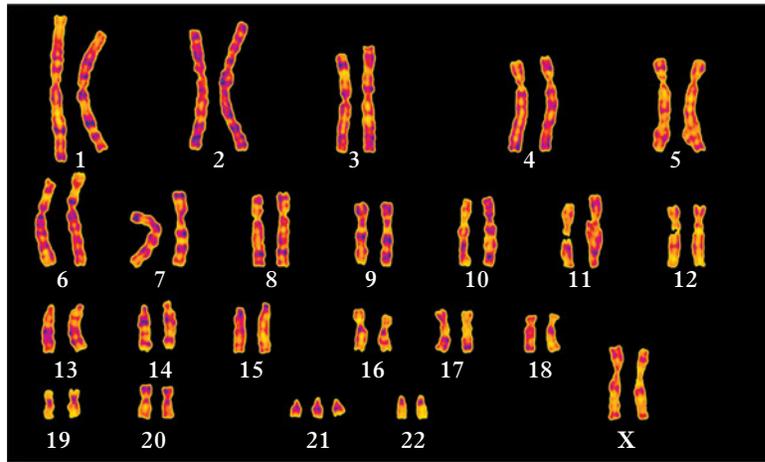
Figure 6 Individuals with Down syndrome have three copies of chromosome 21.

Figure 7 This girl has Down syndrome, which is a result of non-disjunction of chromosome 21.

Non-disjunction in sex chromosomes

Non-disjunction can also occur with the sex chromosomes X and Y. This can result in a variety of syndromes.

Females with Turner syndrome have only one X chromosome (Figure 8). Turner syndrome can appear in many different ways, and it is not always apparent from the person's physical appearance. Symptoms can include shorter than average height, infertility, extra webbing on the neck, swollen hands and feet, diabetes and many other difficulties. Turner syndrome does not normally affect intellectual ability.

Males with Klinefelter syndrome have an extra X chromosome, giving them a total of 47 chromosomes (Figure 9). This can affect their fertility, muscle development and intellectual ability. Many of these individuals will be undiagnosed. Approximately 1 in 660 males are affected.
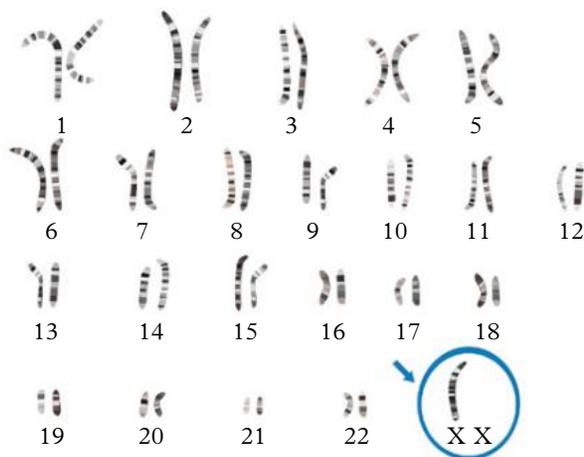
Figure 8 Turner syndrome is a result of non-disjunction of the X chromosome.
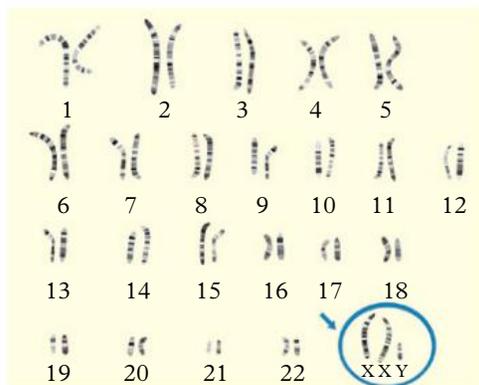
Figure 9 Males with Klinefelter syndrome have an extra X chromosome.

Cri du chat syndrome

Cri du chat syndrome is caused by missing portions of chromosome 5 (Figure 10). Both males and females can be affected. Symptoms include having a high-pitched cry (similar to that of a cat) as a baby. People with Cri du chat syndrome are slow to grow, and they often have a small head and intellectual difficulties. Their fingers or toes can sometimes be fused together.
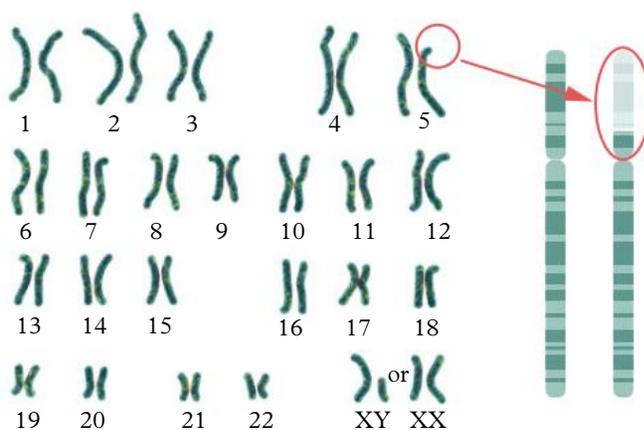
Figure 10 Cri du chat syndrome occurs when part of chromosome 5 is missing.

Check your learning 2.18

Check your learning 2.18

Retrieve

1 **Define** the term "mutation".

Comprehend

2 **Define** the term "mutagen". **Describe** one example of a mutagen and how it acts to cause mutations.

3 **Define** the term "trisomy". **Describe** an example of a trisomy in humans.

4 **Describe** a frameshift mutation.

5 **Illustrate** a series of diagrams that represent non-disjunction occurring in meiosis.

Analyse

6 **Compare** the causes of Turner syndrome and Down syndrome.

2.18

◀ **Apply**

7 Haemochromatosis is a disease where the body stores too much iron in the organs. This can cause complications especially later in life. It is a recessive trait as a result of an inherited substitution mutation. Use non-scientific language to **describe** why a person may be the only person with the disease in their family.

8 **Evaluate** whether a mutation can be advantageous (by defining the term "mutation", describing an example of a mutation that helps an organism to survive, and deciding whether mutations can be advantageous).

9 **Propose** how you would test whether a male had Klinefelter syndrome.

Skills builder: Evaluating

10 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?)

Lesson 2.19
Science as a human endeavour: Genes can be tested

Learning intentions and success criteria

Key ideas

→ DNA can be tested for any genetic diseases or conditions through genetic screening and testing.

→ Ethical issues can arise because of genetic testing.

Introduction

Mutations in genes can be identified by using probes, which are short sections of complementary nucleotides that can bind to mutated alleles. If the mutated allele is TAA CAG TAT, the probe will be ATT GTC ATA. The complementary nucleotides of the probe will bind to the mutated allele and can help identify individuals at increased risk of developing diseases.

Genetic screening and testing

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.

Oxford University Press

Genetic screening refers to testing a large number of people within the community even if they do not have any family history of genetic disease. The development of fast computers has made it possible for more people to access genetic testing. The first human genome took thirteen years to identify the full sequence of nucleotides (the order of the A, T, G, C). Today it can take less than 24 hours to receive the same results.

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 (Figure 1)
- **early detection and predictive testing for adults** – the screening of adults to detect existing disease, those who have a high chance of the disease or those who are carriers with a reproductive genetic risk.

Genetic screening allows individuals to be diagnosed early, before the symptoms of the disease appear. These individuals can then be treated, preventing the worst symptoms from appearing and even preventing death.

Genetic screening can also be used to prevent genetic diseases from being passed on to the next generation. While this prevents future children from suffering, it sometimes involves some very difficult decisions. For example, individuals 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 people prepared to 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. Instead, they help the individuals make their own decisions.

The collection, storage and potential use of genetic information raises many ethical questions, including who should access the information and the possible misuse of such information.

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.

maternal serum screening (MSS) the genetic testing of foetal DNA found in the mother's blood

newborn screening the testing of chromosomes in a baby's white blood cells for the presence of a genetic disease

early detection and predictive testing for adults the testing of chromosomes for the presence of alleles that increase the probability of cancers forming

Sex, Down Syndrome Tests

A growing number of pregnant women in WA are having a simple blood test that can pick up signs of Down syndrome and the baby's sex as early as 10 weeks.

Doctors say demand has gone "crazy" in WA for non-invasive prenatal testing (NIPT), which costs more than $400 but is more accurate than the blood test used in traditional prenatal screening. Women found to be at low risk of Down syndrome by the test could avoid having invasive procedures such as amniocentesis, which increases the risk of miscarriage.

Instead of testing cells from the foetus or the placenta, NIPT picks up traces of foetal DNA circulating in the mother's blood. Because there is an option to screen for sex-linked chromosomes, it can also show the gender of the foetus.

Some ethics experts are worried that detecting the gender early on could make it easier for couples who want a child of a particular sex to terminate the pregnancy.

Prenatal screening is usually aimed at women at higher risk of Down syndrome, such as those aged over 35, but even low-risk women are having the newer test, despite it not having any Medicare or private health insurance rebate. It cost $1,400 when it became available in Australia three years ago but it is now as low as $420. While it is not a diagnostic test, it is 99 per cent accurate and has a very low false positive rate. A WA survey of high-risk pregnant women presented at the Royal Australian and New Zealand College of Radiologists scientific meeting in Adelaide yesterday showed most preferred it.

Obstetric radiologist Emmeline Lee, from Western Ultrasound for Women, said there had been a huge uptake in WA. "The market has gone crazy," she said. "Even though we were cautious about offering it only to high-risk women, we're seeing low-risk women wanting it as an extra layer of security."

Professor Peter O'Leary, from Curtin University's Faculty of Health Sciences, said there was a push to have the test publicly funded but he believed it should be limited to 20 per cent of women at higher risk.

What is NIPT?

- Non-invasive prenatal testing is a new way to screen for genetic abnormalities.
- Unlike invasive tests, such as amniocentesis and chorionic villus sampling (CVS) that collect cells from the placenta (which is genetically identical to the foetus), NIPT uses traces of foetal DNA in the mother's blood.
- It can be done from 10 weeks and is 99 per cent accurate at detecting Down syndrome.
- Samples have to be sent to the Eastern states, with results usually within a week.
- A 12-week ultrasound should still be done to check for structural abnormalities.
- It is not a diagnostic test, so women who test positive may have a false result and need to have it confirmed by amniocentesis or CVS.

Source: The Weekend West, November 7–8, 2015, p.17, by Cathy O' Leary, Medical Editor

Test your skills and capabilities

Describing ethical issues

There are many ethical and legal issues raised by genetic testing.

Select one of the issues listed, and use an ethical approach to **evaluate** the issue by:

- describing the people affected by the issue (including individuals, their family, and medical, personal and societal costs)
- describing how they are affected
- describing the ethical approach you will use (consequentialist or deontological)
- using the ethical approach to describe the issue
- describing an alternative view that could be used by someone else
- describing the decision you would make if faced with the issue.

a A pregnant woman who is at high risk of having a child with a painful genetic disease refuses to have a prenatal genetic test.

b An employer insists on a person having a genetic test before they will be employed.

c A health insurance company demands a copy of the results of a previous genetic test before they will insure the person.

d A couple expecting a child with a non-painful genetic disease ask for your advice about terminating the pregnancy.

Lesson 2.20

Science as a human endeavour: Genes can be manipulated

Key ideas

→ Genetic modified organisms have had their DNA changed or modified for specific purposes.

→ Crops have been genetically modified to improve their nutritional quality or make them pest resistant.

→ GMO can pose a threat to biodiversity, as organisms with the same DNA are at risk of dying out if a disease takes hold.

Learning intentions and success criteria

Introduction

The genetic material of all organisms is made of the same four nucleotides A, T, C and G. The only difference is their order in the DNA. Understanding the nature of DNA led to the question "Can we change it?"

Genetically modified organisms

Genetically modified organisms (GMOs) have had their DNA changed or modified in the laboratory. This can be done by changing the nucleotides to stop genes making protein or to add new genes into an organism's genetic material to improve certain traits, such as increased resistance to herbicides or improved nutritional content. Traditionally, breeders would select breeding organisms who had the desired traits and hope that the offspring inherited those traits (Figure 1).

Today, genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy. For example, geneticists can remove a gene for drought tolerance from one plant and insert that gene into a different plant. The new genetically modified (GM) plant will now be able to survive a 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.

Genetically modified organisms (GMOs) an organism that has had its DNA changed in a laboratory

transgenic organism an organism that has a gene from another organism inserted into its own chromosomes
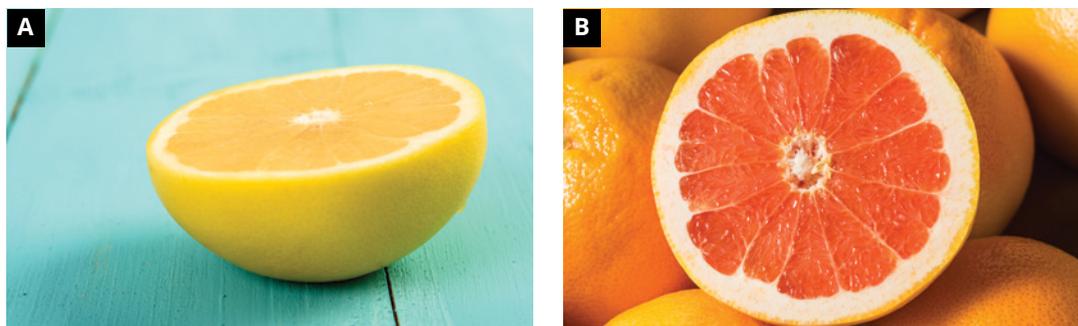
Figure 1 (A) When traditional yellow grapefruit was exposed to radiation, it produced a new variation known as a ruby grapefruit (B).

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.

Engineering crops to resist disease means that farmers can use less pesticide and herbicide when growing them. Reducing the amount of pesticide and herbicide reduces production costs and environmental pollution.

Figure 2 shows the process of introducing a gene from a daffodil into corn to increase its levels of vitamin A.

Step 1: The gene that produces vitamin A is isolated from a daffodil.

Step 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.

Step 3: The bacterial cells containing the plasmid are added to the embryonic corn plant.

Step 4: The transgenic corn grows. The introduced genes produce high levels of vitamin A.

Examples of plants that have been genetically engineered are shown in Figure 3, Figure 4 and Figure 5.
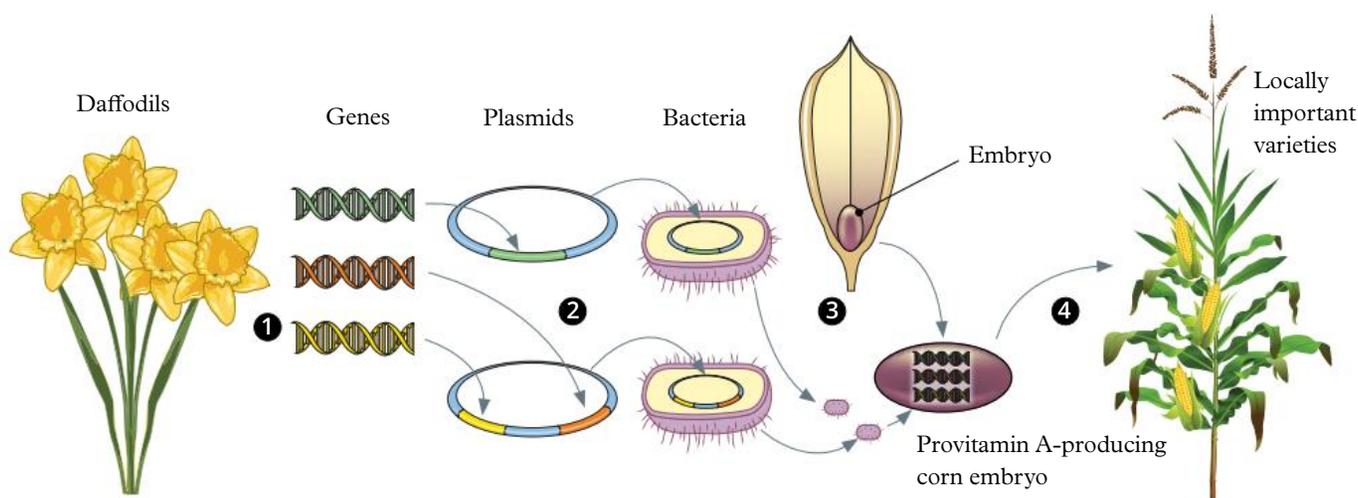
Figure 2 Scientists can grow transgenic corn that produces high levels of vitamin A.

Figure 3 Transgenic variety of cotton that is pest resistant. Genes (that make a protein toxic to insect pests) from the bacterium *Bacillus thuringiensis* have been introduced into the DNA 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.
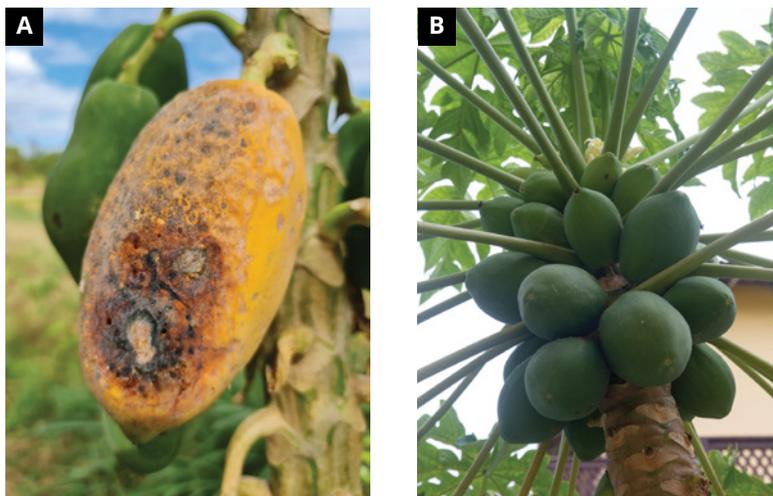
Figure 4 (A) Transgenic papaya plants in Hawaii are resistant to the ringspot virus. (B) Genetically engineering papaya has saved the industry. The technology has also been exported to other countries where ringspot virus is damaging papaya plants.

Figure 5 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. Many people in South-East Asia, a large rice-consuming area of the world, are blind or have severe sight problems due to vitamin A deficiency. Therefore, this high-nutrition rice is most valuable in parts of Asia.

GMO issues

GM crops can pose a threat to **biodiversity** because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. This can generate a monoculture, decreasing the diversity of other plants and animals (i.e. biodiversity) in the growing area.

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. Like the DNA and proteins that exist in all food that we eat, the introduced genes and proteins are digested in our stomach and intestines.

One 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. This may also contribute to pest insects developing resistance to the pesticide and insecticide. This means the GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.

biodiversity the variety of life; the different plants, animals and microorganisms and the ecosystems they live in

◀

Test your skills and capabilities

Evaluating claims

"Since the introduction of GMOs in America in 1996, there has been an increase in chronic illness, food allergies, autism and digestive problems."

1 **Evaluate** this claim from a health blog by:
   – contrasting correlation and causation
   – identifying an example of this contrast in the statement
   – identifying the reason why the author may have made this statement
   – defining the term "bias" and discussing the bias in the statement.

Skills builder: Planning investigations

2 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: Is trusted data already available? Do you have access to the necessary equipment and materials to conduct an investigation?)

Lesson 2.21

Science as a human endeavour: Genetic engineering is used in medicine

Key ideas

→ Gene cloning is where exact copies of the original are made.

→ Gene therapy uses a healthy gene to replace the defective one.

→ Stem cells are cells that can mature into different types of cells; however, there are ethical issues associated with using them as stems cells as one type, embryonic stem cells, are obtained from embryos.

Learning intentions and success criteria

Introduction

Genetic engineering has been used to change the genetic code of animals, to make medicines and to treat people with genetic diseases.

Gene cloning

Before a gene can be used in medicines, an exact copy needs to be made. This exact genetic copy is called a clone. The process of making multiple copies of a gene is called **gene cloning**.

Once the copies of the gene are produced, they can be inserted into bacteria. An example of this is the production of insulin (used to treat diabetes). The human gene for insulin was cloned and inserted into a fast-growing bacteria (Figure 1). The bacteria used the gene to produce multiple copies of the human insulin protein, which was purified and used to treat a person with diabetes. Because it is human insulin made from the human gene, this production method avoids the complications caused when insulin is made from pig or sheep genes.

Gene therapy

Some people are born with a defective gene that affects the health of their body. **Gene therapy** involves inserting a healthy replacement gene into the chromosomes of an individual with a defective gene. Gene therapy that inserts a new gene into 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.

Despite initial setbacks, 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 chloride ions across cell membranes. A major symptom of CF is the accumulation of a thick mucus that can damage lung tissue.

This reduces the lifespan of patients 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 is a harmless virus, and it is added via a spray through the nose of patients.

Biology
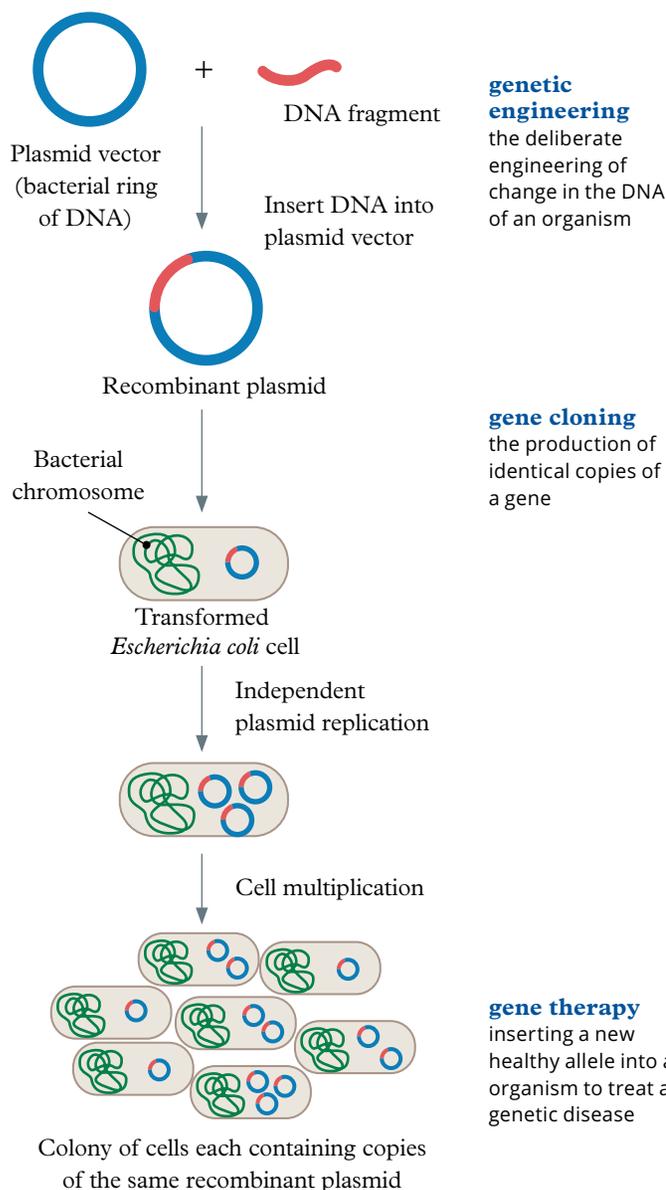
genetic engineering the deliberate engineering of change in the DNA of an organism

gene cloning the production of identical copies of a gene

gene therapy inserting a new healthy allele into an organism to treat a genetic disease

Plasmid vector (bacterial ring of DNA)

+ DNA fragment

Insert DNA into plasmid vector

Recombinant plasmid

Bacterial chromosome

Transformed *Escherichia coli* cell

Independent plasmid replication

Cell multiplication

Colony of cells each containing copies of the same recombinant plasmid

Figure 1 Gene cloning

The virus enters many of the lung cells and inserts the healthy gene into the DNA in the nucleus. When the lung cells divide, the new cells contain the healthy gene (Figure 2).

Normal human gene cloned in bacterium

Normal gene (DNA sequence) inserted into harmless virus (AAV, adeno-associated virus)

Virus dripped into lung through a thin tube inserted in the nose

Lung cell
Nucleus
Virus enters lung cell nucleus

Normal gene (DNA sequence) inserted into lung cell DNA by virus

Cells now with normal genes function normally
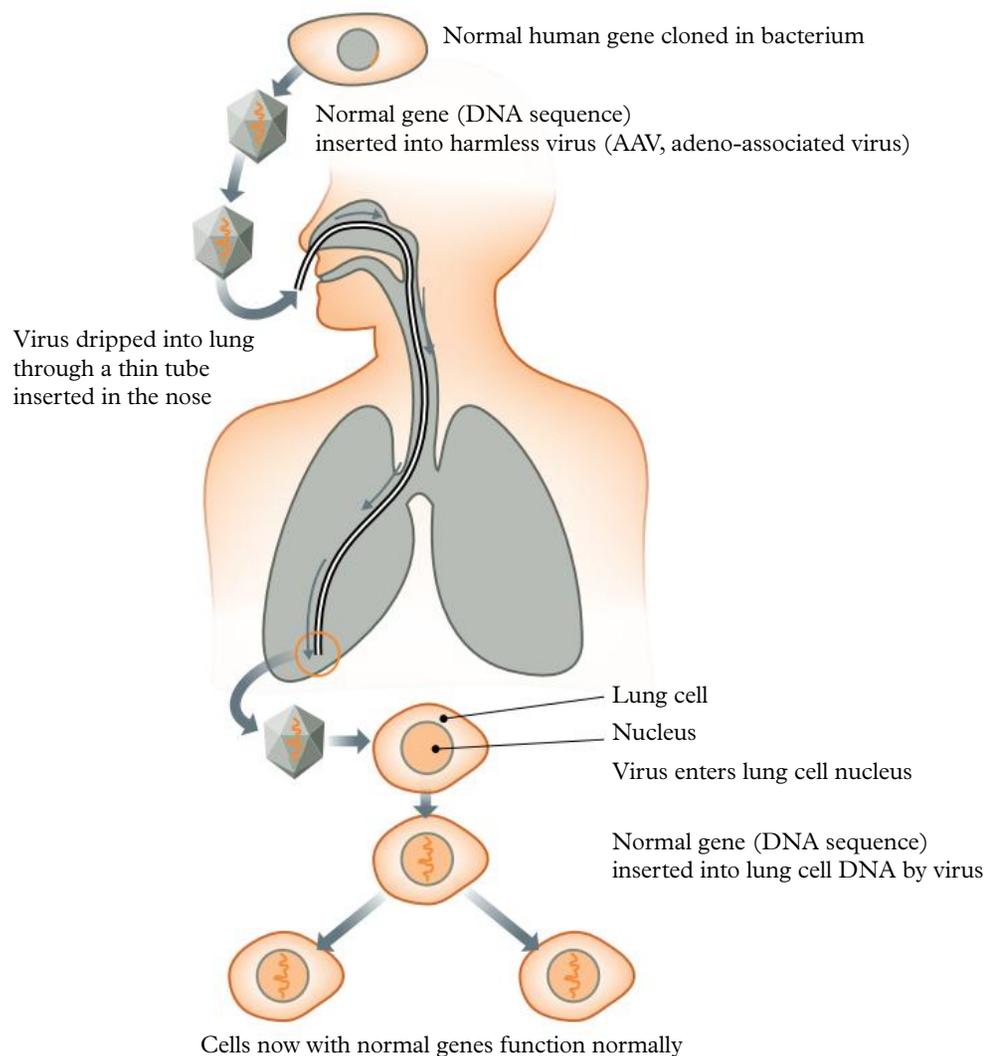
Figure 2 Gene therapy for cystic fibrosis

Stem cells and ethics

stem cell a cell that can produce 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 many types of cells

Stem cells are undifferentiated cells that can differentiate (mature) into many different types of specialised cells, such as muscle, nerve, liver and blood cells. There are two 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"; that is, those originally created for use in in-vitro fertilisation (IVF). However, some people consider the use of these excess embryos to be unethical. They regard the embryos as potential life and their use in research as depriving life to these embryos.

Most recently, scientists have been able to reverse the differentiation process and turn multipotent adult stem cells back into pluripotent stem cells (like the embryo cells).

These cells are called induced pluripotent stem 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.

Test your skills and capabilities

Evaluating ethics

A new form of gene therapy has recently been developed for the treatment of cancer. CAR T-cells (chimeric antigen receptor T-cells) are formed when a cancer patient's immune cells (T-cells) are removed and provided with genes that will allow them to fight the patient's cancer. These treated T-cells are placed back into the patient where they will find and kill the cancer cells. This new form of gene therapy is very expensive (usually starting at $500,000 for a single treatment). The ethical dilemma arises when considering the effectiveness of spending the money to treat one person, or to treat the many thousands of people who are sick due to poverty.

1 **Evaluate** the ethical dilemma presented when deciding whether to treat a 20-year-old cancer patient with CAR T-cells by:
   – describing the people affected by the issue (including individuals, their family, and medical, personal and societal costs)
   – describing how they are affected
   – describing the ethical approach you will use (consequentialist or deontological)
   – using the ethical approach to describe the issue
   – describing an alternative view that could be used by someone else
   – describing the decision you would make if you had to make the choice.

Lesson 2.22
Review: Genetics

Summary

Lesson 2.1 Science as a human endeavour: Scientists review the research of other scientists

- Gregor Mendel's experiments with peas was able to demonstrate that genetic information was passed from parents to offspring.
- Watson and Crick were able to use the research from Linus Pauling, Erwin Chargaff and Rosalind Franklin to discover the structure of DNA.
- Advances in technology now allows the use of computer modelling to generate large data sets and compare them to experimental results.

Lesson 2.2 DNA consists of a sugar–phosphate backbone and complementary nitrogen bases

- Genes are made of a chemical called deoxyribonucleic acid (DNA).
- The DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds.
- DNA has a double-helix shape.

Lesson 2.5 Chromosomes carry genetic information in the form of genes

- Each cell in your body (except red blood cells) contains 46 chromosomes.
- Chromosomes can be arranged from largest to smallest to form a karyotype.
- Females have two X chromosomes; males have an X and a Y chromosome.
- Genes are sections of DNA that have a function. DNA cannot leave the nucleus of a cell.

Lesson 2.6 DNA holds the code for building proteins

- Transcription is the process of copying genetic information from DNA into mRNA.
- Translation is the process of decoding mRNA to form a protein.

Lesson 2.7 Mitosis reproduces a nucleus

- Most of the cells in your body are somatic cells (all except sperm and egg cells).

- Somatic cells are diploid, which means they carry two sets of genetic material – one from the mother and one from the father.
- Mitosis is the division of the genetic material to produce two genetically identical nuclei.

Lesson 2.9 Meiosis forms gamete cells

- A gamete is a sex cell (egg or sperm) that has half the genetic material of the parent cell.
- Meiosis is the process of cell division that produces haploid gametes.
- Two haploid gametes combine to produce the first diploid cell of a new organism.

Lesson 2.11 Alleles can produce dominant or recessive traits

- Genes can have different versions (alleles) at the same location of a chromosome.
- The unique combination of alleles for a gene inherited from parents is called the genotype of the organism.
- Homozygous individuals have two identical alleles; heterozygous individuals have two different alleles.
- A dominant trait only needs a single allele present to appear in the phenotype.
- Recessive traits need two copies of the allele to appear in the phenotype.
- A person who is heterozygous for a recessive trait is said to be a carrier for the trait.

Lesson 2.13 Alleles for blood group traits co-dominate

- The gene for blood type can make protein enzymes that make sugar molecules (A or B) on the surface of a red blood cell.
- The allele symbols for this gene can be expressed together.
- Other genes can produce the Rhesus protein.

Lesson 2.15 Alleles on the sex chromosomes produce sex-linked traits

- The four patterns of inheritance are autosomal dominant, autosomal recessive, X-linked dominant and X-linked recessive.

- Sex chromosomes are chromosomes that determine the sex of an organism.
- Human females have two X chromosomes and human males have an X and a Y chromosome.
- Fathers pass an X chromosome to each daughter and a Y chromosome to each son; mothers pass one X chromosome to each of their children.
- Autosomes are non-sex chromosomes.

Lesson 2.17 Inheritance of traits can be shown on pedigrees

- Pedigrees are a visual way to show the inheritance pattern of a trait.
- Circles represent females and squares represent males.
- Shaded symbols represent individuals who express the trait.
- Recessive traits may skip a generation.
- Once a dominant trait disappears from a family line, it will not reappear.

Lesson 2.18 Mutations are changes in the DNA sequence

- Mutagens such as chemicals, UV light and cigarette smoke can cause permanent changes in the sequence of nucleotides that make up DNA.
- Genetic mutations can involve substituting one nucleotide for another, or deleting or adding a nucleotide.

- Chromosomal mutations result from the centromere failing to separate (non-disjunction) during meiosis.

Lesson 2.19 Science as a human endeavour: Genes can be tested

- DNA can be tested for any genetic diseases or conditions through genetic screening and testing.
- Ethical issues can arise because of genetic testing.

Lesson 2.20 Science as a human endeavour: Genes can be manipulated

- Genetic modified organisms have had their DNA changed or modified for specific purposes.
- Crops have been genetically modified to improve their nutritional quality or make them pest resistant.
- GMO can pose a threat to biodiversity, as organisms with the same DNA are at risk of dying out if a disease takes hold.

Lesson 2.21 Science as a human endeavour: Genetic engineering is used in medicine

- Gene cloning is where exact copies of the original are made.
- Gene therapy uses a healthy gene to replace the defective one.
- Stem cells are cells that can mature into different types of cells; however, there are ethical issues associated with using them as stems cells as one type, embryonic stem cells, are obtained from embryos.

Review questions 2.22

Review questions: Module 2

Retrieve

1 **Identify** which is not a smaller part of all DNA nucleotides.
   A Deoxyribose
   B Nitrogen base
   C Adenine
   D Phosphate molecule
2 **Identify** the missing phrases in the following sentence. Mutations are _____ and mutagens are _____.
   A changes in the gene carried through DNA; a substance that causes permanent change

   B changes in the chromosomes; a substance that causes permanent change
   C a substance that causes permanent change; changes in the chromosomes
   D a change in the genetic structure; substances that cause temporary change
3 **Recall** the definition of "pedigree".
   A A cross that shows inheritance
   B A diagram to show the inheritance pattern of a trait
   C A particular breed of species
   D A plot of chromosomes

4 **Recall** the two vital properties DNA molecules have:

  A DNA can carry information; DNA is organised in pairs.

  B DNA can make copies of itself; DNA can carry information.

  C DNA contains ribose sugar; DNA can make copies of itself.

  D DNA can leave the nucleus and attach to a ribosome; DNA is a nucleic acid.

5 **Identify** the missing phrases in the following sentence. Mitosis is _____ and meiosis is _____.

  A a change in the sequence of the genetic material (DNA); part of a cell division where one parent nucleus divides to form two genetically identical daughter nuclei

  B cell division in which the number of chromosomes is halved; the manipulation of the nucleotides to stop genes making protein

  C the failure of a chromosome pair to separate at the centromere; the type of cell division that occurs when gametes are being made

  D part of a cell division where one parent nucleus divides to form two genetically identical daughter nuclei; cell division in which the number of chromosomes is halved

6 **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

7 **Identify** the four nitrogen bases found in DNA.

8 **Define** the term "monohybrid cross".

9 **Define** the following terms.

  a GMO

  b Transgenic organism

10 **Recall** why it is important to know your blood group.

Comprehend

11 Use the terms "gametes" and "fertilisation" to **explain** how DNA is transferred from one generation to the next.

12 **Describe** Mendel's conclusions from his work on breeding peas.

13 **Explain** what is meant by the following formula: Phenotype = genotype + environment

14 **Explain** the process of:

  a gene cloning

  b gene therapy.

15 **Describe** the sort of information that can be determined from the pedigree shown in Figure 1.
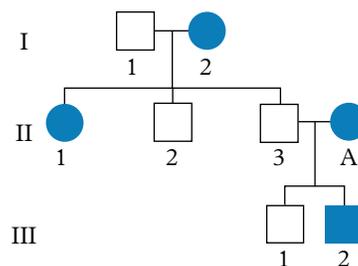

Figure 1 A pedigree

16 **Explain** why large-scale genetic screening programs reduce the prevalence of genetic diseases.

17 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.

Analyse

18 If a gene contains 600 nucleotide bases, **calculate** the number of amino acids that would be incorporated into the resulting protein. (HINT: 3 nucleotides = 1 codon = 1 amino acid.)

19 **Compare** a chromosome and a molecule of DNA.

20 **Contrast** the structure or function of DNA and RNA.

21 Use words and/or diagrams to **contrast**:

   a a nitrogen base and a codon

   b diploid and haploid.

22 **Contrast** the following pairs of terms.

   a autosome and sex chromosome

   b gene and allele

   c heterozygous and homozygous

23 **Contrast** the information provided by a chromosome and a gene.

24 If both parents have achondroplasia, **calculate** the chances of their children being unaffected.

25 **Consider** the Punnett square in Figure 2, which shows the inheritance for green (G) or yellow (g) pea colour in pea plants.

   a **Identify** the genotype and phenotype of Parent 1 and Parent 2.

   b **Calculate** the chances of Parents 1 and 2 producing offspring with green peas.

   c **Calculate** the chances of Parents 1 and 2 producing offspring with yellow peas.

   d **Explain** how you know one of the traits in the Punnett square is dominant.

		Parent 1	
		G	g
Parent 2	G	GG	Gg
	g	Gg	gg

Figure 2 The inheritance of pea colours can be predicted with a Punnett square.

Apply

26 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 **Determine** if the child is male or female. **Justify** your answer (by describing the sex chromosomes present in a male and a female and comparing the descriptions to the karyotype, and deciding if the baby is male or female).

   c As the geneticist, **discuss** what you could tell the parents about their baby.
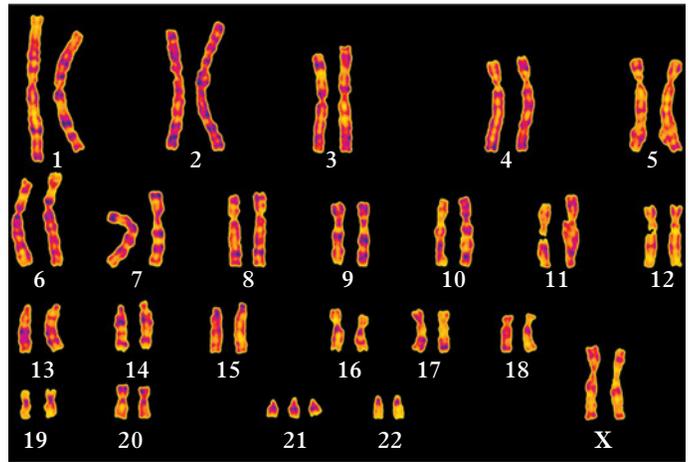

Figure 3 The newborn baby's karyotype

27 Wavy hair in humans is dominant to straight hair. A wavy-haired man and a straight-haired woman have two children. The first child has wavy hair and the second child has straight hair. **Determine** the genotype of all four individuals and use suitable symbols to **justify** your answer.

28 **Explain** whether the blood group of the first child in a family will affect that of the second child. **Justify** your answer (by describing the law of independent assortment, describing how this applies to the alleles of blood groups, and describing whether previous children affect the law).

29 A student wants to check whether her grey cat is heterozygous or homozygous for coat colour. Assuming breeding was ethical and time efficient, **describe** how the student could mate her cat to **determine** whether the cat is heterozygous or homozygous for coat colour. (Hint: Grey colour is a dominant trait.)

Social and ethical thinking

30 The debate around embryonic stem cells is heated. **Investigate** the advantages and disadvantages of using embryonic stem cells to test vaccinations. **Describe** how governments have intervened in this area. Select one ethical approach to **decide** if embryonic stem cells should be used.

31 Scientists have discovered dozens of genes that are believed to influence our athletic ability. In the lead up to the 2022 Winter Olympics, China announced that it would use genetic testing to assess the athletic potential of its athletes. This involved analysing blood samples of potential athletes for the presence of alleles believed to control athletic ability. In contrast, the Australian Institute of Sport has warned against genetic testing for athletic talent, especially in children. Select one ethical approach to **evaluate** this use of genetic testing.

32 Phenylketonuria is an autosomal recessive genetic disorder. It results in the lack of production of an enzyme that is needed to convert 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 problems with brain development. Every child born in Australia is now screened for phenylketonuria within weeks of birth. **Discuss** the benefits of such genetic screening.

Critical and creative thinking

33 Select 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 (genetic or chromosomal abnormality), pattern(s) of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.

34 **Create** a brochure that promotes the benefits of purchasing organic and non-GM foods. Alternatively, produce a brochure promoting the benefits of GM foods.

35 **Create** a teaching resource that could be used to teach a Year 7 student about the process of cell division.

Research

36 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

Cystic fibrosis
Cystic fibrosis is a genetic disease that affects the body's cells, tissues, and ability to make mucus and sweat.
- Describe the symptoms of cystic fibrosis.
- Identify the mutation that causes cystic fibrosis.
- Explain how cystic fibrosis is inherited.
- Describe the test that is used to identify cystic fibrosis.
- Describe how cystic fibrosis is currently 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.
- Describe how the Y chromosome has changed over time.
- Describe the future of the Y chromosome.
- Describe the impact on humans if the Y chromosome were to disappear.

Aboriginal and Torres Strait Islander Peoples' kinship

Early Aboriginal and Torres Strait Islander Peoples understood that traits and diseases could be inherited through generations. The kinship system (a way of identifying where a person fits within their social structure and who they are genetically related to) provides an individual with their skin name that identifies their family lineage and determines who a person can (or cannot) marry.

- Identify a disease that is autosomal recessive.
- Describe the symptoms of the disease and how the person is affected.
- Explain how the disease is inherited.
- Explain why it is discouraged for genetically similar individuals to have children.
- The kinship system was in place when Europeans first settled in Australia in 1778. Explain why they may not have understood kinship laws. (HINT: Mendel completed his experiments in 1856–1863.)
- Kinship and family structures are an important part of the culture for many Aboriginal and Torres Strait Islander Peoples. Describe what is meant by the phrase "cultural rights".
- Explain why scientists should use ethical principles to guide their research into Aboriginal and Torres Strait Islander Peoples' kinship laws.

DNA barcodes

A single cell in a human can contain 3 billion pairs of nucleotides. Other organisms can contain even longer lengths of DNA in a cell. This can make it difficult to compare the DNA between different organisms. To make this easier, scientists use DNA barcoding to quickly identify commonalities.

- Investigate what DNA barcoding is.
- Explain why scientists may use this process.
- Explain how fast computers have been used to compare the DNA sequence data sets in research.
- Explain how it has been used to understand the cause of some genetic diseases.

Module

3

Evolution

Overview

The theory of evolution by natural selection explains how plants and animals change over time. Evidence for evolution comes from the fossil record that shows past life forms; biogeography, showing where species live around the world; and comparing how embryos develop over time.

Humans can influence evolution when they breed plants or animals for specific characteristics. Evolution explains why there is so much biodiversity and shows that all organisms are related to some degree.

Lessons in this module

Lesson 3.1
Science as a human endeavour: Darwin and Wallace were co-conspirators

Key ideas

→ Lamarck believed in evolutionary change – that organisms change over time due to changing environmental conditions and those changes were passed on to their offspring.

→ Darwin found that favourable variations would tend to be preserved in organisms and unfavourable ones would be destroyed and not passed on to their offspring.

→ Alfred Russel Wallace proposed the theory of natural selection as the mechanism of evolution based on his work in the Malay Archipelago.

Learning intentions and success criteria

Introduction

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 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 volcanic eruptions and earthquakes were considered to be expressions 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 (Figure 1). This later became known as relative dating.

Figure 1 These layers of rock are an indication of different time periods. Pale layers can sometimes represent volcanic ash released during an eruption.

Georges Cuvier, a French zoologist, collected and examined many fossils. He concluded that many of the animals represented were remains of species now extinct. Mary Anning collected and sold fossils to support her family and was the first person to discover a 5 m *Ichthyosaurus* fossil. Because women were not allowed to join scientific societies, the fossils she sold were claimed as discoveries by men.

Early evolutionary theory

Evolutionary theories were all proposed without any knowledge or understanding of DNA and genetic inheritance – making the following accounts 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 – that organisms change over time due to 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). The giraffes needed to stretch their necks to reach food in the tops of the trees. Because their necks were strong, their children were born with long and strong necks.

Figure 2 Lamarck believed that giraffes stretched their necks to reach food and that their offspring, and later generations, inherited the resulting stretched long necks.

There are many problems with Lamarck's hypothesis. For example, Lamarck's hypothesis implied that a man who had lost his arm would have children with weak or deformed arms. This was obviously not the case. August Weismann finally provided scientific evidence when he cut the tails off 22 generations of mice, continually allowing them to breed with each other. Unsurprisingly, all their offspring were born with tails.
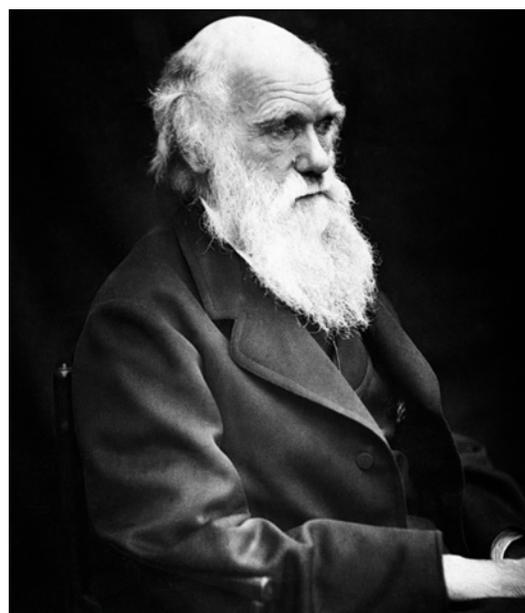
Charles Darwin

Charles Darwin 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 1,000 km off the coast of South America. Here, Darwin made his most significant observations.

Darwin and his helpers collected specimens, trying to obtain at least one of each species. Among the specimens collected were

Figure 3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism.

13 finches, all of which looked very much alike, including 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 4 On the Galapagos Islands, tortoises' shells vary in shape according to habitat.

The dry, volcanic Galapagos Islands archipelago is also home to different species of tortoise. Darwin noted that the different types of tortoise had different-shaped shells (Figure 4). 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 low domed shells to help them push through the shrubbery.

When he returned to England, Darwin became 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".

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 was not held in check by war, famine and disease, such as the plague, or "Black Death", in the fourteenth century (Figure 5). Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

**Figure 5** Was the plague simply nature's way of keeping the human population in check?

At last Darwin had a hypothesis to test. But it would take another 20 years of painstaking hard work discussing dog and horse breeding with farmers, and conducting experiments with pigeon breeding and barnacles, before he was convinced that his hypothesis had enough support to be developed into a theory.

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) 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, which were essentially identical.

They decided to read Wallace's letter and Darwin's paper, one after the other, at the Royal Linnean Society of London. We now associate Darwin with the theory of evolution because, in 1859, Darwin followed the papers with his book *On the Origin of Species by Means of Natural Selection*.
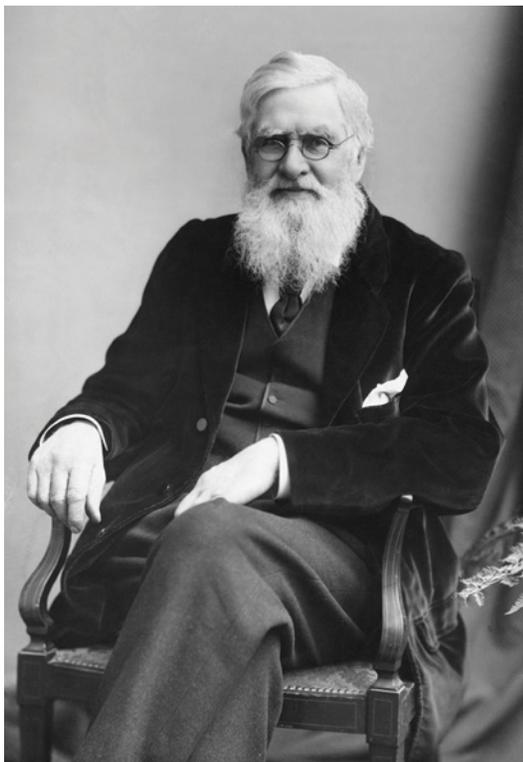
Figure 6 Alfred Russel Wallace formed the same theory as Darwin and at the same time. Wallace's work was conducted in Asia, whereas most of Darwin's observations were made in South America. Darwin had the advantage of a wealthy family that could assist him in being published. Perhaps this is why Darwin receives all the credit.

Test your skills and capabilities

Refining science theories

Although Charles Darwin is credited with the theory of evolution, he built upon the ideas of other scientists, including Jean-Baptiste de Lamarck, Georges Cuvier, Alfred Russel Wallace and August Weismann.

1 **Evaluate** who should receive credit for the theory of evolution by:
   – drawing a timeline of the scientists and their contributions to the theory of evolution
   – comparing (the similarities and differences between) Lamarck's theory and Darwin's theory
   – discussing the importance of August Weismann's experiment
   – comparing the different approaches of Darwin and Wallace
   – deciding which scientists made significant contributions to the theory of evolution.

Lesson 3.2
Natural selection is the mechanism of evolution

Key ideas

→ Evolution is the permanent change in the number of alleles in a population due to natural selection.

→ Natural selection is the process where selection pressures select for or against a trait or characteristic so that a species becomes better suited to its environment.

→ All scientists make observations of the world around them; they then use these observations and reasoning to make a conclusion (an inference).

Observations and inferences

Although scientists knew that living organisms changed 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 three key inferences.

1 There is a struggle to survive, in which some organisms die.
2 The organisms that die are not chosen at random – those individuals that are most suited to their environment survive.
3 Those individuals that survive pass their favourable traits on to their children.

Figure 1 These Siberian huskies have different versions, or alleles, of the gene for eye colour.

Variations in populations

biodiversity the variety of life; the different plants, animals and microorganisms and the ecosystems they live in

Natural selection cannot occur unless there is **biodiversity** in a population. A biodiverse population has many different types of traits, from camouflage colour to the ability to sense and defend against predators. Some species will even have traits that allow them to survive in different temperatures. But where does this variation come from?

Much of the variation between individuals is due to genetic differences that can be inherited – something 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 are not obvious in the appearance of an organism. Other mutations cause variations in the physical appearance (phenotype) of the individual. For example, it was a single mutation about 6,000 to 10,000 years ago that resulted in one human having blue eyes, and passing this trait to their descendants.

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 others of their population. This means they have a greater chance of mating and passing their genetic advantage on to their offspring.

Selection pressures cause some of these new variations to survive and others to die. Selection pressures include any environmental factor affecting an organism's chance of survival. For example, it may be an advantage to be able to survive in hot weather, or to escape a predator by running fast. If an organism is suited to its environment, then it is able to mate and produce offspring.

The offspring will have the same survival characteristics (and the corresponding alleles) as their parent. This gradually changes the frequency of alleles in the gene pool. This process of selecting for or against a characteristic so that the species will be better suited to its environment is called **natural selection**.

gene pool all the genes or alleles in a population

selection pressure the environmental factors that affect an organism's ability to survive

natural selection when the natural environment selects for or against a physical characteristic

Allele frequencies

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 will appear in the next generation.

An example of this is the ability of Aboriginal and Torres Strait Islander Peoples in Western Australia to avoid the damaging effects of high temperatures. It is thought that a single mutation in a gene (creating a new allele) changes how their bodies react to high temperatures. In hot weather, their bodies do not increase metabolic activity, reducing the extra heat that is usually generated. This ability is also useful during an infection, as it can prevent the development of high fevers. It also provides a selection advantage in the extreme heat of the inland areas of Australia. This survival advantage means they are more likely to survive and have children with the same alleles. This increases the number of individuals with the same alleles and increases the frequency of the allele in the population.

Evolution is the permanent change in the frequency of alleles in a population due to natural selection.

evolution the gradual change in the genetic material of a population of organisms over a long period of time

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. During the day, the moths rest on tree trunks. In unpolluted areas, tree trunks are covered with light-grey lichens, against which lighter moths are well camouflaged. In areas with severe air pollution, lichens cannot survive, so 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. This is often described as selection pressure. The darker-coloured bark allowed the dark moths to survive (be selected for), and caused the lighter moths to be eaten (be selected against). Natural selection was increasing the frequency of the allele for dark colour in the population. This was selection pressure in favour of the "dark" colour allele (Figure 2).

In 1952, strict pollution controls were introduced in England, the lichens returned, and the tree trunks became mostly free of soot (Figure 3). Predictably, selection pressures started to operate in the reverse direction. In areas where pollution levels decreased, light moths were selected for and dark moths were selected against. The frequency of dark moths decreased.

Other examples of directional selection include the evolution of pesticide-resistant insects and antibiotic-resistant bacteria. In these cases, our use of chemicals (e.g. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

Industrial melanism in *Biston betularia*

Generation 0
10% dark phenotype

A few generations later
80% dark phenotype
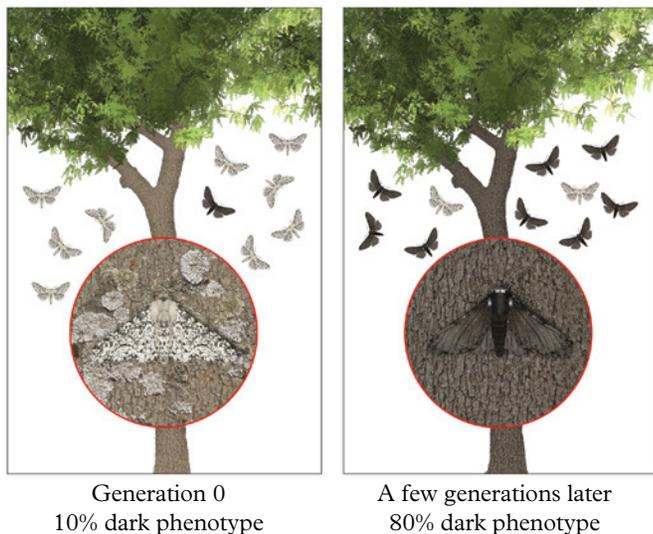
Figure 2 During the industrial age, the soot made the tree bark darken. The light-coloured moths (*Biston betularia*) were visible to predators and eaten. Dark-coloured moths survived and produced more offspring.

Figure 3 When the levels of pollution improved, the tree bark became lighter. This time the light-coloured moths survived and produced more offspring.

Check your learning 3.2

Check your learning 3.2

Comprehend

1 Variation in individuals can occur in different ways, but there is only one way in which new alleles can arise. **Describe** the process that can result in new alleles.

2 **Describe** the selection pressures that caused the allelic frequency of light-grey moths to decrease in England in the 1950s.

3 In your own words, **describe** the mechanism by which natural selection can influence the frequency of alleles in a population.

4 **Explain** why natural selection cannot increase or decrease the frequency of some mutations in a population.

Analyse

5 Darwin made a series of inferences based on observations he made over 20 years. **Connect** each of Darwin's observations with the appropriate inference he made.

Apply

6 **Create** a diagram that illustrates the process of natural selection of the moths in England.

Skills builder: Planning investigations

7 An experiment aims to model the effects of natural selection on a population. The experiment lists the following materials: 30 red counters, 30 yellow counters and 30 blue counters, a timer and coloured paper.

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?)

Lesson 3.3
Experiment: What if the habitat of bean prey was changed?

Aim

To examine the selection pressures involved in hunting prey

Materials

- Paper cups
- Tools: plastic knives, plastic spoons, sticky tape, plastic gloves
- Bean prey: dried 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 should wear plastic gloves to hunt beans but they must turn the thumb of their glove inside out so they cannot use their opposable thumb.

2 On a section of grass, randomly spread out 20 of each bean type.

3 Each tribe has 10 seconds to collect as many beans as they can. Record the data in an appropriate table, as shown in the Results section.

4 The two tribes with the least beans collected become extinct and must sit out the next round.

5 Each bean left on the grass will breed. This means the number of beans remaining on the grass will double. For example, if 6 white beans were collected, then 14 remain, 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?

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.

- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Copy and complete Table 1 to record your results for generation 1.

Create two more tables for the next two generations.

Table 1 Results for generation 1

	Knife tribe	Spoon tribe	Hand tribe	Sticky-tape tribe	Glove tribe	Total
Red-butted beans						
Long-toothed yellow beans						
Panther-toothed black beans						
Wicked white beans						
Total						

Discussion

1 **Identify** the tribes that became extinct first. Describe the selection pressures that contributed to their extinction.
2 **Explain** why the bean prey numbers doubled after each generation.
3 **Identify** the beans that were selected against in the first generation.

4 **Use** the mechanism of natural selection to explain the change in bean prey numbers.
5 **Identify** a similar example to this experiment that might occur in nature.

Conclusion

Describe how the mechanism of natural selection changes the frequency of alleles in a population.

Lesson 3.4
Different selection pressures cause divergence. Similar selection pressures cause convergence

Key ideas

→ Speciation is the formation of a new species that cannot reproduce with other species.

→ Allopatric speciation can occur when a permanent barrier separates a population and prevents gene flow.

→ Divergence occurs when one population becomes two new species.

→ Convergence occurs when two different species become more physically similar due to similar selection pressures.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Introduction

A species is a group of organisms who are able to breed with each other in natural conditions to produce offspring that are viable (alive) and fertile (able to have children of their own).

The process of forming a new species is called **speciation**.

speciation the process that results in the formation of a new species

Speciation

When a variation within a species is favoured by the environmental conditions, it is referred to as an **adaptation**. Variations within a species provide "options" for the species when environmental conditions change. Although individual organisms may be wiped out, some members of the population with the favourable adaptation survive and continue the species' gene pool.

Along the way, entire species may become extinct and new species will emerge. New species can increase the biodiversity of the environment.

Under normal conditions, genes in a given population are exchanged through breeding. This means the genes will flow from one generation to the next as families or groups in the population choose partners and mate. This is called **gene flow** (Figure 1). But the gene flow is interrupted if the population becomes divided into two groups; this is called **isolation**. If there is no exchange of genes between the two groups, then they may begin to look and behave differently from each other.

adaptation a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

gene flow the flow of genes from one generation to the next, or from one population to the next, as different families or groups in the population choose partners and mate

isolation the division of a population into two groups
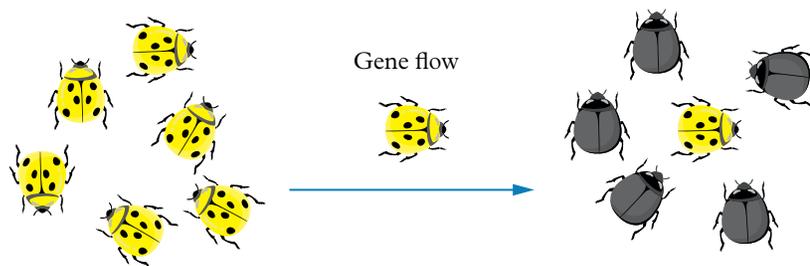
Gene flow

Figure 1 Gene flow occurs when new individuals travel to new populations.

3.4

Over time, different selection pressures occur in the two groups. Different characteristics are selected for. Given enough time for evolution to occur, the two populations may become so different that they are incapable of interbreeding should they ever come together again. The two populations become reproductively isolated and therefore are different species (speciation). The two species have **diverged**. An example of this was the finches Darwin observed when travelling around the Galapagos Islands (Figure 2) and polar bears (Figure 3).

diverge in relation to two species: to become more different over time due to different selection pressures, possibly becoming reproductively isolated
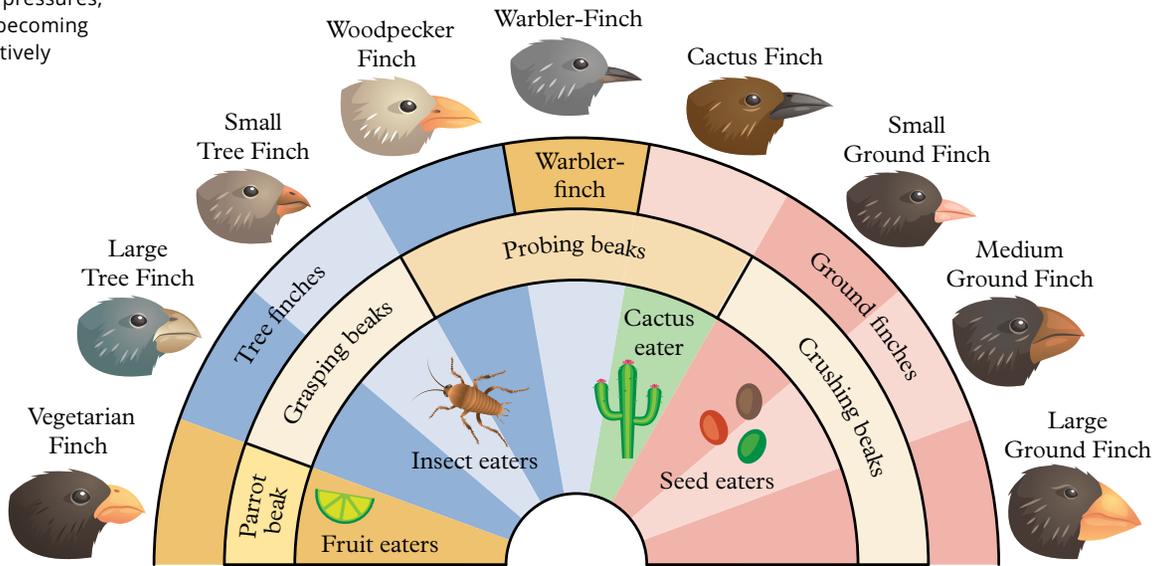
Figure 2 The finches observed on the Galapagos Islands had evolved into multiple species with different beak shapes suited to various food sources. This is a classic example of adaptive radiation.

Figure 3 Polar bears evolved from brown bears who adapted to Arctic conditions. Although they can still interbreed, they are considered separate species due to differences in habitat and behaviour.

Allopatric speciation is one of the most common ways species become different or diverge. In this type of speciation, a permanent barrier such as canyons, rivers, roads or oceans separates a population of organisms, allowing different mutations and selection pressures to change the allelic frequencies until they are different species (Figure 4).

Even though populations diverge and become different species, they retain some characteristics in common. These characteristics, such as forelimbs, may be used for different purposes because the selection pressures have changed. Common structures that are found in different species often have a similar pattern but a 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 (four-legged vertebrates) that ends in five digits (Figure 5). This structure is found in the fins of certain fossil fishes from which the first amphibians are thought to have evolved. All tetrapods have the same basic structure of the pentadactyl limb.

These commonalities indicate that these organisms originated from a common ancestor. But, during the course of evolution, mutations and different selection pressures modified these structures and they are now used for different purposes.

Allopatric speciation
Geographical isolation

Figure 4 Allopatric speciation can occur when there is a permanent barrier between populations such as a mountain range.

homologous structure structure that is similar in different species, because those species evolved from a common ancestor, but do not necessarily have the same function now; an example is forelimbs in different mammal species

Figure 5 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.

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. Although these species do not share a recent common ancestor, they both need to move through water fast enough to catch fish and escape predators. As a result, they both have a streamlined body with fins and a tail. This is an example of **convergent evolution**. The wings of birds and butterflies are also analogous structures (Figure 6).

analogous structures structures in organisms of different species that have the same function but are structurally different, because they evolved independently; for example, wings in birds and bats

convergent evolution the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

3.4
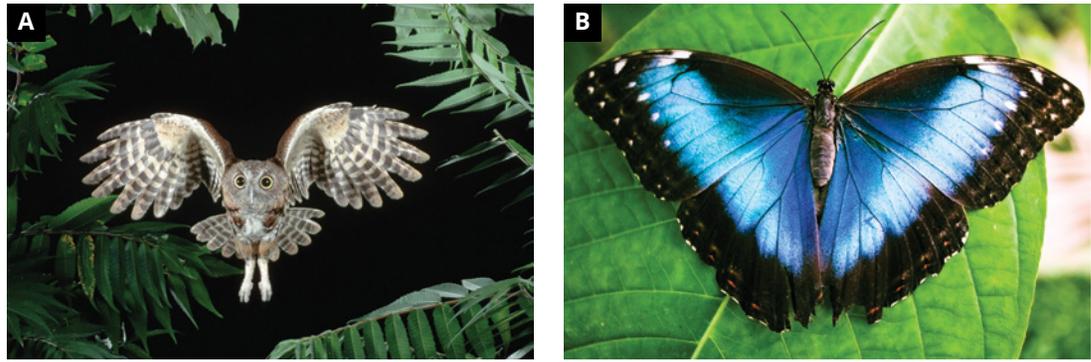
Figure 6 The wings of (A) a bird; and the wings of (B) a butterfly are analogous structures: they perform the same function but have significantly different structures.

Table 1 Summary of homologous and analogous structures

	Divergence	Convergence
Ancestral structure	Homologous (similar)	Analogous (different)
Current function	Different	Same
Example	Pentadactyl limb – arm in humans, fin in whales, wing in bats	Dolphin tail shape (move up and down) versus fish tail shape (move side to side)

Check your learning 3.4

Check your learning 3.4

Retrieve

1 **Define** the term "homologous structure".
2 **Identify** an example of an analogous structure.
3 **Define** the term "speciation".

Comprehend

4 Use an example to **describe** how a permanent barrier could create a new species.
5 **Describe** how gene flow influences the process of speciation.

Analyse

6 **Contrast** an individual organism adapting to the environment, and the adaptation of a species.

Apply

7 **Discuss** how the land ancestors of dolphins evolved to become the streamlined mammals we see now.

Skills builder: Questioning and predicting

8 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 how speciation might have occurred here. (THINK: What are the similarities and differences? What key information do you have?)

Lesson 3.5

Experiment: Divergent and convergent evolution of big beaks and small beaks

Aim

To model divergent and convergent evolution in beak size

Materials

- 6 previously prepared bags of food:
  - North Trayland/Season 1 = 4 handfuls of popcorn + 20 kidney beans + 50 marbles
  - North Trayland/Season 2 = 1 handful of popcorn + 10 kidney beans + 50 marbles
  - North Trayland/Season 3 = 100 marbles
  - South Trayland/Season 1 = 4 handfuls of popcorn + 20 kidney beans + 50 marbles
  - South Trayland/Season 2 = 6 handfuls of popcorn + 10 kidney beans + 5 marbles
  - South Trayland/Season 3 = 8 handfuls of popcorn
- 20 large bulldog clips
- 20 medium 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 are Giant birds (with a large bulldog clip each). Four students are Midbill birds (with a medium bulldog clip each). The remaining four students are Babybill birds (with a small bulldog clip each).

2. A permanent barrier separates the bird population into two groups (North Trayland and South Trayland), with two birds of each type (2 Giant birds, 2 Midbill birds and 2 Babybill birds) 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, and marbles = 10 kilojoules. Table 1 shows how many kilojoules each type of bird needs to survive.

Table 1 Kilojoules needed by each type of bird

Bird	Kilojoules needed to survive	Kilojoules needed to reproduce
Giant	80	160
Midbill	50	100
Babybill	25	50

5. Birds that do not collect enough kilojoules to survive must leave the island and sit down (these birds are eliminated from the game). Record the number of surviving birds in Table 2 and Table 3.

6. If a surviving bird has collected enough kilojoules to reproduce, they should choose another student (who is not already a bird) to be their baby (with the same-sized beak). If a bird has collected enough kilojoules to survive but not enough to reproduce, they continue in the next round but do not have a "baby".

7 Remove any remaining food from the trays and place it back into the plastic bags. Place the food for season 2 in each tray. Repeat steps 3 to 6.

8 Remove any remaining food from the trays and place the food for season 3 in each tray. Repeat steps 3 to 6.

9 Clean up any remaining food.

Results

Copy and complete Table 2 and Table 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 **Identify** if this activity is a case study, modelling/simulation, quantitative analysis or a controlled experiment. Justify your reasoning (by identifying the key characteristics of the activity and comparing these with the definition of the term you chose).

2 **Explain** why the starting population of each bird did not have a single bird of each Bill type.

3 **Describe** what happened to the North Trayland population of birds after they were isolated from South Trayland for three generations.

4 **Describe** what happened to the South Trayland population of birds after they were isolated from North Trayland for three generations.

Conclusion

Use the terms "natural selection" and "selection pressures" to explain the type of evolution that occurred between the two species.

Lesson 3.6
Fossils provide evidence of evolution

Key ideas

→ Fossils are remains or traces of an organism that once existed.

→ Transitional fossils are intermediary fossils that have traits of both the ancestral organism and the more recent organism.

→ Relative dating determines the relative order in which 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.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

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. A species is extinct when there are no living members of the species left. The discovery of many unknown types of plants and animal fossils reinforced the fact that life forms change with changing environmental pressures – even if that simply means that many die and only few survive.

What are fossils?

Fossils are the remains or traces, such as footprints, imprints or coprolite (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 away from oxygen quickly so that weathering and total decomposition do not occur. Skeletal structures or other hard parts of organisms that resist weathering are slower to decompose and therefore are more likely to form fossils.

These are the most common form of fossilised remains. Figure 1 shows how the process of fossilisation occurs.

fossil the remains or traces of an organism that existed in the past

fossilisation the process of an organism becoming a fossil

3.6
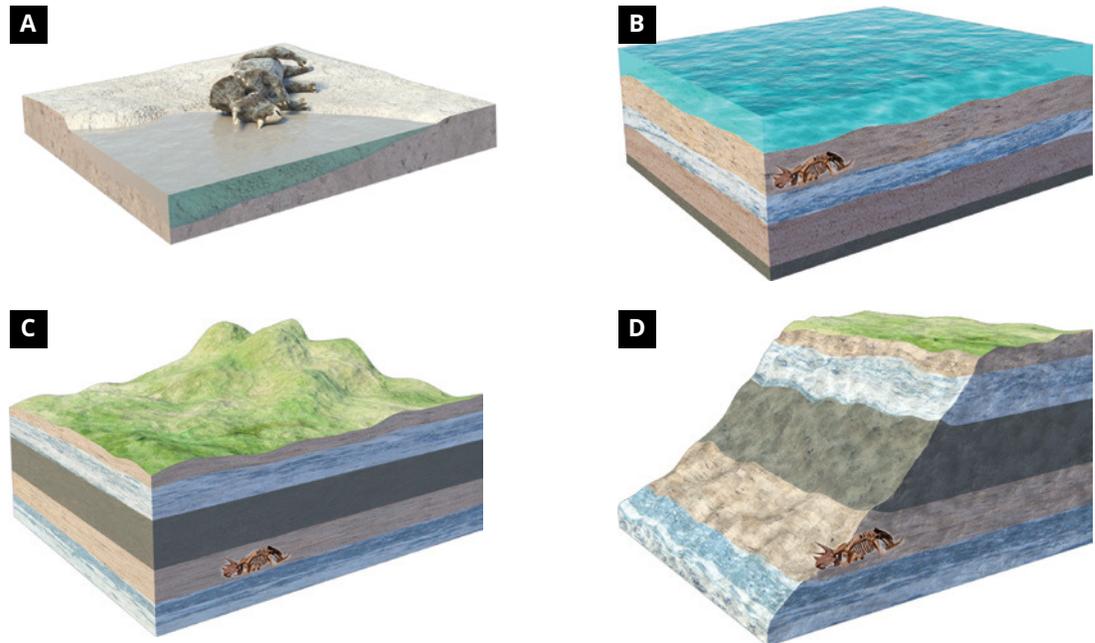
Figure 1 Formation of a fossil. (A) and (B) If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. (C) Over millions of years, more sediment is deposited, replacing the remains so they are transformed gradually into sedimentary rock. (D) Years of geological movement, weathering and erosion may eventually expose the fossil.

Transitional fossils

transitional fossil a fossil or an organism that shows an intermediate state between an ancestral form and its descendants; also known as a "missing link"

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". Transitional fossils will often display some characteristics of two different species.

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* (Figure 2), which was discovered in the Solnhofen area of Germany just 2 years after Darwin's work was published. *Archaeopteryx* is the earliest and most primitive bird.
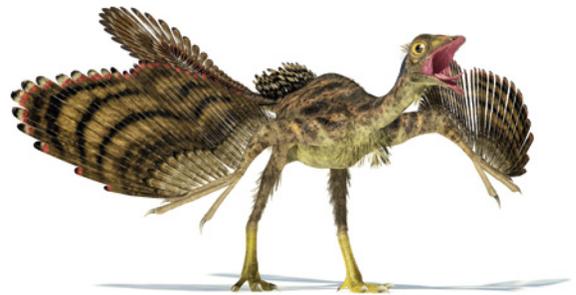
Figure 2 *Archaeopteryx* is an important transitional fossil. It displays a number of features common to both birds (hollow wishbone and feathers) and reptiles (teeth, flat sternum/breastbone, three claws on the end of its wings and a long bony tail).

Dating fossils

relative dating a method of determining the age of an object relative to events that occurred before and after

It is possible to find out how a particular group of organisms evolved by arranging its fossil records in a chronological (time) 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). Over time, the layer containing the fossil is buried deeper under the surface. The deeper the layer, the older the rock. Each layer acts as a time capsule that contains fossils that lived during that period. Older fossils are buried deeper than younger fossils.

Figure 3 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils (Figure 4). **Absolute dating** relies on the level of radioactivity in the fossil. 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 per cent decrease in the initial radioactivity level. In the second half-life, the remaining radioactivity decreases by half again, leaving only 25 per cent of the starting radioactivity level. This will continue until only very small levels of radioactivity are left.

absolute dating a method of determining the age of a fossil, by measuring the amount of radioactivity remaining in the rock surrounding the fossil

half-life the time it takes the radioactivity in a substance to decrease by half
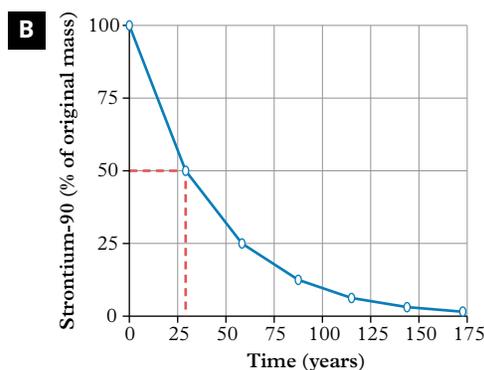
Figure 4 (A) The 65-million-year-old fossil of *Triceratops horridus* was dated using absolute dating. (B) Strontium-90 has a half-life of 28.8 years. This makes it difficult to use when dating fossils that are millions of years old.

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. A combination of relative dating and radioactive dating has been used to develop a timeline of evolution (Figure 5). Worked example 3.6A illustrates how to calculate the number of half-lives that have passed in a fossil.

3.6

This pie chart shows the relative duration of the four eras.
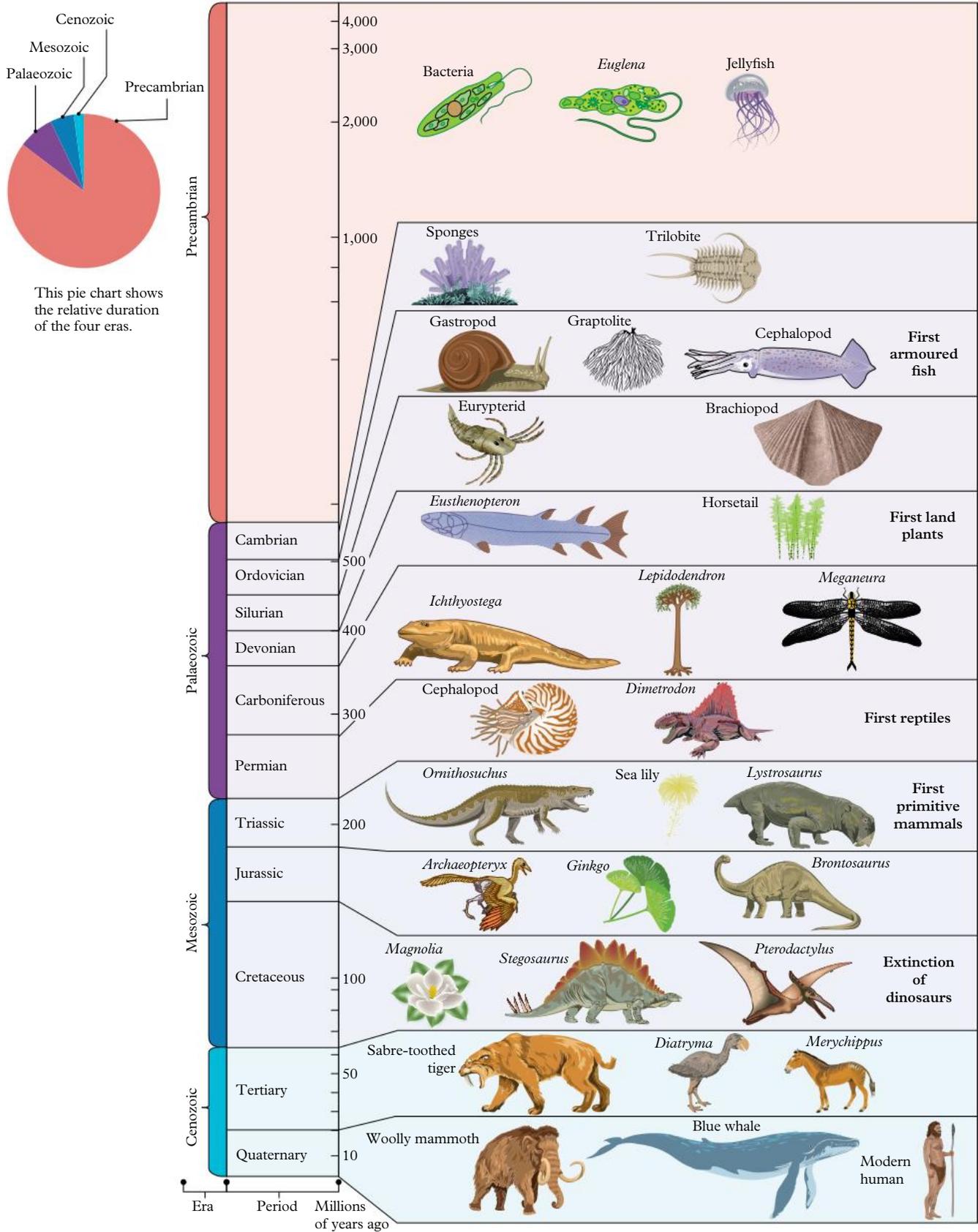
Figure 5 A combination of relative dating and radioactive dating has been used to develop a history of living things (mya = million years ago), as determined by palaeontology (the study of fossils).

Worked example 3.6A Calculating half-lives

A fossilised piece of coral was found at a beach in Beaumaris, Melbourne. Scientists at the Melbourne Museum determined that the fossil has $\frac{1}{8}$ of radioactive carbon-14 remaining.

a Calculate the number of half-lives that have passed in the fossil.
b If 1 half-life = 5,000 years, calculate the age of the fossil.

Solution

a After 1 half-life, $\frac{1}{2}$ of the radioactive material will remain.

– After 2 half-lives, $\frac{1}{4}$ of the radioactive material will remain $\left(\frac{1}{2} \times \frac{1}{2}\right)$.

– After 3 half-lives, $\frac{1}{8}$ of the radioactive material will remain $\left(\frac{1}{2} \times \frac{1}{4}\right)$.

– Therefore, 3 half-lives have passed.

b If 1 half-life = 5,000 years, 3 half-lives = 15,000 years. The fossil is 15,000 years old.

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 plants or animals that have not changed their shape or way of living for thousands or even millions of years. This means the selection pressures for these organisms have not changed and therefore there has been no pressure for the organism to change.

living fossil an existing species of ancient lineage that has remained unchanged in form for a very long time

Trace fossils

Not all fossils are bones. Occasionally, other forms of evidence for living things can be found. Footprints in mud can become permanent indentations when the mud becomes stone. Faeces (or poo) can become buried and form a fossilised coprolite. Plants can leave a leafy imprint. All of these forms of evidence are called trace fossils.

Check your learning 3.6

Check your learning 3.6

Retrieve

1 **Define** the term "transitional fossil".

Comprehend

2 **Describe** the process of relative dating a fossil.
3 Living fossils have remained relatively unchanged, often for millions of years, while around them other species have adapted or become extinct. **Explain** why some species are able to remain unchanged for such a long period.

Analyse

4 A fossil of a giant 7-cm long mega shark tooth (*Carcharocles angustidens*) was found on the beach of Jan Juc. The age of the fossil could be determined using absolute dating. If the amount of hafnium-182 (half-life ~ 8 million years) remaining had decreased from 100 per cent to 12.5 per cent, **calculate** the age of the tooth.
5 **Contrast** relative dating and absolute dating.

3.6

◀ **Apply**

6   **Evaluate** whether the theory of evolution will
    ever become fact (by contrasting the scientific
    terms "theory" and "fact", and deciding whether
    the theory of evolution could become a fact).

7   Fossils were found at four locations (Figure 6).
    Use relative dating to **determine** which location
    had the oldest fossils.

Location 1   Location 2   Location 3   Location 4
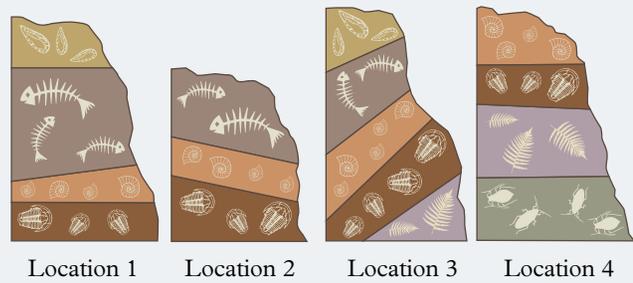
Figure 6 Fossils found at four different locations

Lesson 3.7
Experiment: Popcorn dating

Caution

Do not eat or drink in the laboratory.

Aim

To determine the absolute date of an unknown
sample of popped popcorn

Materials

•   Previously prepared bags of microwave popcorn
    (unbuttered):
    –   Bag A: stop microwave 10 seconds after first
        pop (record the actual time)
    –   Bag B: stop microwave 30 seconds after first
        pop (record the actual time)
    –   Bag C: stop microwave 10 seconds after last
        pop (record the actual time)
    –   Bag D: mystery fossil bag (your teacher will
        have microwaved this bag for a time between
        bag A and bag C)
•   4 large trays

Method

1   Open bag A and count how many corn kernels
    have popped and how many have not popped.

2   Determine the percentage of popped kernels
    using the following equation:

    percentage of popped kernels =

    $$\frac{\text{number of popped kernels}}{\text{total number of kernels}} \times 100$$

3   Repeat steps 1 and 2 with bags B and C.

4   Graph the percentage of popped kernels against
    the time spent in the microwave oven.

5   Repeat steps 1 and 2 with bag D. Use your
    graph to determine how long bag D was in the
    microwave oven.

Results

Copy and complete Table 1, and draw a graph of
your results.

Table 1 Results from the experiment

Bag	Time in the microwave	Number of popped kernels	Number of un-popped kernels	Percentage of popped kernels
A				
B				
C				
D				

Discussion

1 **Define** the term "half-life".
2 **Calculate** the half-life of your popcorn kernels.
3 **Draw** a line graph (curved line of best fit) of your results.
4 **Identify** how long the mystery bag D was heated in the microwave.
   a Compare your answer with that of other students.
   b Compare your answer with the actual time provided by your teacher.
5 **Identify** any data outliers from your graph. Explain why you used a line of best fit rather than a "join the data" approach.

6 **Explain** why the relative age of a fossil is always a range of years (e.g. 350 to 450 years ago) rather than a single date (401 years ago).
7 **Evaluate** the accuracy of this model of a half-life (by describing how a half-life is used to determine the age of fossils, comparing this description with the popcorn model, and deciding whether the model was an accurate representation).

Conclusion

Explain how radioactive materials are used to determine the absolute age of fossils.

Lesson 3.8
Multiple forms of evidence support evolution

Key ideas

→ Biogeography is the study of how the continents move across the Earth and how this directly affects the location of organisms.

→ When continents collide, species can spread, and when continents separate, the new species move with them.

→ The study of how genetic material affects the development of embryos (embryological studies) is a new and growing field of study.

Learning intentions and success criteria

3.8

Biogeography

At the beginning of the seventeenth 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 land mass – Pangaea (Figure 2). This supercontinent then broke into two to form Gondwana in the south and Laurasia north of the equator. Over long periods of time, the two land masses drifted apart and re-joined to form the continents that we now know. During this drift of land masses, populations of organisms were separated, forming new diverged species.

continental drift the continuous movement of the continents over time
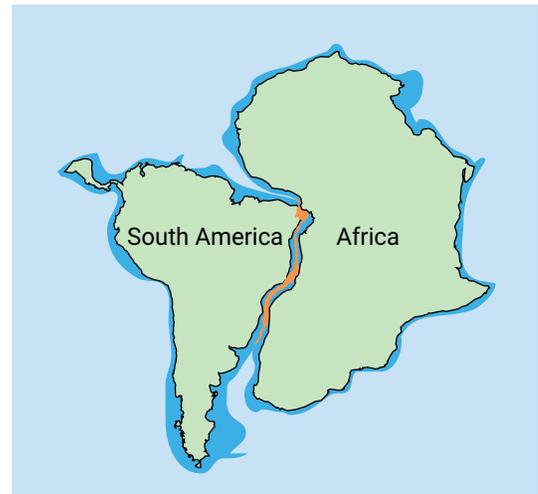
Figure 1 The jigsaw fit of Africa and South America supports the theory of continental drift.
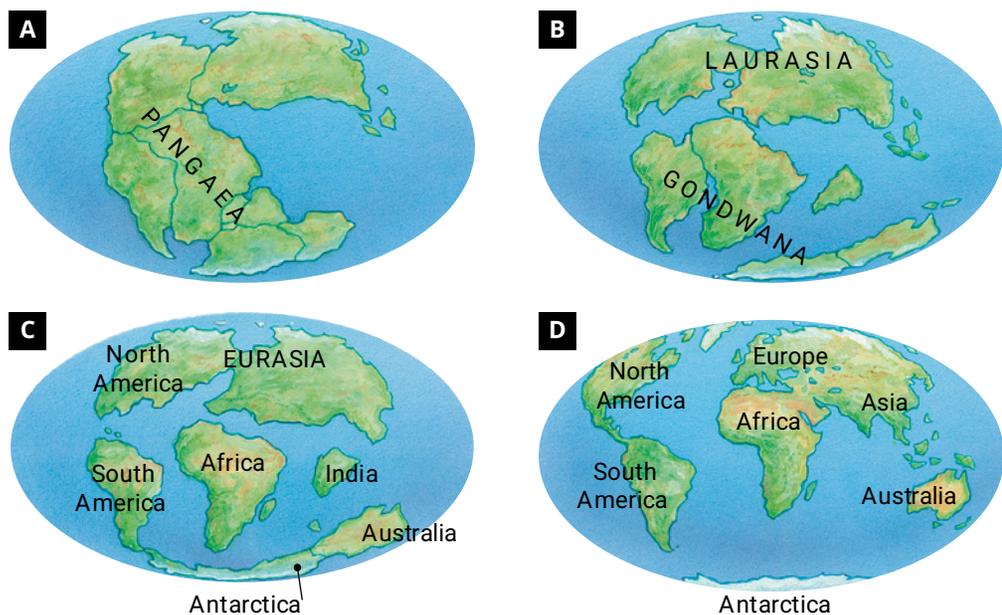
Figure 2 How the continents have drifted: (A) 220 million years ago; (B) 135 million years ago; (C) 65 million years ago; and (D) today

This theory of continental drift is supported by identical fossils buried on the land masses that used to be joined. An example of this is fossilised pollen that has been found in Antarctica, India and Australia (Figure 3). Although animals that could fly or swim could travel from continent to continent, continental drift is the only convincing explanation for the distribution of the plant pollen.

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 (Figure 3 and Figure 4). "Coincidence" is simply not a scientific explanation.

Legend

Fossils of *Mesosaurus* were found in Argentina and Africa but nowhere else in the world

Fossil ferns *Glossopteris* and *Gangamopteris* were found in all the southern land masses

Remains of *Lystrosaurus* were found in Africa, Antarctica, and India

These present-day organisms are similar to organisms on other continents (e.g. marsupials in Australia and South America)

Cynognathus, a Triassic reptile, lived in Brazil and Africa

Distribution of late Palaeozoic glaciers

Locations of major plateau basalts

Figure 3 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

Legend

Lung fish   Possum   Opossum   Large flightless birds
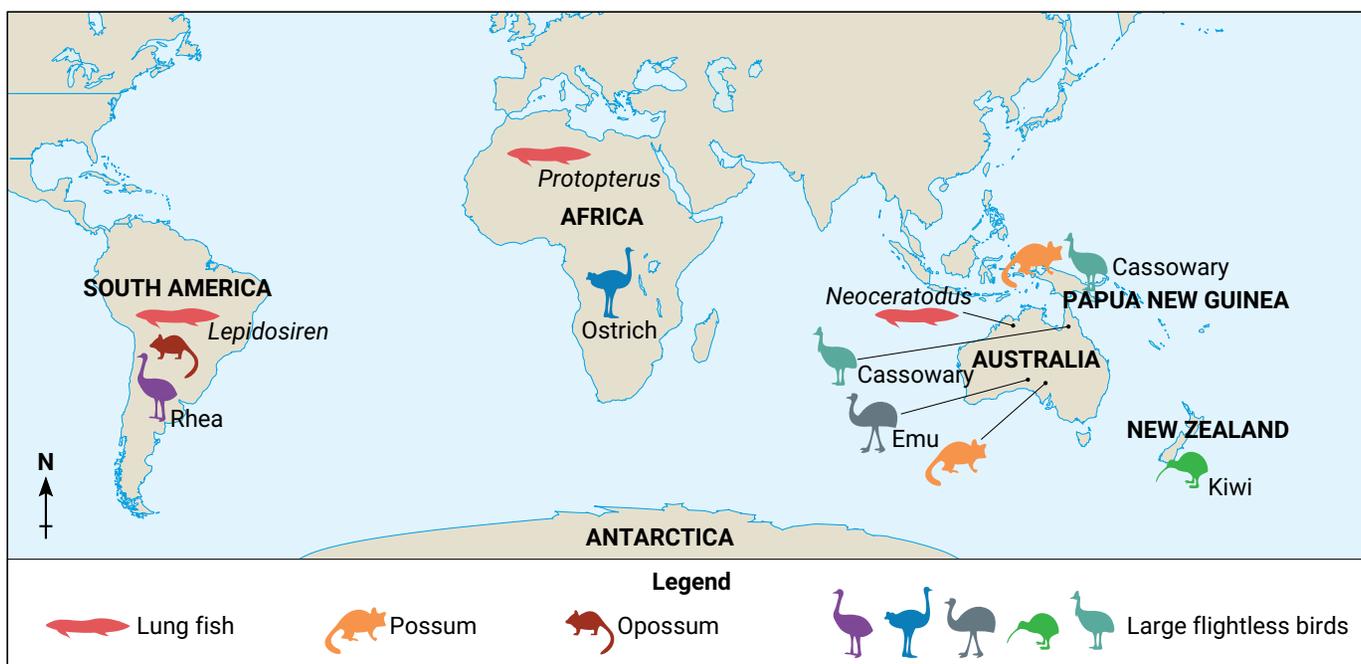
Figure 4 Similar lungfish are found in South America, Africa and Australia. Similar marsupials are found in South America and Australia.

Vestigial structures

Vestigial structures are structures that no longer have a function 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, evidence of their histories.

vestigial structure
a structure in an organism that no longer has an obvious purpose

3.8

Some structures within the organisms would have once been useful; however, their function has since been replaced so they are no longer needed. If the structures are not selected against (it is not harmful to keep them), then there is no reason for the structure to disappear. This means the non-functioning structure stays inside the organism. Examples of this include the tiny wings of a cassowary and the hindlimb buds of many snake species, which still carry vestigial pelvises hidden beneath their skin (Figure 5). These structures are not needed, but they still exist because they were once important.
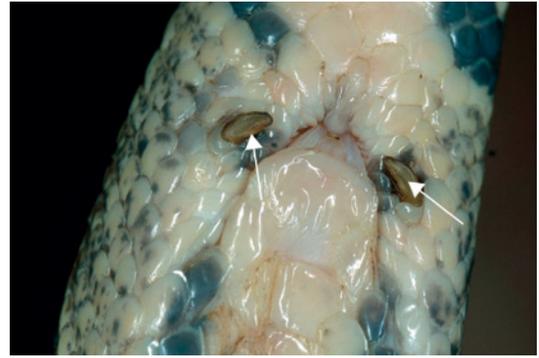
Figure 5 The rear legs on a snake (as shown by the arrows) are an example of a vestigial structure.

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 per cent 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 they may result in illness if they are not removed.

Analysing embryos

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 6). 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.

If the various life forms developed independently, we could think that their embryonic development would be different and consider 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. For example, the gene for a bat's fingers becomes "supercharged" during embryological development so that the fingers start growing faster than the rest of the body (Figure 7). 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. These similar structures, coded by similar genes, provide further evidence supporting evolution.

Fish   Salamander   Tortoise   Chicken   Pig   Rabbit   Human
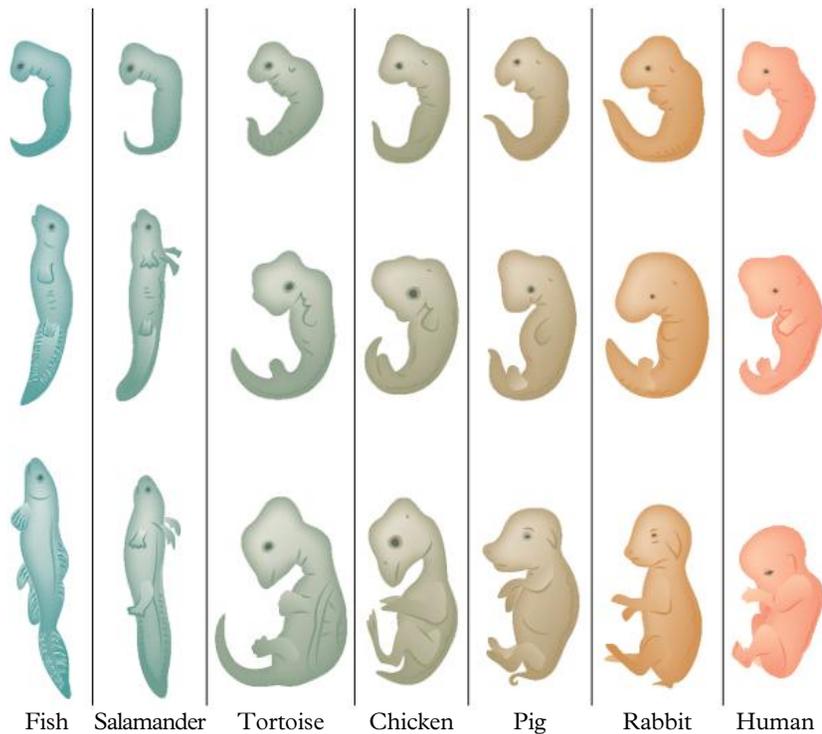
Figure 6 Common structures in the early stage of embryonic development of vertebrates indicate the existence of common genes.

Figure 7 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.

Check your learning 3.8

Check your learning 3.8

Comprehend

1   The frogs in Australia show their closest evolutionary relationships to frogs in Africa and South America. **Explain** how this is possible.

2   **Explain** how the presence of vestigial structures supports the theory of evolution.

3   **Explain** why human embryos temporarily develop gill-like structures.

3.8

◀ 4 **Describe** how the gene that forms fingers changes to form the wings on a bat.

5 Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years. **Explain** how this information could be used to support the theory of continental drift and the theory of evolution.

Apply

6 Jemima thinks that if native Australian marsupials were found in North America, this would support the theory of continental drift. **Evaluate** her claim (by describing two reasons that support her claim, describing two reasons that refute her claim, and deciding which reasons are most convincing).

Lesson 3.9
DNA and proteins provide chemical evidence for evolution

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ The basic structure of DNA and proteins is identical for all species on Earth.

→ Small differences in the sequences of amino acids in proteins and nucleotides in DNA can be used to determine the evolutionary relationship between species.

→ The more differences in the nucleotide sequence between organisms, the more time has passed since they shared a common ancestor, and the greater the evolutionary distance between the species.

Comparing DNA

The best evidence in support of evolutionary theory comes from a study of gene sequences. The order of nucleotides in DNA in chimpanzees and humans is 97 per cent identical. Millions of years in the past, humans and chimpanzees shared a common ancestor. A separation in the population of ancestors allowed mutations (permanent changes in the order of DNA nucleotides) to accumulate. This accumulation of mutations eventually caused the 3 per cent difference in the DNA sequence that resulted in the formation of humans and chimpanzees (Figure 1 and Figure 2).

Comparing the order of the nucleotides in DNA allows scientists to compare the **evolutionary 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 will cause slight differences between the species. The more alike the two DNA sequences are, the more closely related the two species are. The more differences in their DNA sequences, the more time has passed since the two species had a common ancestor and the less related they are now.

evolutionary relationship
the way in which two species or populations are related with respect to their evolutionary descent
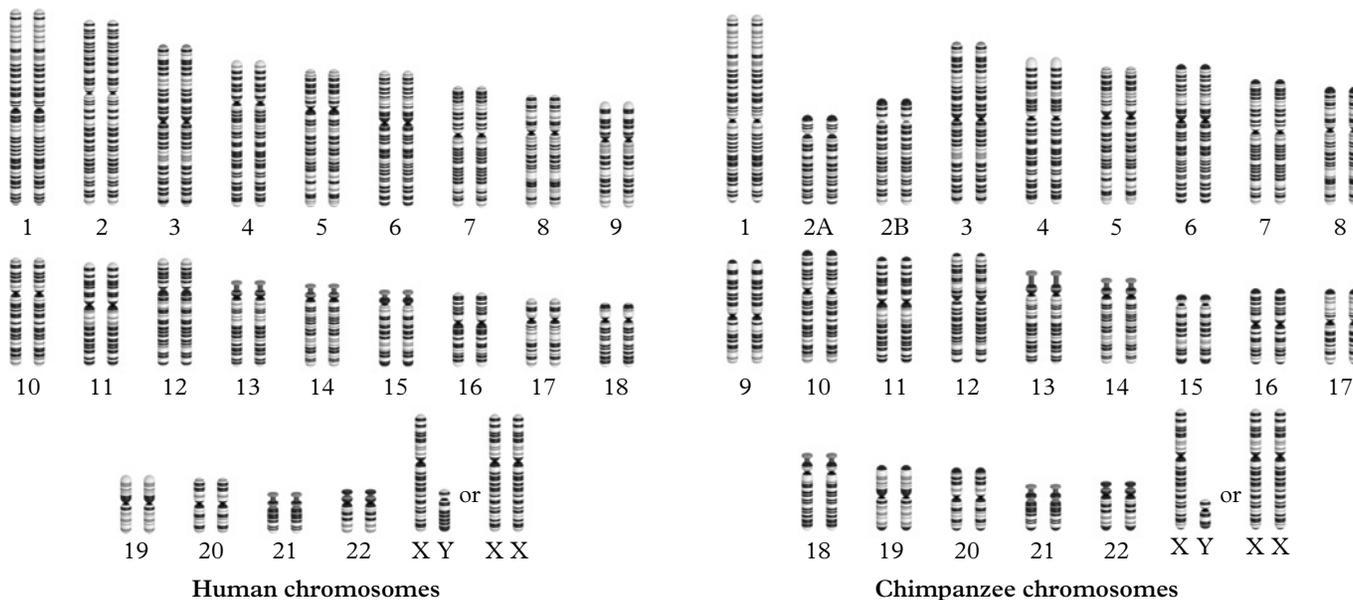
Figure 1 The similarities and differences between the karyotype of a human and chimpanzee
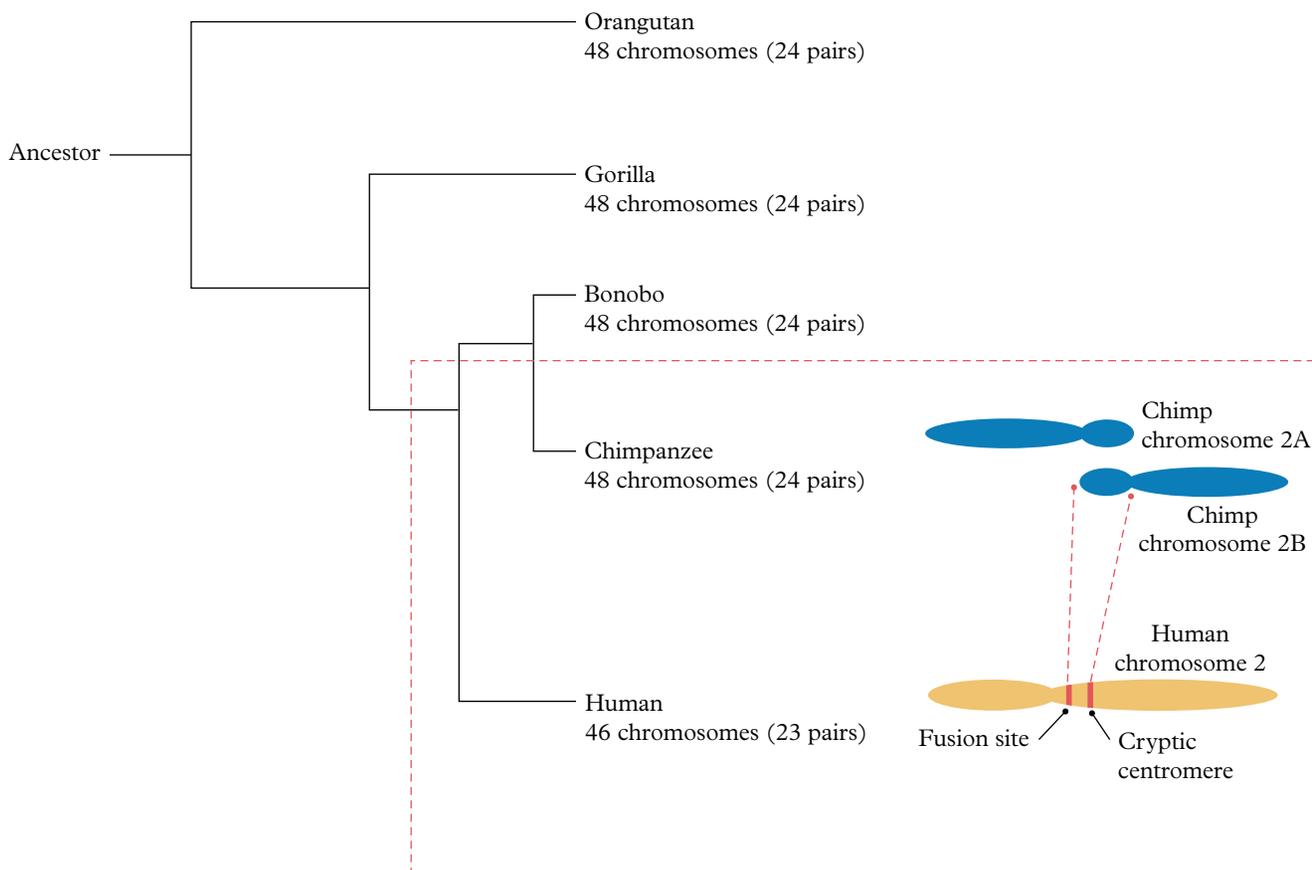
Figure 2 The evolution of humans via phylogenetics (the study of evolutionary relationships based on genetic material)

3.9

Comparing amino acids in proteins

The order of the nucleotides in DNA contains the recipe for the production of proteins. When the DNA changes due to mutation, it can cause changes in the protein it produces. **Proteins** are like long necklaces made up of a series of beads. The beads are called **amino acids**. DNA provides the instructions for the order of the amino acid beads. Proteins range in size from approximately 50 amino acids to thousands of amino acids and are among the most important chemicals in life. They can be enzymes that control chemical reactions, or hormones, the chemical messengers in the body. The characteristics of a protein are determined by the order or sequence of amino acids.

protein a chain of amino acids; an essential part of cells

amino acids small molecules that make up proteins

The same type of proteins in different species can be very much alike. Cytochrome c (Figure 3) is one such example. Several types of cytochrome c proteins are found among different vertebrates and invertebrates (Table 1).

Comparing the sequence of amino acids in a protein can show the evolutionary relationship between different species. Before a species diverges, the organisms 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.
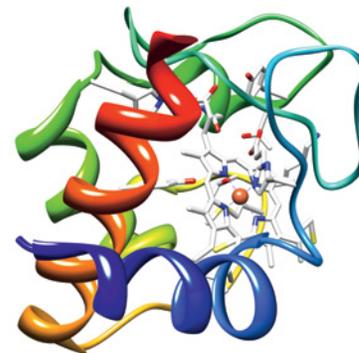
Figure 3 Changes in DNA can cause a change in the shape of the protein produced. Cytochrome c is a protein used to compare the evolutionary relationship of different species.

Table 1 The sequence of amino acids that make up cytochrome c protein in different animals

Chicken	Val	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
Human	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile

Note: Val = valine; Glu = glutamic acid; Lys = lysine; Gly = glycine; Ile = isoleucine; Phe = phenylalanine.

Phylogenetic trees

Before scientists were able to compare proteins and DNA, they examined the structures of organisms to determine whether they were related. The difficulty with this is that 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 (Figure 4).

Species A -GCCATAACCTGAGG-
Species B -GCCATATACTGAGG-
Species C -GCCACATAGTGAGG-
Species D -GCCACATAGTAAGG-

A
B
C
D
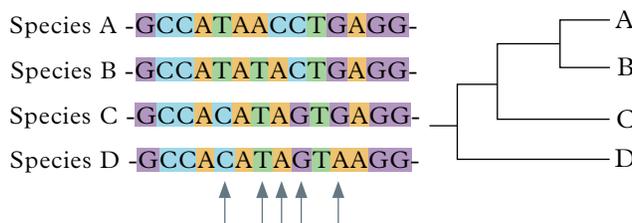
Figure 4 Comparing the DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is most closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

One way of showing how closely related different organisms are is through a **phylogenetic tree** (Figure 2). Comparing the DNA sequences between humans, chimpanzees and gorillas shows that humans are more closely related to chimpanzees than to gorillas. This means that humans and chimpanzees are drawn closer together on the phylogenetic tree (Figure 5).

phylogenetic tree a branching tree-like diagram showing relationships between different taxonomic groups

Biology

Gorillas

Chimpanzees

Humans

7 million years ago

9 million years ago
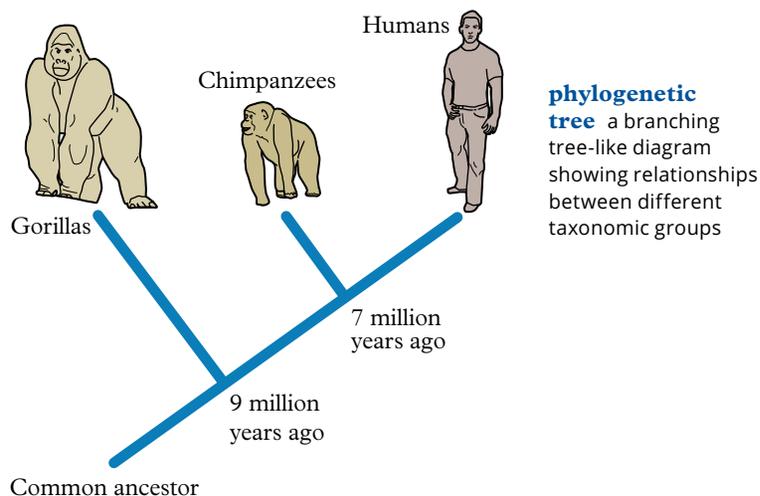
Common ancestor

Figure 5 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

Check your learning 3.9

Check your learning 3.9

Retrieve

1 **Identify** the smaller (bead-like) structures that make up proteins.
2 **Identify** the cause of gradual changes to the sequence of nucleotides in DNA.

Comprehend

3 Cytochrome c is of interest to biologists studying evolution. **Explain** how the study of cytochrome c protein can contribute to the evidence of evolution (by explaining how DNA contributes to the sequence of amino acids in a protein, explaining how mutations affect the sequence of amino acids, and explaining the relationship between common ancestors and diverged species).
4 **Explain** how DNA sequencing supports the concept of evolution from a common ancestor.

Apply

5 Table 1 shows a small section of the cytochrome c molecule for humans, chickens, lungfish and flies. **Identify** the species that shows the greatest similarity to humans. **Justify** your answer (by explaining the relationship between DNA mutations and amino acid sequences, identifying the animal with the least difference, and explaining how this is an indication of evolutionary relationships).
6 Use the phylogenetic tree in Figure 6 to **determine** which species is most closely related to species A.

A

B

C

D

E
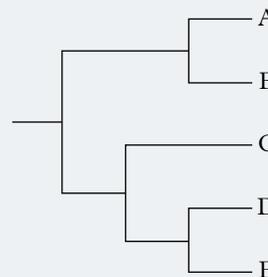
Figure 6 A phylogenetic tree

Lesson 3.10
Challenge: Who is my cousin?

Aim

To determine the evolutionary relationship between different species

Materials

- DNA sequences:
  - Hippo
    AGTCCCCAAAGCAAAGGAGACTATCCTTCCTAAGCATAAAGAAATGCCCTTCTCTAAATC
  - Giraffe
    AGTCTCCAAATGAAAGGAGACTATGGCTCCTAAGCACAAAGAAATGCCCTTCCCTAAATA
  - Rhino
    AGTCCTCCAAACTAAGGAGACCATCTTTCCTAAGCTCAAAGTTATGCCCTCCCTTAAATC
  - Pig
    AGATTCCAAAGCTAAGGAGACCATTGTTCCCAAGCGTAAAGGAATGCCCTTCCCTAAATC
  - Cow
    AGTCCCCAAATGAAAGGAGACTATGGTTCCTAAGCACAAGGAAATGCCCTTCCCTAAATA

Method

1 Compare the DNA sequences with each other and determine the number of differences between each pair.
2 Write your results in Table 1.

Results

Copy and complete Table 1 to show the number of differences between the animals' DNA sequences.

Table 1 Comparison of molecular differences in DNA sequences between animals

	Pig	Hippo	Cow	Giraffe
Hippo				
Cow				
Giraffe				
Rhino				

Questions

1 a **Identify** the animal that has the least number of differences in DNA sequence when compared with a cow.
   b **Describe** what this suggests about the evolutionary relationship between these two animals.
2 a **Identify** the animal that has the most number of differences in their DNA sequence when compared with a cow.
   b **Describe** what this suggests 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.
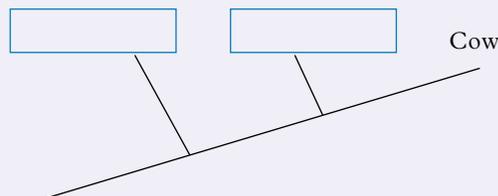
Figure 1 Phylogenetic tree

4 **Evaluate** the repeatability and reproducibility of this activity (by defining the terms "repeatability" and "reproducibility", describing the similarity of DNA between different organisms of the same species, explaining how these similarities or differences affect the repeatability and reproducibility, and deciding whether the activity is repeatable and reproducible).

Conclusion

Describe how DNA sequences can be used to determine the evolutionary relationships between different organisms.

Lesson 3.11
Humans artificially select traits

Key ideas

→ Artificial selection occurs when humans breed organisms that have desirable traits.

→ Rapid regrowth through binary fission or horizontal transfer has led to an increase in some bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA).

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Selective breeding

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 over many generations. After thousands of years, the sheep became unable to shed their wool. This means these once wild animals became more reliant on humans removing their wool to survive (Figure 1). Over many generations, the "wild" traits were lost and the species was considered "domesticated".

Figure 1 Some animals have become so dependent on humans that they struggle to survive in natural conditions. Sheep now rely on humans to remove their wool.

3.11

Artificial selection

The process of humans selecting for or against a particular characteristic or trait is called **artificial selection**. Unlike natural selection, artificial selection does not make the organism more suited to the environment. This is most evident in our pets. Many breeds (or subspecies) of dogs result from certain traits being selected by breeders. These purebred dogs can have very similar genetics, which can result in damaging recessive characteristics appearing (Figure 2).
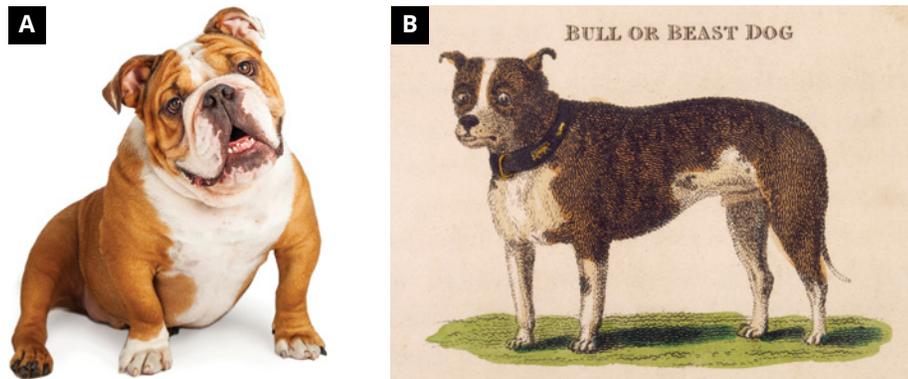
Figure 2 (A) Modern bulldog; and (B) the bulldog 200 years ago. Over the last 200 years, breeders of British bulldogs have selected dogs with large flat faces. This has resulted in many birthing difficulties for female dogs. Up to 90 per cent of bulldogs are born by caesarean. The flat faces also make the dogs more prone to breathing difficulties.

Evolution of super-bacteria

Humans can also influence the evolution of bacteria. One of the deadliest species of bacteria in hospitals is methicillin-resistant *Staphylococcus aureus* (MRSA or golden staph). These bacteria have arisen as a result of humans overusing antibiotics.

Staphylococcus aureus is normally found on the skin and in the noses and throats of many individuals in the population. Antibiotics prevent these bacterial cells from repairing or producing new cell walls, causing the cells to die rather than reproduce. In some populations, random mutations caused some *Staphylococcus aureus* cells to be unaffected by antibiotics. These bacteria became resistant.
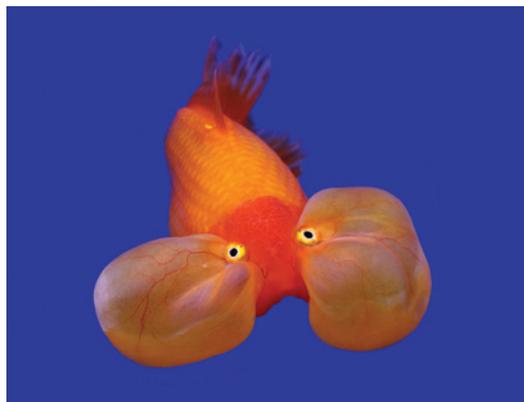
Figure 3 Another example of artificial selection, bubble-eye goldfish can have problems with buoyancy, which affects their ability to swim.

Figure 4 Selected for its hairless coat, the sphynx cat was recognised as a new breed in 2008.

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. This bacterium is not affected by the antibiotic and can easily spread to other patients in a hospital.

MRSA is such a bacterium. The misuse of antibiotics by humans selected the bacteria for its resistance (Figure 5).

Some bacteria do not have to wait for a random mutation to develop resistance to antibiotics. 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 evolve very quickly.
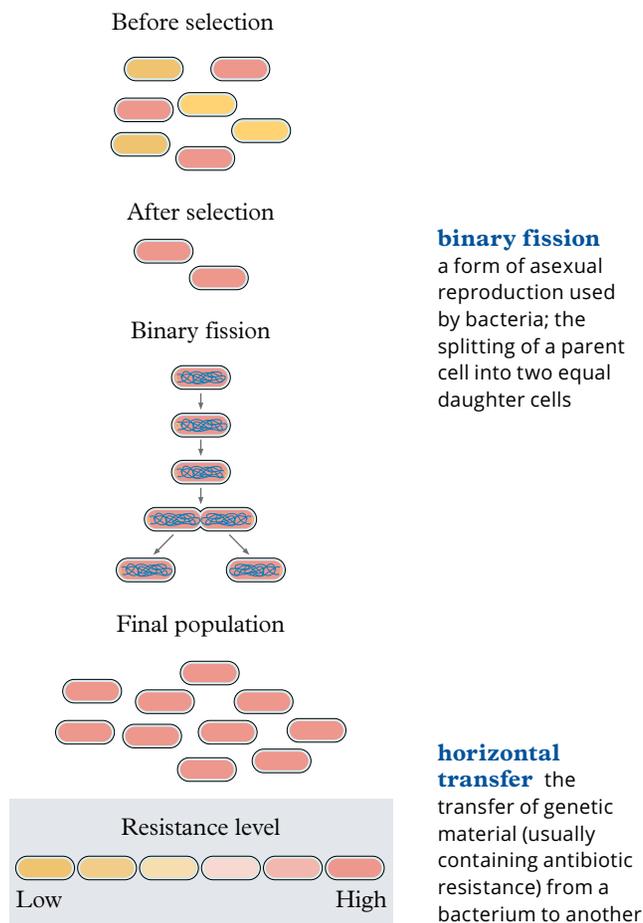
Before selection

After selection

Binary fission

Final population

Resistance level

Low   High

binary fission a form of asexual reproduction used by bacteria; the splitting of a parent cell into two equal daughter cells

horizontal transfer the transfer of genetic material (usually containing antibiotic resistance) from a bacterium to another bacterium that is not its offspring

Figure 5 The frequent use of antibiotics allows for the selection of bacteria that are resistant to antibiotics. This increases the allelic frequency of resistance.

Check your learning 3.11

Check your learning 3.11

Retrieve

1 **Define** the term "selective breeding".
2 **Identify** an example of how selective breeding was used to produce a domesticated animal.
3 **Define** the term "MRSA".

Comprehend

4 **Explain** how misusing antibiotics can contribute to the existence of MRSA.

Analyse

5 **Compare** selective breeding and natural selection.

Apply

6 A student claimed that artificial selection has interfered with nature. **Evaluate** their claim (by describing two reasons that support their claim, describing two reasons that refute their claim, and deciding which reasons are most convincing).

Skills builder: Problem solving

7 Humans are susceptible to viruses and bacteria. Consider how the misuse of antibiotics contributed to the existence of multi-resistant *Staphylococcus aureus* (MRSA) bacteria.
   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?)

Lesson 3.12
Challenge: Selective breeding of dogs

Aim

To examine how selective breeding for chosen characteristics can develop a new breed of dog

What you need:

- Counter
- Permanent marker

What to do:

1   You are a scientist who studies small mammals in the bush. You need a dog 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 of dogs.

2   Identify which two traits are most important for your new breed to inherit.

3   Using Table 2, choose which dogs you need to breed to achieve your desired traits.

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 Table 3.

6   Flip the counter three times for each trait because each pair will have three puppies.

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	Low ability	Any
Sight	High ability	Moderate	Low ability	Any
Hearing	High ability	Moderate	Low ability	Any
Speed	Fast	Moderate	Low	Any
Endurance	High	Moderate	Low	Any

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 ability	Moderate	Low	Low	Moderate	High
Sight	Moderate	Moderate	Moderate	High	High	Low
Hearing	High ability	Moderate	Moderate	High	High	Moderate
Speed	Moderate	Fast	Fast	Fast	Low	Moderate
Endurance	Low	Moderate	High	Moderate	High	Low

Results

Copy and complete Table 3.

Table 3 Results from the experiment

Trait	Puppy 1	Puppy 2	Puppy 3
Trainability			
Temperament			
Bark			
Coat colour			
Hair length			
Smell			
Sight			
Hearing			
Speed			
Endurance			

Discussion

1 **Explain** why all three puppies were not identical.

2 **Identify** the puppy best suited to your original needs. **Justify** your answer (by comparing the two original traits that you identified with the traits of the puppy you chose).

3 If you were to breed the dogs for another generation, **identify** the puppies you would select to be the parents. **Justify** your answer.

4 **Evaluate** whether your puppies are a new species (by defining the term "species", comparing your definition with your puppies, and deciding whether they are a new species).

5 **Evaluate** whether your chosen traits would be beneficial to the species (by describing your chosen traits, explaining how each of these traits would affect the survival of your puppy without humans, and deciding whether each trait would be beneficial to the survival of the species).

Conclusion

Explain how selective breeding can affect the survival of a species.

Lesson 3.13

Science as a human endeavour: Natural selection affects the frequency of alleles

Learning intentions and success criteria

Key ideas

→ Sickle cell anaemia is an autosomal recessive disease that affects the haemoglobin protein.

→ In countries such as Africa, there is a high rate of sickle cell carriers, which protects them from contracting malaria.

→ Malaria is the selection pressure that selects for the sickle cell carriers.

Introduction

Sickle cell anaemia is a disease that affects the structure and function of red blood cells. While few people in Australia have sickle cell anaemia, it is much more common in countries that have the mosquito-borne disease malaria.

Sickle cell anaemia

Sickle cell anaemia is a genetic disease that causes swelling of the hands and feet, fatigue and pain. It is an autosomal recessive disease (Module 2 Genetics (page 72)) that affects the haemoglobin protein found in red blood cells. The haemoglobin protein is made from four genes found on chromosome 11. It is responsible for carrying oxygen around the body. Most people have normal versions (or alleles) of the haemoglobin genes, but some people have a mutated allele, which causes the haemoglobin to clump together (Figure 1,

Figure 1 A person with sickle cell anaemia has crescent-shaped red blood cells (left) that are unable to effectively transport oxygen around the body.

Figure 2 and Figure 3). A single copy of the mutated allele will not affect the quality of a person's life. However, two copies of the mutated allele will cause all the haemoglobin to clump together and the red blood cells to become shaped like a sickle (a curved cutting instrument).
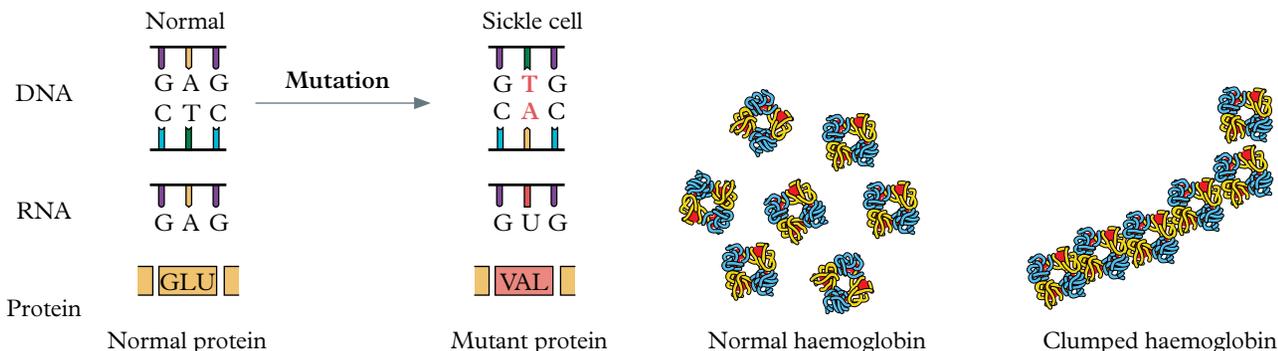
Figure 2 A mutation in the nucleotide sequence causes a change in the amino acid sequence at a DNA level.

Figure 3 A change in the amino acid sequence causes the haemoglobin to clump together at the protein level.

These sickle-shaped cells can become stuck in the blood vessels, causing strokes or damaging the joints and organs of the body. People suffering sickle cell anaemia must be treated regularly to prevent infections. Thirty years ago, sufferers would die by the age of 20. Today, life expectancy is approximately 55 years.

Selection pressures

The rate of sickle cell anaemia is very low in Australia. It is thought that only 5 per cent of the world's population is a carrier for sickle cell anaemia. This means they have one copy of the sickle cell allele and one copy of a normal haemoglobin allele. However, in countries such as Africa, the rate of carriers for sickle cell anaemia is closer to 25 per cent (Figure 4). This is because a person who is a carrier for sickle cell anaemia is protected from contracting malaria (an infectious disease that is contracted through mosquito bites). This means that people who:

- are not carriers of the allele for sickle cell anaemia are at risk of catching malaria and dying
- are carriers of the sickle cell allele do not get sickle cell anaemia or malaria
- have two copies of the sickle cell allele have sickle cell disease and may die young.
  Malaria is the selection pressure that selects for the sickle cell carriers.

🖥 Test your skills and capabilities

Scientific needs and values

Red blood cells are formed from stem cells in the bone marrow. If there are two alleles for the sickle cell "sticky" haemoglobin, the stem cell will produce sickle-shaped red blood cells.

In 2019, scientists removed the bone marrow stem cells from a patient with sickle cell anaemia and replaced the mutated alleles with healthy copies of the genes.

1 **Consider** the potential effect of this process on the evolution of the human species by:
   - describing the effect that replacing the sickle cell alleles will have on the patient
   - describing the effect that replacing the sickle cell alleles will have on the offspring of the patient
   - describing how the patient and their future offspring will be affected by malaria.
   Although the genetic manipulation of somatic (body) cells has been trialled for the last 10 years, there is a moratorium (a temporary ban) on the manipulation of the human genome in human gametes (eggs and sperm).

2 **Evaluate** the reasons for this moratorium by:
   – describing how a genetically modified somatic cell will affect a patient
   – describing how a genetically modified somatic cell will affect the offspring of the patient
   – describing how a genetically modified gamete cell will affect a patient
   – describing how a genetically modified gamete cell will affect the offspring of the patient
   – contrasting the effect of a genetically modified somatic cell or gamete on future generations
   – explaining the reason for the moratorium on human genetic manipulation in gametes.
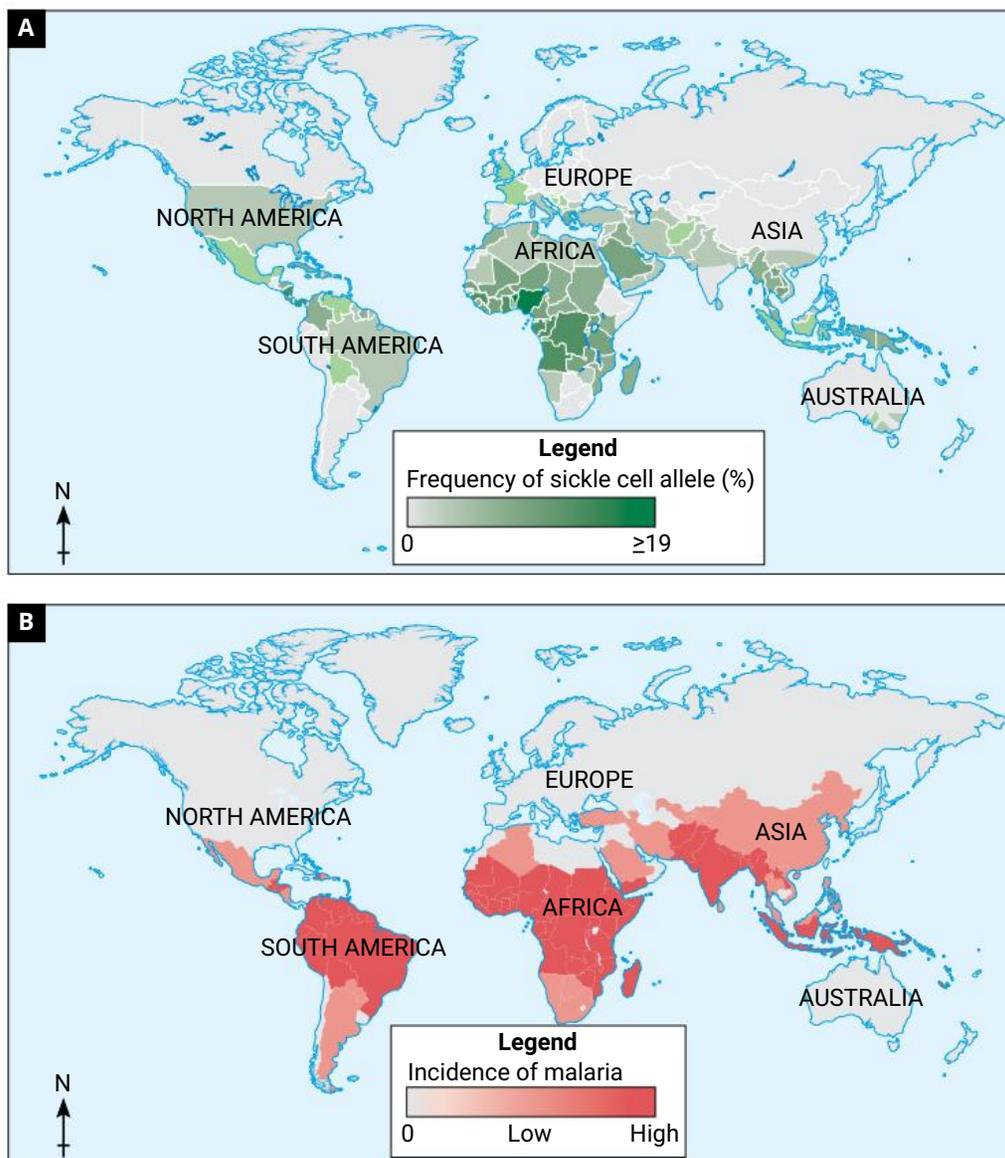
Figure 4 There is a strong correlation between (A) countries that have a high number of carriers for the sickle cell anaemia allele; and (B) countries that have a high incidence of malaria.

Lesson 3.14
Experiment: Selecting for sickle cell anaemia

Aim

To examine how malaria selects for sickle cell anaemia

Materials

- 75 dried red kidney beans (These are the sex cells carrying "H", the unaffected normal haemoglobin allele.)
- 25 white beans (These are the sex cells carrying "h", the affected sickle cell allele.)
- 5 containers
- Coin or counter (for flipping heads or tails)
- Permanent marker

Method

1   Place all the beans in a container and mix them thoroughly. This container represents the total "gene pool" of your population.
2   Label the remaining containers:
    - HH: No sickle cell disease
    - Hh: No sickle cell disease
    - hh: Sickle cell disease
    - Dead.
3   Without looking, randomly select two beans from the gene pool. This represents the two alleles that are present in a baby of the next generation.
4   Flip the coin to determine whether the baby catches malaria. Heads means the baby is infected; tails means it does not become infected. Use Table 1 to determine whether the individual lives or dies.

Table 1 The possible consequences of the genotype for sickle cell disease

Alleles present (bean colour)	Presence of sickle cell anaemia?	Heads – infected with malaria	Tails – not infected with malaria
HH (red – red)	No sickle cell anaemia Susceptible to malaria	Individual dies. Place beans in dead container.	Individual lives. Place beans in HH container.
Hh (red – white)	No sickle cell anaemia Resistant to malaria	Individual lives. Place beans in Hh container.	Individual lives. Place beans in Hh container.
hh (white – white)	Sickle cell anaemia	Individual dies. Place beans in dead container.	Individual dies. Place beans in dead container.

5   Repeat steps 3 and 4 until the gene pool is empty.
6   Record your results in Table 2.
7   Place all the survivors in HH and Hh back into the gene pool and continue breeding for a second and third generation.
8   Combine the class results to ensure that you have a large sample size.
9   Determine the percentage of each allele present in each generation from the following formulas:

Percentage of H alleles present =

$$\frac{\text{number of red kidney beans}}{\text{total number of beans}} \times 100$$

Percentage of h alleles present =

$$\frac{\text{number of white beans}}{\text{total number of beans}} \times 100$$

▶

◄

Results

Copy and complete Table 2.

Table 2 Surviving alleles

Generation	Number of red kidney beans (H)	Number of white beans (h)
1	75	25
2		
3		

Discussion

1 **Describe** the trend in the percentage of "H" (normal) alleles present in the gene pool.

2 **Describe** the trend in the percentage of "h" (sickle cell) alleles present in the gene pool.

3 The hh combination is deadly, and people with this are likely to die before reproducing. **Explain** why the "h" allele has not been removed from the population.

4 If people with sickle cell anaemia were able to survive and reproduce, **describe** what you would expect to happen to the percentage of people carrying the "h" allele in the population.

5 **Evaluate** the validity of this model (by explaining how this model relates to the real world, identifying other factors that may change the outcomes in the real-world example, and deciding whether the model is a valid representation of the real world).

Conclusion

Explain how malaria selects for carriers of sickle cell anaemia.

Lesson 3.15
Review: Evolution

Summary

Lesson 3.1 Science as a human endeavour: Darwin and Wallace were co-conspirators

- Lamarck believed in evolutionary change – that organisms change over time due to changing environmental conditions and those changes were passed on to their offspring.
- Darwin found that favourable variations would tend to be preserved in organisms and unfavourable ones would be destroyed and not passed on to their offspring.
- Alfred Russel Wallace proposed the theory of natural selection as the mechanism of evolution based on his work in the Malay Archipelago.

Lesson 3.2 Natural selection is the mechanism of evolution

- Evolution is the permanent change in the number of alleles in a population due to natural selection.
- Natural selection is the process where selection pressures select for or against a trait or characteristic so that a species becomes better suited to its environment.
- All scientists make observations of the world around them; they then use these observations and reasoning to make a conclusion (an inference).

Lesson 3.4 Different selection pressures cause divergence. Similar selection pressures cause convergence

- Speciation is the formation of a new species that cannot reproduce with other species.
- Allopatric speciation can occur when a permanent barrier separates a population and prevents gene flow.
- Divergence occurs when one population becomes two new species.
- Convergence occurs when two different species become more physically similar due to similar selection pressures.

Lesson 3.6 Fossils provide evidence of evolution

- Fossils are remains or traces of an organism that once existed.
- Transitional fossils are intermediary fossils that have traits of both the ancestral organism and the more recent organism.
- Relative dating determines the relative order in which 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.

Lesson 3.8 Multiple forms of evidence support evolution

- Biogeography is the study of how the continents move across the Earth and how this directly affects the location of organisms.
- When continents collide, species can spread, and when continents separate, the new species move with them.

- The study of how genetic material affects the development of embryos (embryological studies) is a new and growing field of study.

Lesson 3.9 DNA and proteins provide chemical evidence for evolution

- The basic structure of DNA and proteins is identical for all species on Earth.
- Small differences in the sequences of amino acids in proteins and nucleotides in DNA can be used to determine the evolutionary relationship between species.
- The more differences in the nucleotide sequence between organisms, the more time has passed since they shared a common ancestor, and the greater the evolutionary distance between the species.

Lesson 3.11 Humans artificially select traits

- Artificial selection occurs when humans breed organisms that have desirable traits.
- Rapid regrowth through binary fission or horizontal transfer has led to an increase in some bacteria such as methicillin-resistant *Staphylococcus aureus* (MRSA).

Lesson 3.13 Science as a human endeavour: Natural selection affects the frequency of alleles

- Sickle cell anaemia is an autosomal recessive disease that affects the haemoglobin protein.
- In countries such as Africa, there is a high rate of sickle cell carriers, which protects them from contracting malaria.
- Malaria is the selection pressure that selects for the sickle cell carriers.

Review questions 3.15

Review questions: Module 3

Retrieve

1 **Identify** which evolutionary theory proposed that organisms acquired inherited characteristics.
   A Darwinism
   B Lamarckian theory
   C Wallace's theory
   D natural selection

2 **Recall** the term that is used to describe a single population that is divided by a permanent barrier and diverges into new species.
   A Reproductive isolation
   B Speciation
   C Allopatric speciation
   D Convergence

3 Relative dating is used to work out the age of rocks. **Identify** which layer is likely the oldest of the layers in Figure 1.

A Layer 1

B Layer 2

C Layer 3

D Layer 4
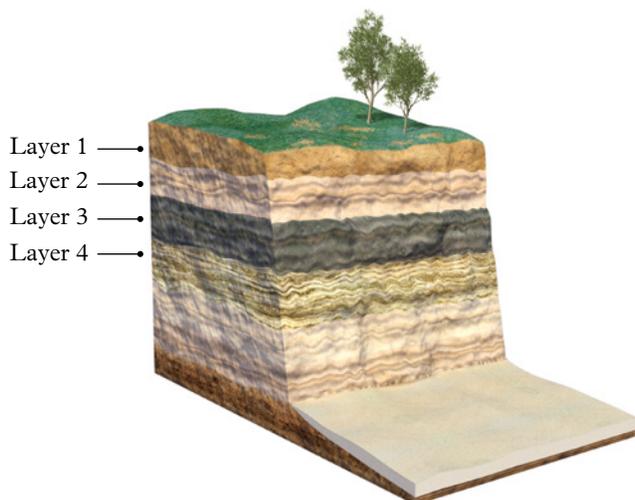
Figure 1 Layers of rock

4 **Define** the term "natural selection" and **identify** the four essential factors for this process.

5 **Define** the term "gene pool".

6 **Identify** the professional title for a person who studies the fossil record and geological time periods.

7 *Archaeopteryx* had features of both birds and lizards. **Identify** the term that is applied to fossils that shows the evolutionary progression between two very different forms.

Comprehend

8 **Explain** the difference between incorrectly suggesting an organism has evolved and correctly suggesting that a population of organisms has evolved.

9 **Describe** Gondwana.

10 The layering of sedimentary rocks is useful in relative dating. **Explain** the basic principle of comparative dating.

11 **Explain** precisely how fossils provide evidence for evolution.

12 **Explain** why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

13 **Explain** how the study of DNA sequences helps in our understanding of evolution.

14 Use examples to **illustrate** the two critical deductions that Darwin made – the struggle for existence and the survival of the fittest.

Analyse

15 **Contrast** a hypothesis and a theory.

16 **Contrast** "transitional fossil" and "living fossil".

17 **Compare** the terms "allopatric speciation" and "gene flow".

18 **Compare** the terms "diversity" and "evolution".

19 Use your understanding of the pentadactyl limb to **describe** why the animal that made the footprint in Figure 2 is not related to humans.

Figure 2 Fossilised footprints can provide scientists with information about the size and type of animal that made it.

Apply

20 The diaries of some early European settlers noted the superior abilities of Aboriginal and Torres Strait Islander Peoples in jumping, throwing accuracy, spatial awareness and stamina. Not all of these abilities can be explained by training and lifestyle alone. Use your understanding of natural selection to explain how many of these traits could be inherited.

21 *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. **Suggest** how this adaptive feature enabled *Callistemon* to exploit the current Australian environment.

Figure 3 *Callistemon* flowers

22 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 have two very different phenotypes.

  b **Describe** how the tortoises that originally reached the islands could resemble any of the tortoises that live there today.

  c Using the terms "variation" and "survival of the fittest", **discuss** 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 that is occurring on these islands.

Figure 4 Tortoises on different Galapagos Islands have unique features.

23 Only two species of native non-marine mammals (both bats) existed in New Zealand before the Polynesians introduced rats and dogs 1,500 years ago. This unusually small number of mammal species, along with New Zealand's separation from Gondwana 60 to 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. Consider this information to **determine** if mammals were likely to have originated on Gondwana.

24 Megafauna are the large animal ancestors that lived in Australia thousands of years ago. One of these was the *Diprotodon*, an early ancestor to wombats and koalas. In 2016, archaeologists discovered a front leg bone of the *Diprotodon* at the Warratyi rock shelter in the Flinders Ranges in South Australia.

  a If the amount of carbon-14 (with a half-life of 5,700 years) remaining in the sample was $\frac{1}{128}$, **calculate** the age of the leg bone.

  b As a large animal (3,500 kg), it became extinct at the same time as many other Australian megafauna. One of the causes is thought to be extreme drought conditions. **Discuss** how drought conditions could act as a selection pressure.

Social and ethical thinking

25 Through selective breeding, humans are able to bring about changes in the gene pool of a population. **Discuss** the various scenarios in which this has occurred in the past and may occur now and in the future. **Describe** three examples of human intervention being positive and three examples of detrimental intervention. **Justify** your decisions.

Critical and creative thinking

26 **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.

27 The theories of Lamarck and Darwin are often compared and contrasted in the form of cartoon strips. **Create** a three-part cartoon strip for each theory that clearly identifies the similarities and differences between these theories.

28 **Evaluate** the strengths and weaknesses of the various forms of evidence that support evolution.

Research

29 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

Eugenics and racism

Eugenics, the use of genetics and evolution to "improve" the human race, gained popularity in the early 1900s. It led to deliberate sterilisation of some individuals in the United States, the Holocaust in Germany and the White Australia policy.

- Research the person who coined the term "eugenics".
- Select one of the examples provided and explain how misconceptions of heredity and evolution led to the development of governmental policies and societal attitudes.

Figure 5 The White Australia policy was one of several inhumane and profoundly hurtful policies based on a misconception of heredity and evolution.

Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Examples of this include weeds that develop a tolerance to herbicides and insects that develop a tolerance to pesticides in general agriculture.

- **Describe** what is meant by the term "tolerance".
- **Identify** a weed or insect that can damage a local food crop.
- **Use** your understanding of natural selection to describe how your selected weed or insect could develop a tolerance to the herbicide or pesticide.
- **Explain** why these organisms demonstrate evolution at such a fast rate.
- **Explain** how the evolution of tolerance could affect the food supply.

Figure 6 *Myzus persicae* (green peach aphid) is resistant to multiple pesticides and is a problem for Australian farmers.

Climate change and natural selection

The last Ice Age occurred 25,000 to 100,000 years ago. Much of the water was frozen into glaciers, providing land bridges between the Australian mainland, Tasmania and New Guinea.

- **Describe** three examples of Australian megafauna that were alive during this time.

  Over a period of 10,000 years (20,000 to 30,000 years ago) the climate slowly warmed.

- **Describe** how this impacted the vegetation available on the land-mass.
- **Describe** how this could have impacted the megafauna.
- Evidence of Aboriginal and Torres Strait Islander Peoples settling on the Australian mainland has been dated to 60,000 years ago. **Evaluate** the argument that Aboriginal and Torres Strait Islander Peoples were the cause of megafauna extinction.

  Climate scientists predict that the average temperature of the Earth will increase by 2 degrees Celsius over the next 100 years.

- **Explain** how this climate change will affect species on Earth.

- **Describe** the species you think will be most affected. **Explain** what this species could do to avoid becoming extinct as a result of changing habitats.
- **Explain** if all species would be able to avoid the effects of climate change.

Figure 7 Increased incidence of bushfires in Australia is one of the devastating effects of increasing global temperatures.

Module

4

Climate change

Overview

Climate change is caused by greenhouse gases, like carbon dioxide, trapping heat in the Earth's atmosphere. These gases come from human activities such as burning fossil fuels for power, deforestation, transport and food production. The Sun's energy interacts with the atmosphere, oceans and land, forming the global climate system. Deep ocean currents, powered by heat and energy differences, help regulate climate and support marine life.

Scientists track changes in the climate using indicators like rising air and ocean temperatures, melting sea ice, higher sea levels, and changes in biodiversity and species locations. Predicting the level of future climate change involves looking at these systems and what we can do to reduce the impact.

Lessons in this module

Lesson 4.1
Climate change is global

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Weather is the short-term changes in temperature, wind, rain, humidity and atmospheric pressure in a small region.

→ Climate is a long-term measure of averages, variations and extremes in weather over large global areas.

→ Solar radiation interacts with and causes the exchange of energy between the atmosphere, ocean and land to affect the global climate system.

Introduction

Many systems in nature are balanced, from the regulation of the body to the carbon cycle of Earth. When the balance is disrupted, it can cause a chain of reactions that can have long-term impacts. For thousands and thousands of years, there has been a balance between the exchange of energy and matter in the geosphere (the rocks and minerals on the surface of Earth), the biosphere (all living things), the hydrosphere (all the ice, water and vapour on Earth) and the atmosphere (the layer of gases surrounding Earth). These spheres act together to make the global climate system one in which humans and other parts of the biosphere are able to survive. **Climate change** refers to a change in the state of the global climate.

climate change periodic change in the Earth's climate

Weather and climate systems

Weather reports tell you the temperature, humidity, rainfall and wind on particular days at a particular place. They provide a snapshot of day-to-day changes in the system formed by the Earth's spheres. **Climate** is concerned with longer periods of time and involves the collection and analysis of large amounts of data that look at the whole system. 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 each year, governments to decide whether to invest in certain technologies or even households to decide whether they'll need to install an air conditioner.

weather the temperature, humidity, rainfall and wind on particular days at a particular place

climate the weather conditions at a particular place, averaged over a long period of time, based on the collection and analysis of large amounts of data

Solar radiation

Light and thermal energy produced by the Sun is something that is often taken for granted. We have all felt the heat of a footpath or road on a hot day. This is due to the energy of **solar radiation** (shortwave, high-energy radiation) heating the rocks and minerals that form the geosphere under our feet. This includes everything from the molten rocks of the mantle to the peaks of the mountains on Earth.

The amount of solar radiation released by the Sun varies by 0.1 per cent every 9 to 11 years (Figure 1). The small variation has had no impact on the amount of solar radiation that reaches the top of the Earth's atmosphere.

solar radiation radiant electromagnetic energy from the Sun
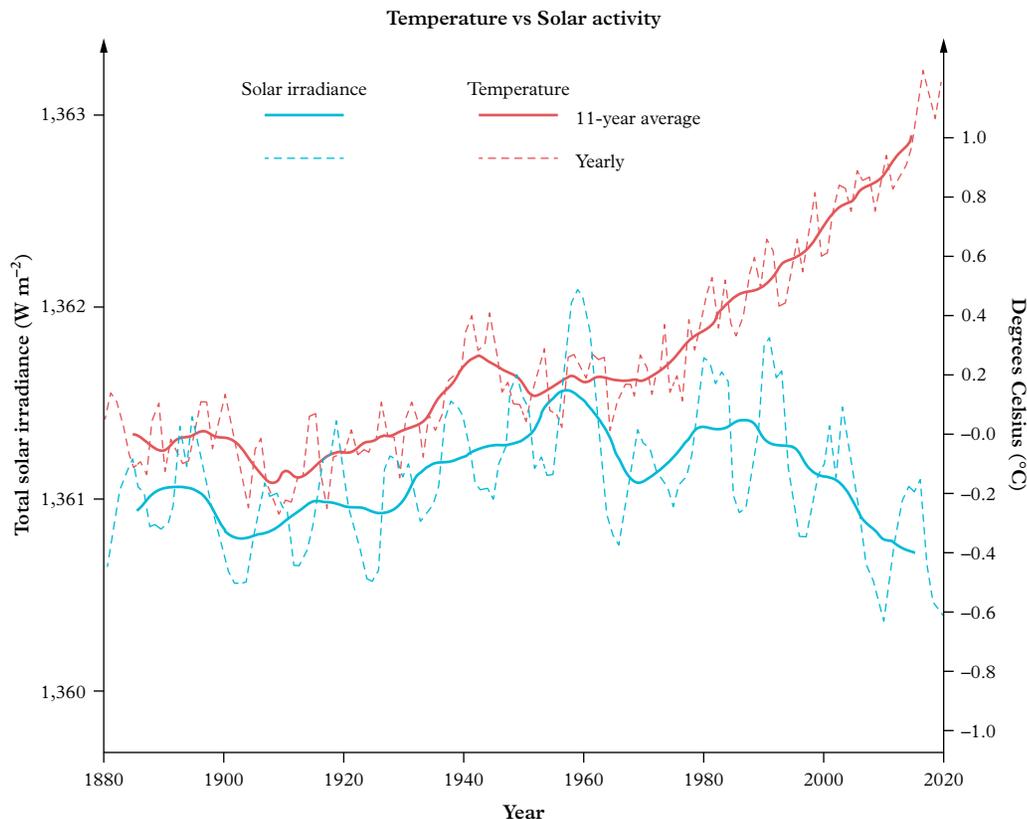
Figure 1 The amount of the Sun's energy reaching the top of the Earth's atmosphere; and the global average surface temperature over time

This means that the variations in the energy released by the Sun are not the cause of the current increase in global average surface temperature (Figure 1).

Solar radiation that reaches the Earth's atmosphere is either absorbed or reflected into space. Seventy per cent of solar radiation is absorbed by the water and rocks that make up the Earth's surface (hydrosphere and geosphere). The absorbed energy causes the molecules that make up the rocks and water to increase their kinetic energy and vibrate faster which results in the increased temperature. This energy is then re-radiated as long-wave, lower-energy wavelengths of infrared radiation (known as heat) into the gases in the air. The more solar radiation that is absorbed by Earth, the hotter the surface becomes. This exchange in energy between the geosphere and atmosphere heats the greenhouse gases (such as carbon dioxide) in the atmosphere.

Some parts of Earth will receive more solar radiation than other parts. At the North or South Pole, the energy from the Sun shines at an angle. As it travels through the atmosphere, some of it radiates back into space. Less energy is available to heat Earth.

Areas of Earth that experience long periods of solar radiation from the Sun have higher temperatures.

Regions near the equator are warmer than regions near the Earth's poles. Near the equator, the Sun spends more time directly overhead. This means more solar radiation is absorbed by the Earth's surface at the equator than at the poles where the Sun is at a steep angle (Figure 2). Because of this, the Earth's surface at the equator is heated

4.1

intensely. The thermal energy in the rocks making up the geosphere heats the gases in the atmosphere. This can lead to higher temperatures lasting longer at the equator. This uneven heating of the geosphere and hydrosphere can affect the global atmosphere and ocean circulation patterns.

Steep angle of incoming sunlight

60°N

30°N

Tropic of Cancer

0° (Equator)

Sunlight strikes most directly

Tropic of Capricorn

30°S

Steep angle of incoming sunlight

60°S

Earth's axis (23.5°)
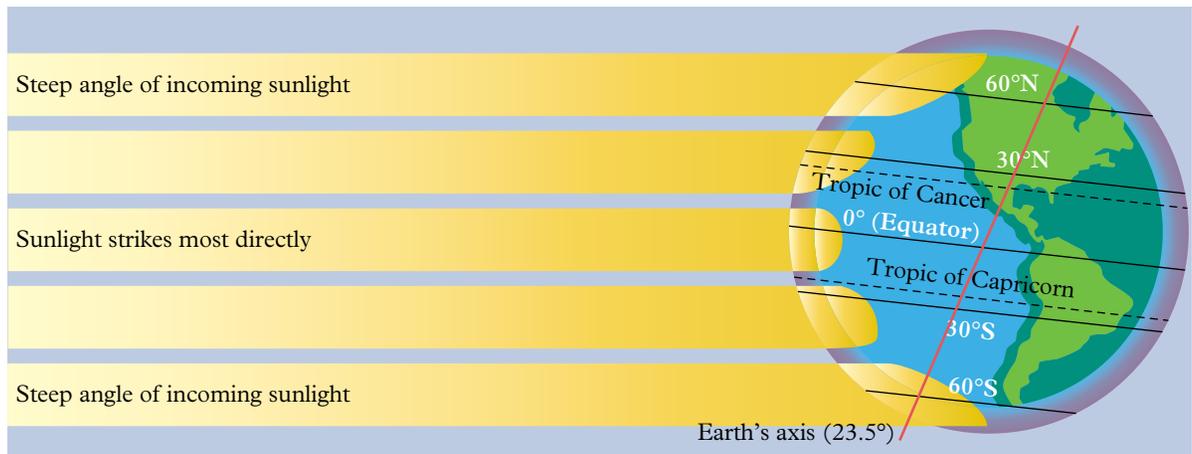
Figure 2 The angle of solar radiation (sunlight) can affect the amount of energy absorbed by Earth's surface.

high-pressure system area of high pressure in the Earth's atmosphere

low-pressure system area of low pressure in the Earth's atmosphere

As the air heats up in a **high-pressure system**, the particles in the air move faster and spread out to the outer regions as wind. In a **low-pressure system**, the air in the centre has lower pressure than the surrounding areas. The surrounding air moves towards the centre and upwards, forming water vapour, clouds and rain (Figure 3). The movement of air is better known as wind. The wind is the result of sideways or horizontal movements of air due to pressure differences.

Coriolis effect the influence of the Earth's rotation on the direction of movement of air or water

The **Coriolis effect** is the influence of the Earth's rotation on the direction of air or water movement. The Coriolis effect of a spinning Earth can cause the winds to appear to move in a circular pattern across Earth (Figure 4). The surface of 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.

Cool air descending

North Pole

Equator

Hot air rising

South Pole

Figure 3 Movement of air at the equator and at the poles can result in the circular movements of air called cyclones.

isobar a line drawn on a weather map that joins places of equal air pressure

On a weather map, the air pressure differences caused by heated air 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 shown on weather maps (Figure 5B). Low-pressure areas are frequently associated with clouds and precipitation and represented by an "L". High-pressure systems bring clear blue skies and are represented by an "H".

Figure 4 Wind patterns over Earth
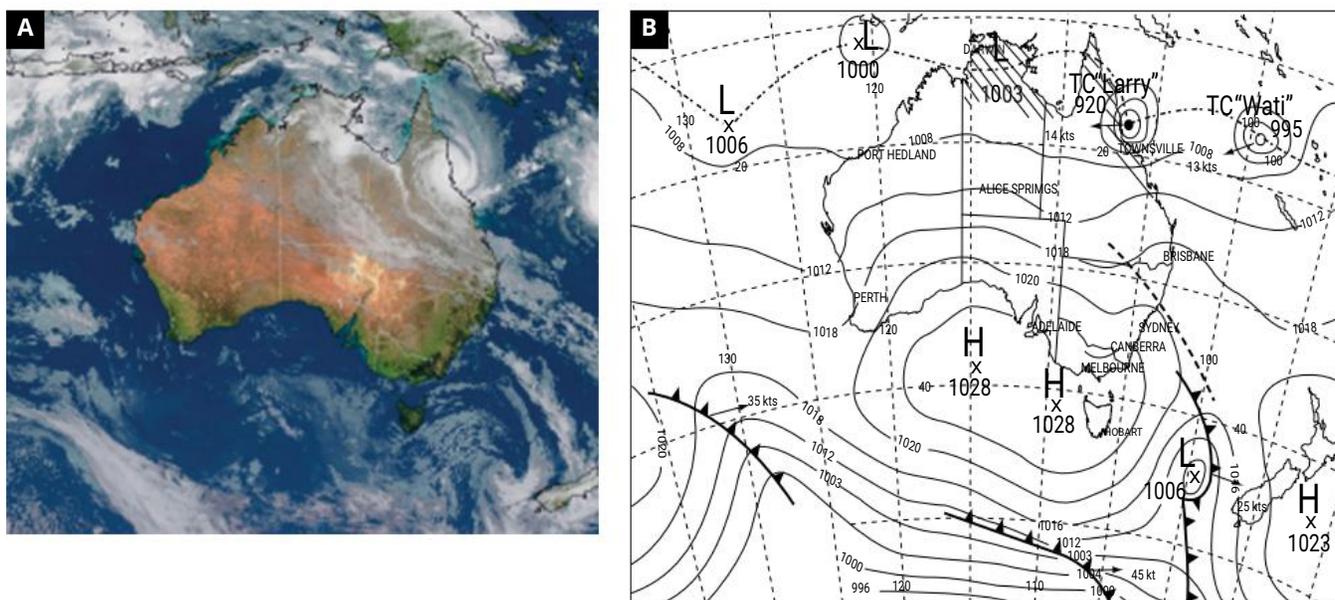
Figure 5 (A) A satellite image; and (B) a weather map showing tropical Cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006

4.1

Check your learning 4.1

Retrieve

1 **Define** the term "air pressure".

Comprehend

2 **Describe** the relationship between winds and rising air.

3 **Explain** what happens to the pressure of the air when it is heated.

4 **Describe** the role of the Coriolis effect on global winds.

Analyse

5 **Compare** weather and climate.

6 **Compare** the wavelength and energy levels of solar radiation and infrared (heat) radiation.

Apply

7 Cyclones are more likely to occur close to the equator during the wet season.

   a **Describe** what is meant by the term "wet season" and **investigate** the climate conditions that contribute to the formation of a cyclone.

   b **Create** a 2-minute video in which you are a meteorologist on the news who is explaining why the cyclone is forming.

Lesson 4.2
Challenge: Making a simple barometer

Caution

Consider if there are any allergies to latex.

Aim

To make a simple barometer that measure changes in air pressure

What you need:

- Balloon
- Scissors
- Glass jar
- 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 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 each day for a week. Mark each position of the straw on the scale and record the date next to the mark (Figure 1).

6 Record the air pressure of your area each day for a week.
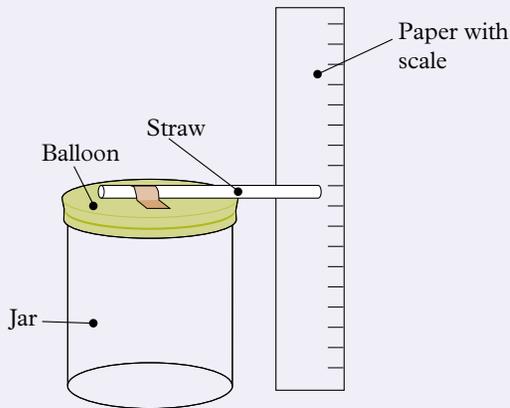
Figure 1 Experimental set-up

Questions

1 **Describe** how the balloon would change if the air pressure surrounding the jar was decreased. Describe how this would affect the movement of the straw.

2 **Describe** how the balloon would change if the air pressure surrounding the jar was increased. Describe how this would affect the movement of the straw.

3 **Compare** the changes in the balloon (indicated by the position of the straw on the scale) with the recorded air pressure each day.

4 **Use** the particle model of air to **explain** why the balloon gets pushed in or out of the jar by the surrounding air.

5 **Explain** why this "barometer" will also respond to changes in temperature in addition to changes in air pressure.

Lesson 4.3

Climate change indicators include increased global temperatures, extreme weather, disease and species distribution

Key ideas

→ Data is used to measure and analyse climate change.

→ Climate change has caused increasing global temperatures and extreme weather events.

→ Climate change has changed the distribution of diseases.

→ Rapid changes in climate have changed and will continue to change the distribution of species.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

4.3

Greenhouse gases

The presence of a gaseous atmosphere allows Earth to maintain a relatively constant environment in which life can survive. The Moon is not large enough to retain a full atmosphere. This means the Moon's temperatures can vary from 123°C when in sunlight to −153°C when it is turned away from the Sun.

Gases in Earth's atmosphere (oxygen, nitrogen, hydrogen, carbon dioxide and methane) can reflect some of the heat from solar radiation during the day. These gases can also retain some of the heat so that Earth's surface does not cool too much at night (similar to how a greenhouse retains heat for plants to grow).

greenhouse gases
a gas (carbon dioxide, water vapour, methane) in the atmosphere that can absorb heat

Not all atmospheric gases are equal in their ability to retain heat. When the Earth's surface absorbs the heat from solar radiation, it passes it on to the **greenhouse gases**. Methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) are gases in the Earth's atmosphere that absorb the majority of the heat. The amount of atmospheric carbon dioxide has increased by more than 50 per cent in the last 70 years because of human-related activities, such as burning fossil fuels and deforestation. The level of carbon dioxide has remained between 180 and 300 ppm (parts per million) over the past 800,000 years. The amount of carbon dioxide trapped in ice sheets and glaciers was used to obtain this data (Figure 1A). In 2024, the level of carbon dioxide reached a new high of 423 ppm which has contributed to the rise in average global temperatures (Figure 1B).

A Carbon dioxide trapped in air bubbles in ice sheets and glaciers (ppm)

B Atmospheric carbon dioxide, 2004–2022 (ppm)
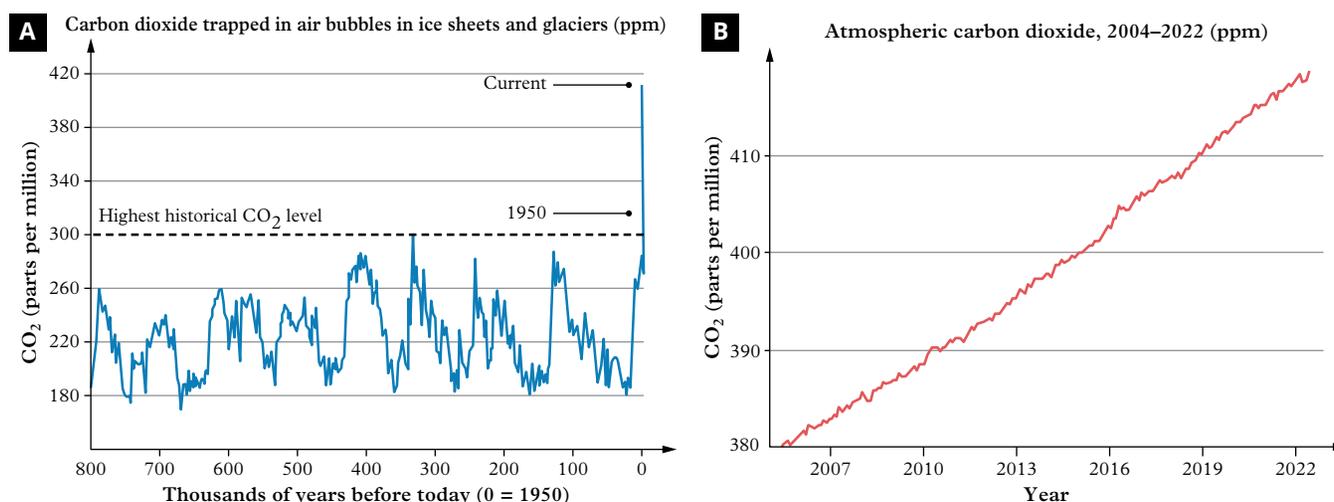
Figure 1 Trends in atmospheric carbon dioxide from (A) air bubbles trapped in ice sheets and glaciers; and (B) atmospheric carbon dioxide recorded by Mauna Observatory, Hawaii

Rising temperatures

Increased atmospheric carbon dioxide from human activities has resulted in a rapid increase in the average global temperature. Figure 2 shows that the increase in average temperature is not evenly spread across Earth. Temperatures might rise by 5°C in the North Pole but only increase by 1.5°C in Australia.

These average temperature changes might not seem large at first; however, they are quite drastic changes.

It only took a drop of 1 to 2°C to cause the Little Ice Age in the seventeenth century. This resulted in widespread crop failure, famine and disease. NASA has predicted that global warming of 1.5°C will cause deadly annual heatwaves, water stress in some countries, increased heavy rainfall and floods in other countries, reduced biodiversity, increased wildfires and melting of the polar ice caps.

2021

Temperature anomaly (°C compared to the 1951–1980 average)

≤−4   −2   0   2   ≥4
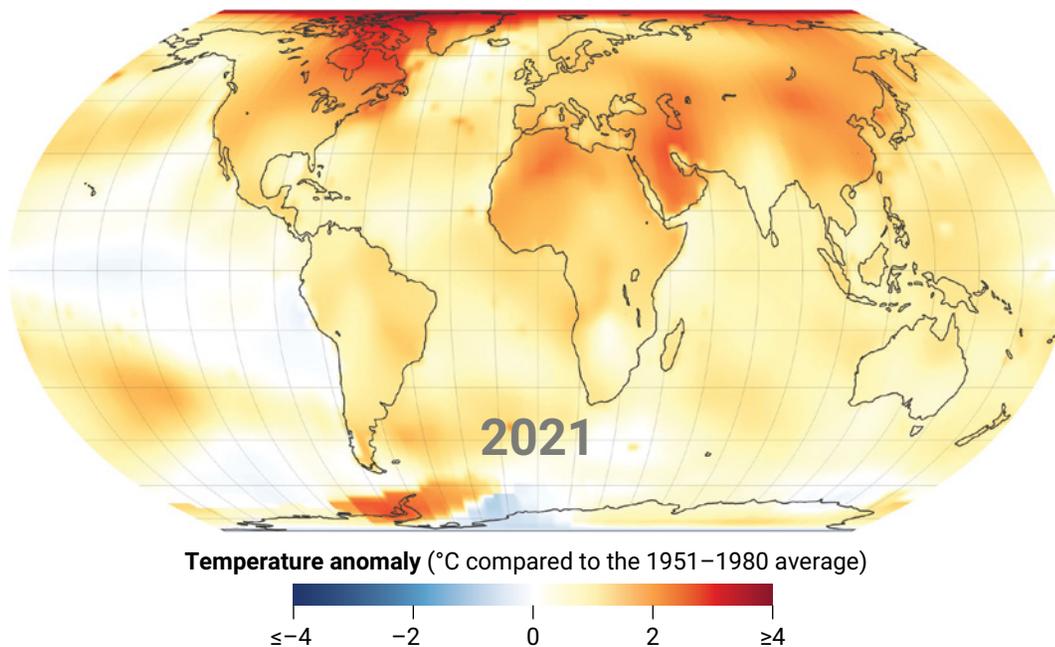
Figure 2 The average change in global temperature compared to the 1951–1980 average

Extreme weather events

The number of extreme weather events in Australia is increasing. An example of this is the increase in the number of bushfire weather days since 1950 (Figure 3).

Warmer oceans increase the amount of water vapour in the atmosphere and rapidly rising hot air causes stronger winds. Based on the current trend of rising global temperatures, scientists have predicted 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 categories 4 or 5 has risen by 15 per cent over the past 20 years (Figure 4). With an increase in extreme weather events, we can expect to see an increase in the loss of human lives.

Change in number of dangerous fire weather days

25
20
15
10
5
0
−5
−10
−15
−20
−25

There has been an increase in the annual frequency of dangerous fire weather days across Australia.

Source: Bureau of Meteorology
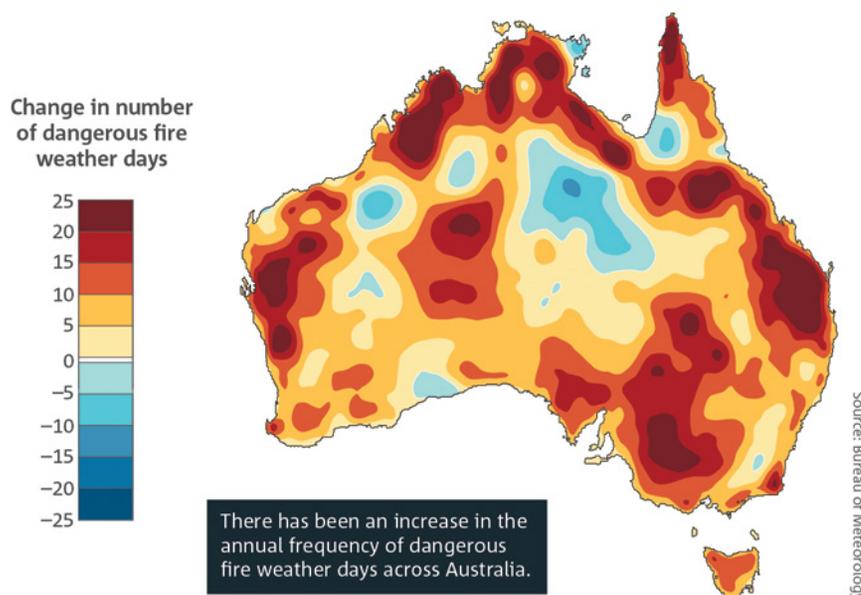
Figure 3 The number of days with dangerous bushfire weather has increased across most parts of Australia.

Figure 4 The aftermath of a cyclone; the number of severe cyclones is increasing.

Health and disease

Higher temperatures in summer have increased heat-related deaths. In 2024, the average global temperature was recorded to have risen by approximately 1.6°C since pre-industrial levels. Heatwaves are now lasting longer, causing people to become more dehydrated, placing more strain on their hearts and causing people to experience sleep deprivation.

These factors contributed to the deaths of 56,000 people during a heatwave in Russia in 2010.

Enhanced global warming is changing the climates in many areas. Some areas are becoming warmer and experiencing more rain. This can extend the zones for infectious diseases, such as dengue fever and malaria, which thrive in warm, moist conditions (Figure 5). In cities such as Beijing, China, stagnant weather conditions can trap both warm air and pollutants, leading to increased smog which results in serious respiratory problems contributing to increased deaths.

Legend

Countries with indigenous cases of malaria in 2000 and their status by 2022

- One or more indigenous cases
- Zero indigenous cases in 2022
- Zero indigenous cases in 2021–2022
- Zero indigenous cases (>3 years) in 2022
- Certified malaria free after 2000
- No malaria
- Not applicable
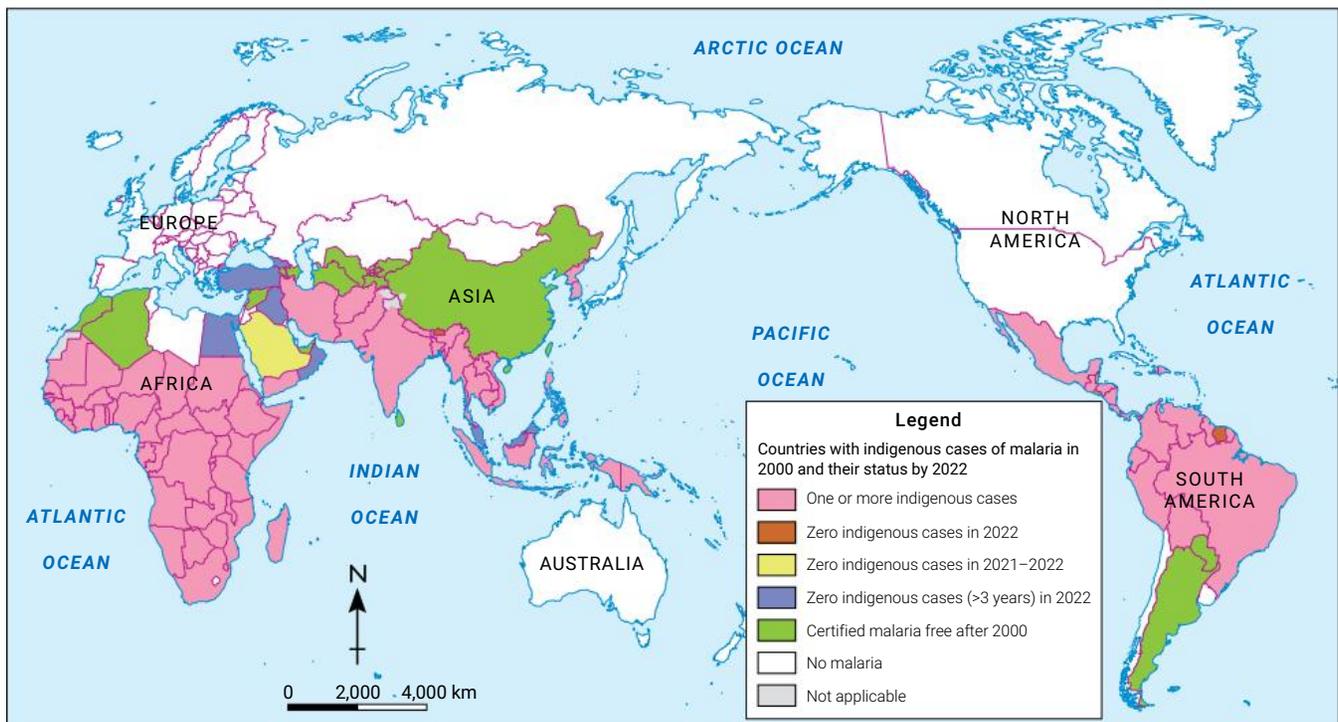
Figure 5 Countries and areas at risk of transmission of malaria, 2023

Species distribution

Rapid climate change over the past 50 years has resulted in many changes to the biodiversity (the variety of plant and animals in an area) and is thought to have caused extinctions. Many of the species at risk are Arctic and Antarctic animals, such as polar bears and emperor penguins, which live on the rapidly disappearing ice (Figure 6A and Figure 6B). Other species, such as the white lemuroid possum, which is only found in high-altitude areas in north Queensland, can only live within certain temperature ranges (Figure 6C). These possums cannot survive extended temperatures over 30°C, which occurred during a heatwave in 2005. After the heatwave, the species was thought to be extinct until recently when small numbers were observed.

Australian native plants and animals are well adapted to year-to-year climate fluctuations, such as floods and droughts.

They can often, however, 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 to 2°C that are expected as a result of climate change.

For example, climate change modelling suggests that the extent of highland rainforest ecosystems of tropical north Queensland may decrease by up to 50 per cent if the temperature increases by 1°C. These changes mean some species may become extinct.

As many species are interdependent, the loss of one species may affect the survival of other organisms. Even a small decline in the number of individuals in a population can reduce the population's diversity, making the population more vulnerable to changing conditions in the future.

Earth and Space

Figure 6 Many animals are at risk of extinction as a result of climate change, including (A) polar bears; (B) emperor penguins, which live in cold climates; and (C) lemuroid possums, which can only live within a certain temperature range.

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4.3

Check your learning 4.3

Retrieve

1 **Define** the term "extreme weather event".

Comprehend

2 **Explain** how increasing levels of carbon dioxide have contributed to global climate change.

3 **Identify** and **explain** two sets of data in this lesson that show how the climate has changed over the last 100 years.

4 **Describe** the ways that climate change can affect human health.

5 **Explain** how the loss of one species can affect other species.

Apply

6 **Evaluate** the statement "An average increase in global temperature of 1°C is not going to have a large effect on me" (by comparing weather and climate, defining "average increase in global temperature", and describing how climate change will affect your environment). State whether you agree with the statement and justify your decision.

Skills builder: Questioning and predicting

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.

7 **Identify** the variable that is changing in this situation. (THINK: What is impacting the decline of the North Atlantic cod?)

8 **Construct** a hypothesis about this population, assuming climate change continues. (THINK: What do you expect to happen to the cod population with a changing climate?)

Lesson 4.4
Challenge: Using computer simulations

Background

Scientists can't always find answers to big questions by doing experiments. Often the risks are too great or the experimental method is outside the limits of current technology. Answers to problems like this can sometimes be found using computer simulations.

A computer simulation takes an established pattern and extends it to make a prediction about future events. A simulation is a type of model and, just like other models, it isn't always accurate, but it is the best available inference or answer to a big question that cannot be tested in any other way. Computer simulations can also be used for experiments that require a lot of repetition that would take a scientist a long time to complete manually, or to infer how things may change in the future.

Scientists have worked with the International Monetary Fund to record the mean surface temperature for Australia for each year between 1961 and 2022 (https://climatedata.imf.org/pages/climatechange-data). This was compared to the mean surface temperature between 1951 and 1980. Your job is to identify the overall trend of temperature changes and to predict the overall temperature difference in the next few years.

Aim

Use a computer to model the change in the mean surface temperature in Australia between 1961 and 2021.

Identify and use a set of secondary data to make a comparison with the data given in Table 1.

What to do:

1 Enter the information from Table 1 into a spreadsheet program, such as Microsoft Excel or similar.

2 Create a line graph of this information using the graphing function of the computer program. Make sure that mean difference in temperature is on the *y*-axis and year is on the *x*-axis.

3 Add labels for each axis. (In Excel, this can be done by selecting the graph and selecting the "+" sign. Select "axis titles".)

4 Add a trendline to the graph. (In Excel, use the same process in Step 3 and select "Trendline".)

5 Extend the trendline in the graph to this year. (In Excel, do this by right-clicking the trendline. Select "Format Trendline" from the menu. Navigate to the "Forecast" section in the "Trendline Options". Type the number of years forward from 2022 that you would like to forecast.)

6 Compare the predicted mean temperature difference you generated to that of a secondary source you identified.

Questions

1 **Describe** the location where you obtained your secondary data.

2 **Describe** how you evaluated the trustworthiness of the data.

3 **Contrast** primary and secondary data.

4 **Compare** the predicted mean surface temperature of Australia obtained from your graph with the value identified in your secondary data. If there is a difference, **explain** why.

5 **Explain** why the results of scientific models are usually compared to real-world data before they are used for predictions.

Table 1 The mean difference in Australia's surface temperature each year when compared to the mean temperature of 1951–1980

Year	Mean difference in temperature (°C)	Year	Mean difference in temperature (°C)
1961	0.157	1992	0.281
1962	0.126	1993	0.484
1963	-0.096	1994	0.221
1964	-0.012	1995	0.413
1965	0.14	1996	0.604
1966	-0.23	1997	0.383
1967	-0.093	1998	1.092
1968	-0.203	1999	0.58
1969	0.103	2000	0.148
1970	-0.007	2001	0.336
1971	-0.044	2002	0.736
1972	0.091	2003	0.835
1973	0.831	2004	0.723
1974	-0.354	2005	1.211
1975	0.048	2006	0.721
1976	-0.522	2007	0.929
1977	0.176	2008	0.625
1978	0.062	2009	1.03
1979	0.375	2010	0.673
1980	0.887	2011	0.208
1981	0.495	2012	0.308
1982	0.186	2013	1.499
1983	0.633	2014	1.198
1984	-0.157	2015	1.087
1985	0.349	2016	1.172
1986	0.388	2017	1.141
1987	0.363	2018	1.129
1988	0.96	2019	1.422
1989	0.153	2020	1.416
1990	0.549	2021	0.629
1991	0.82	2022	0.754

6 Your model used multiple data points to make predictions. **Explain** how the accuracy of the computer model would change if you were able to use thousands of data points.

7 The process you have just followed only works for "linear" data, which is data that increases or decreases at a constant rate. **Describe** another experiment you have conducted this year that you could have used this process for.

8 Similar modelling is conducted using data about weather and climate. **Define** the terms "weather" and "climate".

9 **Describe** the predictions that scientists would make by using weather and climate data.

10 **Explain** why fast computers that can handle millions of data points are required to improve the accuracy of weather and climate predictions.

Figure 1 Computer modelling can be used to represent data from a table.

Lesson 4.5
Deep ocean currents regulate global climate

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Climate change is modelled through scientific principles and data gathered over long periods of time.

→ Increased global temperatures are causing ice caps to melt, resulting in increased sea levels.

→ Deep ocean currents can regulate global climate and affect marine ecosystems.

Modelling the future

While there are many indicators of climate change, from increasing global temperatures and extreme weather events to reduction in biodiversity, scientists are constantly developing a series of models that can predict how we may be able to reduce the impact of the change. Climate change models use scientific principles and data gathered over long periods of time to simulate the transfer of energy through the climate system. Each model uses mathematical equations to describe how the thermal energy will interact with different parts of the ocean, atmosphere, wildlife and land.

Climate change models break large areas into a series of smaller cell volumes ($100\,km^3$) so that the mathematical equations are more accurate.

These equations will estimate the temperature, wind speed and rainfall for each three-dimensional cell before moving on to the next cell and repeating the calculations. Using smaller cells means the calculations for a total area take longer than if using larger cells, because the number of smaller cells per area is greater. Early climate models used very large cells, making them less accurate. The development of supercomputers has allowed scientists and mathematicians to use small cells (reducing them to $50\,km^3$), making the climate change predictions more accurate. The use of current data from satellites and the improvement of mathematical models that predict how the climate will change every 30 minutes for the next 100 years means the current climate models are very accurate (Figure 1).
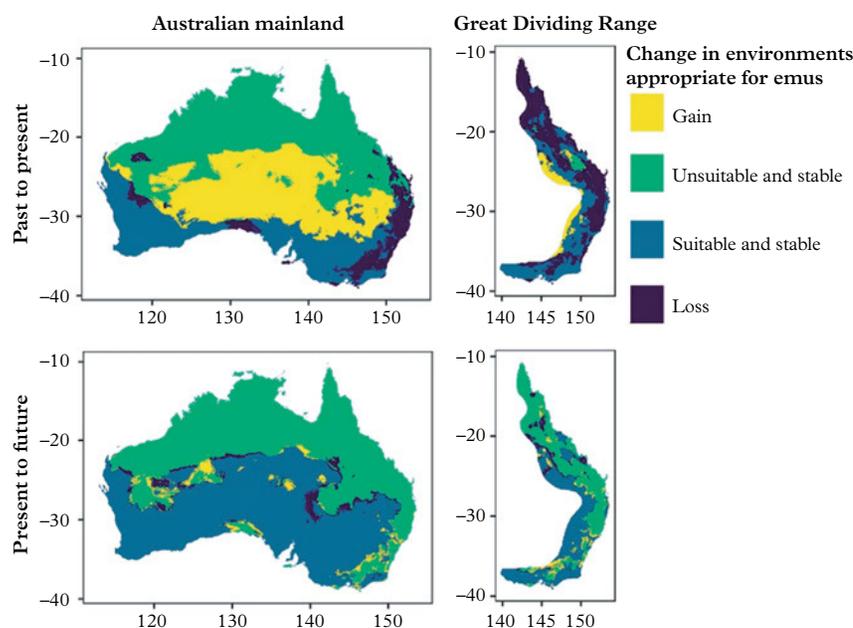
Figure 1 Supercomputers have used satellite data to predict how the changing climate in Australia will affect the distribution of emus.

Changing sea levels

The impact of climate change will vary. Some areas of Earth will experience larger changes in average temperatures than other areas. At the Earth's poles, average temperatures have increased by up to 2°C over the past 40 years (compared to 1.1°C for the rest of Earth). This is due to the increasingly warm ocean currents melting the glaciers and ice sheets (Figure 2). The extremely cold temperatures do not last long enough for the ice to fully re-form during the winter months. The thinner ice melts more quickly each year.

Modelling has shown that as the ice and snow melt at the poles, the rate of global warming due to climate change will increase.

One of the main roles of the white ice and snow is to reflect solar radiation back into space. As the amount of snow and ice cover decreases, the amount of solar radiation reflected will decrease, and the amount of solar radiation that will be absorbed by the geosphere and hydrosphere will increase. This may cause the rate of global warming to increase further as more heat energy is retained by Earth.

The water that is released from the land ice will contribute to increased sea levels. While floating sea ice replaces the water it displaces, melted land ice returns to the sea, increasing the overall sea level. This, combined with an increase in extreme storms, could impact the cities located in Australia's coastal regions (Figure 3).
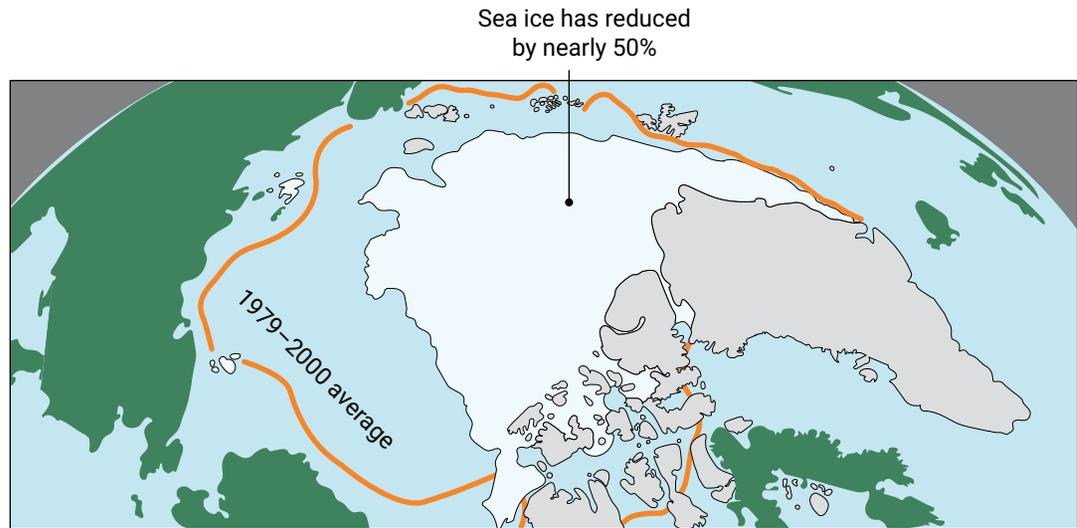
Figure 2 The amount of sea ice at the North Pole has been reduced by nearly 50 per cent in the past 20 years.
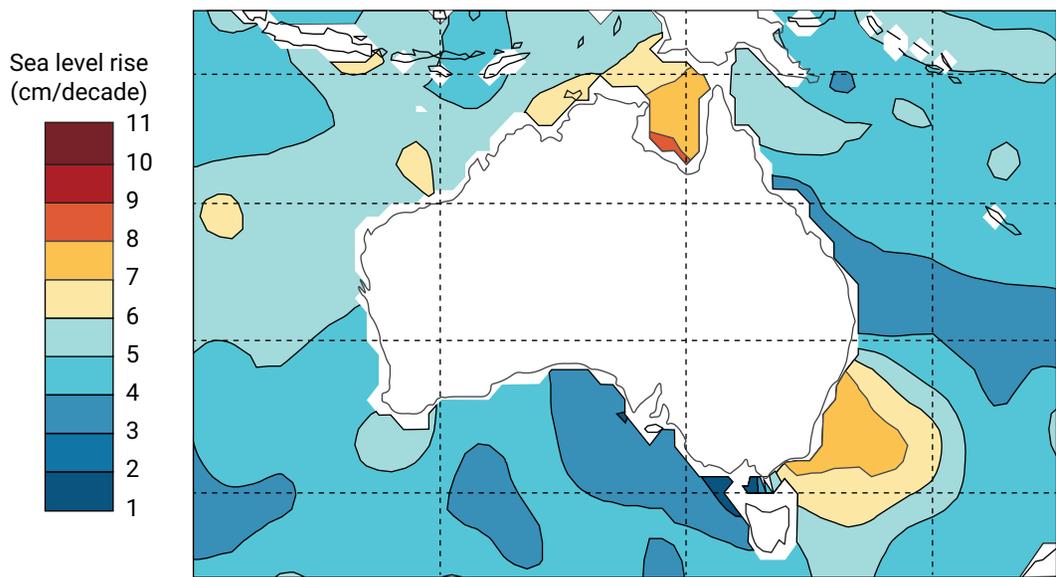
Figure 3 The modelled rise in sea levels in Australia every 10 years.

Melting permafrost

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 the Arctic for over 50 years and they have noticed an upward trend. This means the ice is getting close to melting temperature (0°C) (Figure 4). Scientists hypothesise that as much as two-thirds of the Earth's permafrost could disappear by 2200.

If the Earth's permafrost does melt, the biological material that was trapped will start decomposing and 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.
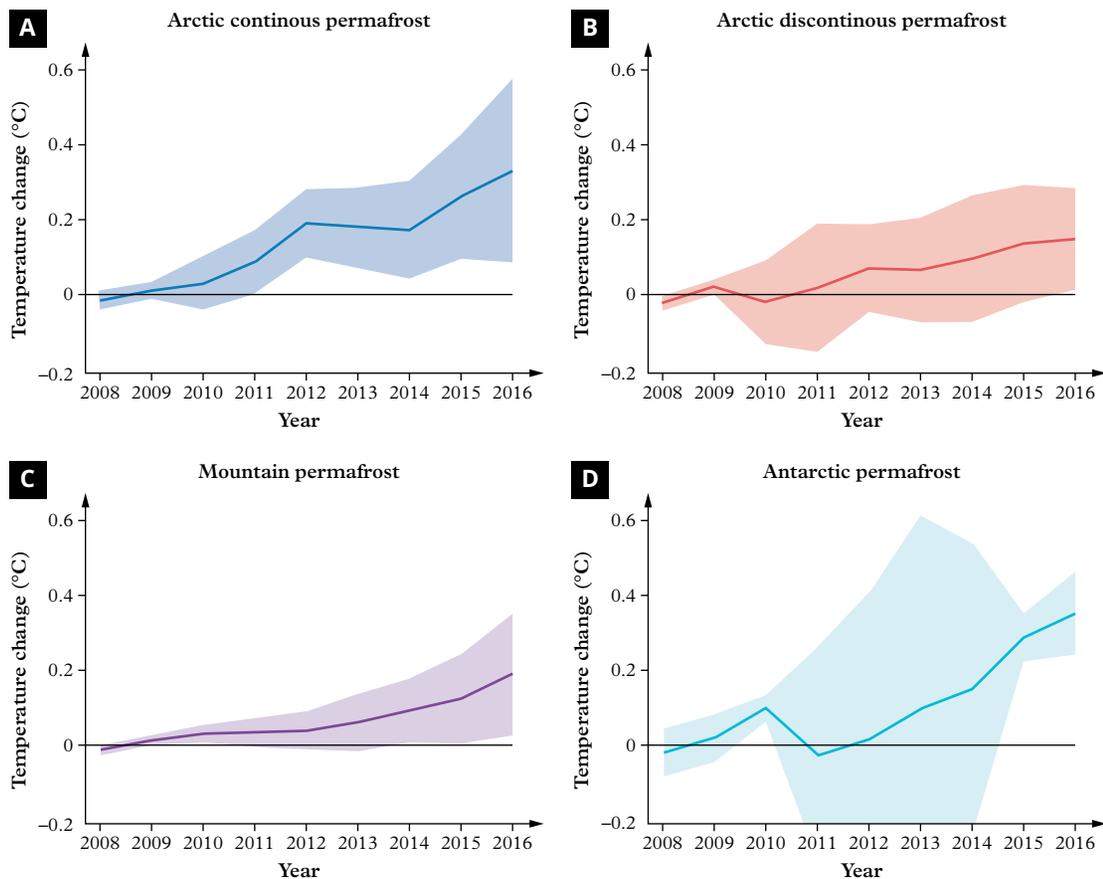
Figure 4 Historical measurements of Arctic permafrost temperatures suggest that the permafrost is becoming warmer.

Deep ocean currents and climate control

Within the oceans are large deep ocean currents that act like conveyor belts, distributing heat through parts of the world and regulating temperature (Figure 5).

Ocean currents have the important job of moving warm water from equatorial regions towards the poles; the water cools and travels from the poles back to the warmer areas of Earth. These large conveyer belts of water are driven by the differences in temperature and salinity (salt content). Cold water is dense and heavy, and it moves towards the ocean floor picking up many nutrients along the way. Warmer water is less dense and moves up 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 which causes the remaining water to become more concentrated in salt. The salty water will continue to sink 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.

Small changes in these large ocean currents can produce large changes in the marine life and the climate (Figure 6). 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 northern Australia. A La Niña event occurs when the Pacific Ocean is cooler than normal, causing increased rainfall and possible flooding in Australia. This means that small changes in the temperature of the Antarctic region will result in large changes in the climate of all parts of Australia.

Earth and Space

4.5
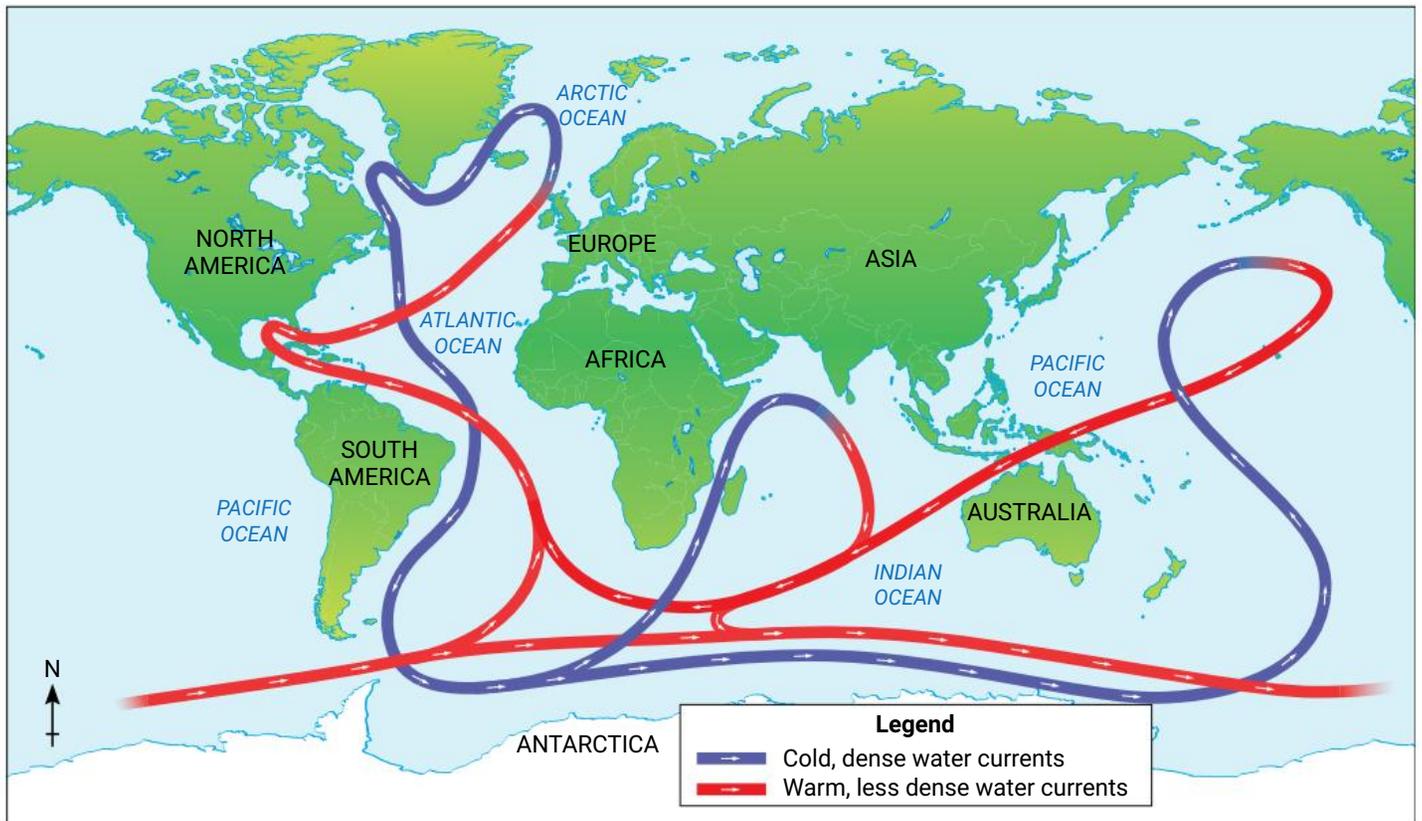
Figure 5 The path of the ocean "conveyor belt", in which differences in temperature and salinity drive the movement of large currents of water

Figure 6 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.

Deep ocean currents have a large impact on marine life. This can be seen in the Galapagos Islands in South America where cold ocean currents carrying nutrient-rich deep water travel up to the surface. This process is known as **upwelling** and helps transport nutrients to the surface of the islands. Nutrients then feed phytoplankton and support the food web of the marine ecosystem. The upwelling process also occurs along the coast of Queensland during monsoon season (Figure 7). Occasionally, the upwelled waters do not completely reach the surface. When this occurs it is called an **intrusion**.
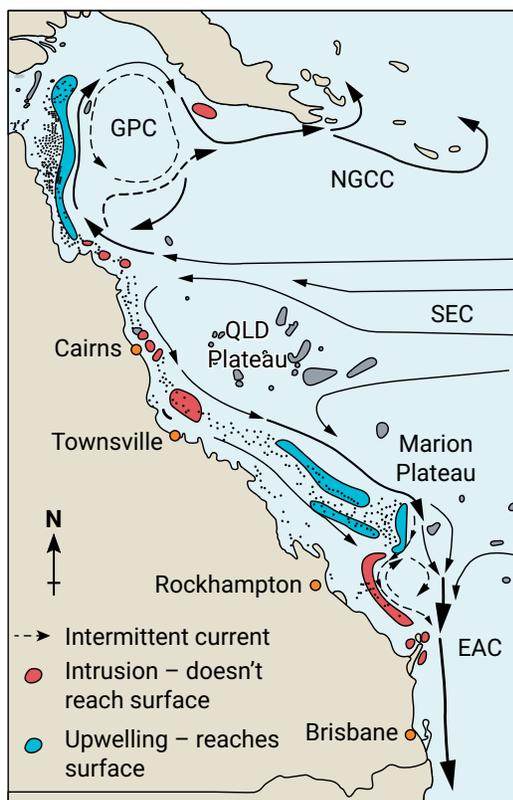
upwelling
a process in which deep, nutrient-rich cold water moves up towards the surface

intrusion when upwelled waters do not reach the surface

Earth and Space

Figure 7 Ocean currents driving marine ecosystems through upwelling and intrusion during monsoon season in Queensland

Check your learning 4.5

Check your learning 4.5

Comprehend

1 **Describe** how scientists and mathematicians model climate change.
2 **Describe** why the development of supercomputers has improved the accuracy of climate modelling.
3 **Explain** the role of ocean currents in regulating global temperature.
4 **Explain** how the temperature of the Pacific Ocean can affect Australia's climate.

Analyse

5 **Compare** the impact of sea ice and land ice on sea levels.

Apply

6 Use Figure 3 to **determine** the expected rise in sea level at the coast closest to where you live.
7 It is expected that as the sea level rises, the inland water table will also rise. Many new housing developments are built just above the water table. **Create** a flyer that explains why the residents in a new housing development should care about global warming.

Lesson 4.6
Experiment: Melting ice and its effect on sea levels

Aim

To observe the effect of melting sea and sheet ice on global sea levels

Materials

- Ice cubes
- 50 mL beaker
- Spatula
- Clay or plasticine
- Marker pen

Method

Part A: Sea ice

Sea ice is floating ice, like the ice found in icebergs.

Design an experiment using the listed materials 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 per cent of Antarctica is covered by sheet ice and the Antarctic ice sheet is one of two polar ice sheets.

Design an experiment using the listed materials 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 experiment in an appropriate format, such as a research poster, digital simulation, or video post.

Discussion

1 **Compare** the water level changes caused by melted sea ice and melted sheet ice.
2 **Explain** the differences you noticed between the water levels for each type of ice.
3 **Compare** this model to what happens in the real world.
4 **Evaluate** the validity of this experiment (by explaining how well the experiment measured what it intended to measure, identifying other factors that may change the outcomes in the real-world example, and deciding whether the model is a valid representation of the real world).

Conclusion

Describe how melting sea ice or melting sheet ice will affect sea levels.

Figure 1 Antarctica is home to both sheet and sea ice.

Lesson 4.7
Challenge: Salt water density

Aim

To determine how salt affects the density of water

What you need:

- 4 × 200 mL beakers
- Water
- Marker
- Salt
- Large spatula or plastic teaspoon
- Food colouring (four different colours)
- Plastic disposable pipette
- Test tube and test-tube rack

What to do:

1. Add 150 mL of water to each beaker. Label the beakers 1 to 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.
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.

Questions

1. **Define** the term "density".
2. **Use** evidence from your results to **identify** which solution has the greatest density – the solution in beaker 1 or beaker 4.
3. **Use** evidence from your experiment to **describe** how the fresh water from rivers will behave as it enters the ocean.
4. Water from melted ice is often denser than the salt water ocean. **Use** a diagram to **describe** how the icy fresh water will behave when it enters the ocean.
5. **Describe** how the density of water can cause ocean currents.

Lesson 4.8
Science as a human endeavour: Climate change can be mitigated

Learning intentions and success criteria

Key ideas

→ Climate change mitigators work to reduce the cause or impact of climate change.

→ Reducing the use of fossil fuels or the production of methane will slow the impact of climate change.

→ Removing carbon dioxide from the atmosphere will reverse the impact of climate change.

Introduction

Increasing awareness of the effects of climate change has resulted in increased urgency to implement change. There are two key approaches humanity is using to respond to climate change: mitigation and adaptation.

Mitigation

climate change mitigation efforts that aim to reduce or prevent greenhouse gas emission

Climate change mitigation refers to actions that work to reduce the production of greenhouse gases, or that increase the rate of greenhouse gas removal from the atmosphere.

Reducing production of greenhouse gases

The greenhouse gas carbon dioxide (CO_2) is produced through the chemical reaction called combustion. In a combustion reaction, a fuel reacts with oxygen and produces carbon dioxide and water as follows:

$$fuel + oxygen \rightarrow carbon\ dioxide + water$$
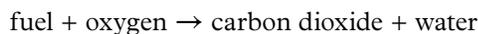
Combustion is used for powering cars, industrial production and even the heating of our homes. The demand for and consumption of oil, coal and gas has steadily increased in Australia over the past 50 years. However, as more people have become aware of the effects of global warming, they are changing their habits. Figure 1 shows that the consumption of electricity generated by coal has gradually reduced since 2009. Reducing the number of trips in cars and aeroplanes, and improving the insulation of houses and businesses to reduce heating and cooling costs can all contribute to the reduction in energy consumption and therefore reduce carbon dioxide production.

Another greenhouse gas that has a significant impact on climate change is methane (CH_4). This gas can store up to 25 per cent more heat than carbon dioxide. Approximately 32 per cent of methane emitted by human activity comes from agricultural manure and gastroenteric releases from agricultural livestock such as cattle (Figure 2). These methane emissions can be reduced by cutting down on the amount of red meat consumed and by opting for plant-based substitutes for dairy and protein.
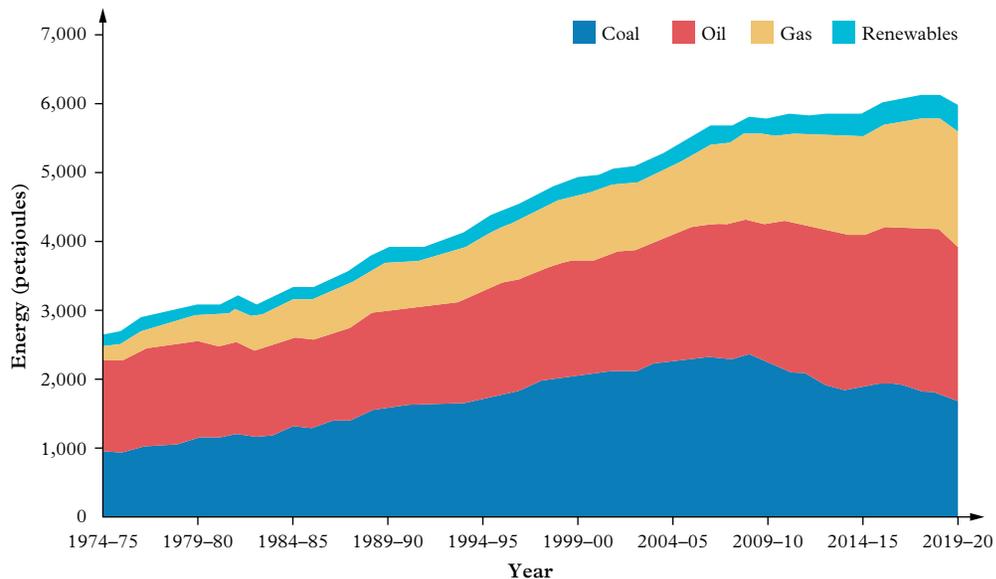
Figure 1 The amount of energy consumed in Australia over time

Figure 2 Reducing the amount of red meat and dairy consumed can reduce the demand for agricultural cattle.

Methane is also produced when food waste is broken down. The National Food Waste Strategy Feasibility Study calculated that food waste produces 3 per cent of Australia's greenhouse gas emissions. This is equivalent to 312 kg per person. This is the reason for the establishment of the National Food Waste Strategy and Action Plan that aims to reduce Australia's food waste by:

• redirecting more food to the food rescue sector
• delivering an education campaign
• making investments that aim to create value from food waste.

Removing greenhouse gases

Several different strategies to remove greenhouse gases (such as carbon dioxide) are currently being applied and having their effectiveness tested to determine best practice. The first of these strategies is **reforestation**. This process involves planting new trees and vegetation (Figure 3). Through the process of photosynthesis, the carbon dioxide is removed from the atmosphere and stored as other molecules in the plants. The risk of this process is that the carbon dioxide could be released during a bushfire.

reforestation the process of replanting trees and vegetation to restore natural habitat

Figure 3 Reforestation restores vegetation which can remove CO_2 from the atmosphere.

Carbon dioxide is also being captured directly from the air using Direct Air Carbon Capture and Storage (DACCS). This process uses chemicals that directly bond to carbon dioxide. The gas is then extracted and stored in sedimentary rock that previously contained oil and gas. Rocks used to store the CO_2 are carefully chosen. They must have high porosity (contain small holes) and permeability (ability to let things in and out). After capturing and storing the carbon dioxide, the sedimentary rock is capped by a mud stone which prevents the carbon dioxide from escaping back into the atmosphere. The DACCS process is currently being trialled in several states of Australia.

A much older method of carbon dioxide removal used by Aboriginal and Torres Strait Islander Peoples involves removing carbon dioxide from the atmosphere using **biochar**. Biochar is a fine-grained charcoal produced from the slow-burning of organic material in a low-oxygen environment (Figure 4). Plants emit carbon dioxide into the atmosphere when they decay. Slow-burning biomass into biochar and then storing it in soil controls the release of CO_2. Instead of being released into the atmosphere, the CO_2 is stored in the ground for hundreds of years. This way, stored CO_2 can act as a fertiliser, improve the quality of water, and reduce soil acidity and the amount of irrigation needed.

biochar a lightweight residue containing carbon and ash that is formed from the slow burning of biomass

Figure 4 Biochar

Adaptation

climate change adaptation coping adjustments made in response to the effects of climate change

Climate change adaptation refers to making changes to adjust to the current or predicted effects of climate change. A major struggle with global climate change is that some communities are currently being affected more than others. For example, low-level islands in the Pacific (such as the Torres Strait Islands) are more susceptible to the effects of extreme

weather and rising sea levels. In December 2016, the Torres Strait Regional Adaptation and Resilience Plan was released. This plan identified several actions that could be made to adapt to and limit some of the impacts of climate change. One action included the construction of a sea wall to protect Saibai Island from erosion and the impact of storm surges (Figure 5).

Torres Strait Islander Peoples are also involved in monitoring the temperature and humidity levels in the community. This is used to reduce the heat stress risk for individuals. Plans have also been generated to organise outdoor activities during cooler times. Another action as a result of the plan includes the monitoring of five climate-sensitive infectious diseases, including tuberculosis, Ross River virus, dengue fever and soil-borne infections. This is to ensure the local health systems of the Torres Strait Islands can adapt to the increasing risk of infections.

Figure 5 The sea wall of Saibai Island in the north-western Torres Strait, Cape York, Queensland

Test your skills and capabilities

Communication

A climate sceptic is someone who does not believe the increasing levels of carbon dioxide in the atmosphere are causing rapid climate change. It can be difficult to change someone's mind. A study published in the scientific journal *Nature* in 2015 identified that emphasising the shared understanding of climate change was an effective way to encourage people to take action.

People are more likely to listen if they know and trust the messenger. This means children are more likely to be persuaded by their parents than by a stranger. It is also important to use data and evidence in arguments.

1   **Calculate** your personal carbon footprint using an online carbon footprint calculator.
2   **Predict** one change to your lifestyle that will reduce your carbon footprint and help mitigate the effects of climate change.
3   **Calculate** your carbon footprint again. In your calculation, make the one change that you predicted would reduce your carbon footprint.
4   **Write** a letter to someone you know **explaining** climate change. **Use** the data and evidence in this module to **explain** why it is important for them to make the changes you tested in the carbon footprint calculator, so they can also reduce their carbon footprint.

Lesson 4.9
Review: Climate change

Summary

Lesson 4.1 Climate change is global

- Weather is the short-term changes in temperature, wind, rain, humidity and atmospheric pressure in a small region.
- Climate is a long-term measure of averages, variations and extremes in weather over large global areas.
- Solar radiation interacts with and causes the exchange of energy between the atmosphere, ocean and land to affect the global climate system.

Lesson 4.3 Climate change indicators include increased global temperatures, extreme weather, disease and species distribution

- Data is used to measure and analyse climate change.
- Climate change has caused increasing global temperatures and extreme weather events.
- Climate change has changed the distribution of diseases.
- Rapid changes in climate have changed and will continue to change the distribution of species.

Lesson 4.5 Deep ocean currents regulate global climate

- Climate change is modelled through scientific principles and data gathered over long periods of time.
- Increased global temperatures are causing ice caps to melt, resulting in increased sea levels.
- Deep ocean currents can regulate global climate and affect marine ecosystems.

Lesson 4.8 Science as a human endeavour: Climate change can be mitigated

- Climate change mitigators work to reduce the cause or impact of climate change.
- Reducing the use of fossil fuels or the production of methane will slow the impact of climate change.
- Removing carbon dioxide from the atmosphere will reverse the impact of climate change.

Review questions 4.9

Review questions: Module 4

Retrieve

1 **Identify** which of the following is the result of sideways or horizontal movements of air due to pressure differences.
   A Deep ocean currents
   B Wind
   C The Coriolis effect
   D Solar radiation

2 **Identify** 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 **Identify** which of the following best describes the "ocean conveyer belt".
   A The movement of water in the ocean
   B The migration of marine life
   C The heating and cooling of the ocean
   D The most effective path for sailing the ocean

4 **Define** the term "solar radiation".

5 **Recall** which of the Earth's spheres describes all the water contents of Earth.

6 **Define** the term "greenhouse gas". **Identify** three greenhouse gases.

7 **Recall** the global temperature increase (in degrees Celsius) that NASA has predicted will cause annual heatwaves, water stress, increased heavy rainfall, floods, reduced biodiversity, increased wildfires and increased melting of the polar ice caps.

Comprehend

8 **Describe** one way that the greenhouse gas methane is released into the atmosphere.

9 **Describe** one way that the greenhouse gas carbon dioxide is released into the atmosphere.

10 **Explain** why cold water from melted sea ice will sink to the bottom of the ocean.

11 **Describe** two causes of climate change in the past 2,000 years.

12 **Explain** why upwelling is important for some marine ecosystems.

13 **Explain** why animals that live in the polar regions of Earth (the Arctic or Antarctic) are at great risk due to climate change.

Figure 1 Polar bears are at risk of extinction.

14 **Explain** how biochar is produced and how it can be used to reduce carbon dioxide emissions.

15 **Describe** how high-pressure and low-pressure weather systems are formed.

16 **Explain** why it is warmer near the equator than elsewhere on Earth.

17 **Explain** why increased melting of sea ice will trigger a more rapid rate of global temperature increase.

Analyse

18 **Contrast** weather and climate.

19 **Compare** climate change mitigation with climate change adaptation.

20 **Compare** ocean currents and air currents.

Apply

21 The Bramble Cay melomys was a rodent native to Bramble Cay, a small island on the surface of a coral reef in the Torres Strait (Figure 2). The species was declared extinct by the Queensland Government and University of Queensland in 2016. It was the first species reported to become extinct because of human-caused climate change.

Investigate the Bramble Cay melomys. **Identify** some of the effects of climate change that caused the species to become extinct.

Figure 2 The Bramble Cay melomys

22 **Discuss** how deep ocean currents can affect climate.

23 Consider the weather map of Australia shown in Figure 3.

a **Predict** whether the Queensland coast is more likely to experience storms and rain, or clear sunny skies. **Justify** your response.

b **Predict** whether the south coast of Western Australia is more likely to experience storms and rain, or clear sunny skies. **Justify** your response.

c **Describe** how quantum computers (that could handle millions of data points at once) could impact the accuracy of long-term weather and climate predictions.
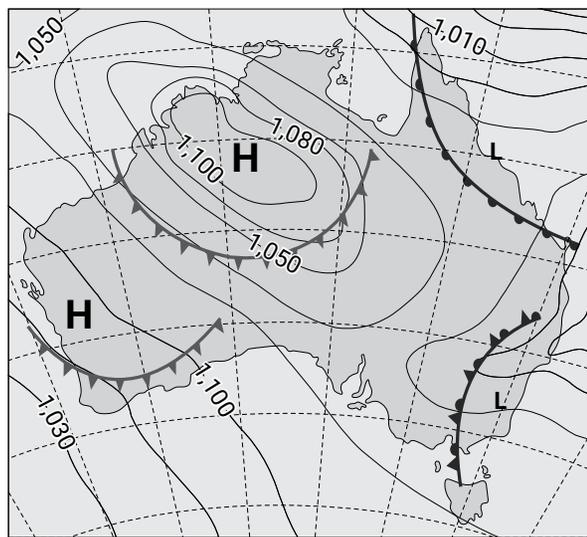
Figure 3 Weather map of Australia

Module 4 Climate change **213**

Social and ethical thinking

24 Red meat and dairy from livestock are heavily consumed in Australia as they offer a range of nutritional benefits and tastes, and are easily accessible to purchase. However, the red meat industry in Australia contributes 11.8 per cent of Australia's total greenhouse gas emissions.

Discuss the ethical dilemma of red meat overconsumption by:

– **investigating** and **describing** the advantages of consuming/purchasing red meat

– **investigating** and **describing** the disadvantages of consuming/purchasing red meat

– **deciding** whether the advantages are more important than the disadvantages.

Justify your response.

Figure 4 Red meat is a popular choice in many Australian households.

25 Not all countries have contributed to climate change equally. Countries that were industrialised earlier or industrialised to a large scale have had longer periods of time and greater capacity to emit greenhouse gases into the atmosphere. Climate debt is a concept that was proposed in the 1990s that suggests developing countries are owed a debt by developed countries for the disproportionate damage developed countries have contributed to climate change.

Investigate climate debt and **discuss** whether you believe it is fair for developed countries to owe a climate debt to developing countries severely affected by climate change.

Critical and creative thinking

26 One of your close personal friends tells you that they don't believe in climate change. **Use** evidence presented in this module to **write** a persuasive passage you could use to try and change your friend's mind about the climate crisis.

27 **Create** a concept map that links all the bolded glossary terms in this module together.

28 **Create** an infographic that highlights the evidence of how climate change is impacting polar ice caps, ocean temperatures and extreme weather events.

29 Imagine you had to reduce your energy impact on the environment. Look at all the appliances and gadgets you use in your home. **Identify** one of these as one that 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.

Research

30 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **Reducing methane production with FutureFeed**
>
> Approximately 1.3 billion people around the world rely on livestock for their livelihoods. Unfortunately, livestock also contributes 15 per cent of global greenhouse gas emissions. Scientists from CSIRO, Meat & Livestock Australia and James Cook University have developed livestock feed called FutureFeed which can reduce the emissions produced by the livestock that consume it.
>
> Research FutureFeed and **describe**:
>
> - what FutureFeed is made of
> - how it works to reduce methane emissions
> - the impact FutureFeed can have if global cattle famers adopt it as feed.

Figure 5 *Asparagopsis* spp. are native to Australia and are used in FutureFeed.

Rising sea level crisis

As the polar ice caps melt and sea levels rise, low-level (low elevation) island countries are at serious risk of disappearing if sea levels continue to rise as they are now. One such island includes the island nation of Kiribati.

Research Kiribati and describe:

- the factors that leave Kiribati so vulnerable to rising sea levels
- the climate adaptation strategies in place to deal with the impact of rising sea levels washing out Kiribati.

Figure 6 Tabuaeran Beach, Kiribati

Responding to climate change

The Paris Agreement (2015) is a legally binding international agreement between countries that aims to reduce greenhouse gas emissions in the atmosphere at a level that would prevent danger to the Earth's climate system.

A key target is to limit global warming to 1.5 degrees Celsius by ensuring that greenhouse gas emissions peak before 2025 at the latest and decline by 43 per cent by 2030.

- **Investigate** Australia's commitment and current goals that have resulted from this agreement.
- **Describe** the strategy that Australia is using to meet its commitment.
- **Evaluate** the strategy to determine if Australia will be able to meet its commitment.
- **Identify** a recent Australian news or social media article that reports on carbon dioxide levels in the atmosphere and a possible consequence.
- **Evaluate** the credibility and accuracy of the headline and the data used in the article.
- **Explain** how this data could be presented in a different way that could be used to mislead the reader.

Module

5

The universe

Overview

Space exploration helps us learn about the universe, its origins, and how humans might live beyond Earth. Living in space affects the human body, especially in microgravity, where fluids and movement behave differently. This means that scientists need to design effective habitats and spacesuits so that humans can survive the challenges of living in space.

The universe includes galaxies, stars, planets and black holes. Telescopes and space technology are used to collect data on the universe. The Big Bang theory explains how the universe began and is supported by evidence of the red shift in light from stars and cosmic background radiation. Aboriginal and Torres Strait Islander Peoples also have deep knowledge of the stars gathered over tens of thousands of years.

Lessons in this module

Lesson 5.1

Science as a human endeavour: The universe was studied by Aboriginal and Torres Strait Islander Peoples

Key ideas

→ Aboriginal and Torres Strait Islander Peoples have been observing the night sky for thousands of years.

→ They use the stars and constellations to determine when certain activities should occur as part of their seasonal calendar, such as hunting and farming.

→ Dreaming stories are used to pass down information and traditions.

Learning intentions and success criteria

Introduction

While many people consider the ancient Greeks (400 BCE) to be the first astronomers, there is increasing recognition of early astronomers among Aboriginal and Torres Strait Islander Peoples, who have been observing the movement of the stars for navigation, animal and plant behaviour, hunting, Dreaming stories and reflections of Earth for over 60,000 years. Aboriginal and Torres Strait Islander Peoples continue to have many practical uses for what they observe in the night sky. The night sky is a calendar and an integral part of Indigenous cultures and spiritualities.

Aboriginal and Torres Strait Islander Peoples' calendars

constellation
a group of stars that form a pattern or picture

Constellations are groups of stars that form a picture in the night sky. To many groups of Aboriginal and Torres Strait Islander Peoples, the appearance of certain constellations at sunrise or sunset and how they track across the sky provide information on animal activity. This provides information about what to hunt and when.

Many people in Australia are familiar with the whitish hazy band that appears across the sky. This is the Milky Way, which is our galaxy (a group of stars held together by their own gravity). Deep within the Milky Way is a dark patch that looks like an emu (Figure 1). Across Australia, there are many Indigenous stories about the emu in the sky. To the Wiradjuri people living on Country in central New South Wales, when the emu, known as Gugurmin, appears on the eastern horizon at sunset, the emus are nesting and there are no eggs to collect. Later in the year, Gugurmin appears directly overhead at sunset and it is time to collect the emu eggs. Stories are often told as a warning not to collect too many eggs or Gugurmin will disappear. This is sustainable practice and part of the seasonal hunting calendar.

To the Boorong people living on Country at Lake Tyrrell in Victoria, the appearance of the ancestral mallee fowl constellation, called Neilloan, during March and September, signals that the bird is building its nest mounds. When the constellation disappears in late September or early October, it is time to gather the eggs.

To the Aboriginal and Torres Strait Islander Peoples living on Country in the Gulf of Carpentaria, in northern Australia, a group of stars (called Scorpius by Europeans) appearing in the night sky in April means the wet season is over and soon the dry south-easterly wind will start. This forms part of their seasonal calendar.
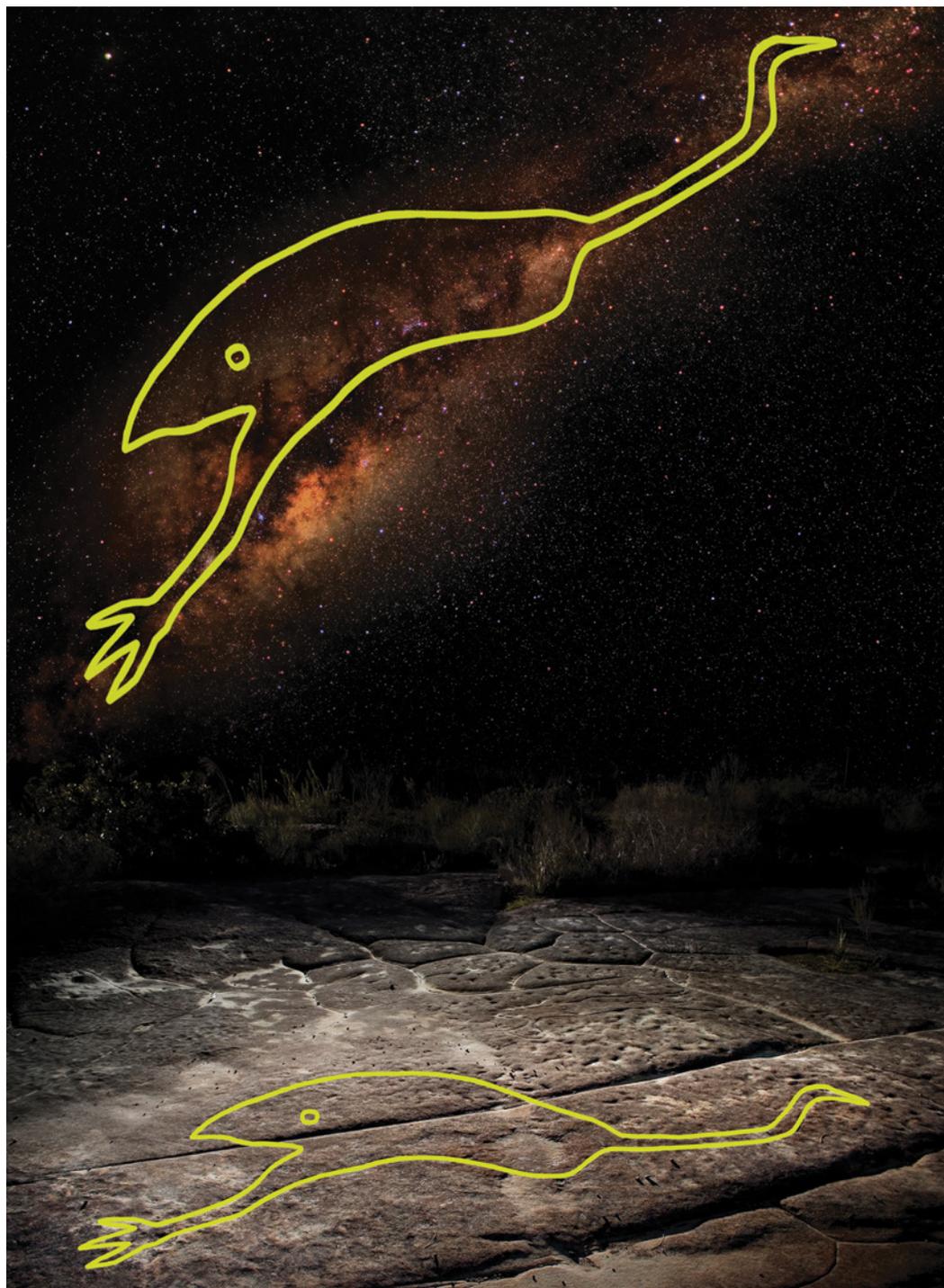
Figure 1 The emu-shaped dark patch in the Milky Way tells Aboriginal and Torres Strait Islander Peoples when it is time to hunt.

Farming by the stars

Some Aboriginal and Torres Strait Islander Peoples also plan farming by the stars. Torres Strait Islander Peoples identify a constellation in the southern sky as Tagai, the great fisherman standing in a canoe. His left hand is holding a spear in the Southern Cross and points to the south. Tagai is used both for navigation and to identify the best time to start planting gardens at the start of the wet season (when Tagai's left hand dips into the sea in November). This also forms a part of the seasonal calendar.

Stories in the stars

Aboriginal and Torres Strait Islander Peoples are diverse and live in all parts of Australia. Each Nation has its own language and Dreaming stories of the stars. Many of the stories are used to pass on information or explain lore and traditions.

The constellation of stars called Orion by Europeans has different stories told about it by different Nations. The Yolngu people of the Northern Territory call this constellation Djulpan (Figure 2). To the Yolngu people, Djulpan tells of three brothers of the King-fish (Nulkal) clan sitting side-by-side in a canoe. The cloud of stars in the nearby nebula are the fish, and the stars marking Orion's sword are the fishing line. The three brothers are forbidden to eat any king-fish. The brothers catch king-fish after king-fish but have to throw them all back. Eventually one of the brothers becomes so hungry he eats the king-fish. The Sun-woman (Walu) sees him kill the king-fish and, in anger, creates a water spout that lifts the brothers up into the sky.

To the Napaljarri-warnu Jukurrpa people of Central Australia, this same group of three stars is a Jakamarra man chasing seven young Napaljarri sisters across the sky. The fleeing women found in a cluster of stars always ahead of the man in the sky act as a warning for the two groups to respect their differences.

Test your skills and capabilities

Early scientists

For thousands of years, Aboriginal and Torres Strait Islander Peoples have observed and recorded the recurring patterns of star movement in the sky. Developing these Dreaming stories requires the use of many scientific skills, such as asking questions about the surrounding environment, making detailed observations, recording data (through oral traditions or painting landscapes), data analysis to recognise patterns, making conclusions, and communicating through paintings or oral traditions.

1 **Identify** the name of the Indigenous language group in your local area.
2 **Describe** a Creation story that is told through secondary sources (books or a trustworthy internet website) or primary sources (a local Elder). Remember to ask the permission of the Elder to write the story down.
3 **Explain** why it is important to seek permission and acknowledge the elders when learning and repeating an Indigenous story.

4 **Identify** which science inquiry skills from the list below were used to develop the story, and **describe** how each skill was used.
   – Questioning and predicting
   – Planning and conducting
   – Processing, modelling and analysing
   – Evaluating
   – Communicating
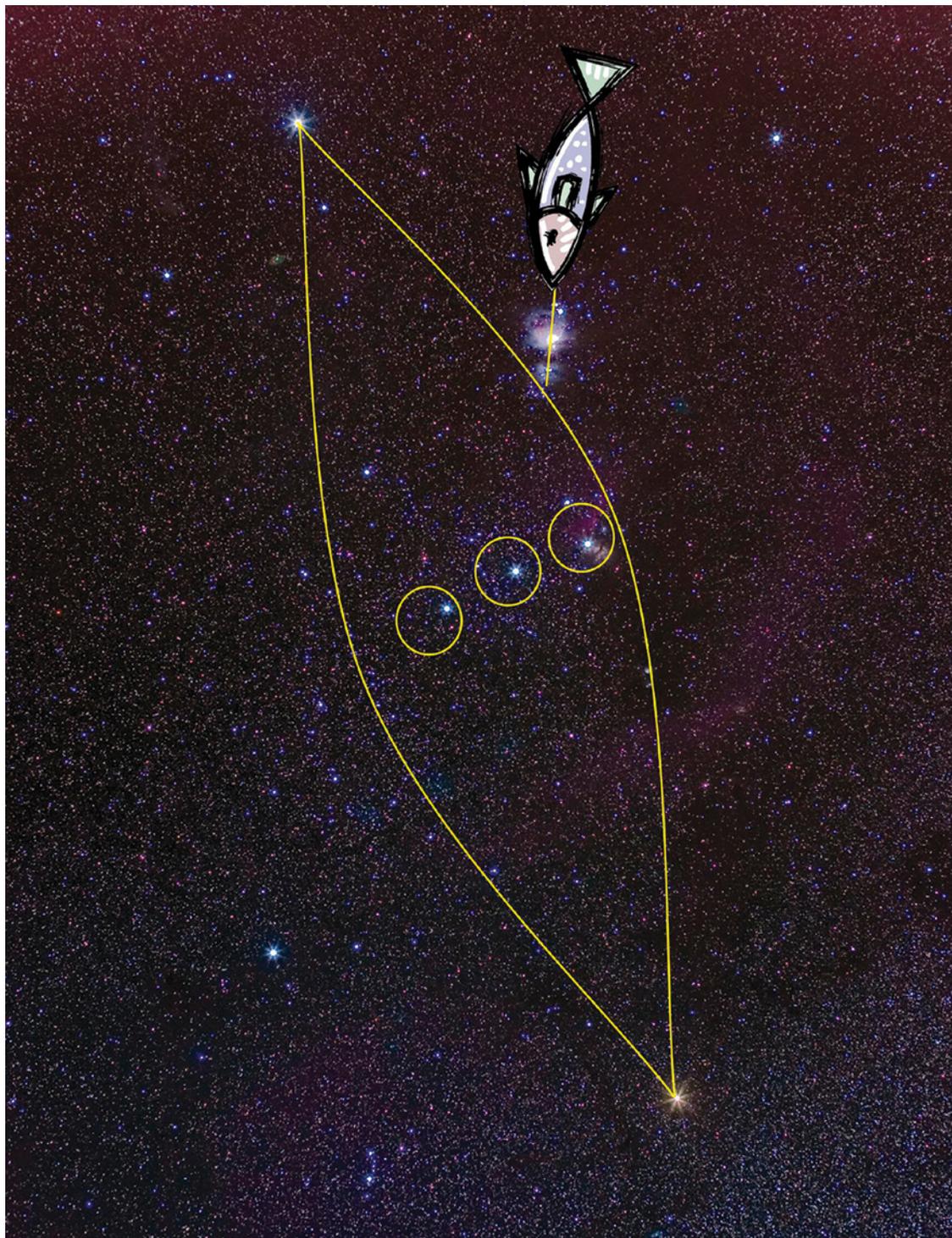
Figure 2 Different Dreaming stories are used by Aboriginal and Torres Strait Islander Peoples to explain the same constellation. The Yolngu people call the Orion constellation Djulpan.

Lesson 5.2
Skills lab: Using a star chart

Context

Planispheres or star charts are very useful maps for locating various stars in the night sky. A sky chart can be easily downloaded each month from the Skymaps website.

What you need:

A copy of this month's sky chart (Make sure you click on the southern hemisphere option.)

What to do:

1 Read the instructions on how to use the sky chart. These are printed around the outside of the circular chart, along with other useful information about the chart.

2 Find the south celestial pole (SCP), which is marked a few centimetres above south on the chart. This is just a place in the sky; there is no star nearby. Over the course of a night, the stars appear to rotate around this point. In the northern hemisphere, the North Star is located at the north celestial pole (NCP) and so it is used in navigation to find north.

3 Look at the bottom right-hand corner of the chart, which gives a key to the symbols on the chart. The star magnitudes give the brightness of the stars as viewed from Earth.

Questions

1 **Identify** the location of the brightest star in the sky (Sirius).

2 **Identify** the star that is the second brightest in the sky.

3 **Identify** which star is brighter – Alpha Centauri or Beta Centauri.

4 Use your star chart to observe the night sky. Circle the stars and constellations you were able to **identify**.

Figure 1 What constellations can you see?

Lesson 5.3
The Earth is in the Milky Way

Key ideas

→ Stars are large balls of gas that undergo nuclear fusion.

→ Stars that appear brighter are described as having a high apparent magnitude.

→ Larger, hotter stars that are farther away have a higher absolute magnitude.

→ As the Earth rotates, stars appear to move in the sky due to stellar parallax.

→ One light-year is the distance light travels in a vacuum in 1 year.

Learning intentions
and success criteria

Earth and Space

Introduction

The universe (all existing matter and space) consists of many different galaxies, stars (suns), planets with and without moons, comets, and clouds of dust and gas. Understanding how all these objects evolve and affect each other allows us to understand how our nearest star (the Sun) will continue to change over time.

Galaxies

Our Sun is one of millions of stars that make up the spiral Milky Way galaxy. Our Sun is found on one of the tail ends of the flattened spiral. When you look up at a darkened sky (away from city lights), you should see a white ribbon of stars across one part of the sky. This is because you are looking across the flattened disc of the Milky Way galaxy (Figure 1).
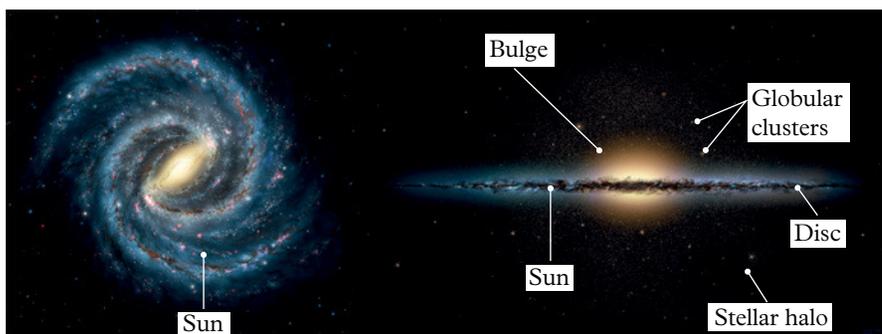
Figure 1 The Earth is located in the spiral galaxy called the Milky Way. When viewed from the side, the galaxy is a disc shape that can be viewed across the night sky on Earth.

Galaxies come in all shapes and sizes, including spiral, elliptical or irregular. The galaxies are constantly moving away from each other. It is thought that the centre of our Milky Way spiral galaxy contains a massive black hole that uses gravity to hold all the other solar systems in orbit. It can take approximately 250 million years for our Sun to orbit the centre of the Milky Way.

5.3

The solar system

The Earth is a very small part of a group of planets that orbit the Sun. Our solar system consists of a single star (the Sun) with eight orbiting planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune), five dwarf planets (Eris, Pluto, Ceres, Makemake and Haumea), and many moons, asteroids and comets, all bound together by gravity.

The Earth is a relatively small planet that takes 1 year (365.25 days) to travel approximately 940 million kilometres around the Sun. This path travelled by the Earth is called an orbit. Every 4 years we have a leap year. This adds an extra day in our calendar (February 29) to allow for the accumulation of the extra distance travelled by the Earth each year.

Light-year

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.

light-year the distance that light travels in 1 year

Light travels very fast, at 300,000 km/s. The distance that light travels in 1 year is called a **light-year** (9,500,000,000,000 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 nearest star in the Southern Cross is Gacrux (88 light-years away from the Earth). The 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!

Worked example 5.3A shows how to use light-years to calculate distance in kilometres.

Stars

A star (including our Sun) is a giant ball of hot glowing gases. Most stars are made almost entirely of hydrogen and helium. These gases are constantly colliding and reacting at the core (centre) of the star. When the atomic nuclei collide and fuse, they release energy to the star through **nuclear fusion**. 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. Stars can be different sizes, masses, temperature and brightness.

nuclear fusion a reaction in which two lighter atomic nuclei fuse to form a heavier nucleus, releasing energy

What does a star's brightness mean?

apparent magnitude scale a scale for measuring the brightness of an object when viewed from Earth

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 closer to zero (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, but it may not actually be very bright (Figure 2). 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.

absolute magnitude scale a scale for measuring the brightness (luminosity) of objects from the same distance

luminosity the actual brightness of a star (amount of energy it radiates); measured using the absolute magnitude scale
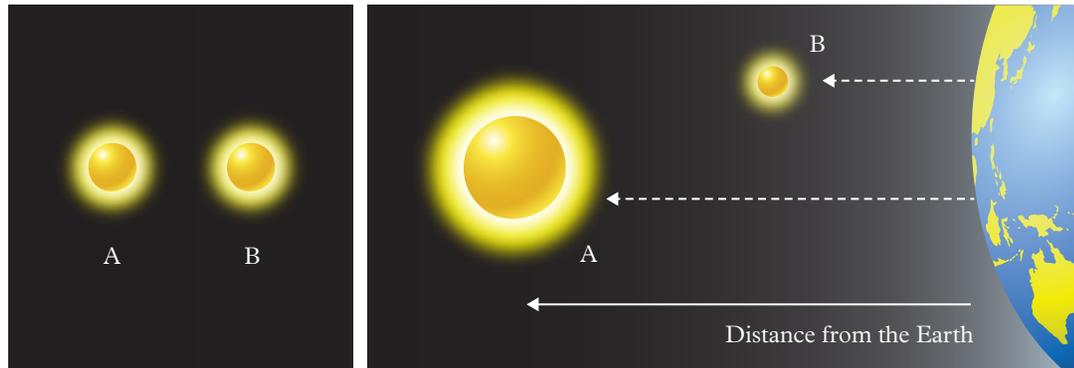
Figure 2 Although both stars A and B have the same apparent magnitude, A is more luminous and has a higher absolute magnitude than B.

In the Southern Cross (Figure 3), Alpha Crucis (Acrux) and Beta Crucis (Mimosa) have the greatest apparent magnitude. Acrux appears brighter because it is two stars that sit close together and are closer to Earth than Mimosa.
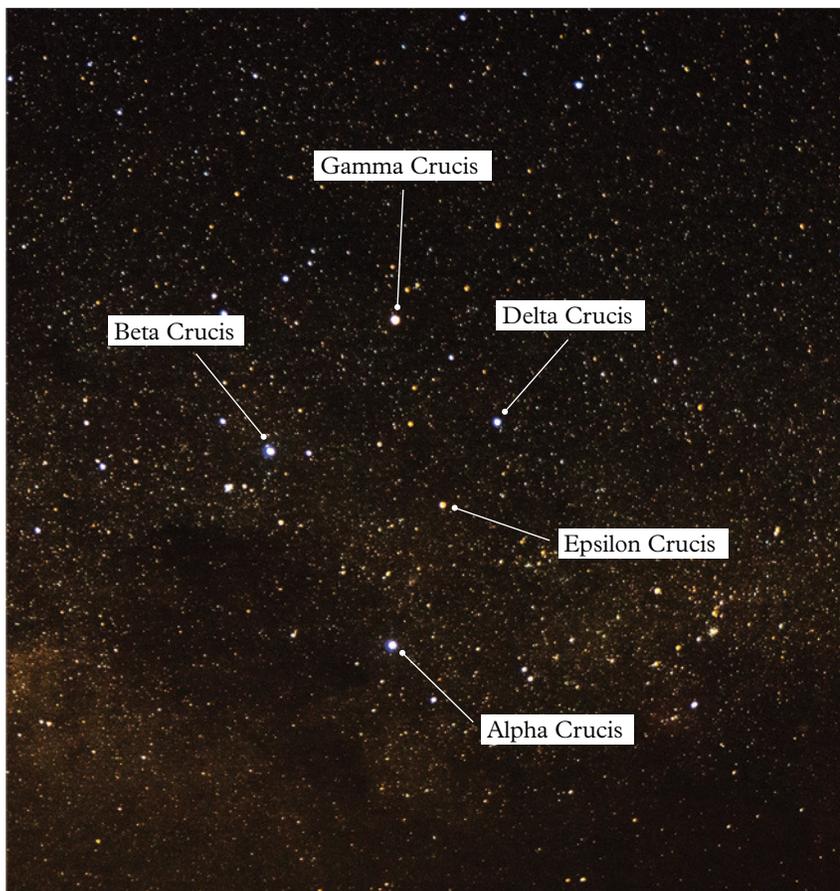
Figure 3 The Southern Cross constellation

Earth and Space

5.3

Worked example 5.3A Converting light-years to kilometres

Calculate the distance from Earth, in kilometres, of the Large Magellanic Cloud, which is 180,000 light-years away.

Solution

1 light-year is $9{,}500{,}000{,}000{,}000 = 9.5 \times 10^{12}$ km/light-year

Distance to Large Magellanic Cloud $= (9.5 \times 10^{12}) \times$ light-years of Large Magellanic Cloud
$$= (9.5 \times 10^{12}) \times (1.8 \times 10^5) \text{ km}$$
$$= 9.5 \times 1.8 \times 10^{(12 + 5)} \text{ km}$$
$$= 17.1 \times 10^{17} \text{ km}$$

What does a star's colour mean?

Hertzsprung–Russell diagram
a graph displaying star data, with the star's spectral class (temperature) on the *x*-axis and its absolute magnitude (luminosity) on the *y*-axis

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.

A method of displaying star data is a **Hertzsprung–Russell diagram** (Figure 4). This shows a plot of the star's temperature (in Kelvin) 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.
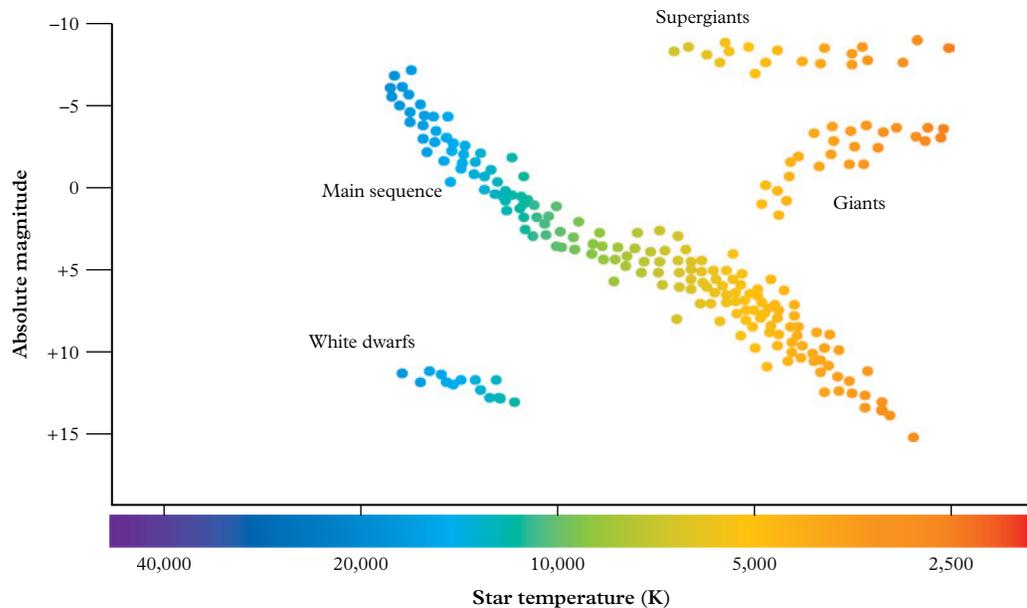
Figure 4 A Hertzsprung–Russell diagram

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 their movement is much less noticeable than that of the Moon, because they are so far away.

This effect, known as **stellar parallax**, is used by astronomers to calculate the distance to nearby stars (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 six months later in July), its position relative to other stars may appear to be different (Figure 5).

stellar parallax
a change in the apparent position of a star against its background when viewed from two different positions
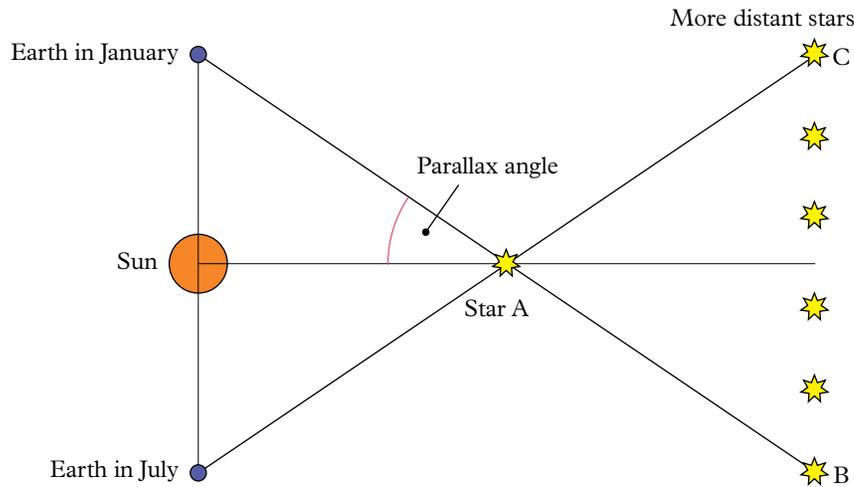
Figure 5 Measuring the distance to stars using stellar parallax. In January, star A, a close star, is in line with a more distant star, star B, but in July it is in line with star C. By measuring the parallax angle and knowing the radius of the Earth's orbit, the distance to star A can be calculated.
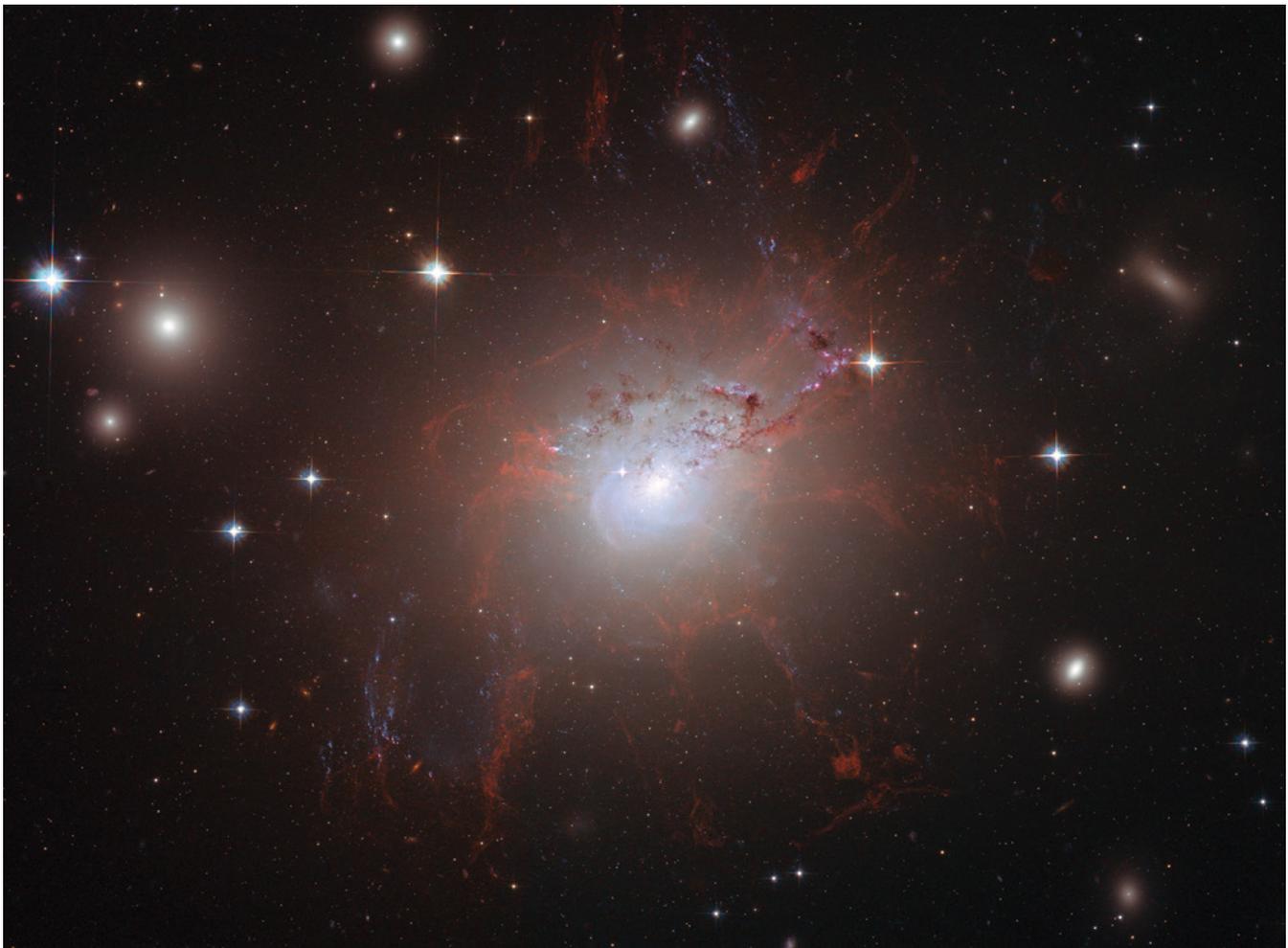
Figure 6 An elliptical-shaped galaxy with very little gas and dust

Earth and Space

5.3

Check your learning 5.3

Retrieve

1 Define the following terms.

   a Star

   b Galaxy

   c Light-year

   d Stellar parallax

2 Recall the name of the galaxy that contains our solar system.

Comprehend

3 Explain the process of nuclear fusion in stars.

4 Describe a main sequence star.

5 Draw the Southern Cross constellation and **describe** what you know about the different stars in the constellation.

6 Explain why the Milky Way galaxy appears so large in the night sky compared with other galaxies.

Analyse

7 Compare absolute magnitude scale and apparent magnitude scale.

8 Calculate the distance (in km) to Beta Centauri at 525 light-years away from the Earth.

9 If a star that was 20 light-years away exploded right now, **calculate** when we would see it exploding.

Skills builder: Processing and analysing data and information

10 Look at Figure 4 (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?)

11 Using Figure 4, **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?)

12 Scientists use scientific notation and specific measurement terms to record and report their findings.

   a One 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.)

Lesson 5.4
Scientists search for life

Key ideas

→ The Goldilocks zone is the area around a star where liquid water might exist.

→ Transmission spectroscopy detects the light that is absorbed by gases in a planet's atmosphere.

→ A star wobbles when an exoplanet's gravity causes it to move slightly.

Learning intentions and success criteria

Goldilocks zone

All living things on Earth need water to survive. Water helps important chemical reactions occur in our bodies. Every reaction that keeps us alive needs water.

Water is special because it can dissolve more substances than any other liquid. It can also carry heat, has a high boiling and freezing point, and lets light pass through for photosynthesis. These things can only happen when water is liquid.

The **Goldilocks zone** is the region around a star where conditions are just right for life, similar to that on Earth (Figure 1). The term comes from the story of Goldilocks and the Three Bears, where she finds something that's "not too hot, not too cold, but just right". In space, this means the distance from a star where the temperature is ideal for liquid water to exist on a planet's surface – not too hot (where water would evaporate) and not too cold (where water would freeze).

Scientists are always looking for **exoplanets** (planets that orbit outside our solar system) in the Goldilocks zone around other stars because they may also have the potential to support life. Not all stars are the same, though. Some stars are hotter or cooler than our Sun, and this affects where the Goldilocks zone is. For hotter stars, the habitable zone would be farther away, and for cooler stars, it would be closer. However, being in the Goldilocks zone doesn't guarantee a planet has life – other factors, like atmosphere and chemical composition, are also important! Venus is similar in size to Earth, but its thick atmosphere (containing carbon dioxide and clouds of sulfuric acid) traps much of the heat from the Sun, making it too hot for human habitation.

Goldilocks zone
the area around a star where it is not too hot or too cold for liquid water to exist on a planet

exoplanet a planet that orbits a star outside of our solar system
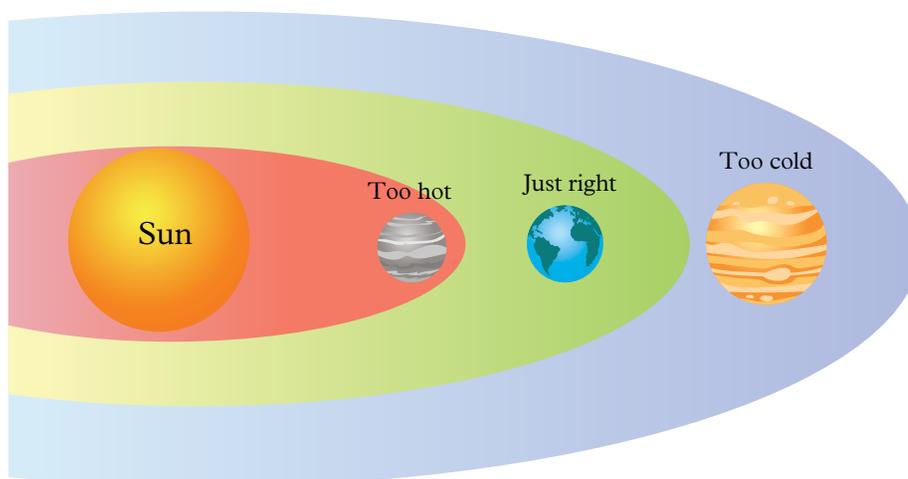
Figure 1 The Goldilocks zone is an orbital area around a star where scientists are hoping to identify an exoplanet that might be suitable for human habitation.

Transmission spectroscopy

All planets orbit around a star. When an exoplanet passes in front of its star from our point of view (a transit), it causes a small dip in the star's brightness. By measuring how much the star's light dims and how long the dimming lasts, scientists can determine the size of the exoplanet and its orbit. As the star's light travels through the exoplanet's atmosphere, some wavelengths of light are absorbed. Different gases will absorb different wavelengths. The James Webb Space Telescope can be used to detect the spectrum of light that is transmitted through an exoplanet's atmosphere. This will tell us if the atmosphere is appropriate for human settlement (Figure 2).

Earth and Space

5.4

Transmission spectrum of an Earth-like atmosphere
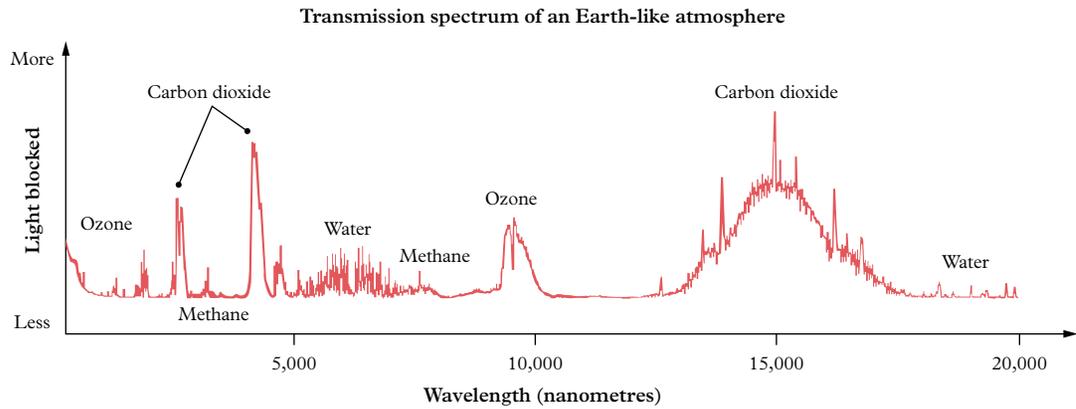
Figure 2 The transmission spectrum of an exoplanet can identify the gases in the atmosphere of a planet.

Detecting wobbly stars

The radial velocity method is used to find exoplanets by looking at the small movements or "wobbles" of a star. It is the gravitational pull of a star that causes the planet to orbit; however, the planet also exerts a gravitational pull on the star. Even though the star is much bigger, the planet's gravity makes the star move a little. This movement causes the star to wobble. Scientists can detect this wobble by noticing changes in the star's light. By studying the changes in light, scientists can find out if a large planet is orbiting the star, how big the planet is and how long it takes to complete its orbit.

Telescopes

direct imaging
directly measuring the amount of light emitted from a star

Large telescopes like Kepler (2009) and TESS (Transiting Exoplanet Survey Satellite, 2020) were launched into space to look for exoplanets in the Goldilocks zone. Both telescopes use **direct imaging** to continuously measure the amount of light produced by a star (Figure 3). Their measurements are compared to look for the small dimming of a star that occurs when an exoplanet moves in front of it. This change in the amount of light is the sign of a planet's transit (when a planet passes between the observer and the star). The dimming of a star's light caused by the exoplanet helps a scientist know the size and orbit of the planet, and its distance from the star.
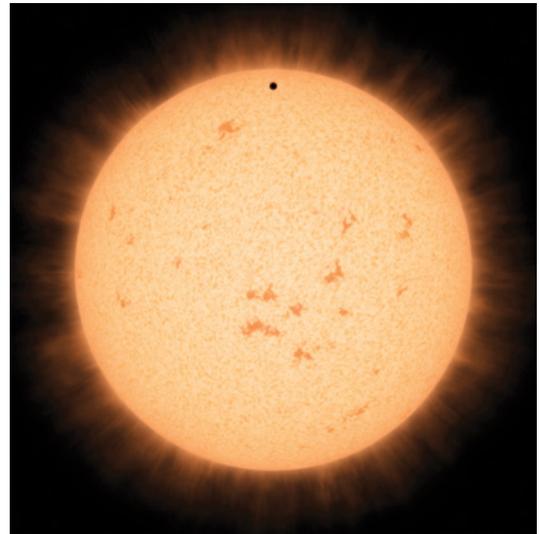
Figure 3 When a planet passes in front of a star, the amount of light reaching Earth will be dimmed enough for the Kepler or TESS telescopes to detect.

Life on Mars

Scientists believe that Mars may have had conditions in the past that could support life, like liquid water on its surface. Photos of the surface of Mars suggest that there were once rivers and lakes (Figure 4). The rovers Curiosity and Perseverance are using instruments to analyse soil samples and search for the molecules that are the building blocks of life. They are also examining the planet's current conditions to see if it might still have bacteria and fungi in places like the suspected underground water.

Figure 4 Images from different robotic rovers on Mars have identified evidence of old lake beds and rivers. This suggests that there was once water on the surface of Mars.

While no direct evidence of life has been found yet, these missions continue to collect data that could one day answer the big question: Did life ever exist on Mars?

Check your learning 5.4

Check your learning 5.4

Retrieve

1   **Describe** the Goldilocks zone.

Comprehend

2   **Describe** why water is important for life.
3   **Describe** what transmission spectroscopy can tell scientists about an exoplanet.

Analyse

4   **Explain** why hotter stars have a Goldilocks zone farther away than cooler stars.
5   **Compare** direct imaging used by the Kepler and TESS telescopes to transmission spectroscopy.

Apply

6   **Explain** how the wobble of a star can help detect an exoplanet and determine its size.

Lesson 5.5
Living in space requires overcoming challenges

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Microgravity can affect the way the human body functions.

→ Oxygen needs to be constantly produced on the International Space Station (ISS).

→ Astronauts can be exposed to high levels of radiation.

Microgravity

Travelling and living in space comes with a lot of challenges because space is so different from Earth. In microgravity, astronauts experience a condition where they feel weightless because there is very little gravity pulling on them. This lack of gravity affects their bodies in several ways. For example, astronauts' muscles and bones can become weaker because they are used less and do not need to support their body's mass. This can lead to muscle atrophy (wasting away) and a decrease in bone density over time. To help prevent this, astronauts have to exercise for several hours each day to keep their muscles strong and prevent bone density loss. Microgravity also affects the fluids in astronauts' bodies. On Earth, fluid is pulled to the feet, and the heart needs to beat hard to push it back up from the legs to the heart. In microgravity, fluid is no longer pulled to the feet. Instead, it can gather in the upper parts of the body, causing headaches and eye problems until the body adjusts. It can also affect the way the heart works, making it more difficult to pump blood efficiently. Many of these changes are reversed when the astronauts return to Earth.

Figure 1 Astronauts need to exercise for several hours each day to reduce the loss of bone and muscle while in space.

Extreme temperatures

Another problem faced by astronauts is the extreme temperatures in space. This occurs because many moons and planets do not have an atmosphere. The atmosphere acts like a warm blanket for a planet, just like a blanket keeps you warm on a cold night. The thicker the blanket, the better it traps heat and keeps you warm. Similarly, Earth has a thick atmosphere, which helps it hold on to heat and stay at a stable temperature, even at night. This means spacecraft and spacesuits need to be specially designed to protect and insulate astronauts from the extremes of temperature (between –121°C and 121°C on the Moon and –153°C and 20°C on Mars).

The weightlessness that is experienced by astronauts can also affect their core body temperature. Normal human body temperature ranges between 36°C and 37°C. Researchers have found that astronauts' body temperature is about 1°C higher than normal, even when they're resting. During exercise, their body temperature can increase to 40°C, which can be dangerous. This is because the body has a hard time getting rid of excess heat in microgravity. When you exercise on Earth, sweat can evaporate, moving heat away from the body. In microgravity, sweat evaporates more slowly and can seem to "stick" to the body, preventing the body from cooling down. This overheating can affect astronauts both physically and mentally.

Figure 2 Microgravity can make it difficult for sweat to evaporate and cool an astronaut's skin.

When travelling outside space vehicles, the spacesuits worn by astronauts have multiple layers. The first layer consists of stretching spandex carrying many metres of tubes that constantly supply cooling water to keep the astronaut cool and to carry heat away from the body. The rest of the spacesuit contains as many as 16 different layers, including a layer containing bladders of oxygen for breathing and to help with the pressure of a vacuum environment. The outer layer is usually white to help reflect the energy of the Sun. It is currently made of three different fibres designed to resist water, provide support, and resist fire (Figure 3).
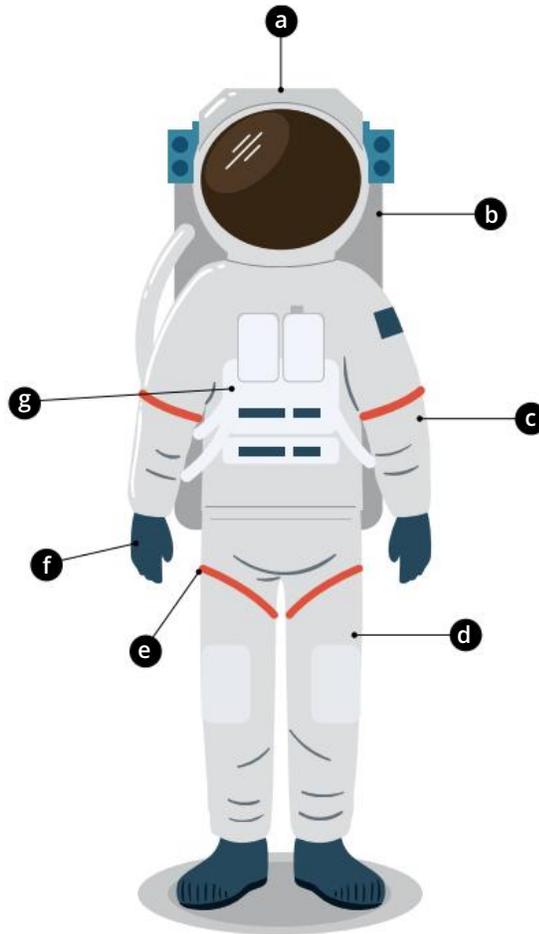
Figure 3 Each layer in a spacesuit has a particular function. A spacesuit can have up to 16 layers!

a Helmet: The helmet used for spacesuits has two main functions: to protect astronauts from the powerful sun rays using a special gold coating, and to provide astronauts with oxygen through a ventilation system.

b Portable Life Support System (PLSS): The PLSS provides multiple services for astronauts when they conduct their space walks, including two-way radios for communication, a water pack for their cooling suits, electricity, a fan and a CO_2 removal system.

c Hard upper torso (HUT): The HUT is the internal connection for the PLSS ensuring all services function as required.

d Lower torso: This section protects the astronauts lower body from the harsh environment in space. The rings around the upper thighs allow for tools to be attached for any external work required on the spaceship/ISS, and also keeps the astronaut tethered to the space station.

e Coloured stripes: The colours on a spacesuit are unique to the astronaut, allowing them to be identified when they are fully suited-up.

f Gloves: The hands are the most susceptible to the cold in space, so these gloves are equipped with heaters.

g Display control module: Known as the brains of the suit, this console controls the various functions of the spacesuit.

Oxygen

Since space is a vacuum with no air to breathe, astronauts rely on life-support systems to provide oxygen to breathe, and to remove carbon dioxide. Most spacecraft carry their oxygen supplies for short flights to and from the International Space Station (ISS). Some spacecraft also carry supplies of pressurised oxygen and other atmospheric gases to support

the station. On the ISS, oxygen is usually produced by passing electricity through slightly salty water in a process called electrolysis. This splits the water molecule (H_2O) into oxygen and hydrogen.

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

A back-up system of "oxygen candles" is also in place. This process uses canisters containing sodium chlorate ($NaClO_3$) and iron powder (Fe). When the material in the canister is ignited, the iron burns at 600°C and releases oxygen.

$$NaClO_3(s) + Fe(s) \rightarrow 3O_2(g) + NaCl(s) + FeO(s)$$

In the long term, space agencies are hoping to use plants to provide oxygen and remove carbon dioxide from the internal atmosphere.

Figure 4 Astronauts on the ISS are currently testing how well different plants grow in microgravity.

Radiation

Space radiation is different from the types of radiation we experience on Earth. On Earth, the high-energy ionising particles (including alpha particles, beta particles, gamma rays and X-rays) released from solar flares are reflected by our atmosphere, or pulled to the North or South Pole. Astronauts that travel beyond the Earth's atmosphere do not have this protection. They are exposed to higher levels of radiation that can damage cells and increase the risk of health issues like cancer and nerve damage.

Earth's Moon and Mars do not have the protection of an atmosphere or a magnetic field. This means astronauts will be exposed to higher levels of radiation during their flights and the time they spend on the celestial bodies. A six-month trip to Mars will expose an astronaut to 300 mSv of radiation (the equivalent of 3,000 X-rays). A visit to Mars would need to be at least 18 months in duration to wait for Earth and Mars to pass close enough for travel. This exposure adds another 400 mSv.

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5.5

The ISS takes measures to protect its astronauts by using hydrogen-rich shielding like polyethylene around the main living areas, such as the sleeping and eating quarters.

Figure 5 Earth's magnetic field pulls the radiation from solar flares to the South Pole. This generates the Aurora Australis lights in the sky.

Check your learning 5.5

Check your learning 5.5

Retrieve

1 **Describe** microgravity.

Comprehend

2 **Describe** how astronauts reduce the amount of radiation they are exposed to.

3 **Describe** three ways astronauts obtain the oxygen they need on the ISS.

Analyse

4 **Explain** why it is important for astronauts to exercise regularly in space.

5 **Explain** why exercise could also affect their health in a negative way.

6 **Compare** the different materials and their functions used to make current spacesuits.

Apply

7 Oxygen is not the only gas that needs to be monitored on the ISS. Carbon dioxide levels are constantly monitored and reduced using special filters and chemical scrubbers. **Explain** why high carbon dioxide levels would be concerning for astronauts.

8 Most spacesuits are designed for the mostly male crews. Consider how these shapes may make working in space difficult for female crew members. **Use** your knowledge of materials to **design** a spacesuit for a female astronaut.

9 Consider the challenges of living in space to **create** a story about a day in the life of a person living on Mars.

Lesson 5.6
Challenge: Exploring microgravity

Aim

To explore the impact of microgravity on the movement of water

What you need:

- Plastic drinking cup
- Baking tray or a flat surface without a rim
- Large rubbish bin
- Raised surface (e.g. chair, step ladder, stairs)
- Camera

What to do:

1   Select a location that will allow for potential water spills (i.e. outside).
2   Fill the plastic cup with water.
3   Place the baking tray on top of the cup with water.
4   Hold the cup tight against the tray and flip them so that the cup and water are upside down on the top of the tray. Be careful not to tip the cup so that the water stays inside the cup.
5   Use the raised surface to hold the tray, cup and water over the rubbish bin.
6   Hold the tray level while you slowly slide the cup off the edge of the tray. Record your observations of the water and cup movements.
7   Repeat steps 2 to 5.
8   This time, quickly pull the tray straight out from under the cup. Record your observations of the water and cup movements.
9   Repeat the challenge using a camera to compare the differences in the movement of the water and cup.

Questions

1   Explain why the water did not leak from under the cup's edge when it was upside down on the tray.
2   Identify the force that caused the cup and water to move downwards.
3   Explain why raindrops tend to form a spherical shape when they fall.
4   Compare the movement of the water and cup when the tray was moved slowly, and when the tray was removed quickly.
5   Explain the differences observed in question **4**.
6   Define microgravity and why astronauts experience it on the International Space Station.

Lesson 5.7
Science progress through collaboration

Key ideas

→ New technologies have been developed to support the needs of space travel.

→ New research and technologies progress when scientists collaborate.

The first rockets

The first rockets were thought to have been developed in China in 1232 CE. These early "fire arrows" were a form of solid propellant tube that had gunpowder packed in one end. When the gunpowder was ignited, it produced fire and gas out of the end. This propelled the rocket forward and was used to repel Mongolian invaders.

Why do rockets fly?

You may have seen videos of a rocket taking off with flames and hot gases pushing against the Earth as it takes off. It is easy to think that the flames and gases pushing against the Earth are what make the rocket move. However, rockets can still move and manoeuvre in space, where there is no atmosphere or Earth to push against. You will learn more about this in Lesson 6.14 Experiment: What if forces were changed on Newton's rocket? (page 293)

Escape velocity

When a rocket takes off from the Earth's surface, it uses a great deal of fuel to resist the pull of the gravitational force and to keep moving away from the surface. If the fuel did not keep burning and producing exhaust gases, the rocket would fall back to Earth. The escape velocity of an object refers to the speed that an object travelling away from the Earth needs to reach to avoid the gravitational pull when all the engines are turned off. This escape velocity for most rockets is 11 km/s.

Figure 1 Rockets use a combustion reaction and Newton's third law to move out of the Earth's atmosphere and into space.

Liquid-fuelled rockets

In the early 1900s, Konstantin Tsiolkovsky, a Russian scientist, explored what would be needed to send a rocket into space. He designed a wind tunnel to test the air resistance of different shapes, developed mathematical formulas that examined the relationship between

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rocket mass, exhaust velocity and rocket speed, and designed the first rocket that used liquid oxygen and hydrogen fuel.

This idea was later adopted by Robert Goddard, an American physicist, who built and successfully launched the first liquid-fuelled rocket on 16 March 1926. His rocket used liquid oxygen and gasoline, a combination that propelled the rocket 41 metres into the air.

During World War II, German Wernher von Braun developed the V-2 rocket, the world's first long-range guided ballistic missile (Figure 2). It was powered by liquid fuel and could carry a payload of over 80 kilometres into the air.

After the war, von Braun went on to work for NASA and was involved in the development of a version of the V-2 rocket called Saturn V (Figure 3), which later took astronauts to the Moon during the Apollo missions.

Figure 2 The V-2 rocket from World War II was modified to carry the first astronauts into space.

Figure 3 The Saturn V rocket was used to carry the first astronauts to land on the Moon.

The Space Race

The Cold War rivalry between the United States and the Soviet Union (now Russia) provided a major push for rocket development. In 1957, the Soviet Union launched Sputnik 1, the first artificial satellite, into orbit. This marked the beginning of the Space Race between the two superpowers, and rockets became the centrepiece of this competition (Figure 4).

Space exploration isn't just being conducted by the US and Russia – many countries around the world are now carrying out space missions. China, through its China National Space Administration (CNSA), launched a series of Chang'e missions, including Chang'e 4 landing on the Moon in 2018 and deploying the Yutu-2 rover on the far side of the Moon. In 2024, Chang'e 6 collected and brought lunar soil samples back to Earth. In 2021, China landed a rover, Zhurong, on the surface of Mars.

The European Space Agency (ESA), which includes 22 countries, has worked on missions like Rosetta, which landed a probe on the comet 67P/Churyumov–Gerasimenko. It also helps to run the International Space Station (ISS).

India's space agency, ISRO, has gained international attention with its successful Chandrayaan-3 mission, which landed a rover on the Moon in 2023, and the Mars Orbiter Mission (Mangalyaan), which made India the first Asian country to reach Mars.

Japan's space agency (JAXA) has also made important contributions, like the Hayabusa missions that returned samples from the asteroid 25143 Itokawa. The capsule containing the samples landed near Woomera, South Australia, in 2010. Analysis of the sample indicated that the asteroid may have been part of a much larger comet and the composition was LL chondrite (low iron, low metal).

Collaboration

The International Space Station (ISS) is a large space station that orbits Earth and is the result of international scientists collaborating. It is a giant science lab in space, built by five space agencies: NASA (USA), Roscosmos (Russia), the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA) and the Canadian Space Agency (CSA).

1962
Vostok 3 and 4: Andriyan Nikolayev and Pavel Popovich in space for several days

1986–2001
Mir space station was constructed and populated

1963
Vostok 6: Valentina Tereshkova, the first woman in space

1975
Apollo-Soyuz: Joint project with USA

2001
Controlled re-entry and disintegration of Mir space station

1961
Launch of Russian Vostok 1, carrying Yuri Gagarin, the first human to orbit the Earth

1967
Soyuz 1 crash: First person to die during a space flight

1991
Collapse of the Soviet Union

Russia

1950　　1990　　2030

1961
Vostok 2: Gherman Titov, the first person to spend a day in space

1964
Voskhod 1: First multi-person crew (3) in space

1971
Salyut 1: First space station populated, but decompression resulted in their deaths

2000–2024
Soyuz rockets deliver astronauts and supplies to the International Space Station

1963
Vostok 5: Longest solo flight (5 days)

1965
Voskhod 2: First space walk

1972–1982
Soviet Union launched a series of space station units

Figure 4 After World War II, Russia and the US began exploring space travel. Today, many other countries are collaborating to explore beyond Earth.

The ISS was built piece by piece, with parts made in different countries, then launched into space. The astronauts used robots and space tools to connect all the pieces, like a giant Lego set. Once finished, the ISS became the largest human-made object in space. It is approximately the size of a football field – 109 metres wide and weighs over 400,000 kilograms.

The ISS orbits Earth at a height of 370 to 460 kilometres above the ground and orbits the Earth every 90 minutes. The station is constantly falling towards Earth, but it moves so fast sideways that it stays in orbit. To keep it in the right position, the ISS has to be "boosted" by rockets every month.

The space station is powered by huge solar panels, which catch sunlight and turn it into energy. These panels cover an area the size of a basketball court (2,247 m²), and the ISS uses this power to run experiments, keep the crew alive, and maintain all its equipment.

The ISS can be home to between 3 and 13 astronauts at a time. They live and work in space for months, doing experiments on how gravity and radiation affect the human body, plants, and materials. Their research is often translated into new technology for the participating countries.

The ISS has been in orbit for over 20 years and is expected to keep operating at least until 2030. Commercial space companies such as SpaceX and Northrop Grumman work with NASA to remove rubbish and keep the astronauts on the ISS supplied with food, oxygen, drinkable water, and replacement parts.

Earth and Space

1958
Mercury-Redstone 1 (MR–1): uncrewed test flight (malfunctioned)

1969
Apollo 11: First Americans landed on the Moon

1981
Shuttle: First manned shuttle program

2003
Columbia disaster: Space shuttle disintegrated on re-entry killing seven astronauts

2020
Commercial Agencies: Space X and other agencies compete to provide services to the ISS

1961
MR–3: Alan Shepard 15-minute flight 186 km above the Earth

1972
Apollo 17: The last American mission landed on the Moon (12 men in total have walked on the Moon's surface.)

1995
Shuttle-Mir: Partnership with Russia

2026
Artemis program: Planned program to return to the Moon

1950

1990

2030

USA

1961
MR–2: Chimpanzee named Ham sent into space

1968
Apollo 1: Fire on the launch pad killed three astronauts

1975
Apollo-Soyuz: Joint project with Soviet Union

1998
International Space Station (ISS): Joint project with Russia, European Space Agency (ESA), Canadian Space Agency (CSA) and Japan Aerospace exploration Agency (JAXA)

1964
Skylab: First American space station

1970
Apollo 13: Mid-flight accident threatened the survival of the crew

1986
Challenger disaster: Space Shuttle disintegrated during launch killing seven astronauts

5.7

Check your learning 5.7

Retrieve

1 **Identify** where the first rockets were developed.
2 **Identify** the countries currently contributing to the International Space Station.

Comprehend

3 **Explain** why the International Space Station needs to be resupplied regularly with oxygen, water and food.

Analyse

4 **Identify** the current inhabitants of the International Space Station and their nationalities. **Describe** any research that they are undertaking.

Apply

5 The Australian Space Agency (ASA) is collaborating with NASA to send our first robot called "Roo-ver" to the Moon. It will collect samples of the Moon's surface to determine if it contains oxygen or water. **Explain** why this will be important to future missions to Mars. (HINT: Consider the fuel that will be required to travel great distances in space.)
6 **Describe** how the space missions of China, India and Japan contributed to global space exploration.

Lesson 5.8
Challenge: Launch a rocket

Aim

To design an air rocket

What you need:

- Bike pump
- Sports ball inflation needle (that attaches to the bike pump)
- 1–2 L plastic bottle
- Wine cork that seals the neck of the plastic bottle
- Thin nail (thinner than the inflation needle)
- Optional: drill and drill bit smaller than the inflation needle
- Duct tape
- Cardboard
- Scissors
- Permanent marker
- Retort stand
- Water

What to do:

1 Cut the cork in half so that it is short enough for the inflation needle to protrude from both ends.
2 Use the nail to make a small hole through the centre of the cork.
3 Push the inflation needle through the hole created in the centre of the cork. Check that air can pass through the centre of the needle.
4 Check that the cork fits snuggly into the neck of the plastic bottle. If it is too small, wind a strip of duct tape around the cork until it seals the bottle.

5   Use the cardboard, marker and scissors to make fins for your bottle rocket. Use the duct tape to fix the fins to the side of the rocket.

6   Fill 1/5 of the bottle with water. Use the cork with the inflation needle inserted to seal the bottle.

7   In an outside area, connect the bottle to the bike pump and invert it so that it sits on the retort stand.

8   Taking care to angle the rocket away from bystanders, yourself and windows, use the bike pump to pressurise the air inside the bottle rocket. When the pressure is high enough, the cork will be pushed out of the bottle and the bottle will launch into the air.

Questions

1   **Identify** the forces acting on the rocket.

2   **Explain** how the amount of air pressure in the rocket affects how far or high the rocket travels.

3   **Describe** the factors that you considered when designing the fins on your rocket.

4   **Describe** an experiment that tests how the amount of water in the bottle affects how high or far the rocket travels.

Lesson 5.9

Experiment: Calculating the distance to the Sun

Background

This experiment 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.

Aim

To determine a value for the distance from the Earth to the Sun using a pinhole screen, and to compare this with the known value

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

◀

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 pinhole 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 needs to fill the two lines by just touching both lines.

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. **Calculate** the difference between L_S and this value. Record this value as 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. **Identify** two factors that contributed to this error. (HINT: Which measurements were not exact?)
4. **Describe** how these errors could have been minimised.

Conclusion

Write a conclusion for this experiment that relates the findings to the aim. Use the formula below to describe the percentage error of your measurement.

percentage error =

$$\frac{\text{your value} - \text{actual value (149,600,000 km)}}{\text{actual value (149,600,000 km)}}$$

Lesson 5.10
Stars have a life cycle

Key ideas

→ Nebulae are large clouds of gas where stars are born.

→ Each star exists in a hydrostatic equilibrium between the gravitational pull to the centre and the release push of energy from nuclear fusion.

→ Small stars will cool and die, forming white dwarfs and black dwarfs.

→ Large stars explode in novas and supernovas, releasing large amounts of light and energy.

Learning intentions and success criteria

Introduction

In the constellation of Orion lies a group of stars informally known as the Saucepan. Just above it is a misty patch, just visible to the naked eye. This is M42, or the Orion Nebula, a region of gas and dust in which new stars are just beginning 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, old and dying stars can be found, as well as exploded stars.

Birth of a star

Across the universe are large clouds of hydrogen gas called **nebulae**. 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.

nebula a cloud of gas and dust in space (plural: nebulae)

Figure 1 This image of Kn 61, a confirmed planetary nebula, was taken by Professor Travis Rector, University of Alaska, Anchorage, using the 8.1 m Gemini Telescope. The nebula appears as a blue bubble, and a bright star and spiral galaxy can also be seen.

Adult stars

The release of energy from the nuclear fusion of hydrogen atoms forces the gas particles out, while the force from 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 **hydrostatic equilibrium**. A main sequence star can maintain this balance between the forces for millions of years.

hydrostatic equilibrium
in relation to the Earth's atmosphere: a state of stability, with upward forces balanced by downward forces

Older stars

Eventually the hydrogen available for nuclear fusion starts to decrease. When this occurs, the force from gravity 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.

red giant a star that has become large and bright with a cool surface, because it has run out of hydrogen fuel
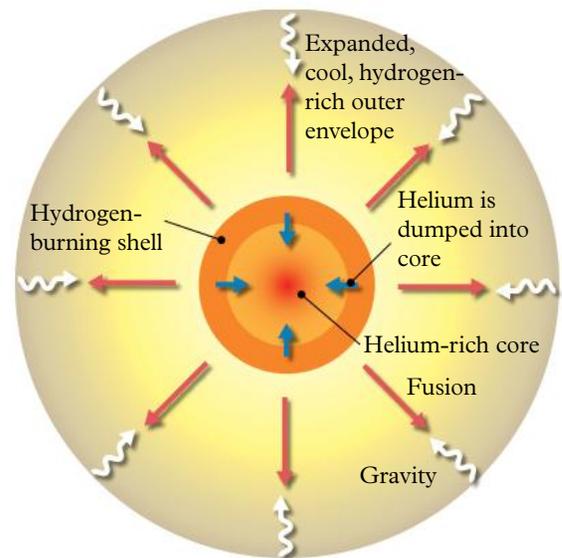
Figure 2 How a red giant star forms

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**.

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 are remarkably dense. A teaspoonful of neutron star material would have the same mass as 100,000 cars!

planetary nebula a glowing shell of gas formed when a star dies

white dwarf a small, hot star that forms when a star (e.g. our Sun) runs out of fuel and slowly fades and cools

black dwarf a remnant formed when a white dwarf star cools and gradually fades away

supernova the explosive death of a star

neutron star a small, highly dense star made mostly of neutrons

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. This is how possible black holes are detected in space, although their existence is still to be determined absolutely.

black hole a region in space of infinite density where gravity is so strong that nothing, not even light, can escape from it

```
                    Gas nebula
                         |
                     Protostar
                         |
              Main sequence star
              /                  \
    Original mass            Original mass
    <8 solar masses,         >8 solar masses,
    red giant star           red supergiant star
         |                        |
    Variable star            Supernova
         |                    /        \
    White dwarf        Core <3 solar    Core >3 solar
    and planetary      masses,          masses,
    nebula             neutron star     black hole
```
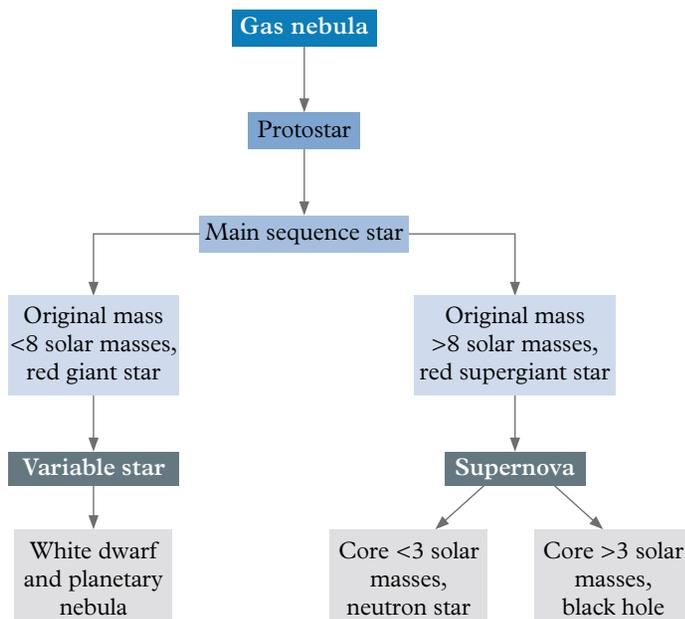
Figure 3 The life cycle of a star

Check your learning 5.10

Retrieve

1 **Identify** the event that occurs between gas atoms that marks the birth of a star.
2 **Define** the term "nebula".
3 **Identify** what is left after a supernova.

Comprehend

4 Use a labelled diagram to **explain** the forces involved in hydrostatic equilibrium.
5 **Describe** a red giant star.

Analyse

6 **Compare** a white dwarf and a black dwarf.

Apply

7 **Create** a flow chart to show the life cycle of a star the size of our Sun.
8 Our Sun is 1 solar mass. **Predict** what will happen when hydrogen becomes limited in our Sun.
9 Blue stars are much larger than our Sun. However, they do not have enough energy to explode. **Create** a flow chart to show the life cycle of a blue star.

Earth and Space

Lesson 5.11
The galaxies are moving apart

Key ideas

→ Elements absorb light energy in specific wavelengths, creating an absorption spectrum.

→ When the same elements return to a stable state, they release the wavelengths of energy as an emission spectrum.

→ The Doppler effect describes the change in frequency of a wave as an object moves towards or away from an observer.

→ A red shift in the emission or absorption spectrum of a galaxy indicates that the galaxy is moving away from the observer.

Measuring the movement of galaxies

As a star undergoes nuclear fusion, it releases energy in the form of light. This is usually a full spectrum of light containing all the wavelengths and colours possible. The outer layers of gas surrounding the star contain elemental atoms that will absorb specific wavelengths of light energy that correspond to the movement of electrons in shells. When the particular amount of energy is absorbed, it appears as dark lines in the spectrum of light that leaves the star. This is called the **absorption spectrum** of a star because the missing wavelengths of light are absorbed from the spectrum. The set of dark bands in the light spectrum is unique to the element contained in the star (Figure 1A).

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** (Figure 1B).

Compare the emission spectrum and the absorption spectrum of helium in Figure 1. The absorption spectrum contains lines in exactly the same positions as in the emission spectrum.

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 the velocity of a distant star – which is what Hubble discovered.

absorption spectrum a spectrum with dark bands missing from the pattern, where the element has absorbed characteristic light wavelengths; the opposite of an emission spectrum

emission spectrum the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element
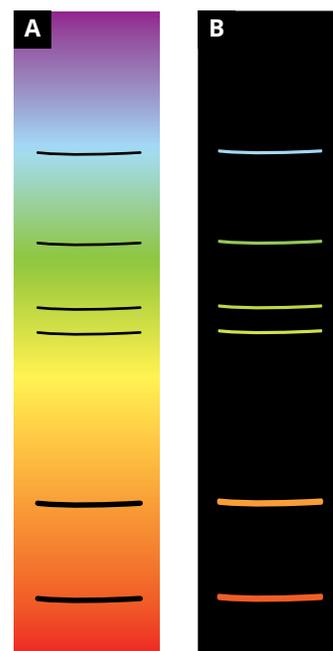
Figure 1 (A) Absorption spectrum; and (B) emission spectrum of helium

Doppler effect

When a racing car zooms 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 2).

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
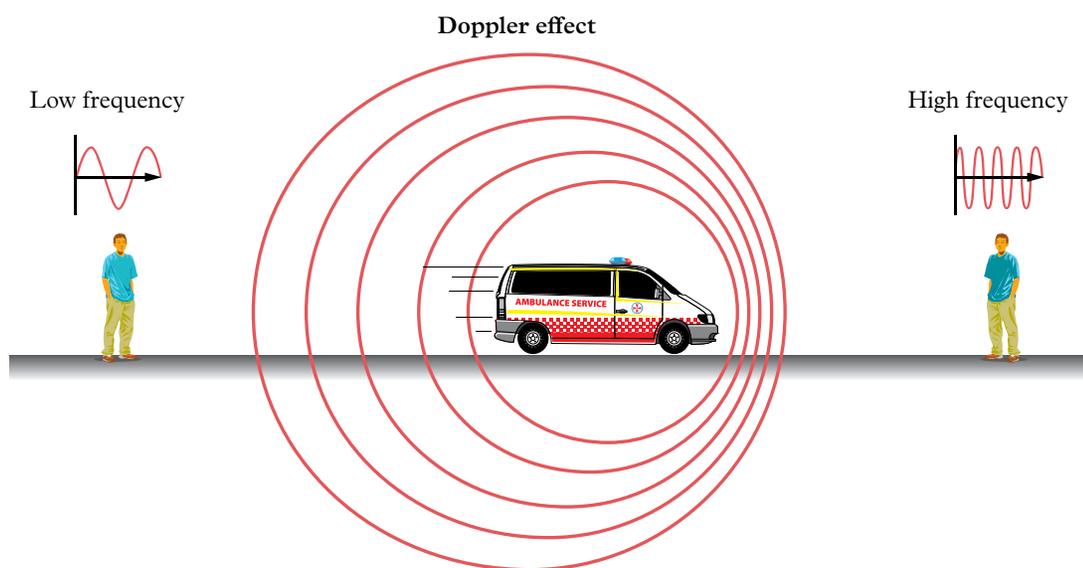
Figure 2 The Doppler effect

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, known as a **red shift**, indicates that the galaxy is moving away from the Earth (Figure 3). 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 United States–born Australian Brian Schmidt. Their research determined that the expansion of the universe is accelerating. As a result, Brian Schmidt was one of three scientists awarded a Nobel Prize in 2011.

red shift the apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

blue shift the apparent increase in frequency (towards the blue end of the spectrum) of light from galaxies that are moving towards the Earth

Big Bang theory the theory that the universe began as a hot, dense, single point at some time in the past, and since then has expanded and will continue to expand into the future

Earth and Space

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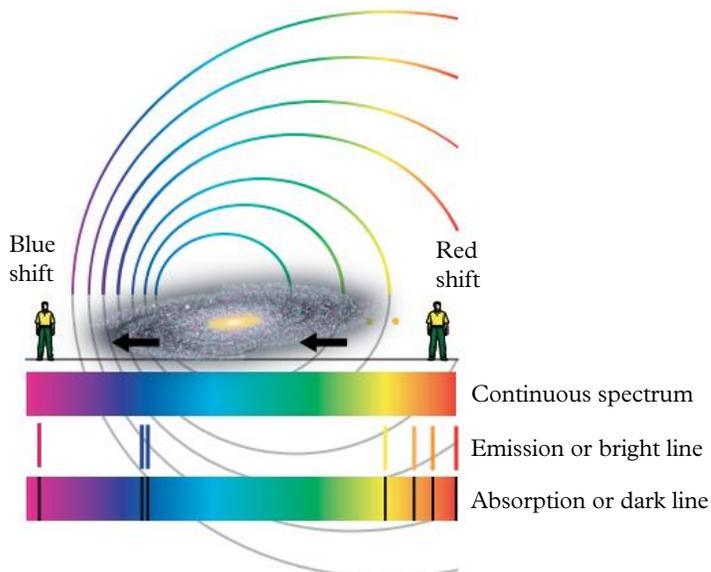
Figure 3 Red shift and blue shift

Check your learning 5.11

Check your learning 5.11

Retrieve

1 **Identify** whether a racing car that has a higher pitch than normal (higher frequency) is travelling towards or away from you.

Comprehend

2 **Explain** the Doppler effect.
3 **Describe** how you would identify an absorption spectrum.
4 **Explain** why red-shifted light shows that a galaxy is moving away from the Earth.

Analyse

5 **Compare** the emission spectra and absorption spectra for helium, shown in Figure 1.

6 Figure 4 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 **Explain** what the dark lines on each spectrum represent.
   b **Identify** which star, B or C, is moving towards the Earth.
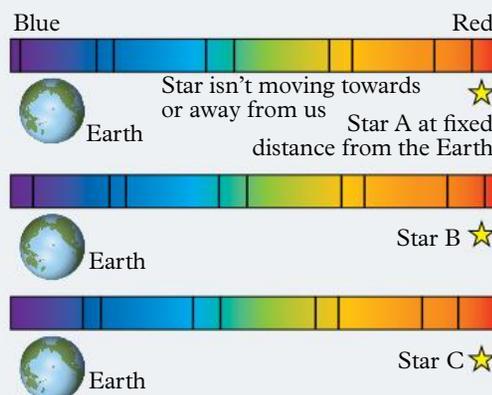
Figure 4 The spectra observed from three stars: A, B and C

Lesson 5.12
Experiment: Investigating emission spectra

Discharge tubes will get hot when in use. Do not touch. Turn off when not in use and allow to cool before handling. Keep electrical equipment away from water.

Aim

To use spectroscopy to investigate the light emitted by various elements

Materials

- Spectroscope
- Discharge tubes for different elements – hydrogen, helium and neon
- Power supply for discharge tubes

Method

1 Connect the equipment and darken the room.
2 Aim the spectroscope at the discharge tube and observe the emission spectrum.
3 Repeat for each tube.

Results

Record the position and colour of the emission lines for each element. Present the results in a table.

Discussion

1 **Compare** the emission spectrum with the absorption spectrum.
2 Each element has a distinct emission spectrum. **Describe** how this is used to identify the elements present in the universe.
3 Some light from a distant nebula can have lines missing from its spectrum. **Explain** the cause of these missing lines, and **identify** the information that scientists obtain from this information.

Conclusion

Explain how the light emitted from different elements varies.

Lesson 5.13
Evidence supports the Big Bang theory

Key ideas

→ The Big Bang is a theory supported by evidence that describes how the universe began.

→ The expansion of the universe is continuing to accelerate.

Learning intentions and success criteria

Introduction

How the universe began has been debated and studied by many scientists. 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 at the time. 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 farther away galaxies were from the Earth, the faster they were moving.
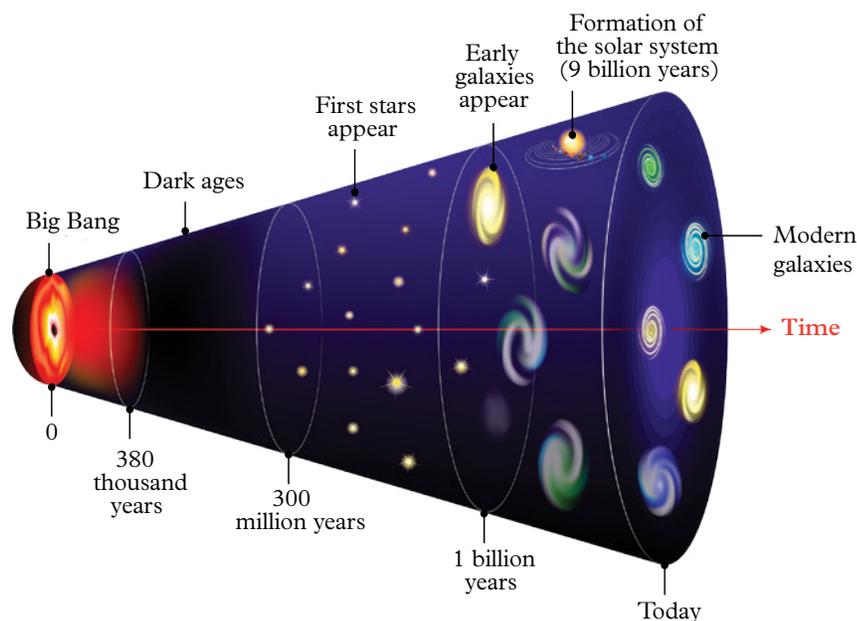
Figure 1 According to the Big Bang theory, the universe began from a rapid expansion from a hot, dense state.

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, rewinding the path of all the galaxies, everything must have come from the same spot. This idea led to the development of the Big Bang theory.

This theory suggests that the universe started 13.7 billion years ago with an enormous amount of energy that eventually formed the subatomic particles called quarks. These quarks eventually formed protons and neutrons that (3 minutes later) cooled to 1 billion degrees Celsius. This allowed the protons and neutrons to fuse to form the nucleus of hydrogen (and some helium) atoms. Twenty minutes later, the fusion slowed and for approximately 380,000 years the mainly hydrogen nuclei were surrounded by a cloud of electrons. Further cooling allowed the electrons to form shells around the hydrogen nuclei, producing the hydrogen atoms we now know. It is thought to have then taken millions of years for the first hydrogen atoms to start nuclear fusion to form the first star.

As with all science, this theory is supported by many forms of evidence.

Microwave background

The concept of the Big Bang relied on the idea of the existence of some sort of thermal 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 2), found evidence that the leftover energy existed as background radiation.

Figure 2 Arno Penzias (left) and Robert Wilson (right) in front of their horn antenna, with which they discovered cosmic microwave 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. Being good scientists, they investigated where it came from and why it occurred. They found that this background noise was a form of electromagnetic radiation known as **cosmic microwave background radiation** (Figure 3).

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 in 1978 for their discovery.

cosmic microwave background radiation remnant electromagnetic radiation left from early stages of the universe

Figure 3 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky. These fluctuations correlate with the formation of nearby matter.

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. If the energy caused the formation of matter, it 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 predicted ripples in temperature fluctuations, which are consistent with the formation of distant galaxies and old stars.

Earth and Space

5.13

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 reach the Earth. As a result, scientists can see old galaxies that developed millions of years before our own Milky Way. Observations of how stars form are consistent with the energy changes predicted by the Big Bang theory.

All these observations have allowed astrophysicists to estimate that the universe is 13.7 billion years old.

Check your learning 5.13

Comprehend

1 **Explain** why the Big Bang was not a bang at all.
2 Use a timeline to **describe** the events that occurred during the Big Bang.
3 **Define** the term "cosmic microwave background radiation", and **explain** why its existence is important.

Analyse

4 A theory is never final. Evidence is always needed to reinforce a theory. The Planck satellite was designed to examine cosmic microwave background radiation. **Describe** the evidence gathered about distant galaxies and old stars. **Compare** the information provided by the images from the different satellites in Figure 4.
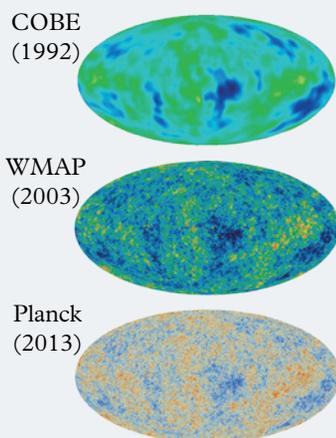
Figure 4 Images from the COBE (Cosmic Background Explorer), WMAP (Wilkinson Microwave Anisotropy Probe) and Planck satellites

Apply

5 Cosmic microwave background radiation has been called "ancient whispers". **Discuss** why this name is appropriate.
6 **Discuss** one other example of evidence that supports the Big Bang theory.

Skills 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?)

Lesson 5.14

Science as a human endeavour: Technology aids cosmological research

Key ideas

→ There are may projects running to discover more about the universe.

→ The Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope project is looking to detect radio waves millions of light-years away from Earth.

→ The Event Horizon Telescope is using telescopes from around the world to image the emissions produced by supermassive black holes.

Learning intentions and success criteria

Introduction

As technology continues to advance, our ability to map and view the universe continues to improve. The improvement and development of supercomputers, radio telescopes and observatory facilities have led to the identification and imaging of new black holes and galaxies.

ASKAP

The Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope is situated at the Inyarrimanha Ilgari Bundara, CSIRO Murchison Radio-astronomy Observatory, in Western Australia. ASKAP consists of 36 large (12-metre wide) antenna dishes that work together as a single telescope. The apex of each ASKAP antenna is attached with a phased array feed (PAF). The PAF acts as a "radio camera" and can detect radio waves millions of light-years away from Earth. Each PAF provides the ASKAP telescope with a large field of view to survey and detect millions of new distant galaxies and black holes.

Figure 1 Three ASKAP telescopes are trained towards the sky east of Geraldton, Western Australia.

Data from ASKAP is generated at a rate of 100 trillion bits per second. This data is processed by supercomputing facilities in Perth's Pawsey Supercomputing Research Centre. Once processed, the data can be used to create optical images we can view. In 2020, ASKAP's surveying capabilities were tested and resulted in ASKAP mapping 3 million galaxies in 300 hours.

One million of the galaxies mapped by ASKAP during this test had never been seen before. Australia's new supercomputer "Setonix" has incredible imaging capacity and is able to produce the likes of highly detailed supernova remnants as shown in Figure 3.
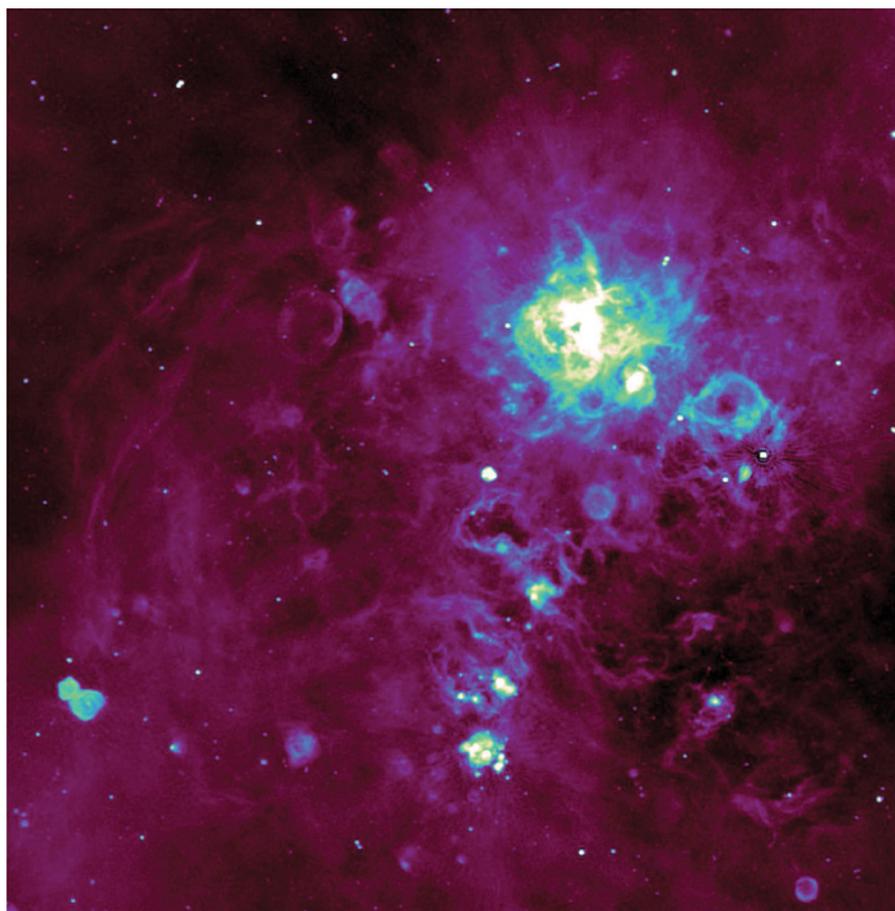
Figure 2 Image of the Large Magellanic Cloud, a galaxy neighbouring the Milky Way, created from ASKAP data
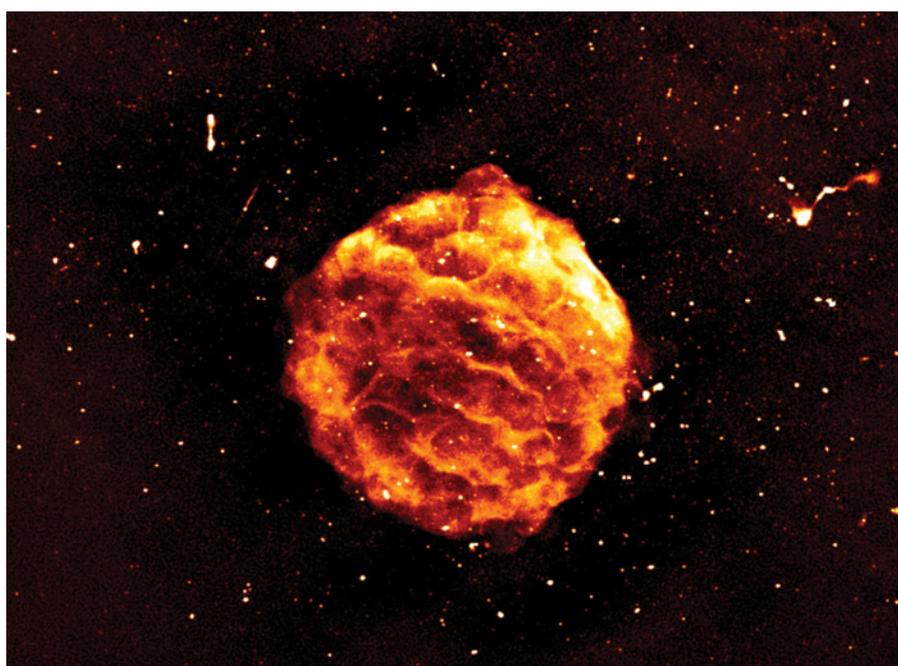
Figure 3 Image of a remnant supernova produced by Setonix processing of ASKAP data

Event Horizon Telescope

Black holes are regions in space where gravitational pull and density are so great that nothing, including light, can escape from them. The surface or "edge" of a black hole is called its **event horizon**. The event horizon is the boundary where velocity needed to escape the gravitational pull of the black hole is greater than the speed of light. Einstein's theory of special relativity states that nothing can travel faster than the speed of light. This essentially means that the event horizon is a "point of no return".

event horizon the boundary around a black hole at which no light or matter can escape

The Event Horizon Telescope (EHT) is a collection of radio telescopes from around the world that work together to image the emissions produced by supermassive black holes. The EHT is a collaborative project that uses radio telescopes from observatories in Europe, North America, South America, Hawaii and Antarctica. These telescopes all work to detect a specific target, and data from each telescope is transferred onto hard drives and sent to the MIT Haystack Observatory in the USA and the Max Planck Institute for Radioastronomy in Germany. Once the data is processed it can be transferred into an image.

In 2019, the EHT produced the first confirmed image of the supermassive black hole M87. The mass of the M87 black hole is approximately 6.5 billion times that of the Earth's Sun. In 2022, the EHT released the first image of the black hole Sagittarius A (Sgr A), a supermassive black hole located at the centre of our own galaxy, the Milky Way.
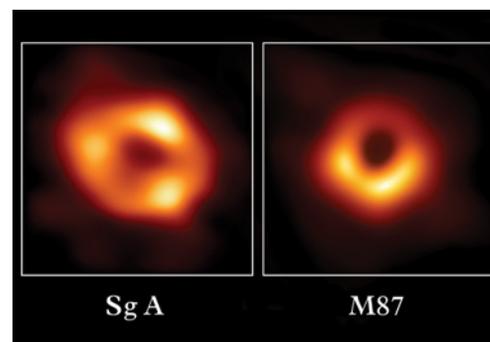
Figure 4 Images of the black holes Sgr A and M87 produced from EHT data

🖼️ Test your skills and capabilities

Communicating science ideas

1 **Investigate** the Square Kilometre Array, a project that ASKAP is part of. Use the following questions to guide your investigation.
   – Why was ASKAP built in Murchison, Western Australia?
   – What benefits are there in having so many countries involved with the ASKAP?
   – Other than astronomers, what other researchers work on the ASKAP program?
   – Why are supercomputers needed to interpret the data from ASKAP?
   – What are the researchers using ASKAP hoping to find?

2 Use your research to write a media release for the public. **Decide** who is the intended audience and what media you will use to reach them. **Consider** their level of scientific knowledge when determining the style of language and illustrations you will use to **describe** the Square Kilometre Array.

Skills builder: Planning investigations

3 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 widely 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?)

Earth and Space

Lesson 5.15
Review: The universe

Summary

Lesson 5.1 Science as a human endeavour: The universe was studied by Aboriginal and Torres Strait Islander Peoples

- Aboriginal and Torres Strait Islander Peoples have been observing the night sky for thousands of years.
- They use the stars and constellations to determine when certain activities should occur as part of their seasonal calendar, such as hunting and farming.
- Dreaming stories are used to pass down information and traditions.

Lesson 5.3 The Earth is in the Milky Way

- Stars are large balls of gas that undergo nuclear fusion.
- Stars that appear brighter are described as having a high apparent magnitude.
- Larger, hotter stars that are farther away have a higher absolute magnitude.
- As the Earth rotates, stars appear to move in the sky due to stellar parallax.
- One light-year is the distance light travels in a vacuum in 1 year.

Lesson 5.4 Scientists search for life

- The Goldilocks zone is the area around a star where liquid water might exist.
- Transmission spectroscopy detects the light that is absorbed by gases in a planet's atmosphere.
- A star wobbles when an exoplanet's gravity causes it to move slightly.

Lesson 5.5 Living in space required overcoming challenges

- Microgravity can affect the way the human body functions.

- Oxygen needs to be constantly produced on the International Space Station (ISS).
- Astronauts can be exposed to high levels of radiation.

Lesson 5.7 Science progress through collaboration

- New technologies have been developed to support the needs of space travel.
- New research and technologies progress when scientists collaborate.

Lesson 5.10 Stars have a life cycle

- Nebulae are large clouds of gas where stars are born.
- Each star exists in a hydrostatic equilibrium between the gravitational pull to the centre and the release push of energy from nuclear fusion.
- Small stars will cool and die, forming white dwarfs and black dwarfs.
- Large stars explode in novas and supernovas, releasing large amounts of light and energy.

Lesson 5.11 The galaxies are moving apart

- Elements absorb light energy in specific wavelengths, creating an absorption spectrum.
- When the same elements return to a stable state, they release the wavelengths of energy as an emission spectrum.
- The Doppler effect describes the change in frequency of a wave as an object moves towards or away from an observer.
- A red shift in the emission or absorption spectrum of a galaxy indicates that the galaxy is moving away from the observer.

Lesson 5.13 Evidence supports the Big Bang theory

- The Big Bang is a theory supported by evidence that describes how the universe began.
- The expansion of the universe is continuing to accelerate.

Lesson 5.14 Science as a human endeavour: Technology aids cosmological research

- There are may projects running to discover more about the universe.

- The Australian Square Kilometre Array Pathfinder (ASKAP) radio telescope project is looking to detect radio waves millions of light-years away from Earth.
- The Event Horizon Telescope is using telescopes from around the world to image the emissions produced by supermassive black holes.

Review questions 5.15

Review questions: Module 5

Retrieve

1 **Identify** the shape of the Milky Way galaxy.
   A Oblong
   B Elliptical
   C Regular
   D Cubic

Figure 1 The Andromeda galaxy

2 **Recall** which of the following makes up nebulae clouds.
   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 distance light travels in 1 year
   D The apparent change in wavelength when the source of the wave or the observer is moving.
4 **Define** the term "event horizon".
5 **Identify** the correct definition for each of the terms in Table 1.

Table 1 Terms and definitions

Term	Definition
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
Star chart	Everything that exists in space
Constellation	Huge collection of stars held together by gravity
Universe	Map used to locate and identify objects in the night sky
Big Bang	Our closest star

6 **List** the following in order of size from largest to smallest: neutron star, the Sun, white dwarf, red giant.

Comprehend

7 **Describe** what is meant by the term "escape velocity".

8 **Describe** the Doppler effect

9 **Describe** why scientists Penzias and Wilson won the Nobel Prize.

10 **Define** microgravity and **explain** the effect it has on the bodies of astronauts on the ISS.

11 **Explain** why the ASKAP is an important tool for astronomers.

12 **Describe** the evidence that supports the Big Bang theory.

13 **Explain** why light-years are used instead of kilometres as a unit of distance in space.

14 **Explain** why it is difficult to judge the distance of a star by measuring only its brightness.

15 **Explain** the link between Hubble's observations and the Doppler effect.

16 **Explain** why liquid water is considered essential for life to exist on an exoplanet.

17 **Explain** why we do not use light-years for measuring distances within our solar system.

Analyse

18 **Explain** why stars "wobble" when an exoplanet orbits them.

19 **Describe** how microgravity affects the movement of liquids in space.

20 **Compare** a white dwarf and a red giant.

21 **Contrast** the emission spectra and absorption spectra of an element.

22 **Compare** red shift and blue shift.

23 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.

Figure 2 The Sun

24 **Calculate** the distance (in kilometres) between the Earth and each of these celestial objects.
   a Altair star at 16.7 light-years
   b Coalsack Nebula at 600 light-years
   c Jewel Box star cluster at 7,600 light-years

25 If the speed of light is 300,000 km/s, **calculate** the distance light travels in:
   a 1 second
   b 1 minute
   c 1 hour
   d 1 day.

Apply

26 **Create** a diagram to **explain** why different stars are visible from different places on the Earth's surface.

27 **Explain** why scientists need to consider more than the location of an exoplanet in a Goldilocks zone.

28 **Explain** how the physical challenges of living in space (like microgravity and radiation) impact the health and performance of astronauts on long missions.

29 Answer these questions.
   a **Describe** how the pitch of an ambulance siren changes as it races past you.
   b **Explain** why this change occurs.
   c **Identify** if the driver of the ambulance could hear this change. **Justify** your answer (by describing the Doppler effect, explaining how it would affect people in front of and behind the ambulance, and deciding if this will affect the sounds the driver hears).

30 **Identify** whether the following statements are true or false. **Justify** each answer.
   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 Earth is its absolute magnitude.
   d Bigger stars are usually hotter, brighter and burn for longer than smaller stars.

31 Many cultures, including those of Aboriginal and Torres Strait Islander Peoples, have beliefs about the origin of constellations based on observations. These observations are used for cultural and farming practices. **Investigate** Indigenous beliefs about constellations and how these were and are used. **Discuss** how these observations still influence how we view and understand the constellations today.

Social and ethical thinking

32 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 (Figure 3). Dawn's journey includes exploration of the asteroid Vesta (in 2011) and the dwarf planet Ceres, between Mars and Jupiter (in 2015). **Investigate** and **describe** the information gathered by Dawn. **Describe** how this information improved our understanding of celestial bodies. Use ethical reasoning to **compare** the cost of this mission and how the money could be spent on Earth.

33 Watch the movie *Interstellar* and **investigate** how the discovery of gravitational waves would help us understand the nature of the dark energy that is causing the universe's expansion to accelerate. Have a class discussion about this.

Critical and creative thinking

34 **Create** an animation or comic strip explaining the Big Bang for Year 10 students who have not yet studied this unit. Include a simple explanation of all the evidence that supports this theory.

35 View a space movie or television series. **Describe** its plot. **Create** a poster identifying the things in the movie that are scientifically correct and the things that are not.

Figure 3 The Dawn space probe is on an interplanetary cruise.

Research

36 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

Dark matter

Vera Rubin studied the way galaxies rotated in the 1970s and discovered that there was extra matter in the universe that is invisible. This is now called dark matter.

- Compare ordinary matter and dark matter.
- Describe the evidence that supports Vera Rubin's hypothesis of the existence of dark matter.
- Describe 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. Describe the effect dark matter has on the future of our universe.

Figure 4 Vera Rubin operating a telescope at Kitt Peak Observatory

Movie science

Watch either of the movies *The Martian* or *Gravity* and investigate the accuracy of the science and technology shown.

- Identify three different science principles or technologies that are shown.
- Describe each science principle or technology accurately.
- Compare the movie's science principles or technology used on Earth with the way it was shown in the movie.
- Evaluate the accuracy of the movie.
- Justify your decision.
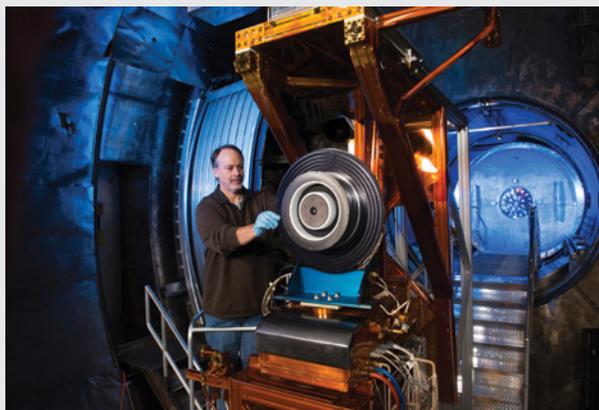
Figure 5 Ion propulsion is a new technology for space travel that has been developed by NASA.

Gravitational waves

Einstein's theory of general relativity predicted that gravitational waves would occur in space-time when massive objects such as black holes and neutron stars collided.

- Explain what gravitational waves are.
- Describe the evidence that supports the existence of gravitational waves.
- Explain why this evidence was not discovered until 100 years after Einstein's prediction.

Figure 6 Laser Interferometer Gravitational-Wave Observatory (LIGO) gravitational wave detector in Louisiana, USA. LIGO first detected gravitational waves from the collision of two black holes in 2015.

Exoplanets

Australian scientist Penny Sackett has led teams of scientists in searching for exoplanets similar to Earth.

- Define the term "exoplanet".
- Describe how astronomers search for them.
- Explain why the existence of these planets may be important.
- Describe the conditions that would be needed on an exoplanet for humans to survive.

Figure 7 Astrophysicist Penny Sackett

Module
6
Motion
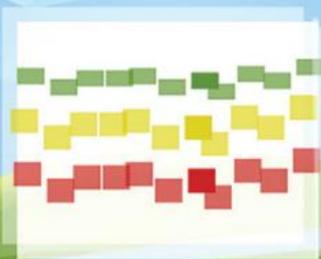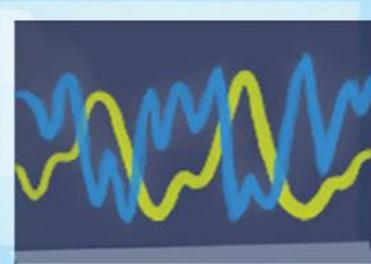
Overview

Newton's laws of motion help us understand how objects move and how force, mass, and acceleration are connected. We can use formulas and graphs to work out things like speed, distance, and how quickly something is moving or slowing down. These laws are used in real life – for example, Newton's laws are used to design safety features like seatbelts, airbags and crumple zones in cars.

Data and Newton's laws are used to argue for lower speed limits near schools. Even programmers of driverless cars need to consider these laws to decide when the car needs to brake or change speed. Understanding Newton's laws helps explain everyday motion and how to stay safe during movement.

Lessons in this module

Lesson 6.1
Displacement is change in position with direction

Key ideas

→ Distance describes how far an object has travelled.

→ Displacement describes the final distance and direction of an object from its starting point.

→ Displacement is a vector quantity because it has position and direction.

Distance and displacement

distance the length of the path travelled by an object

displacement the change of position of a moving object in a particular direction

scalar having only magnitude (a numeric quantity)

magnitude the size or extent of something

vector having magnitude and direction

During a normal day, you may cover a considerable distance – on the way to school, on the way home and 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 – your bed! So, you could say that you haven't really gone anywhere at all.

Distance is how far an object travels. The distance you moved during the day could be large or small. **Displacement** describes the difference between the starting position and the finishing position, including direction. It does not include all the in-between movements. If you end up back in bed after a whole day of moving, then your daily displacement is zero. For distance we use the symbol d, and for displacement we use the symbol s. The standard unit (or SI unit) for both 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 can be a compass direction (north, south, east or west) or a bearing, or it may be as simple as left, right, up, down, forwards or backwards.

Displacement–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 displacement–time graph. A displacement–time graph is a picture of the motion of an object. Displacement–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 displacement is always on the y-axis (Figure 1). Always remember to mark the units (e.g. seconds, metres) on the graph. Worked example 6.1A shows how to calculate distance and displacement over time.
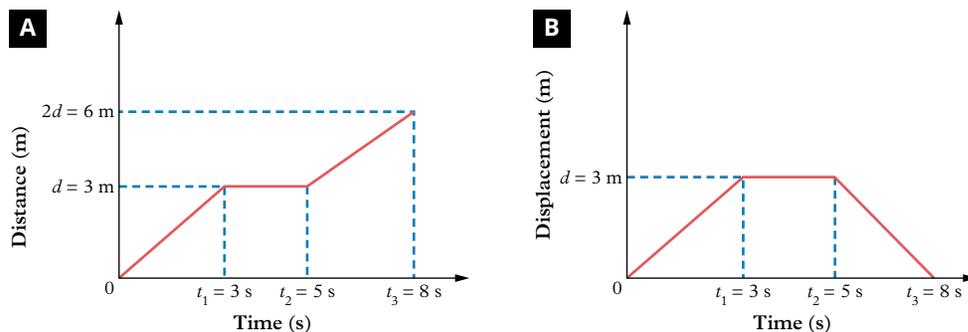
Figure 1 These two graphs show the same journey. (A) A distance–time graph shows a person travelling 3 metres for the first 3 seconds, resting for 2 seconds, before travelling 3 metres in the final 3 seconds. (B) A displacement–time graph shows us the journey and also tells us that the person travelled back to where they came from.

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 m north, then 4 m west and then 2 m south. This gives a total distance covered of 11 m. However, this is not their displacement. Their displacement only compares where they finish to where they started. Worked example 6.1B shows how to calculate distance and displacement using direction.
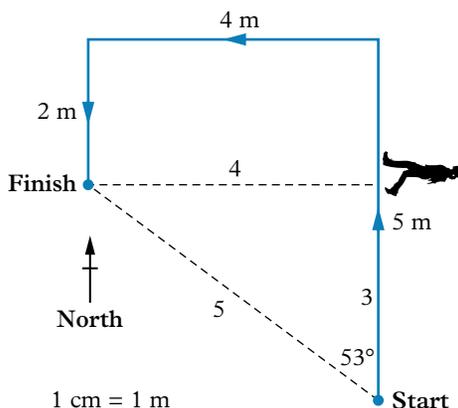
Figure 2 This person walks a total of 11 m. The displacement can be calculated by drawing a right-angled triangle and using Pythagoras' theorem. The final position of the person is 5 m north, 53° west or 5 m on a bearing of 307°.

Worked example 6.1A Calculating distance and displacement over time

The displacement–time graph shown in Figure 1 shows the movements of a person over 8 seconds.

a Calculate the distance the person travelled.

b Calculate the displacement of the person.

Solution

a The person walked away from the starting point 3 m in the first 3 seconds, stopped for 2 seconds, and then walked for 3 m in the next 3 seconds.

Their total distance travelled (sum of all values) = 3 + 3 = 6 m.

b The total displacement is the distance and direction from the starting point.

The displacement graph shows that the person walked away from the starting point for the first 3 seconds and stopped for 2 seconds, before walking back to the starting point. The total displacement is 0 metres.

6.1

> ### Worked example 6.1B Calculating distance and displacement using direction
>
> A person walks 5 m north, 4 m west and then 2 m south.
> **a** Calculate the distance travelled by the person.
> **b** Calculate the displacement of the person from their starting point.
>
> #### Solution
>
> **a** The total distance travelled by the person can be calculated by adding all the distances together.
>
> $5 + 4 + 2 = 11$ m
>
> **b** The displacement of the person must include the distance from their starting point and the direction (Figure 2).
>
> The distance can be determined using Pythagoras' theorem: $c^2 = a^2 + b^2$, where c is the (long) hypotenuse, and a and b are the sides on each side of the right angle.
>
> $a = 3$ m, $b = 4$ m, $c = ?$
> $c^2 = 3^2 + 4^2$
> $\quad = 9 + 16$
> $\quad = 25$ m
> $c = \sqrt{25}$
> $\quad = 5$ m
>
> The angle can be determined by using sine, cosine or tangent.
>
> $\cos\theta = \dfrac{\text{adjacent length}}{\text{hypotenuse length}}$
>
> $\cos\theta = \dfrac{3}{5}$
>
> $\theta = 53°$
>
> The displacement of the person is 5 m north, 53° west (an angle of 53 degrees in the west direction of the north/upwards line).

Check your learning 6.1

Check your learning 6.1

Comprehend

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

2 A car starts from rest (stationary) and moves north at a constant rate for 400 m, then stops for 10 seconds before moving north another 150 m. On a piece of paper, **represent** this movement as a displacement–time graph.

Analyse

3 **Compare** the displacement and distance of a swimmer swimming laps in a pool.

4 **Compare** a vector quantity and a scalar quantity. Use an example to illustrate your comparison.

5 An object moves 14 m north and then 14 m south. **Calculate** the distance that it has covered. **Calculate** its displacement.

6 A person runs 50 m north, then 20 m south and then 30 m west. Draw a diagram of the distance travelled. **Calculate** the total distance covered. **Calculate** the person's displacement.

7 **Consider** the graph in Figure 3.
  a **Describe** the motion shown.
  b **Calculate** the distance covered in the graph.
  c **Calculate** the displacement shown.
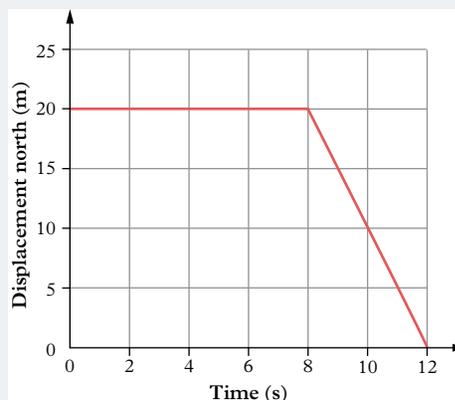
Figure 3 A displacement–time graph

Lesson 6.2
Challenge: Bringing graphs to life

Aim

To model movement from a displacement–time graph

What you need:

- Clear space (maybe outside)
- Tape measure
- Stopwatch
- Masking tape
- Marker pen

What to do:

Working in pairs, act out the displacement–time graph in Figure 1.

1. Lay out a 4 m piece of masking tape on the floor and mark it at intervals of 1 m.
2. Rehearse the motion shown in Figure 1 by discussing it with your group. You could even do 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 m in the opposite direction.
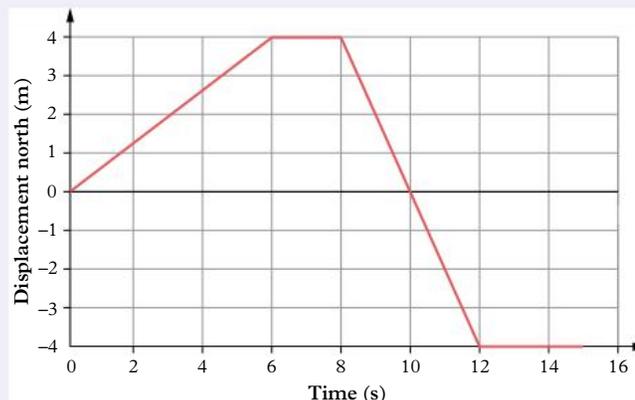
Figure 1 A displacement–time graph

Questions

1. **Describe** the motion completed by your group that was matched to the graph.
2. **Describe** the common errors made by the group when completing this activity.
3. Draw your own displacement–time graph.
4. **Describe** the motion that is illustrated in the graph.

Lesson 6.3
Velocity is speed with direction

Key ideas

→ Speed is a scalar quantity that measures the distance travelled in a set time.

→ The average speed can be determined by dividing the distance travelled by the total time taken.

→ Velocity is a vector quantity and it measures the change in displacement over time.

Speed

speed the distance travelled per unit of time

Speed is a measure of how fast a car, person or 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 uses the symbol v, and is defined as the distance travelled per unit of time. A speed of 5 m/s, for instance, means the object travels 5 m in every second of its motion. Speed is a scalar quantity because it only has size and no direction.

Figure 1 The cheetah is the fastest land animal. It can reach speeds of up to 112 km/h.

Average speed

Often it is more convenient to work out (or calculate) an object's average speed. To calculate average speed (v_{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 2. The triangle is a good memory tool

$$v_{av} = \frac{d}{t}$$
$$t = \frac{d}{v_{av}}$$
$$d = v_{av} \times t$$
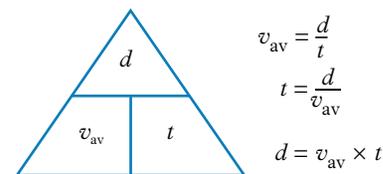
Figure 2 The average speed triangle is used to work out the formula for average speed. Cover the quantity you want to calculate with your finger and the other two quantities will form the formula.

to help you work out three formulas from the one diagram. Worked example 6.3A shows an example calculation.

Average speed can also be determined by the gradient (or slope) of a displacement–time graph (Figure 3).

Instantaneous speed

Over the course of a bus or car trip, your speed changes. When you start moving, your speed increases as you accelerate. Over time, you may reach a constant speed where there is no change. As you become close to your final destination, your speed will decrease. The speedometer in the vehicle gives the instantaneous speed in km/h. This is the speed at each moment of the trip.
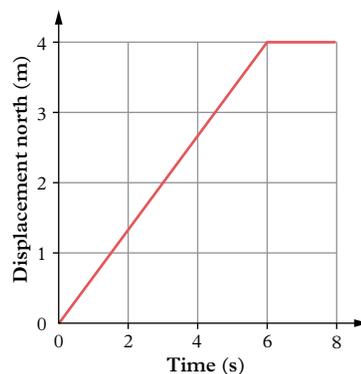
Figure 3 The speed of the object in this displacement–time graph can be calculated by determining the gradient of the graph.

Worked example 6.3A Calculating distance using speed

Calculate the distance travelled by an object moving at an average speed of 5 m/s for 1.5 seconds.

Solution

Use the triangle in Figure 2 to determine the formula for distance travelled.

$$\text{Distance travelled } (d) = v_{av} \times t$$
$$= 5 \text{ m/s} \times 1.5 \text{ s}$$
$$= 7.5 \text{ m}$$

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 as speed (m/s) but uses an arrow over the top ($\vec{v}$) to show that it also has direction. The average velocity of an object ($\vec{v}_{av}$) is calculated in a similar way to average speed, but displacement is used instead of distance (Figure 4).

velocity the vector quantity that measures speed in a particular direction

Figure 4 The average velocity triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

$$\text{Average velocity } (\vec{v}_{av}) = \frac{\text{displacement}}{\text{time}}$$

The direction of the average velocity is the same as the direction of the displacement. Like speed, average velocity can be determined from the gradient of a displacement–time graph, but the nature of the gradient indicates the direction. For example, if the gradient is positive (going up) on a displacement–time graph, the velocity is constant or unchanging in the positive direction. If the gradient on a displacement–time graph is zero (or horizontal), then the object is not moving and the velocity is zero. If the gradient is sloping downwards, then the velocity is constant and moving in the negative direction. Worked example 6.3B shows how to calculate the displacement of the object.

Physics

6.3

Graphing speed and velocity

It is useful to graph either speed or velocity on a graph. As velocity is a vector quantity (with direction) the graph can show a negative velocity when an object moves in the opposite direction. Speed–time graphs do not show negative numbers. In speed–time graphs, speed is plotted on the *y*-axis and time on the *x*-axis. If the graph slopes upwards, then the object is speeding up (accelerating). If the gradient is negative (sloping downwards) towards the *x*-axis, then the velocity is decreasing (slowing down) until it reaches 0 m/s. In velocity–time graphs, if the graph slopes below the *x*-axis, then the object is speeding up in the southerly direction. The area under the graph determines the distance travelled in that time.

Worked example 6.3B Calculating displacement

Calculate the total displacement of the object in Figure 5.
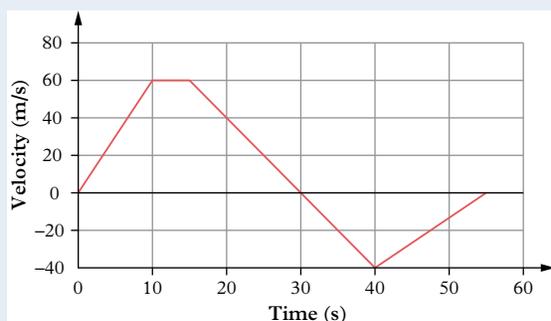
Figure 5 This velocity–time graph shows an object with changing velocity.

Solution

The area under the graph describes the displacement of the object.

The graph needs to be broken into different sections so that the area under the graph can be calculated.

- 0–10 seconds (triangle): The object increased speed or accelerated.

$$\text{Area } (0 - 10 \text{ s}) = \frac{1}{2} \times \text{base} \times \text{height}$$
$$= 0.5 \times 10 \times 60$$
$$= 300 \text{ m}$$

- 10–15 seconds (rectangle): The object kept the same speed.

$$\text{Area } (10 - 15 \text{ s}) = \text{base} \times \text{height}$$
$$= 5 \times 60$$
$$= 300 \text{ m}$$

- 15–30 seconds (triangle): The object slowed to a stop.

$$\text{Area } (15 - 30 \text{ s}) = \frac{1}{2} \times \text{base} \times \text{height}$$
$$= 0.5 \times 15 \times 60$$
$$= 450 \text{ m}$$

- Total displacement in the positive (north) direction:

$$d = 300 + 300 + 450$$
$$= 1,050 \text{ m}$$

- 30–40 seconds (triangle): The object increased speed in the negative (south) direction.

$$\text{Area } (30 - 40 \text{ s}) = \frac{1}{2} \times \text{base} \times \text{height}$$
$$= 0.5 \times 10 \times -40$$
$$= -200 \text{ m}$$

- 40–55 seconds (triangle): The object decreased speed in the negative (south) direction.

$$\text{Area } (40 - 55 \text{ s}) = \frac{1}{2} \times \text{base} \times \text{height}$$
$$= 0.5 \times 15 \times -40$$
$$= -300 \text{ m}$$

Total displacement in the negative (south) direction = 200 + 300 = 500 m

Therefore, total displacement = 1,050 m north − 500 m south = 550 m north.

Check your learning 6.3

Check your learning 6.3

Comprehend

1 Describe what the area under a velocity–time graph indicates.

Analyse

2 Use the average velocity triangle to **represent** the three different formulas.

3 Calculate the value of 80 km/h in metres per second.

Apply

4 Identify 4 m/s as a speed or a velocity. **Justify** your answer (by defining both speed and velocity, and comparing the definition to your decision).

5 A student wanted to measure the average speed of cars driving past the school to determine if the speed zone was appropriate.

   a Describe the reproducibility of surveying the parents of students to determine the amount of traffic in the area.

   b Describe how the student could use equipment in their school laboratory to determine the speed of a car driving past the school.

6 Consider the graph shown in Figure 6.

   a Create a story that describes the motion of a person moving according to the graph.

   b Calculate their displacement from the point of origin.
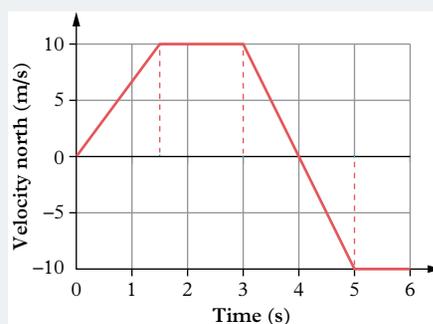
Figure 6 A velocity–time graph

Skills builder: Conducting investigations

7 Scientists make predictions based on information and data. Using the right units to record measurements is important to produce 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 units used are too large to be specific?)

Physics

Lesson 6.4
Experiment: The ticker timer

Aim

To learn how a ticker timer operates and to use it to produce a speed–time graph

Materials

- Ticker timer
- Scissors
- 2–12 V DC 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). Set power source at 6 V. Adjust as required.

Figure 1 Connecting the ticker timer

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).
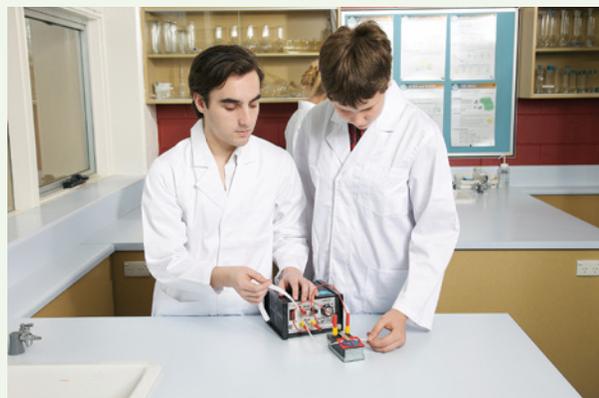
Figure 2 Examining the ticker tape

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.

Discussion

1. **Compare** speed with velocity.
2. **Explain** why the length of each tape column indicates the speed.
3. **Describe** how you could determine the average speed of each section. (HINT: Average speed = distance ÷ time)
4. **Explain** why the lengths of tape are the "average" speed and not the instantaneous speed (by defining average speed, defining instantaneous speed and comparing your chosen definition with the length of the tape).
5. **Design** another experiment you could do using a ticker timer. Ask your teacher for permission to carry out your experiment.

Conclusion

Describe the information you can determine using a ticker timer.

Lesson 6.5
Skills lab: Using a motion sensor

Aim

To become familiar with the operation of a motion sensor and to use it to produce motion graphs

Materials

- Motion sensor
- Dynamics trolley
- Laptop computer
- Cardboard reflector

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.

Figure 1 Motion sensors can be used to measure displacement, speed, velocity and acceleration.

Results

Analyse the data on the laptop to produce a displacement–time graph (and a speed–time graph, and even an acceleration–time graph if possible).

◀

Discussion

1 **Describe** what each graph is showing you.
2 **Compare** the graphs with the actual motion of the trolley.
3 **Evaluate** the accuracy of the graphs produced by the motion sensor (by comparing it with the measurements produced by the ticker timer experiment in Lesson 6.4 Experiment: The ticker timer (page 274) and deciding which is more accurate).

4 **Design** another experiment you could perform with the motion sensor.

Conclusion

Describe the information that can be gained from graphs created by a motion sensor.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Lesson 6.6
Acceleration is change in velocity over time

Key ideas

→ Acceleration is the rate at which the velocity of an object changes.

→ Acceleration can be due to changing speed or changing direction.

→ An object travelling at a constant, unchanging velocity has an acceleration of zero.

Acceleration

Pressing the accelerator pedal in a car makes the car move and increase in speed. This is the same as saying the car accelerates. In physics, acceleration is a vector quantity, which means it also has a direction. This means acceleration is how much an object changes its velocity every second. As velocity can change when the direction changes, acceleration can also change when the direction changes. This means 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.

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. However, other units for acceleration are possible depending on the units of velocity and time.

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To understand acceleration, we will only consider objects travelling in one direction in a straight line and under constant acceleration. Consider a falling object, such as the rock shown in Figure 1.

When 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 a high speed.

After 1 second, it should reach a velocity of 9.8 m/s due to gravity. We say it has accelerated at a rate of 9.8 m per second in 1 second or at 9.8 m per second per second (written as 9.8 m/s/s or 9.8 m/s^2 or 9.8 m s^{-2}).

After another second at the same rate, the rock would reach a velocity of 19.6 m/s.

After 3 seconds, it would reach a velocity of 29.4 m/s. Of course, this analysis ignores the effects of air resistance, which would prevent the rock from reaching a velocity of 29.4 m/s after 3 seconds.

Figure 1 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 downwards.

The acceleration value of 9.8 m/s^2 is called **acceleration due to gravity** and is given the special symbol of *g*. When people skydive, their movement follows the pattern of the rock. They speed up as they fall until they open their parachute and slow down to land.

Calculating acceleration

The formula for calculating acceleration ($\vec{a}$) is:

$$\text{Acceleration } (\vec{a}) = \frac{\text{change in velocity } (\Delta\vec{v})}{\text{change in time } (\Delta t)}$$

where δ is the Greek letter "delta" and means "change in". This can also be seen in the acceleration triangle (Figure 2).

This can also be written as:

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

where $\vec{v}$ is the final velocity and $\vec{u}$ is the initial (or starting) velocity.

Acceleration is indicated by the gradient of a velocity–time graph. The steepness of the gradient indicates the magnitude of the acceleration. This is shown in Figure 3 and Figure 4.

Worked example 6.6A describes the velocity and acceleration of an object, and Worked example 6.6B shows how to calculate the acceleration of the object.

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

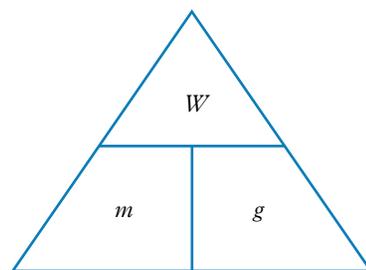**acceleration due to gravity** acceleration of an object due to a planet's gravitational field; on Earth, *g* = 9.8 m/s; the approximate value of 10 m/s^2 is sometimes used

Physics

6.6
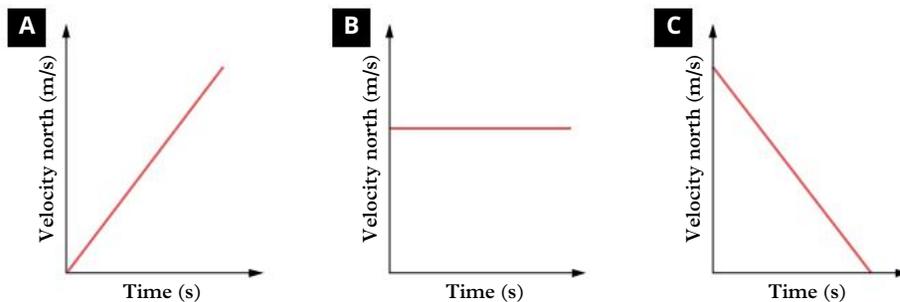
Figure 3 Velocity–time graphs (for an object moving in the positive direction) showing (A) constant positive acceleration (i.e. speeding up); (B) zero acceleration (i.e. constant speed); and (C) negative acceleration (i.e. slowing down or decelerating)
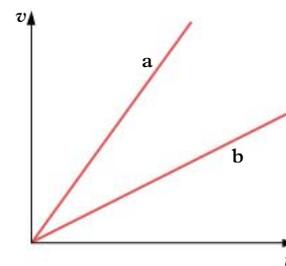
Figure 4 Velocity–time graph showing a (A) steep gradient, indicating high acceleration; and (B) gentle gradient, indicating lower acceleration

Worked example 6.6A Describing velocity and acceleration

Describe the velocity and acceleration of the object in the first 3 seconds of Figure 5.

Figure 5 Acceleration can be determined by the gradient of a velocity–time graph.

Solution

The object in the graph is travelling at a constant velocity of 4 m/s away in the positive direction for the first 3 seconds. Its gradient (and therefore its acceleration) is zero.

Worked example 6.6B Calculating acceleration

Calculate the acceleration of the object in the last second of Figure 5.

Solution

Acceleration is the gradient of the velocity–time graph. The object slows from 4 m/s to 0 m/s in the last 1 second.

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$$

$$= \frac{\text{final velocity} - \text{starting velocity}}{\text{final time} - \text{starting time}}$$

$$= \frac{0 - 4 \text{ m/s}}{4 - 3 \text{ s}}$$

$$= \frac{-4 \text{ m/s}}{1 \text{ s}}$$

$$= -4 \text{ m/s}^2$$

Since the velocity is positive, the negative number indicates the object has decelerated.

Check your learning 6.6

Check your learning 6.6

Retrieve

1 **Recall** the acceleration of an object if its velocity is constant.

Comprehend

2 **Describe** the motion of an object with the speed–time graph shown in Figure 6.
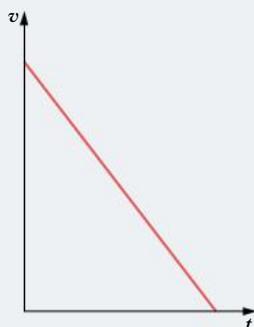
Figure 6 A speed–time graph

3 **Explain** what is meant by the term "deceleration".

4 Use the acceleration triangle to **represent** the three different acceleration formulas.

Analyse

5 An object starts from rest and accelerates at a rate of $4\,\text{m/s}^2$. **Calculate** its velocity after each second for 5 seconds.

6 A car travelling at 60 km/h takes 3 seconds to come to a rest. **Calculate** the distance it travels in that time. (HINT: Remember to change the km/h to m/s.)

7 **Compare** accelerating and decelerating objects.

Skills builder: Questioning and predicting

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

   a Observe what happens when cars travelling at a constant speed suddenly have to travel up a hill. (THINK: Was there a change in the speed or the engine sound 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: How would the hill impact speed? Why?)

Lesson 6.7

Challenge: 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.

Aim

To measure the acceleration of a falling object

What you need:

• 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 Repeat steps 1 and 2 at least three times to determine the average time taken.

Questions

1 Use the results to **calculate** the acceleration due to gravity in units of m/s^2. The formula that describes this situation is: $h = \vec{a}t^2$

(HINT: Rearrange the formula to make a (acceleration) the subject and substitute your values for h and t.)

2 The resulting value for $\vec{a}$ is the acceleration due to gravity (although it usually has the symbol g). **Compare** your calculated value with the known true value of 9.8 m/s^2 near the Earth's surface.

3 **Identify** any sources of error that could have resulted in an inaccurate measurement of the acceleration due to gravity.

4 **Identify** whether this activity is a case study, modelling/simulation, quantitative analysis or a controlled experiment. **Justify** your decision (by identifying the key characteristics of the activity and comparing these with the definition of the term you chose).

Lesson 6.8

An object keeps the same velocity until a net unbalanced force acts on it

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Forces act in pairs between two objects.

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

Introduction

Imagine driving along a road with your schoolbooks sitting next to you on your seat. If the car brakes suddenly, your seatbelt will stop you from moving forwards. Your schoolbooks will not have a seatbelt to stop them, and so they will fly forwards to the front of the car. This can be explained by Newton's First Law of Motion.

Newton's laws

English scientist Isaac Newton (1642–1727) is often pictured as sitting under a tree until an apple falls on his head (Figure 1). We are not sure if this story is true (Newton liked to embellish his stories); however, he was the first person to explain why an apple would fall down instead of up or sideways. He even wrote mathematical formulas to explain how and why the apple would move. In his book the *Philosophiae Naturalis Principia Mathematica*, Newton outlined his laws of motion and his law of universal gravitation.

A force always occurs between two objects. One object will provide a push or a pull force on another object. Force has the symbol *F* and is measured in newtons (N). The push or pull can change how an object moves (its motion). The force can start or stop a movement, or it can change the object's speed or direction. A force is not necessarily needed to keep an object moving, but most objects slow down because of the force of friction. Force is a vector quantity with a magnitude and direction (e.g. 50 N downwards).

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 likely fictional, Newton himself is responsible for its creation.

Newton's first law

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), is being pulled down due to gravity (its weight force). 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) will only change if another force is added (such as someone pushing the object). This will cause the forces to become unbalanced and the object will change its motion. It will start moving.

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

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

Figure 2 Zero net force is shown by two equal length arrows pointing in opposite directions. This person will not move until a new force acts on him.

Inertia and moving objects

Think of any motion you have experienced today, maybe in a car, bus, train or tram, or even on a bike. In constant velocity, you sometimes hardly notice you are moving, but if the vehicle stops or starts suddenly or turns 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 or velocity (Figure 3). The friction of the brakes on the tyres, and the tyres on the road, stops the car; however, it does not stop you. Your seatbelt is the only thing stopping you moving at 60 to 100 km/h

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

Physics

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6.8

(Figure 4). If you are not wearing your seatbelt, Newton's first law says that you will keep moving at the same speed (60–100 km/h), 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 brakes will stop the bus, but you will keep moving forwards until the friction of your shoes or your hand grabbing for a handrail stops you. Your velocity will remain constant unless a new (unbalanced) force stops you. Heavier objects with more mass are more difficult to start or stop moving. For this reason, objects with larger mass are described as having more inertia.

Figure 3 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.
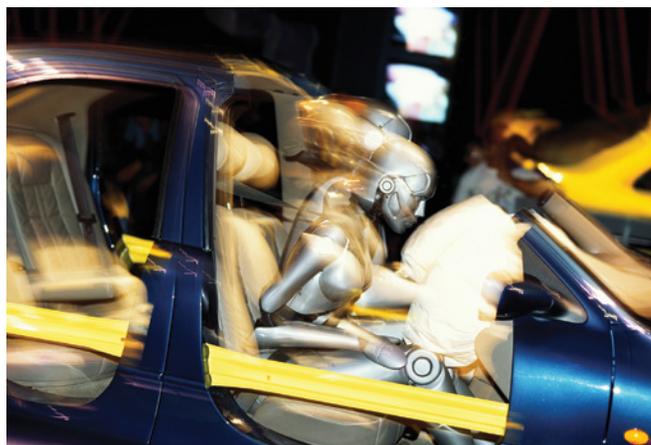
Figure 4 Seatbelts are an inertia device. They are often called "inertia reel seatbelts". The aim of a seatbelt is to transfer the force on the car to the passenger wearing the seatbelt so that the person moves with the car. You start moving when the car starts moving and, when wearing your seatbelt, you stop moving when the car stops moving.

Check your learning 6.8

Check your learning 6.8

Retrieve

1 **Define** the term "net force".
2 **Define** the term "inertia".

Comprehend

3 **Describe** what happens to a moving object with zero net force acting on it.
4 **Describe** what happens to a stationary object with zero net force acting on it.
5 **Redraw** the force diagram in Figure 2 showing an unbalanced force so the person would move upwards.
6 **Describe** how inertia affects your motion inside a car, bus, tram or train.
7 **Explain** why people lurch backwards in a tram when it starts moving suddenly.
8 **Explain** why you should wear a seatbelt in a moving car.

Apply

9 **Create** a poster for Year 7 students that explains why you should wear a seatbelt in a car.

Skills builder: Communicating

10 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 in your own words?)
   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?)

Lesson 6.9
Challenge: Make an accelerometer

Aim

To make an accelerometer

What you need:

- Small glass jar and lid
- Paperclip
- Short length of cotton
- Sticky tape
- Water
- Scissors

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 a 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.

Questions

1. Use Newton's first law of motion to **explain** why the paperclip resists moving when the jar starts moving.
2. Use Newton's first law of motion to **explain** why the paperclip keeps moving forwards when the jar comes to rest.
3. **Describe** what happens to the paperclip when the jar is moving at a constant speed.
4. Use Newton's first law of motion to **explain** your answer to question **3**.
5. **Explain** how our own bodies tell us we are accelerating, decelerating or travelling around a corner.

Lesson 6.10
Net force equals mass × acceleration

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ 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."

→ The equation for Newton's second law can be expressed as $F_{net} = ma$.

Introduction

Newton's laws are used in many unexpected ways. The coding of automated trains (with no drivers) must plan for the number of passengers in the carriages. During peak hour, there are many more passengers, and the carriages have greater mass. This means the trains will need a greater force to slow down than the lighter, empty carriages. The weight is a measure of the forces from gravity acting on the carriages. It is measured in newtons (N).

Force affects acceleration

If an object experiences an unbalanced net force, the object will change its velocity in the direction of the force. This means 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 as it is already moving. This is like a bike rider pedalling harder to increase the driving force (Figure 1). The thrust is in the same forward direction, so the bike will increase its speed.

When the net force acts in the opposite direction, the moving object will slow down (decelerate) and eventually stop. This is like the brake adding a friction force to the moving bike. The net force is 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 2).

Figure 1 Pedalling provides the thrust force when riding a bike.

Figure 2 Braking provides a drag force.

Force, mass and acceleration

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

We can express this relationship in a simple equation:

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

$$F_{net} = ma$$

This relationship can also be expressed in a force triangle (Figure 3). You need a larger force to accelerate a heavy object from rest, and a smaller force to accelerate a lighter object from rest.

When mass is in kilograms (kg) and the acceleration is in metres per second squared (m/s²), the net force will be in newtons (N). Acceleration and net force are both vectors and always act in the same direction.

Often, you need to consider all the individual forces acting on an object in order to work out the net force.

Worked example 6.10A shows how to calculate acceleration using net force and mass.

Figure 3 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.

Figure 4 Various forces act on a cyclist.
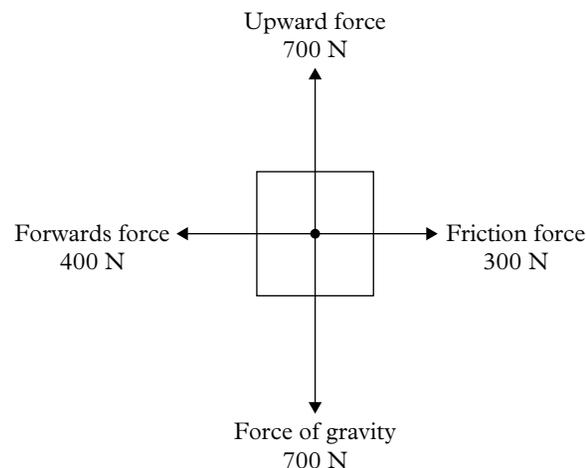
Mass or weight

We often use the term "weight" to indicate how much mass something has in kilograms, but in physics weight is a force, not a mass. Weight is the force from gravity acting on an object. Because it is a force, weight is measured in Newtons. For example, gravity on the Moon is approximately $1.6 \, \text{m/s}^2$ and on the Earth is $10 \, \text{m/s}^2$. This means an object with a mass of 100 kg would have a weight of 160 N (100 kg × $1.6 \, \text{m/s}^2$) on the Moon and 1,000 N (100 kg × $10 \, \text{m/s}^2$) on the Earth.

An object on the Moon will have less weight (N) but the same mass (kg).

Weight can be calculated by using the following formula, or the triangle shown in Figure 5.

$$\text{Weight} = \text{mass} \times \text{gravitational acceleration}$$
$$W = mg$$

Figure 5 Weight is the force of gravity acting on an object's mass. Weight (force) = mass × acceleration due to gravity.

Physics

Figure 6 Cars can accelerate faster than trucks mainly because of their smaller mass. Cars will also decelerate faster. This means a truck will take longer to stop than a car.

Worked example 6.10A Calculating acceleration using net force and mass

Consider the cyclist and bike with a mass of 90 kg shown in Figure 5. The forward-acting force is 400 N, and the total drag force from air resistance and friction is 300 N backwards. Calculate the acceleration of the cyclist.

Solution

The net force is the sum of the vector forces.

Forward forces (thrust) = +400 N

Reverse forces (drag + friction) = −300 N

Net force = 400 − 300 = 100 N forwards

$$\text{Acceleration} = \frac{\text{net force}}{\text{mass}}$$

$$= \frac{100 \text{ N forwards}}{90 \text{ kg}}$$

$$= 1.11 \text{ m/s}^2$$

The cyclist would increase his velocity in the forward direction by 1.11 m/s every second.

Check your learning 6.10

Check your learning 6.10

Retrieve

1 **Define** the term "weight force".

Comprehend

2 **Describe** 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.

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

Analyse

5 **Compare** the acceleration of a bus full of passengers to that of an empty bus, if the same net force was used.

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

Apply

7 **Create** an infographic that explains why trucks need a greater stopping distance than cars.

8 Use your understanding of Newton's second law to construct an argument for lower speed limits for trucks in a pedestrian area. Use data to support your argument.

Skills builder: Problem solving

9 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 diagram or table 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?)

Lesson 6.11
Experiment: Resultant forces

Aim

To investigate the addition of vectors using three spring balances

Materials

- 3 spring balances (0–10 N or 0–20 N are best)
- 2 rubber bands
- Graph paper
- Masking tape
- Scissors

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).

Figure 1 Experimental set-up

Physics

◀
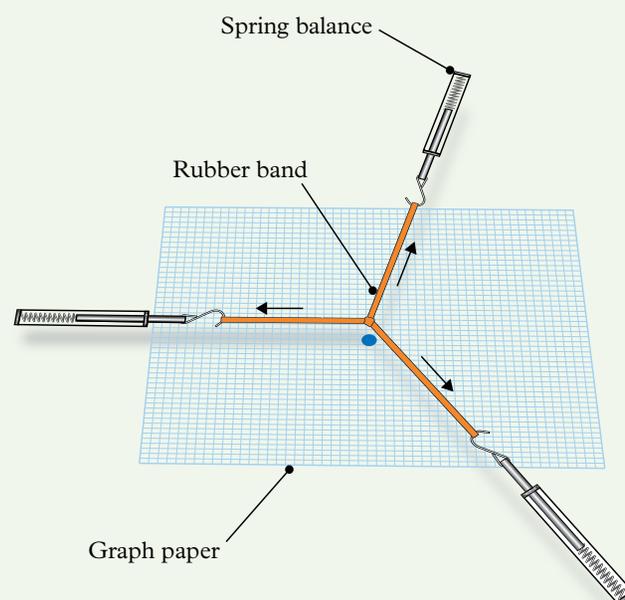
5 Pull on the spring balances in different directions so that the knot stays directly over the dot.

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 experiment 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 the line shows the size of the 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 experiment correctly.

Discussion

1 **Contrast** a force diagram and a vector diagram.

2 **Define** the term "net force".

3 **Describe** the net force on a stationary object.

Conclusion

Describe the vector forces on the three spring balances.

Lesson 6.12
Experiment: Accelerating masses

Aim

To determine the relationship between mass and acceleration

Materials

- Dynamics trolley
- String

- Mass hanger and brass 50 g masses
- Several 1 kg masses
- Desk-mountable pulley wheel with clamp
- Motion sensor or stopwatch
- Tape measure or ticker timer
- 2–12 V power supply
- Ticker tape
- Cushioning material

Method

1   Clamp the pulley wheel to the edge of the desk. Try to arrange the largest height possible above the floor (Figure 1).

Figure 1 Clamping the pulley wheel to the desk

2   Attach one end of the string to the dynamics trolley and the other end to the mass hanger, carrying a total of approximately 200 g of mass (Figure 2).

Figure 2 Attaching string to the dynamics trolley and the mass hanger

3   Measure a fixed displacement for the trolley to move. Record this value.

4   Hang the masses over the pulley so they can pull the trolley along as they fall to the floor. Place the cushioning material under the weights to reduce impact.

5   Record the motion of the trolley as the masses fall, by using a motion sensor, timing with a stopwatch or recording the motion on ticker tape (Figure 3).

Figure 3 Recording the motion of the trolley

6   Successively add 100 g masses to the trolley and repeat your measurements several times.

Results

1   Determine the acceleration of the trolley using one of the following methods.

   a   If you used a motion sensor, use software (Lesson 6.5 Skills lab: Using a motion sensor (page 275)) to determine the acceleration directly or from the gradient of a velocity–time graph.

   b   If you used a stopwatch, calculate the acceleration as (2 × the distance travelled ÷ time squared).

   c   If you used a ticker timer, use the "every fifth dot method" (Lesson 6.4 Experiment: The ticker timer (page 274)) to divide the tape into sections. Determine the speed of each section by dividing the distance covered by 0.1 seconds. Plot a speed–time graph and determine the acceleration from the gradient of the graph.

2   Plot a graph of average acceleration versus total mass. This should give a truncated, or inverse, graph.

Discussion

1 **Define** the term "acceleration".
2 **Define** the term "mass".
3 **Explain** why it is important to repeat the experiment several times and determine the mean acceleration of the trolley. **Identify** how many times you repeated the experiment. **Justify** your decision.
4 **Describe** how increasing the mass on the trolley affected the acceleration of the trolley.

5 Use Newton's second law of motion to **explain** the effect mass has on acceleration.
6 **Describe** a real-world example in which the mass can affect the motion of a moving object.

Conclusion

Describe the relationship between mass and acceleration.

Lesson 6.13

Each action has an equal and opposite reaction

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Newton's third law states: "For every action, there is an equal and opposite reaction."

→ Action–reaction pairs always act on different objects and therefore cannot cancel each other out.

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 another 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.

reaction force the force acting in the opposite direction to an initial force

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 can never cancel under any circumstances because the two forces act on different objects.

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.

A

A   B

Action ← → Reaction

Girl B pushes girl A

B

A   B

More mass ← → Less mass

Lower speed   Higher speed
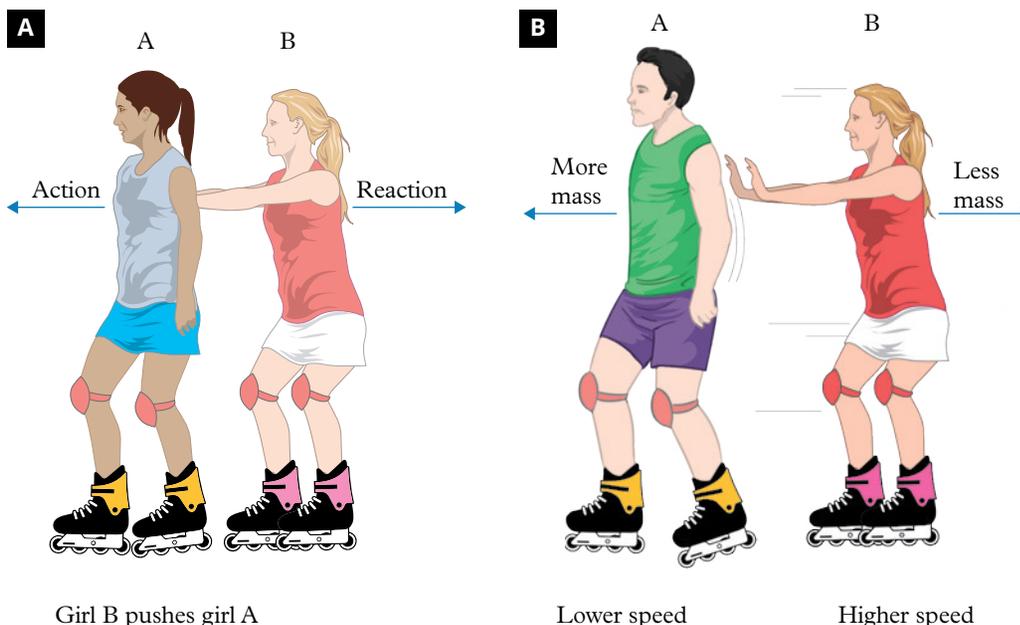
Figure 1 (A) Girls A and B have equal mass. Girl B pushes girl A (action), and girl A pushes girl B backwards (reaction). Girl A moves forwards and girl B moves backwards. (B) Boy A has more mass than girl B. Both the action and reaction forces are identical and opposite in direction. As boy A has more mass, his speed will be less than that of girl B.

The motion of a girl on inline skates pushing off from another girl (Figure 1) works in a similar manner. The two girls experience an identical but opposite force. Newton's second law ($F_{net} = ma$) 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 2).

Upward thrust force 20,000 N

Air resistance 2,000 N

Force of gravity 9,800 N

Figure 2 The rocket pushes exhaust gases back. As a result, the rocket is propelled forwards.

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6.13

Newton's law is also applied in athletics. At the start of a race, sprinters place their feet against string blocks that are angled upwards (Figure 3). This allows the sprinter to push back against the block when the starting gun is fired. The reaction to this action results in the sprinter being pushed forwards and helping them to maximise their speed at the start.

Figure 3 Sprinters use starting blocks to help them start a race with more power.

Check your learning 6.13

Check your learning 6.13

Retrieve

1 **Recall** the action and reaction forces of leaning against a wall.

Comprehend

2 **Describe** Newton's third law in your own words.
3 A boy of weight $500\,N$ sits on a chair. **Describe** the direction and magnitude of the reaction force that acts on the boy.
4 In space, an astronaut pushes on another astronaut with a force of $80\,N$. **Describe** the magnitude and direction of the reaction force in this case. **Explain** why the second astronaut might have a higher acceleration than the first astronaut.

Analyse

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

Skills 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 farther.
   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?)

Lesson 6.14

Experiment: What if forces were changed on Newton's rocket?

Aim

To examine the action and reaction of a balloon rocket

Materials

- Balloon and balloon pump
- 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 (Figure 1).
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   Repeat steps 5 and 6 five more times.
8   Determine the mean, median and mode speed of the balloon.
9   Compare the difference in values of the mean, median and mode speeds and describe which would be the most appropriate value to use.
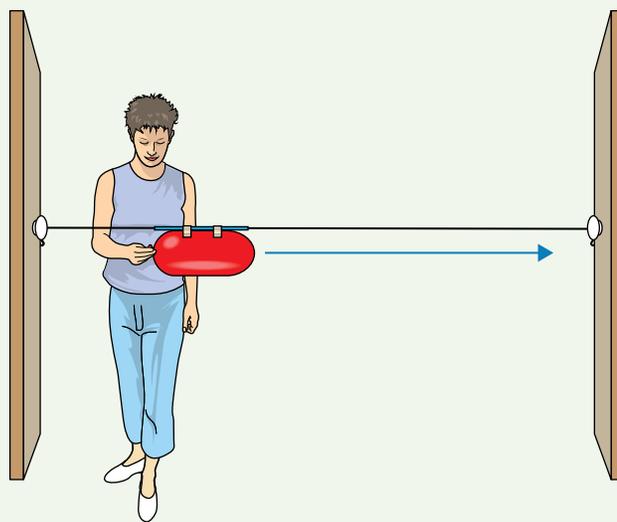
Figure 1 Experimental set-up

Results

Record your results in an appropriate table.

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 in relation to your inquiry.

1   Write a hypothesis (If … then … because …) for your inquiry.
2   Identify the (independent) variable that you will change from the first method.
3   Identify the (dependent) variable that you will measure and/or observe.

4 Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.

5 Identify the materials that you will need for your experiment.

6 Write down the method you will use to complete your investigation in your logbook.

7 Draw a table to record your results.

8 Show your teacher your planning for approval before starting your experiment.

Discussion

1 **Explain** why the balloon moves forward.

2 **Construct** 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 **Explain** how you would expect the average speed to change if the balloon was inflated less.

5 **Compare** the mean, median and mode values you obtained. **Evaluate** which value could be considered the most accurate. **Justify** your answer (by describing how each value was determined, comparing the effect an added outlier would have on the values, and deciding which value could be considered most accurate).

Conclusion

Describe how Newton's third law applies to your balloon rocket.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Lesson 6.15
Momentum is conserved in a collision

Key ideas

→ Momentum is the product of the mass and velocity of an object.

→ The law of conservation of momentum states that in an isolated system, the total momentum does not change during a collision.

Introduction

Modern cars are fitted with many safety devices, but arguably the most important are the airbags that deploy in the event of a crash. Sensors inside the car act like mini accelerometers and when they detect rapid deceleration, the airbag system is triggered. These innovations are the result of the scientific understanding of movement and, more importantly, collisions. All collisions involve force, mass and momentum, and these quantities link together according to the laws of motion as we know them.

Momentum

All moving objects possess "mass in motion" or **momentum**. Momentum is not a form of energy, although the faster an object travels, the more momentum it has. A cricket ball is harder to stop than a tennis ball travelling at the same speed. This is because the cricket ball has more mass in motion than the tennis ball. So, objects with more mass have more momentum, if they are travelling at the same velocity.

The velocity of a travelling object will also affect its momentum. A tennis ball travelling at 60 km/h will have more momentum (and hurt more) than a tennis ball travelling at 30 km/h. The formula for calculating momentum is:

$$\text{Momentum} = \text{mass} \times \text{velocity}$$
$$\vec{p} = m\vec{v}$$

where mass is in kilograms (kg), velocity is in metres per second (m/s), and momentum is in kilogram metres per second (kg m/s).

This relationship can also be expressed in a momentum triangle (Figure 1).

In an isolated system where there are no outside interactions, momentum is passed from one object to another in a collision, but the total momentum of the system is conserved or remains constant. This means the initial momentum before the crash is equal to the final momentum of all objects after the crash. This is known as the **law of conservation of momentum** and is similar to the law of conservation of energy.

The isolated system referred to in the law of conservation of momentum is the set of objects that interact in the collision. In the case of Newton's cradle (Figure 2), this would be the two spheres that collide. Because velocity is a vector, momentum is also a vector quantity. We can indicate opposite directions in a collision as positive and negative.

To stop a moving object, a force is used to reduce its momentum. If the brakes are applied slowly, a force is used over a long time to bring the car to a slow stop. In a car crash, a force on the front of the car causes it to stop quickly. In both examples, the force exerted on the car is related to the initial momentum of the car.

Worked example 6.15A shows how to calculate initial momentum, and Worked example 6.15B shows how to calculate momentum.

momentum the product of an object's mass and velocity
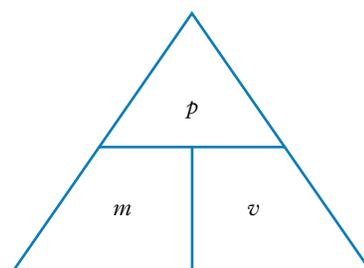
Figure 1 The momentum triangle. Cover the quantity you want to calculate and the other two quantities will form the formula.

Law of Conservation of Momentum a scientific rule that states that the total momentum in an isolated system does not change during a collision

Physics

Figure 2 Newton's cradle clearly demonstrates how momentum can be passed from one object to another.

6.15

Worked example 6.15A Calculating initial momentum

Figure 3 represents a relatively safe head-on collision between two dodgem cars.

a Calculate the initial momentum of each car.

b Calculate the total initial momentum of the two cars.

Solution

a Velocity (green car) = 0.8 m/s; mass (green car) = 701 kg

Initial momentum (green car):

$$\vec{p} \text{ (green car)} = m\vec{v}$$
$$= 701 \times 0.8$$
$$= 561 \text{ kg m/s}$$

The purple car is moving in the opposite direction and therefore the velocity is negative.

Velocity (purple car) = −0.7 m/s; mass (purple car) = 660 kg

Initial momentum (purple car):

$$\vec{p} \text{ (purple car)} = m\vec{v}$$
$$= 660 \times -0.7$$
$$= -462 \text{ kg m/s}$$

b The total initial momentum of the two cars = 561 − 462 = 99 kg m/s.

The positive number tells us that the total momentum is to the right, 99 kg m/s.

A 0.8 m/s   0.7 m/s

Mass = 701 kg   Mass = 660 kg

B Stopped   0.15 m/s

Mass = 701 kg   Mass = 660 kg
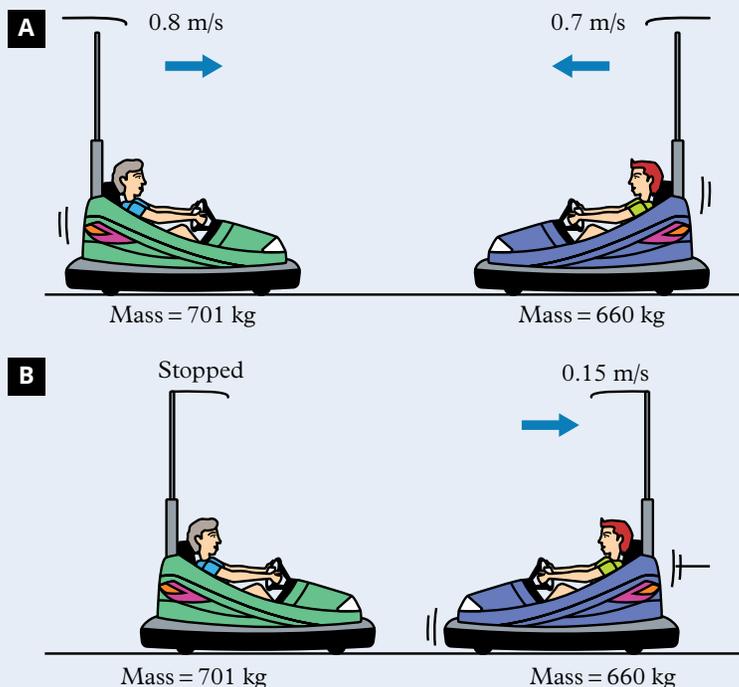
Figure 3 (A) Before the collision; and (B) after the collision

Worked example 6.15B Calculating momentum

Calculate the momentum of the purple car in Figure 3 after the collision.

Solution

The total momentum before the crash was 99 kg m/s to the right.

As total momentum is conserved, the total momentum after the crash should also be 99 kg m/s to the right. As the green car is not moving, it will not have momentum (mass in motion).

Therefore, the momentum of the purple car = 99 kg m/s to the right.

Check your learning 6.15

Check your learning 6.15

Retrieve

1 **Identify** the units of momentum.

Comprehend

2 **Describe** the law of conservation of momentum.
3 Use the momentum triangle to **represent** the three different momentum formulas.
4 **Explain** why it is harder to stop a cricket ball than a tennis ball travelling at the same velocity.
5 **Explain** why it is harder to stop a fast-moving tennis ball than a slow-moving tennis ball.

Analyse

6 **Calculate** the momentum of a 600 kg golf cart that is travelling at 0.8 m/s.

Apply

7 Use your understanding of momentum to **evaluate** which would cause the greatest damage: colliding with a truck or colliding with a car.

Physics

Lesson 6.16
Experiment: Colliding trolleys

Aim

To investigate whether total momentum is conserved during a collision

Materials

- 2 dynamics trolleys
- Metre ruler
- Ruler
- Several 1 kg masses to add to the trolleys
- 2 rubber bands tied together that will stretch to 20 cm quite easily
- Level benchtop
- Piece of A4 paper
- Masking tape

Method

1 Attach the piece of A4 paper to the benchtop with masking tape. Rule two parallel lines on the paper, 20 cm apart (Figure 1).

Figure 1 Setting up the paper

2 Link the two trolleys with the rubber bands (Figure 2).

Figure 2 Linking the trolleys

3 Pull the trolleys apart and hold them with their front ends on the two lines (Figure 3).

Figure 3 Pulling the trolleys apart

4 Release the trolleys. The trolleys will accelerate towards each other and collide. How far the trolleys travel in a given time is proportional to their relative velocities. Determine where the trolleys collide and mark the collision point on the paper.

5 Measure the distance from one line to the collision point (d_1) and the same for the other line (d_2). Because the trolleys collide at the same time, there is no need to measure the times because the distances are proportional to the collision velocities.

6 Add various masses to one (or both) of the trolleys and repeat the experiment. Test approximately five different mass combinations.

Results

Record the results listed in the header row of Table 1 in a spreadsheet or table.

Table 1 Results from the experiment

m_1 = mass of trolley 1	d_1 (in m)	$m_1 \times d_1$	m_2 = mass of trolley 2	d_2 (in m)	$m_2 \times d_2$	$(m_1 \times d_1) - (m_2 \times d_2)$

The final column gives a measure of the total momentum of the two trolleys just prior to the collision. The negative sign is used because the two trolleys are travelling in opposite directions and therefore one momentum is negative.

Discussion

1 **Define** the term "momentum".
2 Use an example to **explain** the law of conservation of momentum.
3 **Explain** why the trolleys travel towards each other for the same period of time when they are released.

4 **Describe** the magnitude of the force acting on each trolley.
5 If both trolleys come to a stop after the collision, **explain** the final total momentum of the "system".
6 Use the last column of results to **calculate** the initial total momentum of the "system".

Conclusion

Describe what this experiment demonstrated about the total momentum before and after a collision.

Lesson 6.17

Science as a human endeavour: Understanding motion improves vehicle safety

Key ideas

→ Newton's laws are used to improve vehicle and passenger safety.

→ The introduction of seatbelts has allowed more people to survive accidents by stopping them from continuing their path of motion.

→ Other safety features in cars include airbags, crumple zone, ABS and passenger safety cells.

→ A helmet should be worn when riding a bike or e-scooter to protect the head in case of an accident and reduce the forces it may experience.

→ Autonomous cars can be helpful in reducing accidents as they use sensors and cameras to identify potential crash risks.

Learning intentions and success criteria

Introduction

When buying a car, one of the key messages from the dealer is the list of safety features offered. This was not always a priority in a car. Prior to 1970, the wearing of seatbelts was not compulsory in Australia. When the seatbelt laws were first introduced, there were media reports suggesting that seatbelts increased the number of injuries experienced in an accident. This can be explained using Newton's laws.

Car safety

When a car is in an accident, it stops quickly. Newton's first law (a body in motion remains in motion until an unbalanced force stops it) suggests that if a person in the car is not wearing a seatbelt, they will keep moving through the windscreen until the road, tree or something else stops them. If they are wearing a seatbelt, then the belt will stop the passengers and driver when the car stops. Although this may increase the number of seatbelt-related injuries, these people would have died without the seatbelt. Modern cars also feature several other safety mechanisms to protect passengers from injury (Figure 1).

Collapsible steering column
In an accident, the column supporting the steering wheel will collapse down and away from the driver, preventing injuries.

Seatbelts
Reduce the motion of passengers on impact.

Passenger safety cell
A reinforced shell around the people limits crash injuries. In an accident, the engine block slides under the shell.

Rear crumple zone

Airbags
These bags automatically inflate with compressed air within 1/100 seconds. This reduces the acceleration by having it occur over a longer period and reduces the forces experienced.

Front crumple zone
The front and rear of the car are designed to crumple to dissipate energy and slow the deceleration of the car. This reduces the force on passengers.

Antilocking braking system (ABS)
Sudden braking can cause wheels to lock and cause a skid. A computer system optimises the size of the braking force so that the driver can maintain control of the steering.

Figure 1 Safety mechanisms built into modern cars

Bike and e-scooter safety

The recent increase in the number of electric scooters has caused much debate. Although e-scooters and pushbikes have similar weights, the speeds they travel can vary considerably. The momentum of a moving object is related to the combined mass of the rider, their bike or scooter, and the speed they are travelling. A larger person or a faster traveller will have more momentum in an accident than a smaller person or a person travelling slowly. If the scooter or bike was to crash into a standing pedestrian, the momentum would be conserved. This means the pedestrian would be thrown backwards with the shared momentum. Because they weigh less than the scooter and rider combined, the pedestrian would experience a sudden large acceleration and be thrown farther.

Both bike and scooter riders are expected to wear a helmet to protect themselves from an accident. The helmet acts like the airbag in a car, slowing the deceleration of the head and reducing and spreading the force experienced by the head on impact.

Driverless cars

Most car accidents are due to drivers overestimating their skills or not understanding the conditions of the road or car. Driverless cars can help to address these issues. These autonomous vehicles use sensors and cameras to identify potential crash risks. Lidar (light detection and ranging) sensors use a 3D laser to scan their environment. Pulses of light are regularly sent into the local environment. Any objects that are nearby will reflect the light back to the car. The time taken between the pulse and reflection can be used to determine the distance between the car and object. The system uses physics to calculate the risk of an

Physics

accident and can send a warning to the driver or take corrective action to prevent a potential accident. When combined with virtual maps and route planning, this has the potential to remove the need for the driver to pay attention to other drivers on the road.
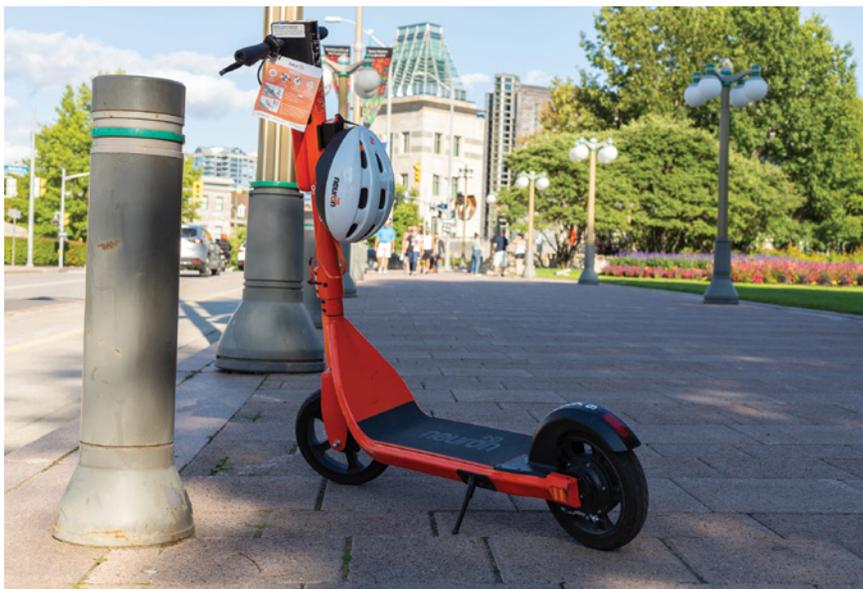
Figure 2 Helmets are required when riding a bike or e-scooter.

Driverless sensor systems are not perfect, as low-light conditions and rain can confuse the lidar systems. In 2016, a large 18-wheeler truck crossed a highway in the United States. The sensors on a partially automated Tesla car did not recognise that the white side of the truck was different to the white sky and attempted to continue driving, causing a crash. The court ruled that the occupant/driver of the car was at fault as they would have had time to stop if they had been paying attention.

Test your skills and capabilities

Ethical conundrums

While automated cars can be programmed to follow all the road rules to prevent injuries, there are many ethical decisions that must be programmed into the pre-written lines of code. This can be best illustrated through a variation of the "trolley problem". Use your understanding of consequential ethics and deontological ethics (go to Lesson 1.6 Scientists use specialised equipment (page 29) to refresh your memory about these ideas) to **justify** which decision should be programmed into an automated car to act in the following scenario.

A driverless car carrying you is crossing a bridge when it detects a presence in the middle of the road on the bridge. If the car swerves off the bridge, you will fall to your death. The car cannot stop in time to prevent hitting the presence detected on the bridge.

Which decision should be programmed into the car if:

- the person on the bridge is six years old
- the person on the bridge is elderly with a walking stick
- there is a group of three people on the bridge
- there is one person on the bridge and three of your friends in the car with you?

Lesson 6.18
Review: Motion

Summary

Lesson 6.1 Displacement is change in position with direction

- Distance describes how far an object has travelled.
- Displacement describes the final distance and direction of an object from its starting point.
- Displacement is a vector quantity because it has position and direction.

Lesson 6.3 Velocity is speed with direction

- Speed is a scalar quantity that measures the distance travelled in a set time.
- The average speed can be determined by dividing the distance travelled by the total time taken.
- Velocity is a vector quantity and it measures the change in displacement over time.

Lesson 6.6 Acceleration is change in velocity over time

- Acceleration is the rate at which the velocity of an object changes.
- Acceleration can be due to changing speed or changing direction.
- An object travelling at a constant, unchanging velocity has an acceleration of zero.

Lesson 6.8 An object keeps the same velocity until a net unbalanced force acts on it

- Forces act in pairs between two objects.
- Newton's first law states: "An object remains at rest or in constant velocity in a straight line unless acted on by a net unbalanced force."

Lesson 6.10 Net force equals mass × acceleration

- 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."
- The equation for Newton's second law can be expressed as $F_{net} = ma$.

Lesson 6.13 Each action has an equal and opposite reaction

- Newton's third law states: "For every action, there is an equal and opposite reaction."
- Action–reaction pairs always act on different objects and therefore cannot cancel each other out.

Lesson 6.15 Momentum is conserved in a collision

- Momentum is the product of the mass and velocity of an object.
- The law of conservation of momentum states that in an isolated system, the total momentum does not change during a collision.

Lesson 6.17 Science as a human endeavour: Understanding motion improves vehicle safety

- Newton's laws are used to improve vehicle and passenger safety.
- The introduction of seatbelts has allowed more people to survive accidents by stopping them from continuing their path of motion.
- Other safety features in cars include airbags, crumple zone, ABS and passenger safety cells.
- A helmet should be worn when riding a bike or e-scooter to protect the head in case of an accident and reduce the forces it may experience.
- Autonomous cars can be helpful in reducing accidents as they use sensors and cameras to identify potential crash risks.

Review questions 6.18

Review questions: Module 6

Retrieve

1 **Identify** which term relates to the following sentence. "An object's acceleration directly relates to the magnitude and direction of the net force acting on the object."

   A Newton's first law

   B Newton's second law

   C Newton's third law

   D Law of inertia

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

Table 1 Terms and definitions

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

3 **Recall** the formula that is used to calculate average speed.

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

4 **Identify** each of the following quantities (and their units) as scalar or vector.

   a Force

   b Distance

   c Velocity

   d Momentum

   e Speed

   f Displacement

   g Acceleration

5 **Identify** the quantity that can be determined by the gradient of a displacement–time graph.

6 **Identify** the quantity that can be determined by the area under a velocity–time graph.

Comprehend

7 **Describe** an object's speed if it travels with zero acceleration.

8 **Describe** an object's speed if it travels with constant deceleration.

9 Renee catches a softball.

   a **Describe** the action.

   b **Describe** the reaction.

10 **Describe** the motion for each of the following time periods in Figure 1.

   a 0–5 seconds

   b 5–10 seconds

   c 10–15 seconds
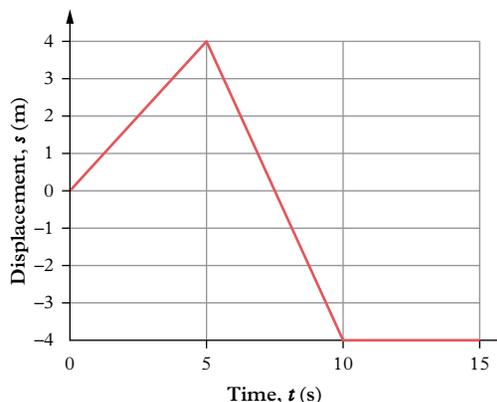
Figure 1 A displacement–time graph

11 Motion is the result of forces acting in different directions. **Describe** the forces acting when an object is stationary.

12 Some objects or devices require high accelerations that are many times greater than $9.8 \, \text{m/s}^2$ the acceleration due to gravity. Think of an object or device in this category. **Describe** the force that is used to propel the object. **Identify** the forces involved. **Explain** how these forces enable it to achieve such a high acceleration.

Analyse

13 **Identify** whether the following statements are true or false. Rewrite any false statements so that they are true.

   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.

14 Object A has more mass than object B. **Compare** the acceleration of the two objects if they are pushed with the same force.

15 **Compare** velocity and speed.

16 A bike travels 100 m in 5 seconds before stopping for 2 seconds. It then travels back to the starting point in 10 seconds.

   a   **Calculate** the total distance travelled by the bike.

   b   **Calculate** the final displacement of the bike.

   c   **Calculate** the average speed of the bike.

17 A parachutist jumps out of a plane and falls at 10 m/s².

   a   **Calculate** their speed at $t = 0$ seconds.

   b   **Calculate** their speed at $t = 1$ second.

   c   **Calculate** their speed at $t = 3$ seconds.

18 A person walked 3 km east, then 4 km north and then 9 km east again (Figure 2).

   a   **Calculate** the total distance travelled.

   b   **Calculate** the final displacement (by calculating the total distance east and total distance north, drawing a right-angled triangle with these values and using Pythagoras' theorem).
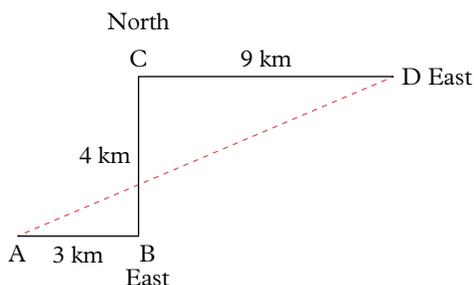
Figure 2 The displacement of a person

19 A professional bike rider measured their velocity over time (Figure 3).

   a   **Describe** their motion over the 50 seconds.

   b   **Calculate** the acceleration in the first 10 seconds.

   c   **Calculate** their acceleration in section B.

   d   **Calculate** the displacement travelled in section D.
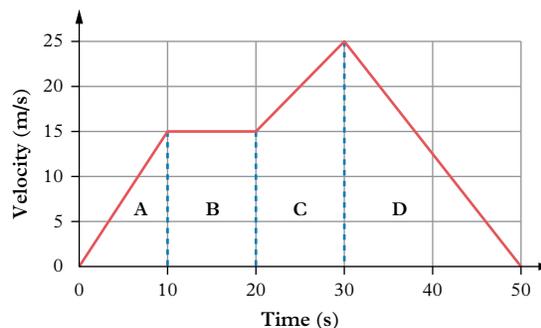
Figure 3 The velocity–time graph of a bike rider

20 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 to a halt over a period of 30 seconds.

   a   **Calculate** the maximum speed of the car in m/s.

   b   **Calculate** the maximum speed in km/h.

   c   Plot a speed–time graph for the car using SI units.

   d   Use the graph to **calculate** the distance moved in metres and then in kilometres.

21 Charlie walked 1 km to the supermarket from her house, then 3 km to the florist and then 3 km back home again. **Calculate** Charlie's total displacement and **identify** the correct answer from the list below.

   a   7 km

   b   0 km

   c   21 km

   d   14 km

22 Figure 4 shows a rear-end car crash between two dodgem cars, causing them to stay together. Before the collision, the green car had a velocity of 2.2 m/s and a mass of 140 kg. The purple car had a velocity of 1.7 m/s and a mass of 160 kg.

   a   **Calculate** the momentum of each of the two dodgem cars before the collision.

   b   **Calculate** the total momentum of the two dodgem cars before the collision.

   c   **Calculate** the velocity of the two dodgem cars after the collision.
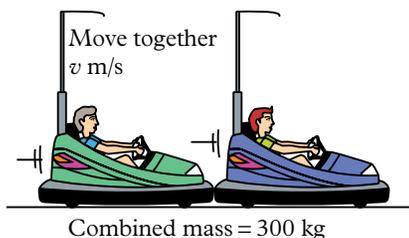
Figure 4 A collision between two dodgem cars

23 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 arrives 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 **Calculate** the time the bus will arrive at school in the morning.

   c **Calculate** the average speed of the bus.

   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".

24 **Calculate** the mass of an object that would accelerate at 3.5 m/s^2 under the influence of a net force of 70 N.

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

Apply

Social and ethical thinking

26 **Identify** the safety features of the car shown in Figure 5. **Identify** the safety features that could be added to this car. Adding extra safety features adds to the cost of the car. **Discuss** how the socioeconomic status of a person can determine the safety of the car they drive.

Figure 5 A crash test car

Critical and creative thinking

27 **Create** a poster on motion that explains each of Newton's three laws. Use a detailed example that illustrates each law and is not already mentioned in the text.

Research

28 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

Female crash test dummies

Crash test dummies are used to test the safety features of a car. The average test dummy was developed in 1970 and is male, 175 cm tall and weighs 77 kg.

- Compare these dimensions to the average Australian male.
- Describe how differences in height and weight would affect the way the dummy would be affected in a crash.
- Research the development of female test dummies.
- Describe the differences in the size, mass and shape between the male and female dummies.
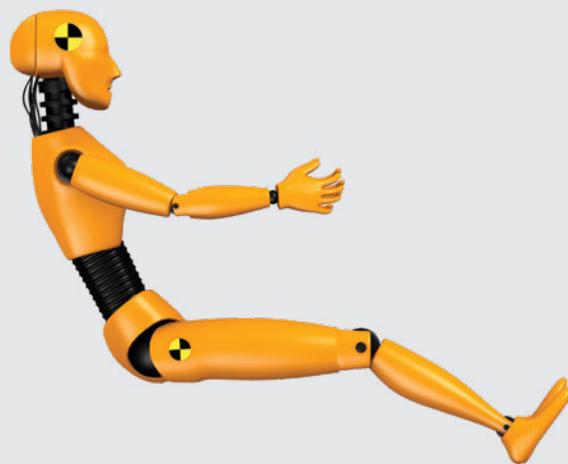
Figure 6 A female crash test dummy

Aboriginal and Torres Strait Islander Peoples' use of forces

For thousands of years, Aboriginal and Torres Strait Islander Peoples have experimented with forces when designing weaponry such as spearthrowers and bows and arrows for hunting. Research and describe how variables including force, mass and acceleration have been used to increase the speed and impact force of spearthrowers and bows.

Figure 7 Stone spear-points used by Aboriginal and Torres Strait Islander Peoples in Australia

School speed limits

The speed limit on a road can vary according to the conditions of the road, the amount of traffic and the likelihood of pedestrians crossing the road.

- Identify the speed limit around your school.
- Describe why the speed limit might be different to similar roads 1 km away from the school.
- Consider the distance taken for cars to stop. Use Newton's laws to explain why the speed limit will vary between the two roads.

Movement of aircraft

Aircraft are the second fastest mode of transport, after rockets.

- Investigate different types of aircraft and how they move.
- Explain the interactions between lift, weight, thrust and drag in aircraft movement.
- Identify the maximum speeds aircraft can attain.

Figure 8 Aircraft use a combination of the forces of lift, weight, thrust and drag in different balances for different movements.

Module
7
The periodic table

Overview

The periodic table is a way of organising elements based on the structure and properties of their atoms. Experiments like flame tests and studying emission spectra show that each element gives off specific colours of light, linked to its atomic structure. The Bohr model of electron shells helps to explain these patterns.

Elements in the same group (columns) have similar chemical properties because they have the same number of electrons in their outer shells. Elements in the same period (rows) have the same number of electron shells. As you move across or down the table, you can see consistent patterns in reactivity, atomic size, and whether an element is a metal or non-metal.

Lessons in this module

Lesson 7.1
The structure of an atom determines its properties

Key ideas

→ 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 around the nucleus in electron shells.

→ An atom's outermost electron shell is called the valence shell.

→ The number of electrons in the valence shell determines many of the properties of an element and therefore its position in the periodic table.

The periodic table

period in chemistry: a horizontal list of elements in the periodic table

group a vertical list of elements in the periodic table that have characteristics in common

The periodic table organises elements (or types of atoms) in rows and columns (Figure 1). The horizontal rows are called **periods**. The atomic number increases by one for each element as you go across a period (from left to right). The vertical (up–down) lists of elements are called **groups**. Elements in each group have similar properties.

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

Atoms are electrically neutral because they have an equal number of protons and electrons. Protons carry a positive charge, while electrons have a negative charge, so their charges cancel out. 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. The standard notations for atomic number is Z. Atoms with the same atomic number have identical chemical properties.

atomic number the number of protons in an atom

In contrast, electrons have a "negligible" mass, meaning the mass is so small it is ignored; it is almost too small to measure. However, because electrons orbit the nucleus, they affect the way the atoms bond with other atoms.

mass number the total number of protons and neutrons in the nucleus of an atom

The **mass number** of an atom is the total number of protons and neutrons in its nucleus. The number of neutrons can be found by subtracting the atomic number (number of protons) from the mass number. The standard notations for mass number is A (Figure 2).

Figure 1 The periodic table of elements

Figure 2 The conventional representation of an element. The mass number is always the largest number shown.

7.1

Electron configurations

You learnt about Ernest Rutherford's model of the atom in Year 9 Science. After Rutherford had refined his model, another scientist, Niels Bohr, concluded that the electrons in the atom do not behave exactly like the planets around the Sun.

He used a spectroscope (a device that shows all the energy levels and wavelengths of light) to show that electrons move about the nucleus in spaces that are at set distances and energy levels from the nucleus. These spaces are known as **electron shells**. There is a limit to the number of electrons that can be in any of the shells. This special arrangement of electrons around an atom is called the **Bohr model** (Figure 3).

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. For example, the maximum number of electrons that the 3rd shell can hold is $2 \times 3^2 = 18$.

Figure 3 Oxygen represented using the Bohr model

electron shell a defined area of space in which electrons move around an atom's nucleus

Bohr model a model of the atom in which electrons orbit the nucleus in a series of defined orbits known as shells

Table 1 The Bohr model of the atom

Shell number (from the nucleus outward) (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 atomic number 19 (potassium). Once the third shell has 8 electrons, the remaining electrons start moving into the fourth shell.

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. Shells that are farther from the nucleus need more energy to stay in the high-energy shell (until calcium).

The arrangement of electrons in an atom is called its **electron configuration**. The electronic configurations of oxygen and calcium are compared in Figure 7.

Figure 4 Niels Bohr proposed the idea of electron shells.

electron configuration a numerical way of showing the number of electrons in each electron shell around a particular atomic nucleus

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 in an atom that contains electrons

Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are presented in pairs of dots. When drawing the electronic shell configuration, the innermost shell (maximum 2) needs to be filled first. The second shell (maximum 8) fills next, followed by the third shell (maximum 18). Worked example 7.1A provides an example of this process. 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 affects how the atom will bond with other atoms.

Evidence for electron shells

Many substances give off coloured light when a small sample is introduced into a flame (Figure 5). This pattern of coloured lines of light can be seen through a spectroscope. This pattern is known as an **emission spectrum** and is unique for each element (Figure 6). Bohr explained this by saying that a particular atom is 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 is unstable, the electrons then jump back to their normal levels almost instantly. The extra energy that the electrons no longer need is released as light energy. The wavelength of the light (and therefore its colour) represents 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" of that element. The development of the spectroscope allowed scientists like Bohr to identify the number and energy levels of electron shells that exist around different atoms.

emission spectrum
the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element
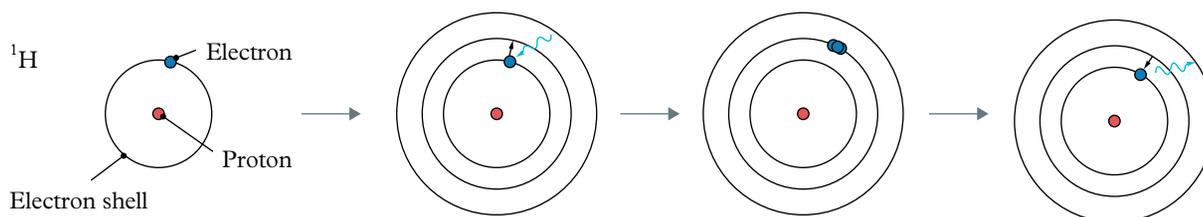
Figure 5 In a flame, the electron gains energy to move to an outer shell. When the electron moves back to its lower energy level, the extra energy is released as light.
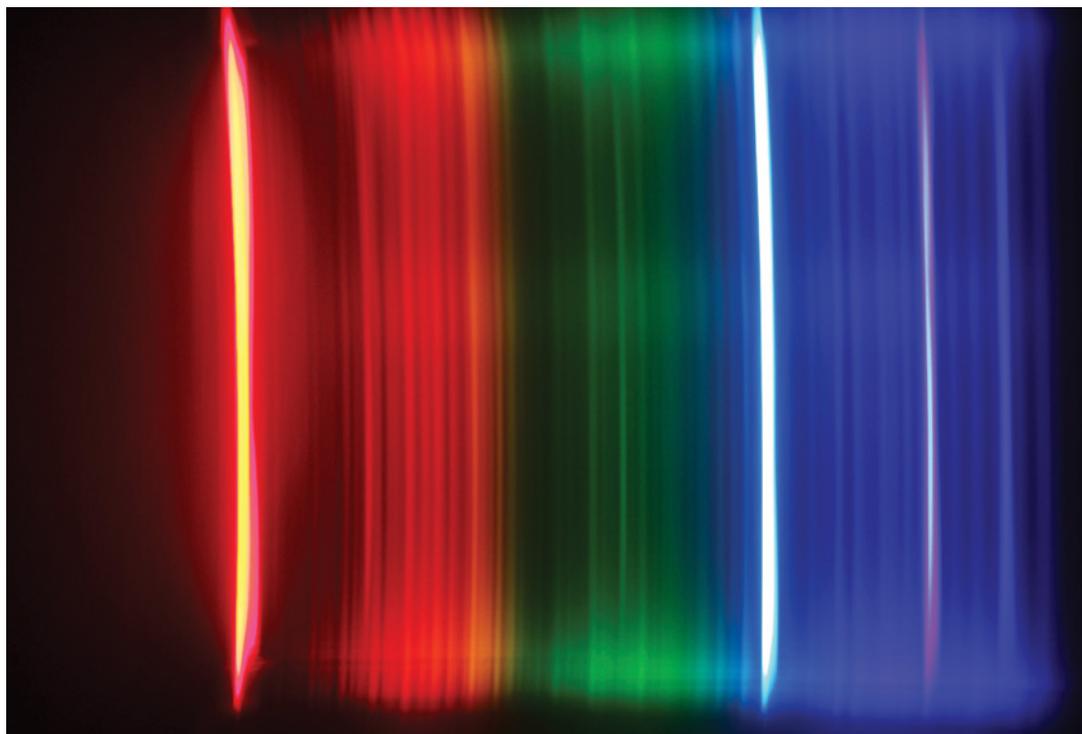
Figure 6 The emission spectrum of hydrogen

Chemistry

7.1

Worked example 7.1A Determining electron configuration

Determine the electron configuration of:

a oxygen

b calcium.

Solution

a 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 electron configuration of oxygen is 2, 6.

b 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 electron configuration of calcium is 2, 8, 8, 2.

2, 6
Oxygen

2, 8, 8, 2
Calcium
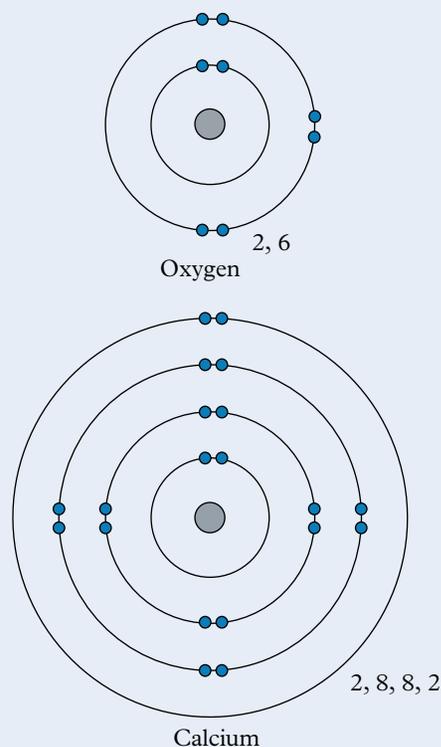
Figure 7 The electron configurations for oxygen and calcium are shown as simple shell diagrams.

Electrons and properties of elements

The electron 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 electron shell arrangements, the properties of elements and the types of bonds that form in their compounds.

Groups and valence electrons

The vertical groups of the periodic table are numbered 1 to 18. Elements in the same group have similar chemical properties, which we now know are due to the arrangement of their electrons.

Elements in the same group have the same number of electrons in their valence (outermost) shell. For example, all the elements in group 13 have three electrons in their valence shells, which means they have very similar properties. Outer valance shells with eight electrons are more stable than electron shells with less electrons. The valence-shell electrons often interact with other atoms.

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7.1
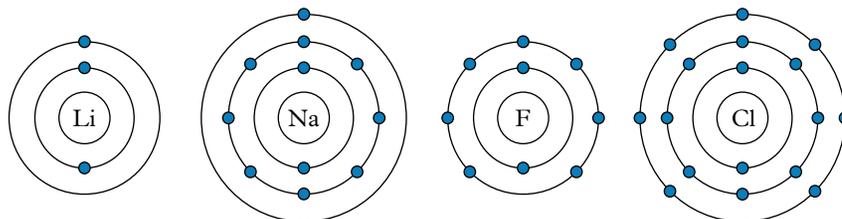
Figure 8 In group 1, the electron configuration of lithium is 2, 1, whereas that of sodium is 2, 8, 1. The atoms of all other group 1 elements also have one electron in their outer valence shell of electrons. Elements in group 17 (e.g. fluorine and chlorine) have seven valence electrons.

Check your learning 7.1

Check your learning 7.1

Retrieve

1 **Identify** the key feature of an atom that determines its atomic number. Use an example of two different elements to illustrate your answer.

2 For the Bohr model of the atom, **identify** the maximum number of electrons that the fourth electron shell can contain.

Comprehend

3 **Explain** why the second shell can contain more electrons than the first shell.

4 **Describe** the valence shell of an atom.

Analyse

5 Copy and complete Table 2.

6 **Identify** the element that is in period 3, group 1. Draw its electron configuration according to the Bohr model.

Apply

7 A potassium atom contains 19 protons.

   a **Identify** the number of electrons that will be present in a potassium atom.
   Justify your answer (by identifying how a potassium atom is given its atomic number, defining a neutral atom, and identifying the number of electrons in a neutral potassium atom).

   b Use the Bohr model to **identify** the electron configuration of a potassium atom.

   c From the electron configuration of potassium, it is clear that electrons do not normally occupy the fifth shell. **Propose** how the electrons in a potassium atom could be moved into this shell.

Table 2 Elements, atomic numbers and electron configurations

Element	Atomic number	Electron configuration
Beryllium		
	9	
Magnesium		
Neon		
		2,8,3
	11	
		2,8,7
Sulfur		

8 Robert Bunsen (1811–1899) was a German chemist who investigated the coloured flames given off by heated elements. From your results in the flame tests in Lesson 7.2 Experiment: Flame tests (page 316), **determine** the atom that caused the yellow colour that Bunsen saw when he was heating glass.

7.1

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◀ **Skills builder: Processing and analysing data and information**

9 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: Can I 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?)

Lesson 7.2
Experiment: Flame tests

Caution

- Wear safety goggles and a lab coat. Ensure hair is tied back and loose clothing is removed or tucked away.
- Wire loops and flames are hot. Be careful not to burn yourself.
- 1 M hydrochloric acid can give a small chemical burn. Wash skin with tap water immediately.

Aim

To observe the coloured light emitted when certain substances are heated in a flame

Materials

- Solid samples of sodium carbonate, copper carbonate, potassium carbonate and strontium carbonate
- 1 M hydrochloric acid
- Bunsen burner
- Heatproof mat
- Wire loops

Method

1 Set up your Bunsen burner, observing safety instructions, and light your Bunsen burner on the (red) safety flame.

2 Adjust your Bunsen burner to the blue flame. Take a wire loop and dip it in a small beaker of 1 M hydrochloric acid. Flame the loop. This will clean the loop, ready for your solid sample. Avoid getting too close to the flame. Stand back a little.

3 Take a loop of solid chemical and place it in the flame. Observe the colour of the flame. Try not to lose the solid down the Bunsen burner barrel. This could block the burner and contaminate the flame, changing the colour.

4 Once you have finished your observation, dip the loop in the 1 M hydrochloric acid again and re-flame it. This will clean the loop for the next sample.

5 Repeat steps 3 and 4 for the other samples.

Results

Include your results in a table.

Discussion

1 **Explain** why the loop was treated with hydrochloric acid before any carbonates were tested.
2 **Explain** why the flame colour changed in the different chemicals.
3 **Evaluate** whether the colour change is a chemical change or a physical change (by defining chemical change, defining physical change, comparing the change in the chemicals to these definitions and deciding the type of change).
4 **Explain** why electrons in different elements produce different colours.
5 **Identify** whether the colour change is caused by the metal or the carbonate part of the powder. **Justify** your answer (by describing the differences between the chemicals tested and describing how these differences caused the colour changes).

Conclusion

Describe what you know about the different coloured flames produced by different elements.
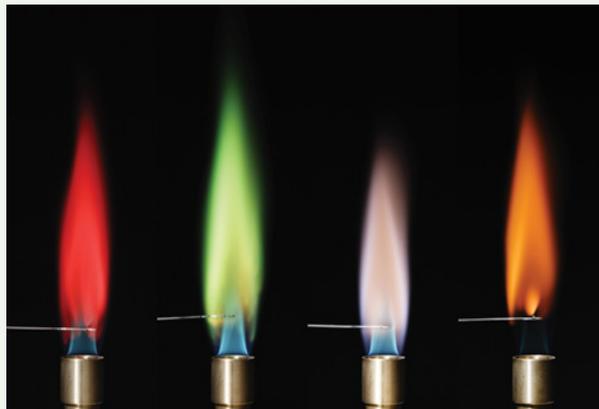
Figure 1 Flames can change colour depending on what substances are heated.

Lesson 7.3
Groups in the periodic table have properties in common

Key ideas

→ 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.

→ Transition metals have properties that are unique to groups 3–12.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

7.3

Metals

metals elements on the left-hand side of the periodic table; they are malleable, lustrous, ductile and highly conductive

Metals are one of the main types of elements in the periodic table. Almost all metal elements are solid at room temperature because they have high melting temperatures. The only exception is mercury, which is a liquid at 22°C. Metallic elements have many properties in common. Pure metals are usually:

- lustrous (shiny)
- able to conduct heat and electricity
- malleable (can be beaten into a new shape)
- ductile (can be drawn into a wire).

Figure 1 Metals, which are the more prevalent elements on the periodic table, have many properties in common.

Figure 2 Aluminium is a metal.

Group 1 metals

alkali metal an element in group 1 of the periodic table

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 valence shell. The alkali metals have quite low melting points and are soft and highly reactive.

In their pure state, they often resemble plasticine and, when cut, are very briefly shiny silver before reacting with the air to become white again (Figure 3). 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 (Figure 4).

Figure 3 Freshly cut sodium, a group 1 metal

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 valence 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 4). Metals become less reactive as you go right across the periods and the group number increases.

Figure 4 Potassium reacts spectacularly with water.

alkaline earth metals elements with similar properties found in group 2 of the periodic table

Transition metals

The **transition metals** are found in a large block of the periodic table that consists of the 10 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 (such as the gemstones in Figure 7).
- Many form more than one compound with a non-metal such as chlorine. For example, iron forms $FeCl_2$ and $FeCl_3$.
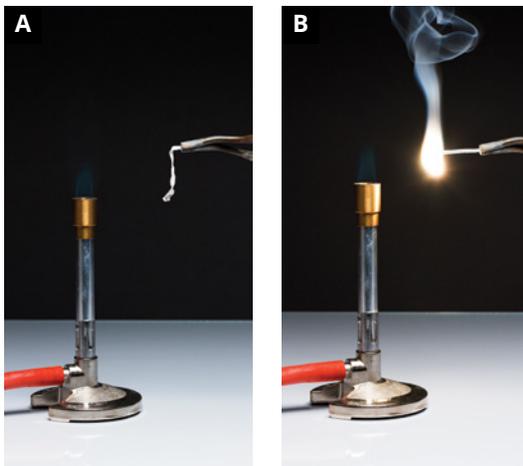
Figure 5 Magnesium, an alkaline earth metal (A) before burning; and (B) during burning

transition metals the elements in groups 3–12 of the periodic table

Figure 6 Calcium is a soft grey metal; calcium carbonate is a white powder or stone.

Chemistry

Figure 7 Gemstones contain atoms of different metals, which give them their different colours.

Reactive metals

Reactivity is a measure of how quickly or easily a metal is able to react with other elements or compounds. The most reactive metals can be found in group 1. The transition metals are much less reactive. The level of reactivity increases as you go down the periodic table, and as you move from the right-hand side to the left-hand side of the table.
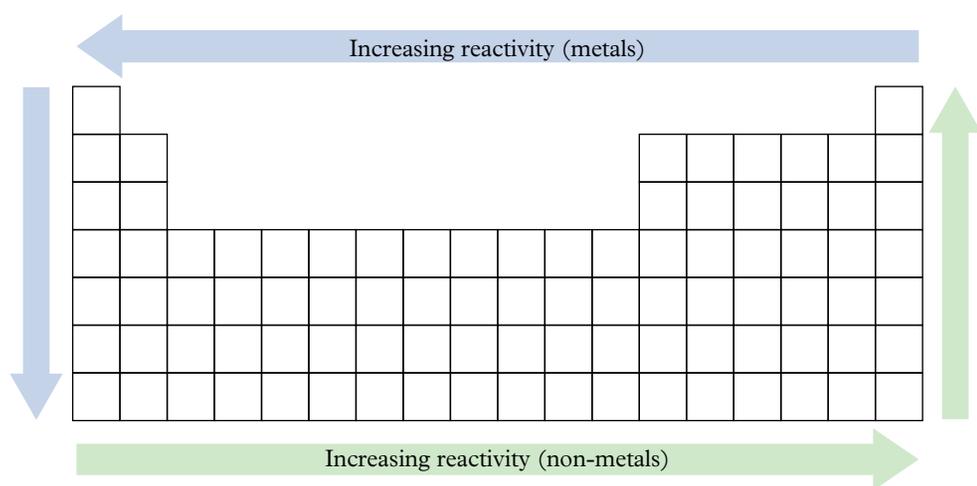
Figure 8 The reactivity of metals increases as you move down the periodic table, and as you move from the right to the left.

Check your learning 7.3

Check your learning 7.3

Retrieve

1 **Identify** three properties common to metals.

2 **Identify** two properties shown by some transition metals that are not shown by group 1 or group 2 metals.

Comprehend

3 **Describe** the properties that are shared by all metallic elements.

4 Use the properties of groups in the periodic table to **explain** why copper is found as a native element on Earth, but calcium metal is never found as a native element.

Analyse

5 **Calculate** the proportion of the periodic table that is composed of metals.

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7.3

6 **Examine** the periodic table in Figure 1 of Lesson 7.1 The structure of an atom determines its properties (page 311).

   a **Identify** the period and group for each of the following elements: fluorine, bromine, tin, radium, potassium, platinum, arsenic.

   b **Identify** the elements listed in part **a** that are in the same group. **Explain** what this tells you about their properties.

   c **Identify** the elements listed in part **a** that are in the same period.

Apply

7 Use your knowledge of the periodic table to **identify** the metal that will react the most strongly with cold water: copper, iron, magnesium, sodium or zinc.

   Justify your answer (by explaining what you know about how the reactivity of metals varies between the groups on the periodic table, comparing the properties of each element based on their group and identifying which element is the most reactive).

8 **Propose** a way to represent the different groups of metals clearly and informatively, identifying the distinguishing properties of each group.

Skills builder: Communicating

9 A teacher is presenting information about metals to a group of students – specifically, alkali metals (sodium and potassium) and transition metals (cobalt and nickel). The teacher wants to present this information visually for ease of understanding and to compare the properties of each metal.

   a **Explain** whether the teacher 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 the teacher 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 the teacher. (THINK: Do I have the correct information with the right element? Have I included all the required information? Are my headings and labels correct?)

Lesson 7.4
Experiment: Reactivity of metals

Caution

Wear safety glasses, a lab coat and gloves when working with chemicals.

Aim

To compare the reactivity of various metals by observing their reaction with hydrochloric acid

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

Chemistry

◀

- Timer
- Bench mat
- Plastic disposable pipette

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 and place the test tube into the test-tube rack. Set the timer for 5 minutes and record your observations, including the height of the foam produced, in Table 1.
5 Repeat the process for the remaining metals.
6 Record your observations over 30 minutes.
7 This equipment can be left set up overnight to observe any further changes.

Results

Copy and complete Table 1.

Table 1 Observations from the experiment

Metal	Observations	Height of foam (cm)
Magnesium		
Aluminium		
Iron		
Zinc		
Copper		

Discussion

1 Identify the metal that was the most reactive.
2 Identify the metal that was the least reactive.
3 Explain why the metals were cleaned with steel wool before being exposed to the acid.
4 Explain why the detergent was added to the test tubes with the hydrochloric acid.
5 Describe the link between the reactivity of the metals and where they are located in the periodic table.
6 Identify other properties that the most reactive metal may exhibit. Justify your answer (by comparing your answer to the previous question with the properties you identify).
7 Describe the reliability of this experiment (by identifying other variables that may affect the outcome of the experiment, describing how these variables are or are not controlled, and explaining whether the experiment is repeatable and reproducible).

Conclusion

Explain how the reactivity of metals can vary across the periodic table.

Lesson 7.5
Non-metals have properties in common

Key ideas

→ Non-metals (groups 14 to 18) do not conduct electricity or heat, are very brittle and have a dull appearance.

→ Metalloids are found between metals and non-metals on the periodic table, and their properties are a combination of those of metals and non-metals.

Check the next lesson for a linked practical activity or experiment.

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 drawn into a wire); a small number of non-metals are coloured; and some are brittle (the solids break easily).

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 1 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 use in cooking.

non-metals elements on the right-hand side 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 Jacob Berzelius. Some halogens have bleaching properties as well (Figure 2).

As you go down the group, the melting points and boiling points of the halogens increase.

Figure 2 Bleaches often contain halogens.

halogens the group of elements in group 17 of the periodic table

Chemistry

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.

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. 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

noble gases the stable gaseous elements in group 18 of the periodic table

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 (Figure 3).

Figure 3 Radon is responsible for most background radiation experienced in outdoor spaces. It occurs naturally as the decay product of uranium, and it can be found in natural springs.

Metaloids

Metalloids are the small set of elements along the "staircase" diagonal boundary between the metals and non-metals (Figure 4). They are in this location because the metalloids have a mixture of properties between those of metals and non-metals. Some of their properties are similar to those of non-metals; however, metalloids conduct electricity like the metals. Three of the metalloids are semiconductors, which means they only conduct electricity in a certain way under certain conditions.
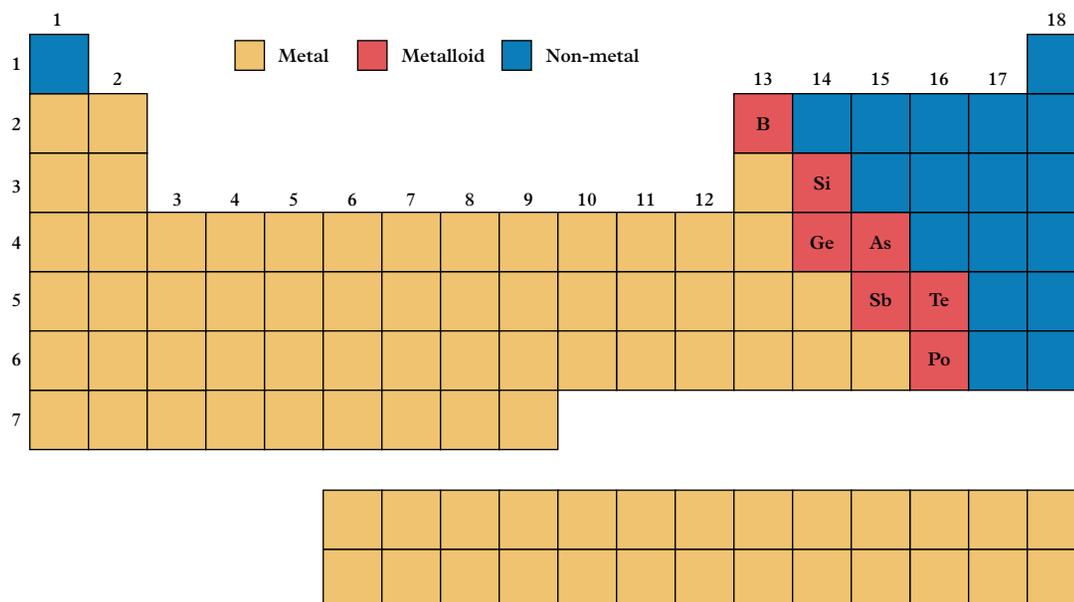
Figure 4 Regions of the periodic table

Check your learning 7.5

Check your learning 7.5

Retrieve

1 **Identify** the dominant (most common) state of matter within the groups of non-metals.
2 **Identify** the properties that metalloids share with metals.
3 **Define** the term "semiconductor".

Comprehend

4 **Explain** why non-metals are named according to what they are "not" rather than what they have in common.
5 The two main groupings of non-metals are in groups 17 and 18.
    a **Describe** what the group number tells you about the elements it contains.
    b **Describe** the properties that are shared by elements of group 17 and group 18.
6 **Explain** why many fluorescent lights contain an element from the top of group 18, instead of an element from the top of group 17.

Apply

7 **Explain** why the term "metal-like" could be used to describe metalloid elements. **Propose** a better name for this group of elements. **Justify** your answer.

Skills builder: Planning investigations

8 Two students wanted to conduct an experiment that investigated the boiling point of different halogens. They think 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 the students' method would not produce reliable results. (THINK: Are the variables being kept constant?)

Lesson 7.6
Challenge: Identifying patterns in the periodic table

Aim

To identify 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 need to insert, as detailed in steps 3 to 5.

2 Use highlighters to colour hydrogen red, metals blue, noble gases purple and other non-metals green. 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. As an example, chlorine (Cl) has the following properties:
   – needs to gain one electron
   – charge on ion = 1–

Discussion

1 **Describe** the patterns in the alkali metal group.

2 **Describe** the patterns in the alkaline earth metal group.

3 **Describe** the patterns that apply to all the metals listed.

4 **Describe** the patterns in the halogen group.

5 **Describe** the patterns in the group 16 elements.

6 **Describe** the patterns that apply to the non-metals, except for hydrogen and the noble gases.

7 In general, **describe** what you expect to happen when a metal atom and a non-metal atom meet. **Identify** the groups of non-metals that will not react in this way. **Justify** your answer (by explaining the properties of the group of non-metals you chose).

8 **Predict** what might happen in the following circumstances. **Justify** your predictions (by drawing shell diagrams of the atoms and describing what happens in the reaction).
   a a potassium atom and a fluorine atom meet
   b a calcium atom and an oxygen atom meet.

9 **Explain** why hydrogen and the metalloids were not considered in this activity.

Lesson 7.7
Ions have gained or lost electrons

Key ideas

→ Electrons have a negative charge.

→ When an atom loses electrons, it forms a cation (positive charge).

→ When an atom gains electrons, it forms an anion (negative charge).

Learning intentions and success criteria

Atoms and ions

Atoms are neutral. This means that the amount of negative charge within the atom is always the same as the amount of positive charge. This is because 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 an **ion**. The process of forming 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. A valence shell that has all of its electrons, or that has eight electrons, is stable. This means the electron shell is less likely to gain or lose electrons.

For example, the first three shells of a chloride ion are full, with 2, 8 and 8 electrons respectively.

An atom that originally had two electrons in its valence shell, such as magnesium, would lose both these electrons to achieve a full outer shell – it is easier to lose two electrons than to gain six.

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 to have a stable outer valence shell.

Figure 1 shows how magnesium and chloride ions are formed.

ion an atom that is charged because it has an unequal number of electrons and protons

Calculating ion charge

When an ion is formed, the number of protons in the atom stays the same, because protons are located 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 because there are more protons than electrons. One electron lost means there is effectively one extra proton. A positively charged ion is called a **cation**.

anion a negatively charged ion formed when an atom gains electrons

cation a positively charged ion that results from an atom losing electrons

Chemistry

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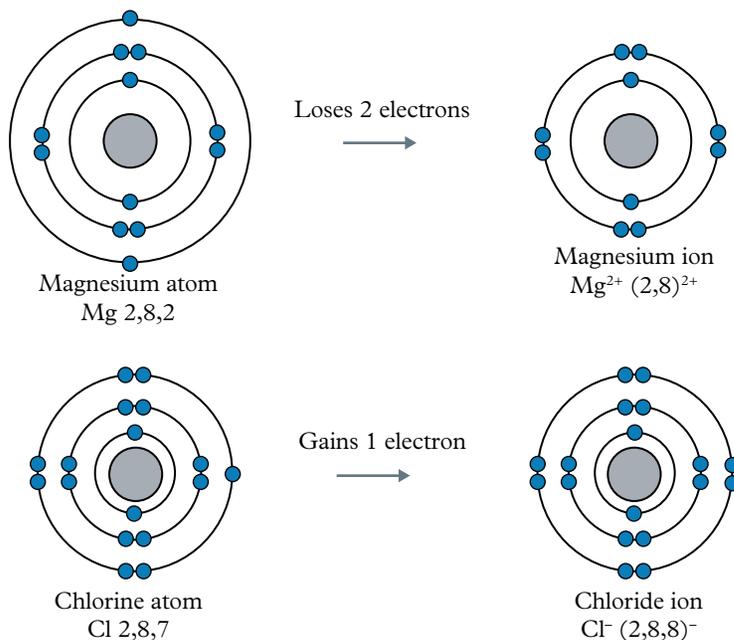
Figure 1 How magnesium and chloride ions are formed
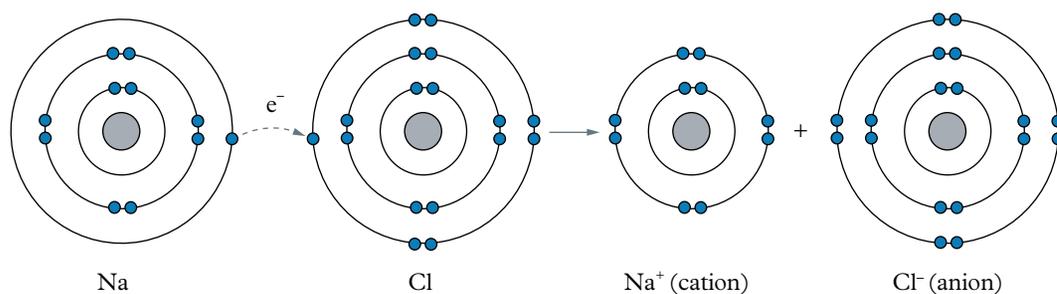
Figure 2 A sodium atom loses an electron to become a positively charged cation. Chlorine gains an electron to become a negatively charged anion. In this way, salt (sodium chloride, NaCl) is formed.

The charge on an ion can be determined by following five steps.

1. Determine the valence electrons

The number of electrons in the outer valence shell determines if electrons are gained or lost.

2. Identify the type of ion formed

If electrons are lost, a positive cation will be formed. If electrons are gained, a negative anion will be formed.

Figure 3 To remember the difference between cations and anions, think of a "paw"sitive CATion.

3. Calculate the charge

The number of electrons that are gained or lost determines the charge. For example, if a chlorine atom gains one electron, then the resulting chloride ion will have a charge of −1 (Cl^-). If a copper atom loses two electrons, the copper ion will have a charge of +2 (Cu^{2+}).

4. Use the periodic table for common charges

The elements in each group of the periodic table have the same number of electrons in the outer valence shell. This means they will have common charges.

- **Group 1 (Alkali metals)**: 1+ charge
- **Group 2 (Alkaline earth metals)**: 2+ charge
- **Group 13 (Aluminum, etc.)**: 3+ charge
- **Group 15 (Nitrogen, etc.)**: 3− charge
- **Group 16 (Oxygen, etc.)**: 2− charge
- **Group 17 (Halogens)**: 1− charge

5. Consider transition metals and polyatomic ions

Transition metals can have more than one type of charge or ionic state (e.g. Fe^{2+}, Fe^{3+}). Some atoms form polyatomic ions that have specific charges (e.g. SO_4^{2-}, NH_4^+).

Table 1 contains some examples of anions and cations.

Table 1 Examples of positive and negative ions

Name and symbol of atom	Electron configuration of atom	Electron configuration of ion	Metal or non-metal?	Change	Charge of ion	Name and formula of ion
Oxygen (O)	2,6	2,8	Non-metal	Gained 2 electrons	2−	Oxide (O^{2-})
Chlorine (Cl)	2,8,7	2,8,8	Non-metal	Gained 1 electron	1−	Chloride (Cl^-)
Sodium (Na)	2,8,1	2,8	Metal	Lost 1 electron	1+	Sodium (Na^+)
Calcium (Ca)	2,8,8,2	2,8,8	Metal	Lost 2 electrons	2+	Calcium (Ca^{2+})

Worked example 7.7A Calculating the charge of atoms

Determine the likely charge of the following atoms:

a sodium ion

b oxide ion

c neon atom.

Solution

a Sodium atoms are in group 1. This means they have one valence electron. It is easier to lose one electron than to gain seven electrons. This means the sodium ion will have one less negatively charged electron and have one more positive proton than electrons. Therefore, the sodium ion will have a charge of 1+. (The number 1 is not usually shown.)

b Oxygen atoms are in group 16 (with six valence electrons). It is easier to gain two electrons than to lose six electrons. This means the oxide ion will have two extra electrons and have a charge of 2−.

c Neon is a noble gas (in group 18). This means neon atoms already have eight valence electrons (a stable outer shell) and will have no extra electrons or protons. The neon atom will be neutral.

Chemistry

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7.7

Check your learning 7.7

Check your learning 7.7

Retrieve

1 **Define** the term "cation".

Comprehend

2 **Use** an example from the periodic table to **explain** how an anion is formed.

3 **Describe** the patterns you observe in Table 1 for each of the following.
  a Names of the negative ions
  b Electron configurations of the ions
  c Differences between the metals and non-metals

4 **Explain** why the elements neon (atomic number 10) and argon (atomic number 18) do not normally form ions.

5 **Explain** the relationship between the groups in the periodic table and the ions that are formed.

Analyse

6 **Calculate** the ionic charges of the following.
  a Calcium cation (group 2)
  b Chloride anion (group 17)
  c Magnesium cation (group 2)
  d Argon atom (group 18)

7 **Use** the groups in the periodic table to **identify** the charges on the following ions.
  a Potassium (atomic number 19)
  b Aluminium (atomic number 13)
  c Nitride (produced from nitrogen atoms with atomic number 7)

Lesson 7.8
Metal cations and non-metal anions combine to form ionic compounds

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Positive cations are attracted to negative anions and form ionic compounds.

→ Polyatomic ions form when two or more atoms combine to form a charged ion.

Forming ionic compounds

Metallic elements are usually found on the left-hand side of the periodic table. This means they have fewer than four electrons in their valence shell. Therefore, metallic atoms tend to lose electrons and become positively charged cations.

In contrast, most non-metal atoms have almost-full valence shells. This means they need to gain only a few electrons to achieve a full valence shell. As a result, non-metal atoms will usually become negatively charged anions.

Positively charged cations are attracted to negatively charged anions. A cation with a 2+ charge is likely to combine (bond) with an anion of 2− charge or with two anions each with a charge of 1−. The positive charge is balanced by an equal negative charge. The bonds that are formed when ions interact are referred to as **ionic bonds** (Figure 1).

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 or push each other and the oppositely charged ions attract each other. After all the pushing and pulling, the ions settle into alternating positions, as shown in Figure 2, 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.

When naming ionic compounds, the cation is always written before the anion. For example, a sodium cation (Na^+) combined with chloride anion (Cl^-) is written as NaCl.

Figure 1 Ionic bonds form when a positive cation is attracted to a negative anion.

ionic bond a bond between a negatively charged anion and a positively charged cation

ionic compound a substance made up of a negatively charged anion and a positively charged cation
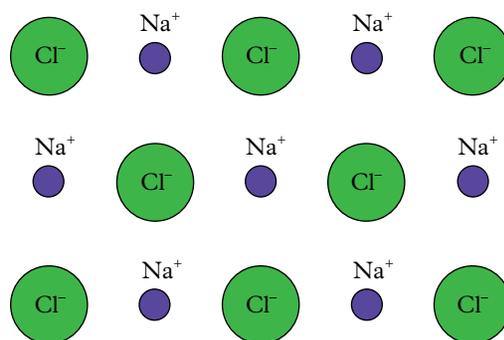
Figure 2 In an ionic compound, such as sodium chloride, the ions are arranged in alternating positions.

Naming ionic compounds

Ionic compounds are those formed from the bonding of ions. Consider sodium chloride, which is produced when sodium and chlorine meet and react. In this compound, the metal sodium is present in the form of positively charged ions (Na^+) and the non-metal chlorine is present as negatively charged ions (Cl^-). Notice that the:

- metal is named first and its name is not changed
- non-metal is named second and the end of its name is changed from -ine to -ide.

This obeys the following standard naming convention.

The positively charged ion (cation) in the compound is written first and keeps the name of the metal from which it was formed.

The negatively charged ion (anion) in the compound is written second. The end of the name of the anion from which it was formed is replaced with -ide.

Some transition metals can form more than one ion. In these cases, a Roman numeral is used to show the charge on the ion.

For example, copper forms two ions: one with a 1+ charge and one with a 2+ charge. These ions are called copper(I) and copper(II), respectively.

The names and formulas of some common ions are listed in Table 1.

Table 1 Common (positive) cations and (negative) anions are attracted to each other to form ionic bonds.

Common ions			
Positive ions		**Negative ions**	
Hydrogen	H^+	Fluoride	F^-
Lithium	Li^+	Chlorine	Cl^-
Sodium	Na^+	Bromide	Br^-
Potassium	K^+	Iodide	I^-
Magnesium	Mg^{2+}	Oxide	O^{2-}
Calcium	Ca^{2+}	Hydroxide	OH^-
Aluminium	Al^{3+}	Nitrate	NO_3^-
Silver	Ag^+	Sulfate	SO_4^{2-}
Copper(II)	Cu^{2+}	Carbonate	CO_3^{2-}
Zinc	Zn^{2+}		
Lead	Pb^{2+}		
Iron (II) & (III)	Fe^{2+} & Fe^{3+}		
Ammonium	NH_4^+		

Ionic formulas

The formula for sodium chloride is NaCl, whereas the formula of magnesium chloride is $MgCl_2$. The formula NaCl means that the cations and anions are present in a ratio of $1:1$. That is, for every Na^+ ion present in a sodium chloride crystal, there is one Cl^- ion present. The formula $MgCl_2$ means that the cations and anions are present in a ratio of $1:2$. That is, for every Mg^{2+} ion present in a magnesium chloride crystal, there are two Cl^- ions present. This is necessary to achieve an overall neutral charge.

We can use this principle to determine the formula of an ionic compound.

1 Use Table 1 to list the formulas for the cations and anions present.

2 Work out the simplest ratio they need to be in so that the total positive charge and total negative charge are equal.

Note: Worked example 7.8A will assist you in your calculations.

Worked example 7.8A Determining ionic formulas

Determine the formula for the following compounds.

a Iron(II) oxide

b Silver sulfide

Solution

Think	Do
For part **a**, identify the charges for iron(II) and oxygen	Iron(II) - Fe^{2+} Oxygen - O^{2-}
Determine the ratio of ions required to achieve an overall neutral charge of zero.	Because the charges 2+ and 2– are equal, the ions only need to be in a ratio of 1:1.
Write down the ionic formula without charges	FeO
For part **b**, identify the charges for silver and sulfur.	Silver - Ag^+ Sulfur - S^{2-}
Determine the ratio of ions required to achieve an overall neutral charge of zero.	Because the charges are 1+ and 2–, the ions need to be in a ratio of 2:1 (making it a total of 2+ and 2–).
Write down the ionic formula without charges	Ag_2S

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.

polyatomic ion a charged ion that consists of two or more atoms bonded together

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 ions (one each of oxygen and hydrogen), there are nine protons and 10 electrons. This means the two atoms that form the ion have an overall charge of 1–.
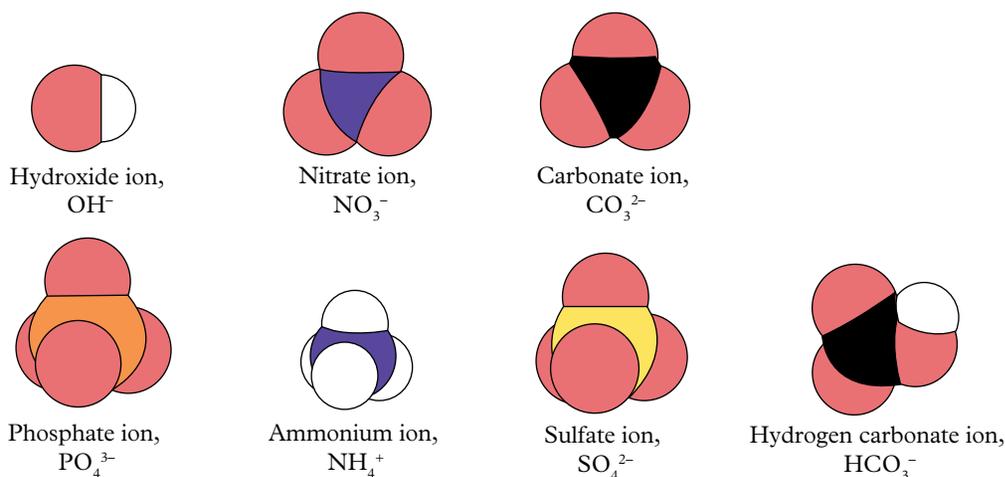
Figure 3 Some common polyatomic ions; the charge number indicates how many electrons have been lost. A negative charge number indicates how many electrons have been gained.

Calcium carbonate, the main constituent of chalk, 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

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7.8

charge equals the total negative charge. This means the final compound calcium carbonate ($CaCO_3$) will be neutral. This means that all ionic compounds have no charge.

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 $2:1$ (two NH_4^+ for every CO_3^{2-}). The formula of ammonium carbonate is $(NH_4)_2CO_3$. The brackets around the ammonium ion (NH_4^+) are used to show that there are two groups of these atoms that make up the whole cation.

Check your learning 7.8

Check your learning 7.8

Retrieve

1 **Define** the term "ionic compound".

2 Write the formulas for:
   a lithium bromide
   b iron(III) chloride
   c sodium nitride
   d aluminium oxide.

3 **Identify** the charge of elements in:
   a group 1
   b group 2
   c group 6
   d group 7.

Comprehend

4 **Explain** why elements in group 8 do not usually form ions.

5 **Describe** why the group of an element can be used to quickly identify one or more of its properties.

6 Use your knowledge of atomic structure and valence electrons to **explain** why many ionic compounds are made up of a metal and a non-metal.

Analyse

7 Carefully **examine** the periodic table in Figure 1 in Lesson 7.1 The structure of an atom determines its properties (page 311).
   a **Identify** the groups that are likely to form positively charged ions.
   b **Identify** the groups that are likely to form negatively charged ions.
   c **Explain** why elements from group 1 and group 17 are likely to form ionic compounds.

Apply

8 Use the information from Table 1 to **determine** the formula of the following ionic compounds:
   a a phosphate ion and a potassium cation
   b an ammonium ion and a hydroxide ion
   c a sodium ion and a hydroxide ion.

9 **Calculate** the maximum number of electrons that can be gained or lost by any atom. **Justify** your answer (by contrasting how elements such as Al in group 13 and P in group 15 form ions, explaining why it can be difficult to determine the charge on elements such as C in group 14, and explaining how this allowed you to calculate the maximum).

Skills builder: Evaluation

10 "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 that outlines the evidence that supports this statement.
   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?)

Lesson 7.9

Experiment: Conductivity of ionic compounds

Aim

To investigate the electrical conductivity of two ionic compounds as a solid and in an aqueous solution

Materials

- Large sodium chloride crystals
- Coarse sea salt crystals
- Small Petri dish
- 4 V battery or other 4 V DC power supply
- Ammeter
- Wires with alligator clips (for solids)
- 2 graphite electrodes (for liquids)
- 3 × 100 mL beakers
- Large spatula
- Glass stirring rod
- Paper towel

Method

1   Set up the electrical circuit as shown in Figure 1. Have your teacher check that it is correct before proceeding. Ensure that you know how to use the ammeter and its scales correctly.

Figure 1 Experimental set-up

2   Using the spatula, place the largest sodium chloride crystal onto the Petri dish, then touch each end with an electrode, making sure that the two electrodes do not touch each other. If the crystal does not appear to conduct electricity, connect the wire to the more sensitive scale on the ammeter to check further. Record your result.

3   In a 100 mL beaker, place half a large spatula of sodium chloride crystals and add 50 mL of water. Stir to dissolve the crystals.

4   Attach the graphite electrodes to the alligator clips and place the ends of the electrodes into the solution, ensuring they do not touch each other. If the crystal does not appear to conduct electricity, connect the wire to the more sensitive scale on the ammeter to check further. Record your result.

5   Turn off the power supply and rinse the electrodes with fresh tap water, then dry them with a paper towel.

Inquiry

What if large coarse sea salt was used?

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Create a simple table or spreadsheet in which to record your results.

Discussion

1 Sea salt is a mixture of different ionic compounds, including sodium chloride. **Describe** your conclusions about the ability of solid ionic compounds to conduct electricity.
2 **Describe** how dissolving an ionic compound in water changes its ability to conduct electricity.
3 **Explain** why a substance must have charged particles that can move about before it can conduct electricity.

4 The melting point of sodium chloride is 801°C, so it is not practical to melt it in the school laboratory. **Predict** whether molten sodium chloride would conduct electricity. **Justify** your answer (by describing the essential property necessary for a material to conduct electricity and identifying whether this property would be present in molten sodium chloride).

Conclusion

Describe what you know about the conductivity of ionic compounds.

Lesson 7.10
Non-metals combine to form covalent compounds

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Two non-metals merge their valence shells to share two electrons (one from each atom) so that each has a full valence shell.

→ The sharing of pairs of electrons between atoms is called a covalent bond and can be used to explain the compound's properties.

Introduction

You have seen that when electrons are transferred from one atom to another, positive and negative ions are produced and ionic compounds are formed. However, two non-metals that complete their outer shells of electrons by sharing electrons can also bond together.

We can see this with the smallest, lightest atom: hydrogen (Figure 1).
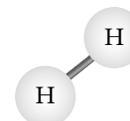
Figure 1 The ball-and-stick model is often used to show atoms (balls) and the bonds (sticks) between them. This image shows a ball-and-stick model of a hydrogen (H_2) molecule.

Hydrogen molecules

An uncharged (neutral) atom of hydrogen has just one electron in the first shell. If it could gain one more electron, this shell would contain its maximum number of electrons – two. If hydrogen was in contact with a reactive metal such as lithium, the hydrogen atom could gain that extra electron from a lithium atom. An ionic compound would form as a result. But what if only other uncharged hydrogen atoms are present? The only way each hydrogen atom can gain an extra electron is by sharing its electron with another.

+	Positively charged nucleus
−	Negatively charged electron
-------	Electrostatic force of attraction

Figure 2 Some diagrams of molecules can show the electrons being shared between the atoms.

As two uncharged hydrogen atoms come close together, the electrons are drawn into the region between the two nuclei. The atoms partially merge into one another, with the nuclei of both atoms now sharing the two electrons in a **covalent bond**. The electrons travel in the spaces surrounding the nuclei of each atom. In effect, each atom now has a stable electron configuration because its outer shell is full.

The particle produced has two hydrogen atoms bonded strongly together and is called a molecule. A **molecule** is a particle produced when two or more atoms combine so that the atoms share electrons.

A molecule has no overall charge because the total number of electrons and the total number of protons is the same.

The hydrogen molecule is given the formula H_2 because there are two hydrogen atoms present in the molecule.

The hydrogen molecule is an example of a molecule of an element. It is called a **diatomic molecule** because it is made up of two atoms. Other examples of diatomic molecules of non-metals are fluorine (F_2), chlorine (Cl_2), oxygen (O_2) and nitrogen (N_2).

In a molecule such as the hydrogen molecule, there is strong electrostatic attraction between the shared electrons and the positively charged nucleus.

The electrons spend a considerable part of their time between the two nuclei. This electrostatic attraction is termed covalent bonding. The two shared electrons create a strong bond between the two atoms.

covalent bond a bond formed when two or more atoms share electrons

molecule group of two or more atoms bonded together (e.g. a water molecule)

diatomic molecule a molecule that consists of two atoms

Molecular compounds

Molecules can also be formed by combining different types of atoms into compounds. Water is an example of a **molecular compound**. Its formula is H_2O. To gain a more stable electron configuration, an:
- uncharged hydrogen atom, which has one valence electron, requires a share of one more electron
- uncharged oxygen atom, which has six valence electrons, requires two more electrons.

A single hydrogen atom cannot supply the two electrons the oxygen atom needs, but two hydrogen atoms can supply one electron each. This is why there are two hydrogen atoms and just one oxygen atom in a water molecule. An oxygen atom now effectively has eight electrons in its valence shell, and each hydrogen atom has two electrons. This is shown in Figure 3. Notice that each atom now has a full, stable outer shell of electrons.

molecular compound a molecule that contains two or more different atoms bonded together

Chemistry

There are other ways of representing the structure of molecules, including with three-dimensional models (Figure 1 and Figure 4). However, remember that in any representation, a single chemical bond holding the molecule together is actually a pair of negative electrons, shared between two atoms, attracted to the positive nuclei of both of these atoms.
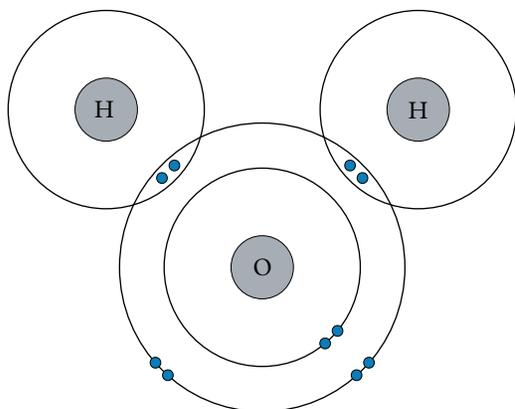
Figure 3 A shell diagram of a water molecule
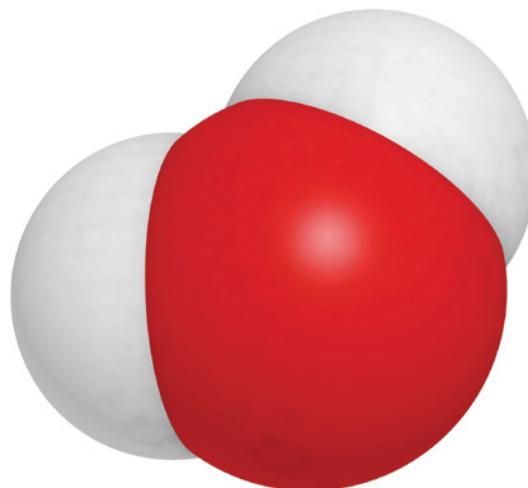
Figure 4 A 3D model is often used to show the arrangement of atoms in a molecule of water (H_2O).

Properties of molecular substances

Almost all molecular substances do not conduct electricity, even in the liquid state, because the molecules do not have free charged particles and so they cannot carry a current. There are only weak forces of attraction between molecules, so most molecular substances are liquids or gases at room temperature. It does not take much energy to separate the individual molecules and get them to move around.

Check your learning 7.10

Check your learning 7.11

Retrieve

1 **Define** the term "diatomic molecule".
2 **Identify** the types of atoms (metals, non-metals) that form covalent bonds.

Comprehend

3 **Describe** a covalent bond.
4 **Explain** why molecular substances cannot conduct electricity.
5 **Explain** why carbon dioxide has the formula CO_2. (HINT: It has covalent bonding.)

Analyse

6 Answer these questions.
   a **Calculate** the number of electrons needed to be shared between two chlorine atoms when they combine to form a molecule.
   b **Compare** the process of forming chlorine molecules to the process of forming an oxygen molecule.
7 **Compare** ionic bonding and covalent bonding.

Apply

8 In terms of the structure of the substance, **discuss** why it is easier to turn liquid water into a gas than to break the covalent bonds between the hydrogen and oxygen atoms.

Lesson 7.11
Challenge: Modelling covalent molecules

Aim

To model the sharing of electrons in covalent molecules

What you need:

Molecular modelling kits (or use different coloured marshmallows and toothpicks)

What to do:

1   Choose three different colours to represent carbon, hydrogen and oxygen.
2   For each of the molecules shown in Table 1:
    a   state the numbers of each atom
    b   make and draw a model of the molecules
    c   draw the number of electrons in the valence shell of each atom, including the shared electrons.

Results

Copy and complete Table 1.

Table 1 Atomic modelling

Molecule	Atoms present	Numbers of each atom	Drawing of model	Electron dot diagram
H_2				
H_2O				
CH_4				
CO_2				
$CHCl_3$				

Discussion

1   Identify and describe the type of bond that occurs between a metal and a non-metal.
2   Identify and describe the type of bond that occurs between two non-metals.
3   Define the term "valence shell".
4   Explain the meaning of the term "sharing electrons" in covalent bonds.

Conclusion

Describe a covalent bond and the types of elements that form this bond.

Figure 1 The structural arrangement of molecules can be modelled.

Lesson 7.12
Metals form unique bonds

Key ideas

→ All metals arrange their atoms into layers that can easily slide over each other.

→ Metals are good conductors because some valence electrons are delocalised and are able to freely move from one atom to another.

→ Metal alloys are mixtures of two or more metals that are stronger than pure metals.

Metallic structure

Many metals are malleable (can be bent into any shape) and ductile (can be drawn into a wire). This property of metals is a result of the arrangement of atoms. Metal atoms arrange themselves into layers. When the metal is bent or hammered into shape, the atoms slide over one another (Figure 1).

Metals and conductivity

Remember that metals are found on the left-hand side and centre of the periodic table. Metals do not have many electrons in their outer shells, and it does not take much energy for these outer electrons to move from one atom to another. This is the clue as to why metals are so good at conducting electricity.
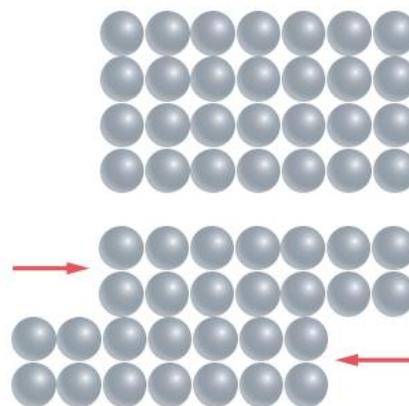
Figure 1 The arrangement of atoms in metals allows them to slide over each other when the metals are bent or hammered into shape.

A substance will conduct electricity if it contains charged particles that are free to move around the structure. In metals, these charged particles are electrons. Scientists refer to the outer-shell electrons as **delocalised electrons** because they are not "stuck" in one locality (Figure 2). (Most electrons in metal atoms are not delocalised because they move around the nucleus of each metal atom in the inner electron shells.) Metals are good electrical conductors because the outer-shell electrons are free to move from nucleus to nucleus along the metal.

delocalised electron an electron in a molecule that can easily move between atoms

Metals are also good conductors of heat. This is because the atoms are closely packed together so they can easily pass on the kinetic energy of heat.

Table 1 gives the electrical conductivity of a number of elements at 25°C.

All metals conduct electricity in the solid state – some better than others. They continue to conduct electricity when molten liquid, but not as well as when in the solid state. The higher the temperature, the lower a metal's electrical conductivity.
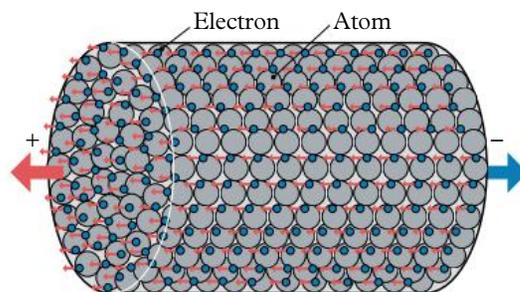
Figure 2 Delocalised electrons move about randomly in a metal, but they move towards the positive terminal of the power source when connected into a circuit.

Only some metals are used for their electrical conductivity. For example, power lines have a core of steel and an outside layer of aluminium. Household wiring is usually copper coated with a special kind of plastic. Metals like silver and gold are used in more specialised applications, such as in electronic devices.

Delocalised electrons are responsible for a pure metal being lustrous (shiny). The delocalised electrons in its surface reflect light extremely well (Figure 3).

Table 1 Electrical conductivities of some common elements at 25°C

Element	Electrical conductivity ($\times 10^6$ ohm^{-1} cm^{-1})
Aluminium	0.37
Carbon (graphite)	0.100
Copper	0.596
Gold	0.452
Iron	0.093
Lead	0.048
Magnesium	0.226
Silver	0.63
Sodium	0.210
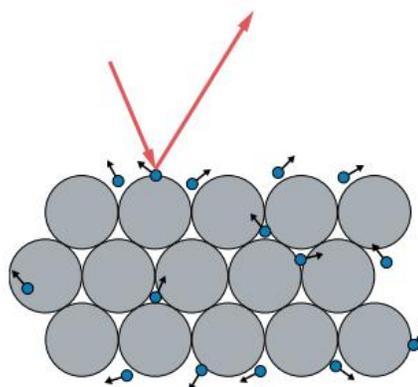
Figure 3 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

Metal alloys

A metal alloy occurs when a metal is mixed with another metal or compound. Because the atoms are different sizes, they are not arranged in the usual way. This means the atoms in an alloy cannot slide over one another as easily as in a pure metal. Alloys are usually stronger and harder than pure metals as a result.

Soft metals such as copper, gold and aluminium are often mixed with other metals to make alloys that are hard enough for everyday use.

Brass (70 per cent copper and 30 per cent zinc) is used in electrical fittings and hinges.

Jewellery is often made of 18-carat gold (75 per cent gold and 25 per cent copper and other metals).

Smart alloys

Some alloys have unique properties. When nitinol (a mixture of nickel and titanium) is cast into a particular shape and heated to 500°C, the atoms arrange themselves into a compact and regular pattern. This allows the alloy to create a memory of this shape. If the alloy is bent out of shape, heat or electrical current can cause it to return to its original shape. These metals are often called memory alloys (Figure 5).

An example of memory wires are those used in orthodontic braces. The wires will constantly return to their original shape, reducing the need to retighten or adjust the wire.

Chemistry

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7.12
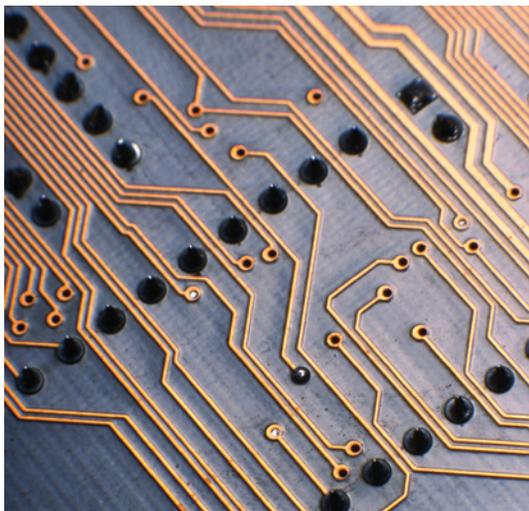
Figure 4 Gold bonding wire is used in integrated circuits.

Figure 5 Memory wire is useful in eyeglass frames, allowing them to be bent out of shape without breaking.

Check your learning 7.12

Check your learning 7.13

Retrieve

1   **Identify** the arrangement of atoms in a metal that enables each of the following properties.
    a   Malleability
    b   Conductivity
    c   Shiny appearance
2   **Define** the term "alloy".

Comprehend

3   **Describe** the structure of a metal.
4   **Describe** what is meant by the phrase "delocalised electrons".

Analyse

5   **Compare** the properties of an alloy with those of pure metal.
6   Memory alloys have been used to repair broken bones. **Consider** why a memory alloy would be beneficial in this situation.

Apply

7   Nitinol (NiTi) is one of the most common memory alloys used in biomedical engineering. It is super-elastic and can resist corrosion in the body. **Evaluate** the effectiveness of using NiTi to replace part of the skull of a person who needed brain surgery (by comparing the properties of NiTi to the properties of the skull and deciding whether NiTi will be effective).

Lesson 7.13
Challenge: Modelling alloys

Aim

To compare the properties of model alloys

What you need:

- 4 different colours of softened plasticine or play dough (35 g of each)
- Sand (12 g)
- Newspaper
- Balance
- Magnifying glass

What to do:

1 Weigh 2 g of sand onto the newspaper.
2 Work one of the plasticine colours until it is soft and malleable. Roll it out into a 0.5 cm layer.
3 Sprinkle the sand onto the plasticine and work the plasticine until the sand is spread through it evenly.
4 Repeat steps 2 and 3 with 4 g and 6 g of sand.
5 Roll out each of the four pieces (one of which contains no sand). In your results table, note which piece was easiest to roll out.
6 Work the four pieces of plasticine (one of which will contain no sand) until they are at room temperature.
7 Form each piece of plasticine into a long, thin cylinder ("wire") of the same size and length.
8 In your results table, note which piece was easiest to draw out into a long, thin cylinder ("wire").
9 Hold the ends of one plasticine cylinder firmly and pull it apart.
10 Repeat the pull test for each plasticine cylinder.
11 In your results table, note which piece snapped soonest.
12 Use the magnifying glass to examine the broken ends of each cylinder.
13 In your results table, estimate the surface area of the broken ends.

Results

Record your observations in an appropriate table.

Discussion

1 **Identify** the "alloy" that was most malleable (able to be rolled out easily when cold).
2 **Identify** the "alloy" that was most ductile (able to be drawn out into a "wire" shape easily).
3 **Identify** the "alloy" that was most brittle (snapped quickly).
4 **Identify** one other variable in this model that could affect the properties of the plasticine "alloy". **Describe** how the properties of the "alloy" could be affected by this variable. **Describe** how this variable was or could be controlled.
5 **Evaluate** how the amount of sand in the "alloy" affected the size of the largest fracture surface (by comparing the amount of sand and the size of the surface area of the broken end for each amount of sand and summarising your findings in a single sentence: "As the amount of sand in the 'alloy' increases, the fracture surface …").

Conclusion

Describe how the alloying of metal affects its properties.

Figure 1 Use plasticine and sand to model alloys.

Lesson 7.14

Science as a human endeavour: Nanotechnology involves the specific arrangement of atoms

Key ideas

→ The use of nanobots in medicine would see tiny structures monitor everything happening in a patient's body, including looking for diseases or chemical imbalances.

→ Carbon nanotubes could be used in medicine, technology and textiles due to their flexibility and light weight.

Introduction

The average atom is 0.3 nanometres (0.0000003 mm) in diameter. Understanding the structure and properties of individual atoms allows scientists to control how these atoms are arranged.

nanotechnology
the manipulation of individual atoms to form structures

Nanotechnology operates at the scale of the nanometre, which is approximately one ten-thousandth of the width of a human hair. This is the level of atoms or molecules. Nanotechnology allows artificial manipulation of atoms or molecular processes or objects. For example, computers the size of blood cells with tiny wireless transmitters could report on the health of a person without that person requiring surgery. Nanomachines (or nanobots) are tiny structures that are being designed to rearrange the atoms in our bodies or to detect imbalances in chemical reactions. Scientists hope to develop nanobots as small as viruses or bacteria to perform tasks on a nanometre scale.

Nanobots in medicine

Many medical scientists are very excited about the use of nanobots in medicine. Imagine tiny structures monitoring a patient's body, constantly looking for viruses or bacteria that can cause disease. If a virus is detected, the nanobot could break it down molecule by molecule.

Nanotechnicians have designed a nanobot that is capable of carrying 9 billion oxygen and carbon dioxide molecules. This could potentially remove the need for blood transfusions in the future.
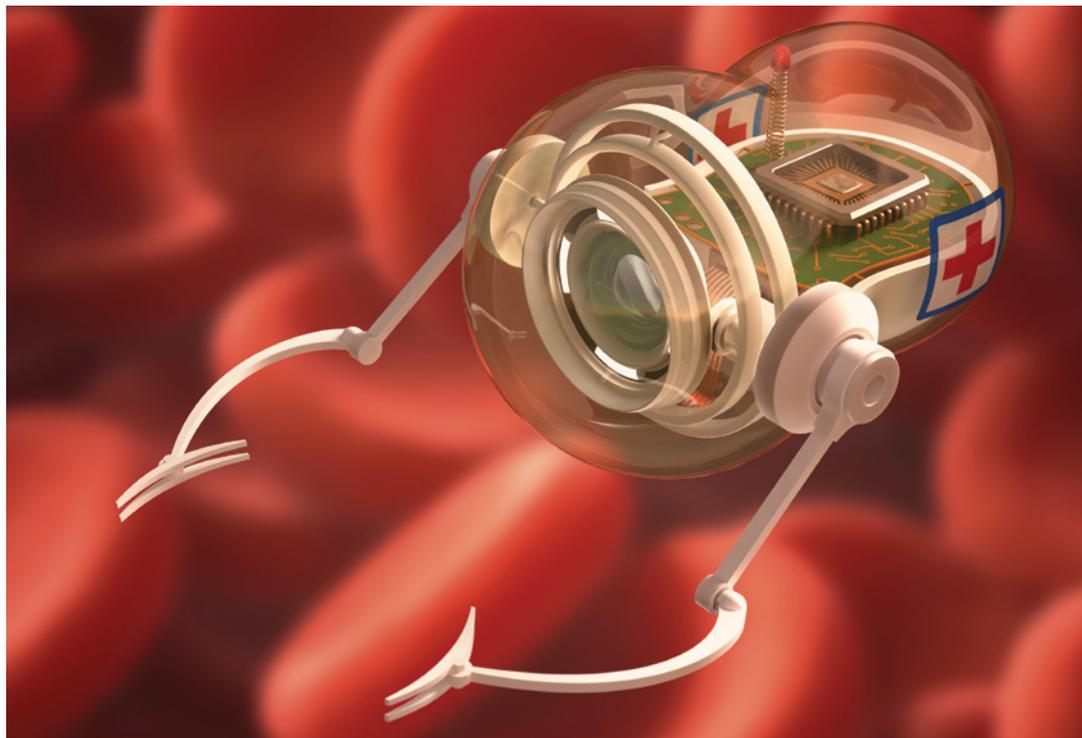
Figure 1 Nanobots could be used to treat viruses.

Carbon nanotubes

A **carbon nanotube** is an arrangement of carbon atoms that has very different properties from other arrangements of carbon atoms, such as graphite and diamond. Carbon nanotubes are the focus of intensive research for many applications in the future.

Carbon nanotubes are extremely hard, have high tensile strength and are efficient conductors of heat and electricity. That is, carbon nanotubes exhibit many properties usually found in metals. However, in contrast with most metals, carbon nanotubes are extremely light and flexible. Carbon nanotubes might be used:

- in medicine, where their high electrical conductivity may make them suitable to bypass faulty nerve cell wiring in damaged brains
- to create clothing with unique properties, such as protection against bullets
- in computing and television, where they are being used to develop flat, folding, futuristic television screens with greater image resolution than the human eye can detect
- for renewable energy devices, such as solar panels, due to their efficient absorption of heat, and in wind turbines for making blades lighter and stronger
- to break down pollution in waterways or in smog-ridden cities.

carbon nanotube
a very small tube of
carbon atoms, made
synthetically

How carbon nanotubes are made

The emergence of nanotechnology as a key scientific force has resulted from relatively recent and rapid developments in the capacity of scientists to:

- put nano-sized quantities of matter where they are wanted
- use controlled amounts of nano-sized materials for a practical purpose
- detect and monitor the location and configuration of nanoscale materials.

There are two manufacturing approaches to making nano-sized materials.

1. The top-down method involves using mass materials and breaking them down by physical or other means into nanoscale components.

2. The bottom-up method, also known as molecular manufacturing, is a more complicated process because it relies on the construction of templates on which nanomolecules will form under the appropriate chemical and physical conditions.

A good example of the top-down method can be found in the sunscreen industry, where materials to block UV light, such as titanium oxide and zinc oxide, are transformed by a grinding process from their white, opaque mass forms into invisible, nano-sized particles. These are known as nanopowders.

A good example of the bottom-up method is the production of carbon nanotubes. A layer of metal catalyst particles is exposed to high heat and a carbon-containing gas. The nanotubes form at the interface between the gas and the metal catalyst.
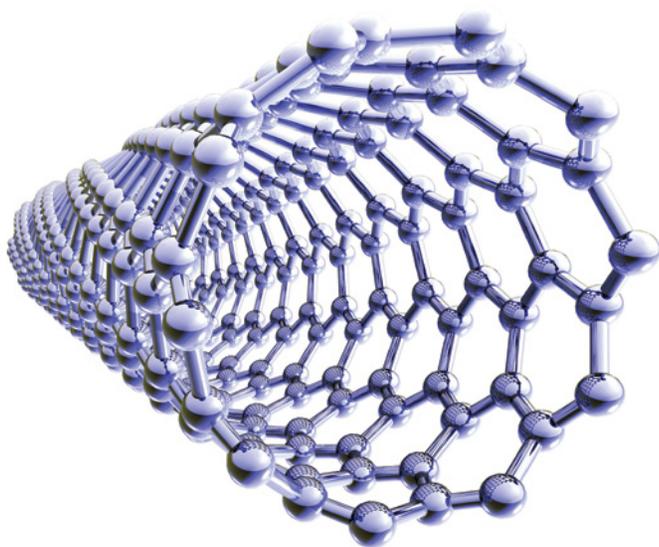
Figure 2 Nanotube technology is being investigated for a wide range of technological and medical uses.

Figure 3 An illustration of zinc oxide nanoparticles

Test your skills and capabilities

Evaluating claims

There are many claims about the wonderful things that nanotechnology can achieve. As these things refer to objects that are so small, it is easy to accept what you are being told without questioning whether it is true.

Examine the following blog entry and answer the questions to critically assess the information.

> Many sunscreens use zinc oxide and titanium dioxide particles to reflect the sunlight that can cause sunburn and skin cancer. Recently, these particles have been shrunk to nanoparticles, which are particles that are small enough to be taken into the body through the skin cells. This makes them dangerous!

a   **Identify** the source of the blog. **Describe** the author's level of experience in nanotechnology. (HINT: Use your search engine to help you identify the source.)

b   **Describe** the argument the author is presenting.

c   **Identify** an assumption that the author is making.

d   **Describe** an experiment that could be used to provide evidence that nanoparticles of zinc oxide can enter skin cells.

e   **Describe** an alternative argument to that of the author. **Describe** the potential outcome of the experiment in part **d** that would support your alternative argument.

f   Based on the previous questions, **evaluate** the validity of the claim made by the author of the blog.

Lesson 7.15
Review: The periodic table

Summary

Lesson 7.1 The structure of an atom determines its properties

- 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 around the nucleus in electron shells.
- An atom's outermost electron shell is called the valence shell.
- The number of electrons in the valence shell determines many of the properties of an element and therefore its position in the periodic table.

Lesson 7.3 Groups in the periodic table have properties in common

- 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.
- Transition metals have properties that are unique to groups 3–12.

Lesson 7.5 Non-metals have properties in common

- Non-metals (groups 14 to 18) do not conduct electricity or heat, are very brittle and have a dull appearance.
- Metalloids are found between metals and non-metals on the periodic table, and their properties are a combination of those of metals and non-metals.

Lesson 7.7 Ions have gained or lost electrons

- Electrons have a negative charge.
- When an atom loses electrons, it forms a cation (positive charge).
- When an atom gains electrons, it forms an anion (negative charge).

Lesson 7.8 Metal cations and non-metal anions combine to form ionic compounds

- Positive cations are attracted to negative anions and form ionic compounds.
- Polyatomic ions form when two or more atoms combine to form a charged ion.

Lesson 7.10 Non-metals combine to form covalent compounds

- Two non-metals merge their valence shells to share two electrons (one from each atom) so that each has a full valence shell.
- The sharing of pairs of electrons between atoms is called a covalent bond and can be used to explain the compound's properties.

Lesson 7.12 Metals form unique bonds

- All metals arrange their atoms into layers that can easily slide over each other.
- Metals are good conductors because some valence electrons are delocalised and are able to freely move from one atom to another.

- Metal alloys are mixtures of two or more metals that are stronger than pure metals.

Lesson 7.14 Science as a human endeavour: Nanotechnology involves the specific arrangement of atoms

- The use of nanobots in medicine would see tiny structures monitor everything happening in a patient's body, including looking for diseases or chemical imbalances.
- Carbon nanotubes could be used in medicine, technology and textiles due to their flexibility and light weight.

Review questions 7.15

Review questions: Module 7

Retrieve

1 **Identify** the transition metal.
   A Caesium
   B Palladium
   C Fluorine
   D Radon
2 **Recall** what rows of the periodic table are called.
   A Groups
   B Periods
   C Valences
   D Electron configurations
3 Use the periodic table in Lesson 7.1 The structure of an atom determines its properties (page 310) to **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 electron configuration is 2,8,6,2.
   D It has six electron shells.
4 **State** 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

5 **Identify** the group number of:
   a alkaline earth elements
   b halogens
   c noble gases
   d alkali metals.

Figure 1 Neon lights use neon, a noble gas.

6 **Define** the term "valence shell".
7 **Identify** the characteristics that elements in group 1 have in common.
8 When naming an ionic compound, **recall** which ion (anion or cation) is written first.

Comprehend

9 **Describe** how electrons are arranged in the Bohr model of an atom.

10 **Describe** the characteristic that determines the overall order of elements in the periodic table.

11 An inert substance is one that will not react with any other substance. Originally, group 18 elements were known as the "inert gases". **Explain** why the name was changed to "noble gases".

12 **Describe** the key characteristic of metals that allows them to conduct electricity in the solid state.

13 **Explain** why elements in group 8 are more stable than elements in group 1.

14 **Explain** each of the following statements.
   a Argon will not react with any other element.
   b The reaction between sodium and chlorine gives out a lot of heat and light.
   c When you accidentally spill sodium chloride onto a stove while cooking, it does not melt.

15 Only two elements are liquids at room temperature – bromine and mercury. Bromine is a non-metal and mercury is a metal. **Describe** how these two liquids are likely to appear and behave differently from each other.

Figure 2 Mercury is a liquid at room temperature.

16 A substance will conduct electricity if it contains charged particles that are free to move across the sample. The charged particles can be electrons or ions. **Explain** why ionic compounds cannot conduct electricity when in the solid state, but they can conduct electricity when melted.

Analyse

17 **Consider** the following pairs of elements: chlorine and oxygen, oxygen and lithium, fluorine and argon, and aluminium and potassium.

   a **Draw** the electron configuration for each element.
   b **Identify** the pair(s) that will react to form an ionic compound.
   c **Identify** the pair(s) that will react to form a molecular compound.
   d **Identify** the pair(s) that will not react to form a compound.
   In each case, **explain** your answer by **contrasting** the properties of the elements.

18 **Compare** a cation and an anion.

19 When the uncharged atoms of potassium lose an electron, they then have an electron configuration of 2, 8, 8. This is the same as the electron configuration of argon. **Compare** the potassium ion and argon atom.

Apply

20 Scientists deduce what it is like inside an atom from indirect evidence, similar to how astronomers determine the temperature and composition of stars. **Discuss** two advantages and two disadvantages of using indirect evidence to develop scientific theories.

21 **Identify** two elements that you would expect to react together in the most violent way. **Justify** your answer (by identifying a group of metals and non-metals that are very reactive, identifying which element in those groups is the most reactive, and describing how you made your decision).

22 Before the 1980s, the groups of the periodic table were numbered with Roman numerals. Some scientists prefer this version because the atoms of the elements in group III (now 13) have three electrons in their valence shell, those in group IV (now 14) have four electrons in their valence shell, and so on. **Examine** how the groups of transition metals were numbered in the old way. **Propose** a reason why the numbering system was changed.

23 A particle was found to contain 16 protons and 18 electrons.
   a **Identify** the element that makes up the particle. **Justify** your answer (by describing the key characteristic that you used to make your decision).
   b **Identify** the charge of the particle. **Justify** your decision.
   c **Identify** the symbol (including the charge) of the particle. **Justify** your answer.

24 According to the Bohr model of the atom, the electron configuration of the uncharged atoms of a particular element is 2, 8, 8.

a **Calculate** the atomic number of the element.

b **Identify** the element.

c **Describe** the electronic configuration of the next element on the periodic table. **Justify** your answer (by explaining how you made your decision).

Critical and creative thinking

25 A student claimed that sodium chloride is made of molecules. **Evaluate** this statement (by defining the term "molecules", describing the bonded sodium chloride atoms, and comparing the definition to the description of bonded sodium chloride atoms).

26 **Create** a poster that shows the different models of the atom, from the original theory that it was a solid particle, 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.

Figure 3 (A) John Dalton; and (B) Niels Bohr

Research

27 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

The noble gases

The story behind the discovery of the noble gases is a fascinating one. The challenge was how to detect the existence of something that only exists as a gas, does not react with anything, and is only present in the air in extremely small concentrations (except for argon).

• Describe how the first noble gas was found.

• Describe the role Mendeleev's periodic table of that time played in helping chemists hunt for other noble gases.

• Describe how the periodic table has been refined as the new elements were discovered.
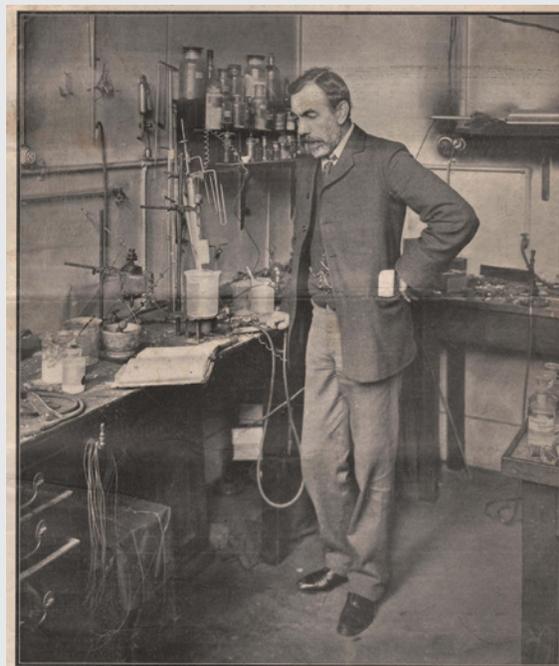
Figure 4 William Ramsay's discoveries added the noble gases to the periodic table.

Developing the periodic table

When Mendeleev first published his version of the periodic table in 1869, he arranged the elements according to their atomic mass and their properties including how reactive they were. At the time, he left many gaps in it for the elements that were yet to be discovered. Since then, many other versions of the periodic table have been developed.

- Identify an alternative version of Mendeleev's periodic table.
- Evaluate the effectiveness of the alternative periodic table by:
  - describing the information that can be obtained about hydrogen from the periodic table. (HINT: Consider the shape of the diagram and the size and location of hydrogen. Is it the same colour as other elements? What do you know about the other elements around it?)
  - describing the information that can be obtained about hydrogen from Mendeleev's periodic table
  - contrasting the two periodic tables
  - deciding which version of the periodic table is most appropriate for your chemical needs.

Validating discoveries

Marie and Pierre Curie won a Nobel prize for their discovery of the element radon. To do this, they needed to provide evidence of their discovery.

- Few women were educated in the nineteenth century. Describe how Marie Curie (nee Sklodowska) was educated.
- Describe how X-rays were discovered.
- Explain how the Curies first realised that there was a new element in a sample of uranium.
- Describe the process they used to isolate the radon.
- Explain why they needed to provide the evidence of radon to fellow scientists.

Figure 5 Many of the papers and equipment used by Marie and Pierre Curie are still radioactive today.

Module

8

Chemical reactions

Overview

Chemical reactions happen when atoms are rearranged to form new substances. According to the law of conservation of mass, no atoms are lost or gained during a reaction – the total mass stays the same. This means the number of atoms in the reactants equals the number in the products. We can show chemical reactions using word equations or balanced symbol equations, which help us understand what's happening during the reaction.

Green chemistry tries to make reactions more environmentally friendly by reducing waste, saving energy, and avoiding harmful chemicals. Understanding how chemicals react allows us to minimise the impact on the environment.

Lesson 8.1
Synthesis, decomposition and displacement reactions can be represented by equations

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Synthesis reactions combine multiple reactants to form a new compound.

→ Decomposition reactions break down a reactant into multiple products.

→ Displacement reactions involve an atom or group of atoms of a molecule being displaced by another atom or group of atoms.

Introduction

Almost every substance that you will use today was made in a chemical reaction. One of the roles of chemists is to understand chemical reactions and the products they form. This is possible because of the law of conservation of mass, which states that atoms cannot be created or destroyed. This means the number and type of atoms at the start of a chemical reaction must be equal to the number and type of atoms produced.

Classifying reactions

Classifying compounds into groups makes them easier to name and identify. Because all the compounds in the same group have similar properties, you can predict most of the properties of an unknown substance if you know to which group it belongs.

Similarly, the chemical reactions that are used to make compounds can also be classified. Classifying reactions into different types helps us predict what products will be produced. Reactions can be classified as synthesis, decomposition, displacement, combustion or hydrolysis (reaction with water) reactions, among others.

Synthesis reactions

synthesis a reaction that involves the building up of compounds by combining simpler substances, usually elements

Synthesis is the building up of compounds by combining simpler substances, normally elements:

$$A + B \rightarrow AB$$
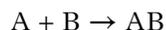
This equation is a general equation and it helps you determine what will be produced in a synthesis reaction. In synthesis reactions, the two reactants combine to form a new product. For example:

$$\text{sodium} + \text{chlorine} \rightarrow \text{sodium chloride}$$

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8.1
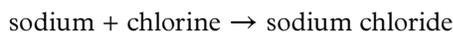
Writing chemical equations

Once you have predicted the product that will be formed and written the word equation, you can write the chemical equation.

1 Write the chemical formula for each of the molecules. Are they ionic compounds or covalent compounds? Use subscript numbers to indicate the number of each type of atom in the molecule:

$$Na + Cl_2 \rightarrow NaCl$$
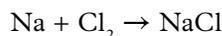
2 Count the number of atoms on each side of the equation to ensure that no atoms are created or destroyed (law of conservation of mass). If more atoms are needed, add a large number (coefficient) before the molecule or atom:

$$2Na + Cl_2 \rightarrow 2NaCl$$
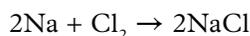
3 Determine whether the reactants and products are solids (s), liquids (l), gases (g) or aqueous solutions (a soluble solution mixed with water) (aq):

$$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$$
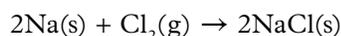
Remember that all chemical equations should be written in a balanced form. To view an example of how to balance equations, see Worked example 8.1A.

Ammonia

Ammonia (NH_3) is an important chemical that is required to make fertilisers, explosives and household cleaning products. Ammonia is produced in a synthesis reaction between nitrogen (from the air) and hydrogen. The modern method used to produce ammonia is called the Haber process, which relies on the reaction:

$$3H_2(g) + N_2(g) \rightarrow 2NH_3(g)$$
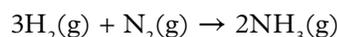
Nitrogen is not a very reactive element so the reactants must be heated under very high pressure to encourage the production of the ammonia.

Decomposition reactions

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 electrodes: an anode and a cathode. A different part of the chemical reaction occurs at each electrode (Figure 2). These reactions are endothermic because they need energy for the reaction to occur.

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:
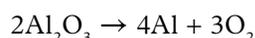
$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

decomposition a reaction that involves the breakdown of a compound into simpler substances

Chemistry

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 ($CaCO_3$):

$$calcium\ carbonate \rightarrow calcium\ oxide + carbon\ dioxide$$
$$CaCO_3 \rightarrow CaO + CO_2$$

A Synthesis reaction

B Decomposition reaction

Oxygen   Hydrogen   Water   Water   Oxygen   Hydrogen
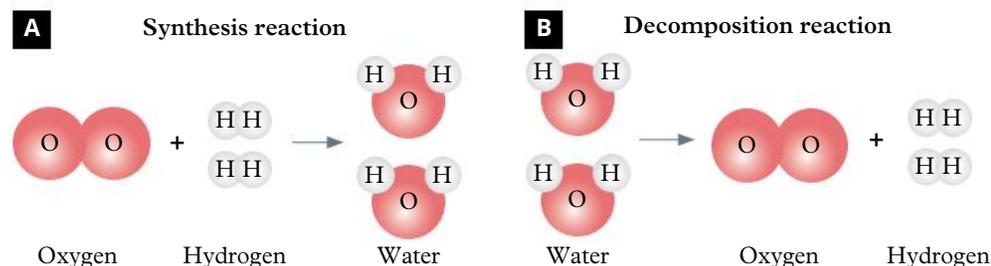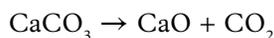
Figure 1 (A) Synthesis reactions combine the reactants to make a more complex product. (B) Decomposition reactions break the chemical bonds in the reactants to form simpler substances.

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. 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 1,000°C.

Today, limestone is roasted in more modern furnaces, often fuelled by gas, where the temperature can be regulated by controlling the flow of gas and air into the furnace.

$$2H_2O \rightarrow 2H_2 + O_2$$
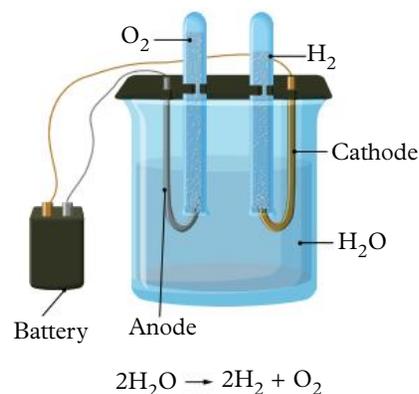
Figure 2 Electrolysis equipment. At the anode, water is being broken down into oxygen gas and hydrogen ions. At the cathode, hydrogen gas is being produced from hydrogen ions and electrons.

Displacement reactions

displacement reaction a reaction resulting in the displacement of an atom or group of atoms

Displacement reactions are reactions that result in an atom or group of atoms of a molecule being displaced or shifted by another atom or group of atoms. For example, Figure 3 shows the reaction of potassium with sodium chloride. In this reaction, the potassium ion displaces the sodium ion of sodium chloride. The products of the reaction are potassium chloride and sodium. Since only one molecule had an ion or group of atoms displaced, reactions similar to this are considered a single displacement reaction. **Single displacement reactions** occur due to a more reactive element replacing a less reactive element on a molecule.

single displacement reaction a reaction in which a more reactive element displaces a less reactive element on a molecule

K   NaCl   Na   KCl

Figure 3 A single displacement reaction involves a molecule's atom or group of atoms being displaced by another atom or group of atoms.

Worked example 8.1A Writing balanced chemical equations

Write the chemical equation for the following reaction:

Hydrogen combines with oxygen to produce water.

Solution

The equation can be written using the following steps.

1 Write out the word equation for the reaction.

$$\text{hydrogen} + \text{oxygen} \rightarrow \text{water}$$
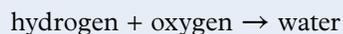
2 Write a simplified chemical equation using the formulas of each molecule involved. Identify the number of atoms in each molecule. For example, water is H_2O (two hydrogen atoms with a single oxygen atom), and hydrogen and oxygen exist as pairs of atoms. This is represented as subscripts (small numbers at the lower half of the symbol).

$$H_2 + O_2 \rightarrow H_2O$$
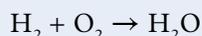
3 Work out the number of each type of atom in the reactants (left-hand side) and in the products (right-hand side), as shown in Table 1.

Table 1 Number 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

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 product 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. We cannot change the subscripts (from H_2O to H_2O_2) as this would change water into hydrogen peroxide. Instead, we need to add a whole water molecule by including numbers (called coefficients) before the formula of the substances. This balances the number of oxygen atoms but also doubles the number of hydrogen atoms (Table 2).

$$H_2 + O_2 \rightarrow 2H_2O$$
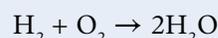
Table 2 The number of oxygen atoms is balanced

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2	2		4	2

The unbalanced hydrogen atoms can be balanced by doubling the number of hydrogen molecules (Table 3).

$$2H_2 + O_2 \rightarrow 2H_2O$$
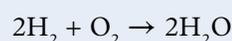
Table 3 Check the equation is balanced

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	4	2		4	2

This allows the number of reactant atoms to equal the number in the product – the equation is said to be balanced.

5 Add the state (solid, liquid, gas or aqueous) of each molecule.

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$
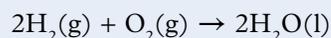
The other type of displacement reaction is called a double displacement reaction. In a double displacement reaction, two reactants will exchange ions and form two new products. You will learn more about double displacement reactions in Lesson 8.4 The solubility rules predict the formation of precipitates (page 361). A summary of each different type of reaction covered in this topic is shown in Table 4.

Chemistry

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8.1

Table 4 A summary of synthesis, decomposition, single displacement and double displacement reactions

Reaction type	Summary	Visual example
Synthesis	Two or more reactants react to form one product.	A + B ⟶ A B
Decomposition	A compound reacts and breaks down into two or more products.	A B ⟶ A + B
Single displacement	A more reactive element replaces another less reactive element on a molecule.	A B + C ⟶ A C + B
Double displacement	Two reactants exchange ions to form two new products.	A B + C D ⟶ A C + B D

Check your learning 8.1

Check your learning 8.1

Retrieve

1 **Define** the term "synthesis reaction".

Comprehend

2 **Describe** the law of conservation of mass.
3 **Explain** why decomposition reactions always produce more than one product.
4 **Explain** why synthesis reactions are sometimes called combination reactions.
5 **Explain** why energy is required in:
   a decomposition reactions
   b synthesis reactions.

Analyse

6 **Contrast** the reaction used to produce ammonia and the reaction used to produce calcium oxide, in terms of the types of chemical reactions.
7 **Compare** single and double displacement reactions.

Apply

8 **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

Skills 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?)

Lesson 8.2
Experiment: Direct synthesis with a "pop"

Aim

To produce water by direct synthesis

Materials

- Magnesium ribbon
- Dilute hydrochloric acid (1 M)
- 2 test tubes and test-tube rack
- Rubber stopper
- Wooden splint
- Matches
- Bench mat
- Timer

Method

1 Identify a current Safety Data Sheet (SDS) for magnesium ribbon and hydrochloric acid. Describe the precautions that you will take with these materials.

2 This reaction produces magnesium chloride and hydrogen gas. Identify a current SDS for these materials and describe the precautions that you will take.

3 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 dilute hydrochloric acid (Figure 1).

Figure 1 Magnesium ribbon is reacted with 10 mL of HCl.

4 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 A second test tube is used to trap the hydrogen gas.

5 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.

6 Place the sealed test tube containing the hydrogen gas into the test-tube rack.

7 Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.

8 Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1 **Describe** the evidence that water was formed in the reaction.
2 **Write** a balanced chemical equation for the reaction, remembering that no atoms are created or destroyed in the process.

3 **Explain** why heat was required to start the reaction.
4 Apart from synthesis, **identify** another way this reaction could be classified. (HINT: Think about the energy involved in this reaction.)

Conclusion

Describe the direct synthesis of water that occurred in this reaction.

Lesson 8.3
Experiment: Decomposing a carbonate

Caution

- Wear safety glasses, a lab coat and gloves when working with chemicals.
- Ensure the open end of the test tube is facing in a safe direction while heating.

Aim

To use heat to decompose copper(II) carbonate to produce copper oxide and carbon dioxide

Materials

- Copper(II) carbonate
- Pyrex (high-strength) test tube
- Test-tube rack
- Test-tube holder
- Bunsen burner
- Matches
- Spatula
- Gloves and safety glasses
- Heatproof mat

Method

1 Identify a current Safety Data Sheet (SDS) for the reactant (copper carbonate) and product (copper oxide and carbon dioxide). Describe the precautions that you will take with these materials.
2 Describe the appearance of copper(II) carbonate.
3 Carefully place one spatula of copper(II) carbonate into the test tube.
4 Hold the test tube at an angle of approximately 45° towards the wall, and gently heat the bottom of the test tube by moving it carefully in and out of a Bunsen burner flame (Figure 1).
5 Carefully observe the changes that occur.

Figure 1 Point the test tube away from you as you move it in and out of the Bunsen burner flame.

Figure 2 Copper carbonate is a green powder before it is heated.

Results

Record your observations in an appropriate format.

Discussion

1   **Describe** the evidence that copper(II) oxide was formed in the reaction.

2   **Describe** the evidence that a gas was produced in the reaction.

3   Write a chemical equation for the reaction, including the state of matter symbols.

4   Apart from decomposition, **identify** another way this reaction could be classified.

5   **Describe** the precautions you took to ensure the safety of other people in the room.

Conclusion

Describe the decomposition reaction that occurred.

Further investigation

Redesign this experiment to provide evidence that carbon dioxide gas is produced in the reaction. Write an experimental method, including labelled diagrams, and list any additional equipment you will need. Show your design to your teacher and, if it is safe, try your method using copper(II) carbonate.

Lesson 8.4
The solubility rules predict the formation of precipitates

Key ideas

→ 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.

→ 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.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

8.4

Precipitation reactions

precipitate
a solid, 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:

$$AB(aq) + CD(aq) \rightarrow AD(s) + CB(aq)$$
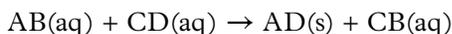
This means that in a water (aqueous) solution, the ions A and B separate, and the ions C and D separate. Ion A is positively charged so it forms a bond with negative ion D, and positive ion C forms a bond with negative ion B. It is important to note that the positive ions (A and C) are always written first in the molecule. This is a **double displacement reaction** as both substrates change (or displace) their partners. It becomes a **precipitation reaction** if either AD or CB is insoluble and forms a solid.

double displacement reaction when two reactants exchange ions to form new products during a chemical reaction

precipitation reaction a reaction used to produce solid products from solutions of ionic substances

The solubility rules

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.

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.

Double displacement

CaCl$_2$ Na$_2$S   CaS   2NaCl

Figure 1 A double displacement reaction involves chemical compounds exchanging ions to form new compounds.

When a solution of lead(II) nitrate is added to potassium iodide – both colourless solutions – a bright yellow precipitate of lead iodide (PbI_2) is formed. The reaction can be written as:

$$\text{lead (II) nitrate} + \text{potassium iodide} \rightarrow \text{lead(II) iodide} + \text{potassium nitrate}$$
$$Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$$
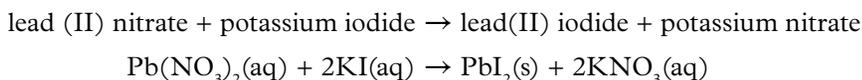
The lead ions and the iodide ions have combined to form an insoluble precipitate of lead(II) iodide. This new compound forms as a solid in the solution. The potassium and nitrate ions are still dissolved in solution. They are not taking part in the reaction. They are called **spectator ions**. Because of this, it is possible to write the equation in a different way that shows only those ions that are forming a precipitate in the reaction:

spectator ion an ion that does not take part in a chemical reaction

$$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$$
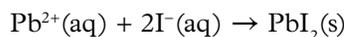
Table 1 Solubility of some ionic compounds in wate`r

Salts	Soluble	Insoluble
Sodium	All	None
Potassium	All	None
Ammonium (NH_4^+)	All	None
Nitrate (NO_3^-)	All	None
Chlorides, bromides and iodides	Most	Lead(II), silver, CuI_2, $CuBr_2$
Sulfate (SO_4^{2-})	Most	Barium, calcium, lead(II), silver
Carbonate (CO_3^{2-}), hydroxide (OH^-) and phosphate (PO_4^{3-})	Group 1 ions, ammonium	Most carbonate and phosphate compounds

Because the lead ions and iodide ions are dissolved in the solution, they are described as aqueous (aq). This reaction is shown in Figure 2.

These ions move independently through the solution.

Two different ionic compounds in solution.

Key:
- ⊕ Lead ions
- ⊕ Potassium ions
- ⊖ Nitrate ions
- ⊖ Iodide ions

⊖ and ⊕ ions are so attracted to each other that they cluster together to form a solid.
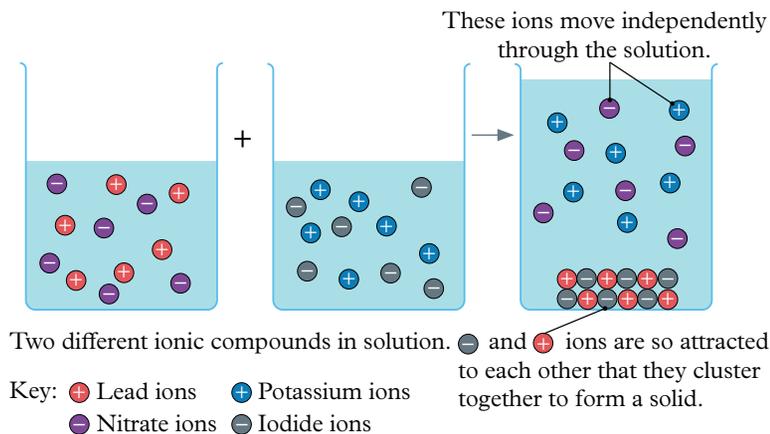
Figure 2 At the particle level, when a solution of lead(II) nitrate $(Pb(NO_3)_2)$ is added to potassium iodide (KI), the ion partners are swapped.

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 (Figure 4). Similarly, Table 1 tells us that $Cu(OH)_2$ (a hydroxide) 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 been precipitated:

$$NaCl(aq) + AgNO_3(aq) \rightarrow NaNO_3(aq) + AgCl(s)$$
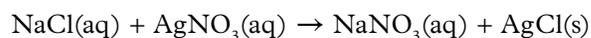
Figure 3 Three test tubes containing (left to right) precipitate of copper hydroxide, precipitate of iron(III) hydroxide and precipitate of iron(II) hydroxide. All were made by adding sodium hydroxide.

Figure 4 Yellow lead(II) iodide forming in a precipitation reaction

Chemistry

8.4

Check your learning 8.4

Retrieve

1 **Identify** the symbol that is used to show the state of an insoluble compound.

Analyse

2 Use the solubility rules to **identify** which of the following substances would be insoluble:

copper(II) chloride, calcium hydroxide, silver nitrate, magnesium bromide, silver bromide, magnesium nitrate, potassium chloride, lead(II) nitrate, potassium nitrate, lead(II) chloride.

Apply

3 **Draw** a diagram to show which particles are present in a beaker containing a sodium chloride solution.

4 **Predict** what precipitate would form if solutions of lead(II) nitrate and sodium sulfate were mixed.

5 Complete the following word equations and then **construct** balanced chemical equations for each reaction.

a Zinc nitrate + potassium hydroxide →

b Calcium nitrate + sodium carbonate →

Lesson 8.5
Experiment: Precipitation reactions

Caution

Wear safety glasses, a lab coat and gloves when working with chemicals.

Aim

To determine which compounds form precipitates and to write equations for the reactions occurring

Materials

- Plastic document sleeve or spotting tile
- 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)

Method

1 Ask your teacher about the precautions that you should take with each of the materials in this experiment.

2 Draw up a large table with group B solutions listed across the first row and group A solutions in the first column, as shown in Table 1.

Table 1 Results from the experiment

	NaCl	NaOH	Na$_2$SO$_4$	Na$_2$CO$_3$
Ca(NO$_3$)$_2$				
Cu(NO$_3$)$_2$				
Mg(NO$_3$)$_2$				
AgNO$_3$				
CuSO$_4$				

3 Make a 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 is your working area for the experiment. You will add drops of the solutions to the corresponding cells on the results table, which is now protected by the plastic sleeve.

4 Place 1 drop of each of the group A solutions in each cell of the results table in the correct rows.

5 Add 1 drop of each of the group B solutions to the drops of group A solutions in the correct columns. Do not touch the tip of the dropper bottles to the group A solutions already resting on the plastic sleeve.

Results

1 Using your other copy of the results table, describe any precipitate that forms.

2 Use Table 1 in Lesson 8.4 The solubility rules predict the formation of precipitates (page 362) 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, **identify** 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$^+$, Cu^{2+}, Ca^{2+} and Mg^{2+}. Of these, **identify** which:

  a did not form any precipitates

  b formed precipitates with only one or two anions.

3 **Compare** the precipitation reactions you observed with the predictions from Table 1 in Lesson 8.4 The solubility rules predict the formation of precipitates (page 362). **Explain** any discrepancies (differences).

4 Write balanced chemical equations for the reactions between:

  a silver nitrate and sodium chloride

  b magnesium nitrate and sodium hydroxide.

5 **Explain** why it was important not to touch the tip of the dropper bottles to the top of the solution already on the plastic sleeve.

6 **Identify** other factors that may affect the outcome of these precipitation reactions. **Explain** how each of these factors would affect the outcome of the experiment.

Conclusion

Describe what you know about predicting the formation of a precipitate in a chemical reaction.

Lesson 8.6
Acids have a low pH; bases have a high pH

Key ideas

→ Acids taste sour and contain at least one hydrogen ion; bases taste bitter and feel soapy to touch.

→ A pH scale is used to describe the strength of an acid (less than 7) or a base (more than 7).

→ Indicators are used to determine the pH of a solution.

→ Acids have a pH less than 7, and bases have a pH greater than 7.

Acids

acid a hydrogen-containing substance that has the ability to donate a proton

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 is 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 touch your skin. All acids contain at least one hydrogen atom and they react with many metals.

Acids can be strong or weak. Strong acids are dangerous because they can corrode through objects. Weak acids are safer, and we can eat and drink some of them. Acids also act as a preservative by preventing the growth of microorganisms.

Bases

base a substance that has the ability to accept a hydrogen proton

alkali a base that dissolves in water

alkaline solution a solution that consists of a base dissolved in water

Bases are the "chemical opposite" of acids. They are bitter to taste 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.

Figure 1 Many cleaning products are alkaline solutions.

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

Acids	
Strong	**Weak**
Hydrochloric acid, HCl	Ethanoic acid, CH_3COOH
Nitric acid, HNO_3	Carbonic acid, H_2CO_3
Sulfuric acid, H_2SO_4	Phosphoric acid, H_3PO_4
Bases	
Strong	**Weak**
Sodium hydroxide, NaOH	Ammonia, NH_3
Potassium hydroxide, KOH	Sodium carbonate, Na_2CO_3
Barium hydroxide, $Ba(OH)_2$	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.

An **indicator** is a substance that changes colour in the presence of an acid or a base. Some of these substances are found in plants.

In the laboratory, scientists use **litmus paper** and **universal indicator**. Litmus paper is the most common 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 more accurate because it indicates the strength of the acidic or basic solution that it is testing.

Strong and weak acids (strength)

There are two types of acids. There are strong acids (such as hydrochloric acid) and weak acids (such as ascorbic acid). Strong acids donate their protons more easily, which makes them more acidic than weak acids.

Concentrated and dilute acids (concentration)

Concentrated acids have a large number of acid molecules per litre of solution. Dilute acids have a smaller number of acid molecules per litre of solution. Strength and concentration of an acid are not the same.

pH scale

The **pH scale** describes the relative acidity or alkalinity of a solution (Figure 3). All acids have a pH less than 7. The pH of an acid depends on the strength and concentration of the acid. A strong, concentrated acid may have a pH of less than 1. A weak, dilute acid may have a pH between 6 and 7. 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.

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

universal indicator a solution that is used to determine the pH (amount of acid or base) of a solution

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

neutral having a pH of 7, so neither an acid nor a base; an example is water

Figure 2 Some vegetables, such as red cabbage, can be used to make pH indicators.

Chemistry

8.6

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.
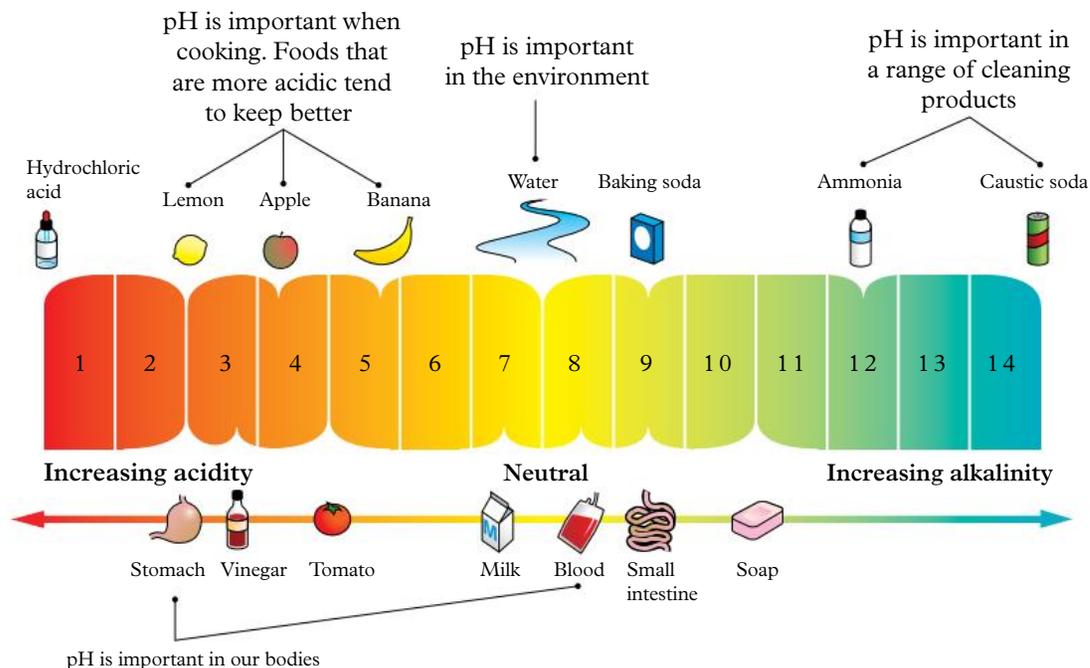
Figure 3 The pH scale

Check your learning 8.6

Check your learning 8.6

Retrieve

1 **Identify** three properties of acids.
2 **Identify** three properties of bases.
3 **Identify** one substance that has a pH of 7.
4 **Define** the term "indicator" as it is used in chemistry.
5 **Recall** the colour of litmus paper in a solution of:
   a   an acid
   b   a base.

Analyse

6 **Contrast** the pH of an acid and a base.
7 **Contrast** a strong acid and a concentrated acid.

Apply

8 **Investigate** other types of indicators and their pH ranges. Based on your research, **decide** what kind of indicator would be suitable for testing each of the following items and **predict** their pH.

   a   Lemon juice
   b   Black coffee
   c   Vinegar
   d   Ammonia

Skills builder: Questioning and predicting

9 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 could be measured at the end of the experiment?)
   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?)

Lesson 8.7
Experiment: Testing with pH paper

Aim

To identify the pH of common substances

Materials

- pH paper and pH colour chart or universal indicator
- White tile
- Variety of laboratory acids and bases
- Vinegar
- Milk
- Toothpaste
- Lemon juice

Method

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.
6 Dilute some of the substances with water and measure the pH of the diluted solutions with more indicator paper.

Results

Construct a table to include the results of your tests.

Discussion

1 **Identify** which substance was the most acidic solution that you tested (lowest pH).
2 **Identify** which substance was the most basic solution that you tested (highest pH).
3 **Describe** what happens to the pH of an acid when the acid is diluted in water.
4 Use your answer to question **3** to **describe** a way of treating a burn caused by acid.

Conclusion

Describe the pH scale using some of the common examples you tested.

Figure 1 pH paper and colour chart

Lesson 8.8
Experiment: What if plants were used to create an indicator?

Context

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.

Aim

To make an indicator from red cabbage and demonstrate how it can be used to identify acids and bases

Materials

- 2 leaves from a fresh red cabbage (shredded)
- 0.1 M sodium hydroxide
- Water
- Stirring rod
- 250 mL beaker
- Strainer
- 0.1 M hydrochloric acid
- Hotplate or Bunsen burner, tripod and gauze mat
- Test tubes and test-tube rack
- Variety of products for testing (e.g. shampoo, vinegar, baking soda)

Method

1 To make the indicator:
   a Cut a few red cabbage leaves into smaller pieces and place in a beaker.
   b Cover the cabbage leaves with water and boil the mixture until the water is purple.
   c Cool the liquid and then strain it, 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?

- Write a hypothesis (If ... then ... because ...) for your inquiry.
- Identify the (independent) variable that you will change from the red cabbage method.
- Describe how you will measure whether the plant, flower or fruit (dependent variable) is an indicator. Predict the colour changes you might expect.
- Name two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials you will need for your experiment.

- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Include your table of observations.

Discussion

1 **Identify** a colour change that can be used to determine the pH of a substance added to red cabbage.
2 **Identify** the colour that the extract from your plant becomes in:
   a   an acid
   b   a base
   c   water.

3 **Describe** any limitations of your experiment (by describing where your extract will become inaccurate, describing the sensitivity of your extract or if it can determine the difference between pH 1 and pH 2, and how expensive your extract would be to produce for chemical laboratories or manufacturing chemicals).

Conclusion

Describe what you know about indicators and how they are produced.

Figure 1 Many plants, including red cabbage, can be used to make an indicator.

Acid reactions depend on strength and concentration

Key ideas

→ A neutralisation reaction occurs when an acid reacts with a base to produce a neutral solution (pH 7).

→ Acids react with metals to produce hydrogen and a metal salt.

→ A concentrated acid has many acid molecules present with very little water.

→ A strong acid readily donates a hydrogen ion to a base.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

8.9

Acids

All acids contain hydrogen. They taste sour, turn litmus paper red and have a pH of less than 7. Strong acids are dangerous because they are corrosive and can cause severe burns. Weak acids are much less reactive, and many are found in food and drinks, such as lemonade.

Although most acids are molecular compounds (with covalent bonding), when they dissolve in water they form ions. This is called an ionising reaction. This reaction is what gives acids their name. All acids donate a hydrogen ion (H^+) to a base. A hydrogen ion is a hydrogen atom that has lost its electron, so it is really just a proton.

Before colonisation, the Palawa women of Tasmania produced acid by heating particular woods to a very high temperature and collecting the smoke through water in a form of distillation. This pyroligneous acid was then used to expose the bright nacre layer on maireener shells. Today, this has been replaced by acetic acid.
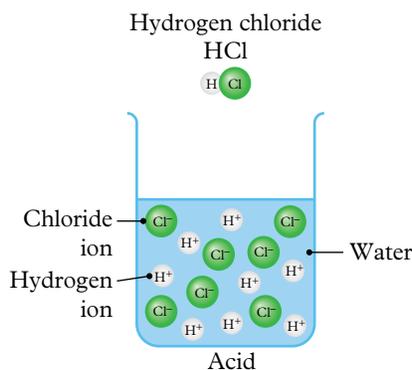
Figure 1 When acids dissolve in water, they form ions.

Figure 2 Zinc metal reacting with acid

Bases

A base is defined as a substance that gains a hydrogen ion. It is this property that causes the litmus paper indicator to turn blue. Although all bases have a pH greater than 7, some are more reactive than others. Some, such as caustic soda ($NaOH$), can burn the skin.

Neutralisation reactions

When an acid and a base are mixed together, hydrogen ions from the acid combine with hydroxide ions (OH^-) commonly found in bases to form water. The remaining ions form a metal salt. Water is considered neutral (pH 7).

neutralisation
a reaction in which an acid and a base combine to produce a metal salt and water

This reaction is called a **neutralisation** reaction:

$$\text{acid} + \text{base(metal hydroxide)} \rightarrow \text{water} + \text{metal salt}$$

For example:

$$HCl + NaOH \rightarrow H_2O + NaCl$$
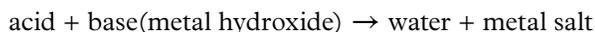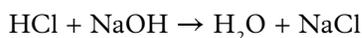
Acid and metal reactions

The reaction between acids and metals is most obvious with acid rain. The carbon dioxide or sulfur dioxide gases in the air cause the formation of acid rain. This contributes to the corrosion of metalwork on buildings:
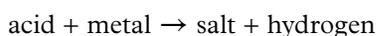
$$\text{acid} + \text{metal} \rightarrow \text{salt} + \text{hydrogen}$$

For example:

$$\text{sulfuric acid} + \text{zinc} \rightarrow \text{zinc sulfate} + \text{hydrogen}$$

$$H_2SO_4(aq) + Zn(s) \rightarrow ZnSO_4(aq) + H_2(g)$$
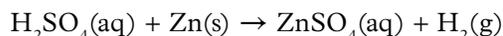
Note: Only the more reactive metals will form a metal salt and hydrogen when reacting with acids. Copper, silver and gold are less reactive metals.

Acids and metal oxides

An acid and a metal oxide react to form a metal salt and water:

$$\text{acid} + \text{metal oxide} \rightarrow \text{metal salt} + \text{water}$$

For example:

$$\text{nitric acid} + \text{magnesium oxide} \rightarrow \text{magnesium nitrate} + \text{water}$$

$$2HNO_3(aq) + MgO(s) \rightarrow Mg(NO_3)_2(aq) + H_2O(l)$$
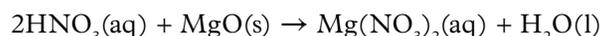
Acids and metal carbonates

An acid and a metal carbonate react to form a metal salt, water and carbon dioxide:

$$\text{acid} + \text{metal carbonate} \rightarrow \text{metal salt} + \text{water} + \text{carbon dioxide}$$

For example, acid rain can affect the calcium carbonate that makes up marble.

$$\text{nitric acid} + \text{calcium carbonate} \rightarrow \text{calcium nitrate} + \text{water} + \text{carbon dioxide}$$

$$2HNO_3(aq) + CaCO_3(s) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$$
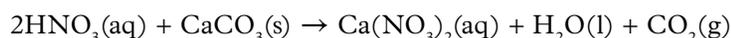
Concentrated or strong?

If you were to make a drink of cordial and not add enough water, you might describe it as "too strong". A chemist would describe it as "too concentrated". The strength and concentration of an acid or a base are two different things, so chemists need to be precise when using these terms.

The **concentration** of an acid or base is a measure of how many molecules of the acid or base are present in each volume of solution. A concentrated acid or base has very little water present – it is mostly molecules of acid or base. The labels of a container of concentrated hydrochloric acid might say, "Conc. HCl" or "10 M HCl". These solutions are very dangerous to handle.

The **strength** of an acid is a measure of how readily it will give away hydrogen ions to a base. Acid strength is compared at the same concentration – usually a very low concentration of 0.1 M, a very **dilute** (watered down) **solution**. Strong acids and strong bases are still dangerous at this concentration.

concentration the number of active molecules in a set volume of solution

strength how easily an acid releases a hydrogen ion in a chemical reaction; also describes the bond between different atoms

dilute containing a small number of solute particles in the volume of solution

solution a mixture of a solute dissolved in a solvent

Figure 3 When working with chemicals, it is important to wear safety gloves.

Chemistry

Check your learning 8.9

Check your learning 8.9

Retrieve

1 **Identify** what must be reacted with an acid to produce:
   a hydrogen gas
   b carbon dioxide.

Comprehend

2 **Identify** the name of the reaction of an acid with a base. **Explain** why it is given this name.
3 **Explain** why metal containers are unsuitable for storing acids.

Analyse

4 **Contrast** the terms "concentrated" and "strong". **Explain** whether a solution can be both concentrated and strong.

Apply

5 **Explain** whether it would require more, less or the same amount of base to neutralise 20 mL of 0.1 M strong acid than it would to neutralise 20 mL of 0.1 M weak acid. **Justify** your response.
6 Write chemical equations for:
   a dilute nitric acid (HNO_3) reacting with magnesium metal
   b dilute ethanoic acid (CH_3COOH) reacting with solid potassium carbonate (K_2CO_3)
   c dilute hydrochloric acid (HCl) reacting with calcium hydroxide ($Ca(OH)_2$) solution.
7 **Create** a diagram of acid and base molecules before and after a neutralisation reaction.

Lesson 8.10
Experiment: Acid titrations

Caution

Wear safety glasses, a lab coat and gloves when working with chemicals.

Aim

To compare the reactions of a strong acid (hydrochloric acid) and a weak acid (ethanoic acid, common name acetic acid)

Materials

- Dropper bottles containing:
  – 0.1 M hydrochloric acid (HCl)
  – 0.1 M ethanoic acid (acetic acid) (CH_3COOH)
  – 0.1 M sodium hydroxide (NaOH)
  – 1 M hydrochloric acid (HCl)
  – 1 M ethanoic acid (acetic acid) (CH_3COOH)
  – universal indicator solution
- pH colour chart
- Small pieces of magnesium ribbon
- 4 test tubes and test-tube rack
- Pipette
- Matches
- Bench mat

Method

Part A

1   Identify a current Safety Data Sheet (SDS) for the reactants and products in this experiment. Describe the precautions that you will take with these materials.

2   Draw up a table to record each test and the results for each acid.

3   Place 2 mL of 0.1 M hydrochloric acid in one test tube and add 2 drops of universal indicator solution. Record the colour of the indicator and the corresponding pH from the colour chart.

4   Repeat Step 2 with 0.1 M ethanoic acid, using a fresh test tube.

5   To the first test tube add 0.1 M sodium hydroxide drop by drop, counting the drops, until the solution is neutral (i.e. pH = 7).

6   Repeat Step 5 with the ethanoic acid.

Part B

1   Add 2 mL of 1 M hydrochloric acid to a fresh test tube.

2   Add a small piece of magnesium ribbon to the test tube and invert a clean test tube over the top.

3   Record your observations.

4   Lightly touch the base of the bottom test tube. Record your observations of the temperature of the mixture.

5   When the reaction has ceased, light a match and hold it just inside the inverted test tube. Do you hear a loud popping sound? This is evidence of hydrogen gas being produced.

6   Repeat steps 1 to 6 with 2 mL of 1 M ethanoic acid.

Results

Record your results in an appropriate table.

Discussion

1   When you tested the pH of the two acids, you used the same concentration (0.1 M).

   a   **Explain** why the reactions were compared at the same concentration.

   b   **Compare** the concentration of an acid with the strength of the acid. **Identify** which (strength or concentration) is related to the pH of the acid.

   c   **Compare** the strength of ethanoic acid with the strength of hydrochloric acid.

2   **Define** the term "neutralisation".

3   Write a balanced equation for each neutralisation reaction.

4   The pop test is the standard test for hydrogen gas. The "pop" sound is a mini-explosion due to the combustion of hydrogen gas in air, which is a very exothermic (heat-producing) reaction. The equation for the reaction is:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) + energy$$
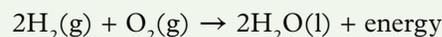
   a   **Identify** whether hydrogen gas was produced in your reactions.

   b   **Compare** the rate of the reactions with the two different acids. Provide an explanation for any differences observed.

Conclusion

Explain what you know about:

• neutralisation reactions

• reactions between metals and acids

• the difference between the strength and concentration of acids.

Lesson 8.11
Metals and non-metals react with oxygen

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Oxidation occurs when an element reacts with oxygen.

→ Combustion reactions between non-metals and oxygen produce large amounts of energy in the form of heat and light.

→ Combustion of hydrocarbons produces water and carbon dioxide.

Oxidation reactions with metals

oxidation a chemical process where a substances loses electrons (gains oxygen or loses hydrogen)

When molecules react with oxygen, it is called **oxidation**.

When metals react with oxygen, a basic metal oxide is formed:

$$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide}$$
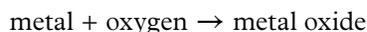
As the metal has formed a compound, this is also classified as a **corrosion reaction**. The metal oxide produced is an ionic compound.

corrosion reaction a chemical reaction that produces a metal oxide due to a metal reacting with oxygen

exothermic a chemical reaction that releases energy as heat (and sometimes light)

In the case of very reactive metals, this oxidation is highly **exothermic** (it releases energy) and rapid (Figure 1). For example:

$$\text{magnesium} + \text{oxygen} \rightarrow \text{magnesium oxide}$$

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$
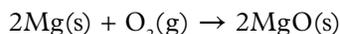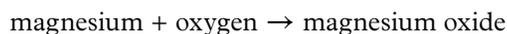
In the case of moderately reactive metals, the oxidation reaction is still exothermic but slow.

Figure 1 The oxidation of magnesium is highly exothermic and produces a very bright flame.

Oxidation reactions with non-metals

Non-metals in group 18 of the periodic table do not react with oxygen, which is also a non-metal. Other non-metals do react with oxygen. Reaction results in the formation of a covalent bond. Consider the formation of water and carbon dioxide:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

$$C(s) + O_2(g) \rightarrow CO_2(g)$$
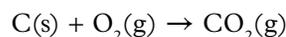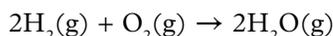
Both of these reactions are highly exothermic. The first reaction can cause explosions. (This is the reaction that causes the "pop" in the pop test for hydrogen.)

Carbon is the principle constituent of coal. Both reactions produce a flame and so are classified as combustion reactions.

Figure 2 In oil refineries, distillation towers are used to isolate the different liquid fractions in crude oil as part of the process of making petroleum.

Combustion reactions require oxygen and a fuel. 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. According to this definition, fuels are the substances we use to produce heat and/or electricity, and to run engines and motors.

Combustion of hydrocarbons

The most common fuels we use for combustion are compounds of carbon and hydrogen (known as **hydrocarbons**) (Figure 3). When pure hydrocarbons burn in unlimited oxygen, carbon dioxide and water are produced:

hydrocarbon
a molecule that contains only carbon and hydrogen atoms

$$\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$
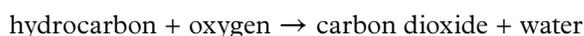
When there is less oxygen available, carbon monoxide forms:

$$\text{hydrocarbon} + \text{limited oxygen} \rightarrow \text{carbon monoxide} + \text{water}$$

CH_4	C_2H_6	C_3H_8
Methane	Ethane	Propane
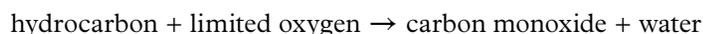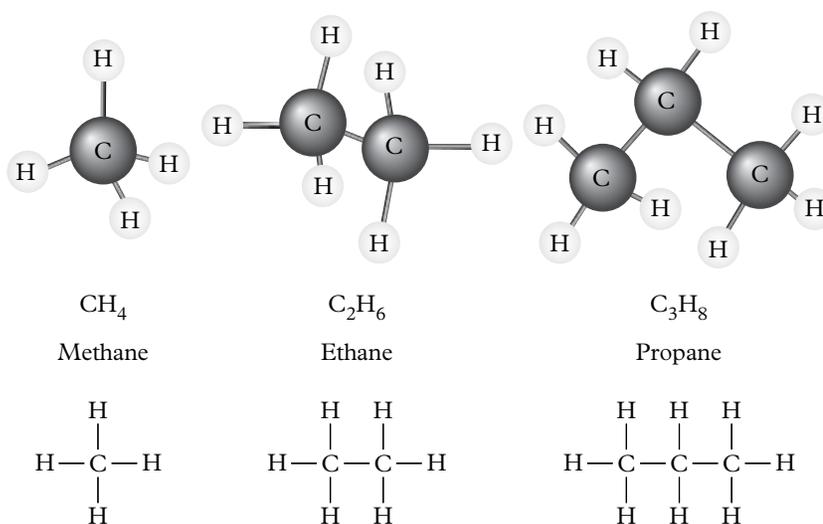
Figure 3 Hydrocarbons are compounds containing only carbon and hydrogen molecules.

Chemistry

Carbon monoxide (CO) is a poisonous gas that binds tightly to haemoglobin in red blood cells, much tighter than oxygen binds. Carbon monoxide poisoning can be fatal because it starves the brain and other body tissues of oxygen.

With even less oxygen, unburnt carbon (soot) is formed, with water:

$$\text{hydrocarbon} + \text{limited oxygen} \rightarrow \text{carbon} + \text{water}$$

Small particles of soot cause breathing problems, especially in people with asthma. It is important that all users of hydrocarbon fuels burn them cleanly. In addition to releasing less pollution, burning these fuels cleanly provides more energy.

Our carbon economy

The chemical fuels that our society relies upon are based on carbon. Our ancestors burned wood, which is mainly the carbon compound cellulose. Later generations burned coal, which comes from buried plant remains that have been naturally dehydrated and compacted underground for tens of thousands of years. Coal is approximately 95 per cent pure carbon and 5 per cent other elements. Currently, we use coal to produce electricity and we use petroleum as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Petrol is mostly octane (C_8H_{18}(l)), diesel is a mixture with the average formula $C_{12}H_{23}$(l), natural gas is mainly CH_4(g), and liquefied petroleum gas (LPG) is propane (C_3H_8(l)).

Petrol, diesel, natural gas and LPG are fossil fuels. The energy in them was captured by photosynthesis millions of years ago. This carbon in fossil fuels has been locked away underground for millions of years. Burning fossil fuels releases that carbon into the atmosphere as carbon dioxide. 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.

You could say that our society runs on carbon. It is a very important fuel. Carbon is the mainstay of our economy, which is why it is sometimes called a carbon economy.
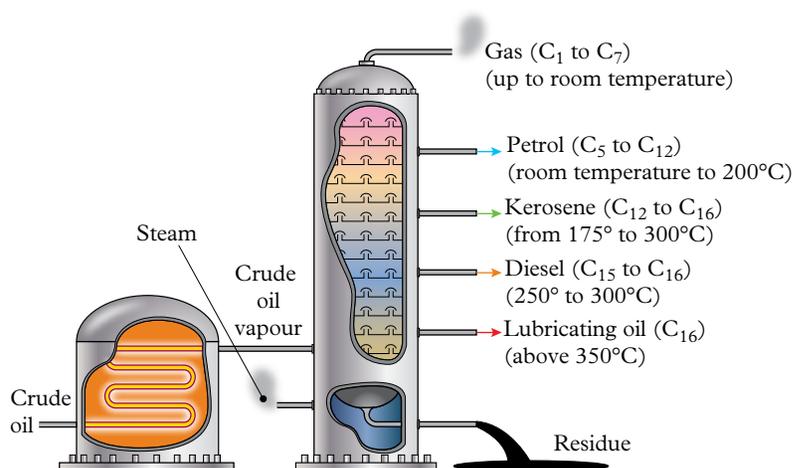
Figure 4 As the crude oil is slowly heated, vapour (gas) forms. As the vapour rises, it cools. When the vapour reaches the height where the temperature is equal to the fraction's boiling point, it condenses into a liquid.

Check your learning 8.11

Check your learning 8.11

Retrieve

1 **Define** the term "oxidation reaction".
2 **Identify** which group of elements does not react with oxygen.
3 **Identify** an example of a substance that might be considered a fuel by a:
   a firefighter
   b chemist.

Comprehend

4 **Explain** why carbon fuels are so important to our society.
5 **Explain** why the amount of oxygen available can affect the products formed in the combustion process.
6 **Explain** why it is important to burn hydrocarbons in a well-ventilated area.

Apply

7 **Construct** a balanced equation for the combustion of each of the following hydrocarbons with unlimited oxygen. Add states to your equations.

   a CH_4
   b C_3H_8
   c C_8H_{18}
   d $C_{12}H_{23}$

8 **Determine** which fuel in question **7** requires the most oxygen to burn cleanly.

Skills builder: Planning investigations

9 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?)

Lesson 8.12
Experiment: Combustion of wire wool

Caution

- Wear a laboratory coat and safety glasses throughout this experiment.
- The wire wool becomes very hot. Do not touch the wool until it has cooled.
- Use a non-flammable bench mat.

Aim

To observe the oxidation of wire wool

Materials

- Wire wool
- 9 V battery
- Crucible

Chemistry

- Heatproof mat
- Balance
- Small spatula

Method

1. Make a small ball out of the wire wool and place it in the crucible.
2. Record the weight of the crucible and wire wool.
3. Place the crucible in the centre of the heatproof mat.
4. Quickly touch both terminals of the 9 V battery to the wool and then pull them away (Figure 1). (If the wool sticks to the battery, use a small spatula to separate them.)
5. Write your observations of the reaction.
6. When the wire wool has stopped reacting, weigh the crucible and contents a second time.
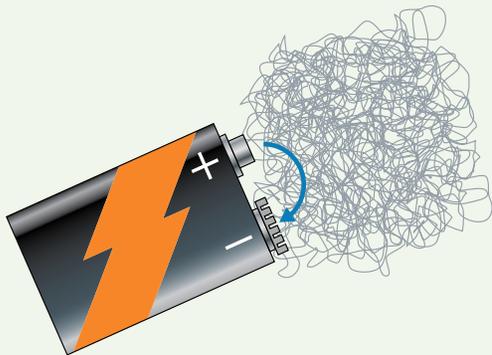
Figure 1 Experimental set-up

Results

Record your masses and observations in an appropriate table.

Discussion

1. **Identify** this reaction as an exothermic or endothermic reaction. Justify your decision (by comparing the reaction you completed with the definition of the term you chose).
2. **Compare** the mass of the reactants with the mass of the products. Explain any discrepancies (differences).
3. Write a word equation for this reaction.
4. Write a balanced chemical equation for this reaction.
5. **Evaluate** the validity of this experiment (by describing a real-world example of this reaction, identifying other factors in the real world that might change this reaction, describing how these factors were controlled in this experiment, and deciding whether the experiment is valid).

Conclusion

Describe what you know about the oxidation of wire wool.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Lesson 8.13
Polymers are long chains of monomers

Key ideas

→ Polymerisation is the process of forming a long-chain polymer from smaller monomer molecules.

Different types of polymers

The plastics we use every day are a result of **polymerisation**. A polymer is a giant molecule that has been produced by joining many, many smaller molecules together – often thousands. **Polymer** means "many parts". The small molecules from which the polymers are made are called **monomers**.

If the polymer has been produced by chemists or chemical engineers, it is called a synthetic polymer. An example of a synthetic polymer is nylon. Before nylon was created, stockings were made from silk, which is a natural fibre produced by silkworms. Apart from being expensive, stockings made from silk easily developed holes and "ladders". Toothbrush bristles were made from another natural fibre – the fine hairs from boars! Nylon could replace both silk and boar bristles because nylon fibre is much tougher and more suitable for these applications.

There are three types of polymer structures: linear polymers, occasionally cross-linked polymers (also known as elastomers) and cross-linked polymers.

Linear polymers and elastomers

Linear polymers are in the form of long chains (Figure 1). Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups attached to the carbon atoms. In some linear polymers, the atoms of another non-metal are found at regular intervals along the chain of carbon atoms. For example, in nylon a nitrogen atom is found about every tenth atom along the chain. There may also be "branches" hanging off the main chain.

Figure 1 The basic structure of a linear polymer. The small circles represent small groups of atoms.

Figure 2 The basic structure of an elastomer

The structure of **elastomers** is like a ladder (Figure 2). Elastomers are in the form of long chains that are connected every now and then with a small chain of atoms.

They are termed "elastomers" because they are elastic; that is, they can be stretched and, when you let them go, they spring back into shape.

Cross-linked polymers

Cross-linked polymers are giant covalent lattices (Figure 3). Generally, they are largely made up of carbon atoms, although the atoms are much more haphazardly arranged than the carbon atoms in other covalent lattices, such as diamonds.

Apart from being classified according to their structure, polymers are classified according to how they respond to heat. This is a very important property.

Figure 3 A cross-linked polymer

Polymer properties

Thermoplastic polymers soften when heated gently. This means they can be formed into new shapes by warming and pressing them, squeezing them through holes or even blowing them into the required shape. "Plastic" means being able to have its shape changed. So, these are the only polymers that really should be described as "plastic". Thermoplastics include plastic film used to wrap foods and thermoplastic paint used to mark roads.

polymerisation the process of joining smaller units (monomers) to form a long-chain molecule (polymer)

polymer a long-chain molecule formed by the joining of many smaller repeating molecules (monomers)

monomer a small molecule from which polymers are made

linear polymer long single chains of polymers

elastomer long chains of polymers occasionally linked together like a ladder

thermoplastic polymer a polymer that softens and forms new shapes when heated

Chemistry

8.13

thermosetting polymers polymers that do not melt or change shape when heated

Thermosetting polymers do not melt or change shape when heated. If heated very strongly, they may char (turn black). These polymers must be produced in a mould because once they are formed they will not change shape again but stay hard and rigid (Figure 4).

Figure 4 The plastics that make up the covers of gaming consoles such as the Nintendo Switch are made of thermosetting polymers.

Formation of polymers

There are many different types of polymerisation reactions, but they all follow the same process. Small molecules are reacted under specific temperature and/or pressure conditions that allow them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polyethene is produced in this way, with molecules of ethene (C_2H_4) reacting together to form long-chain molecules of polyethene. This process can be represented using a diagram, as shown in Figure 5.

This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.

Ethene units

Polymerisation by opening of double bonds

Polyethene chain   Hydrogen   Carbon
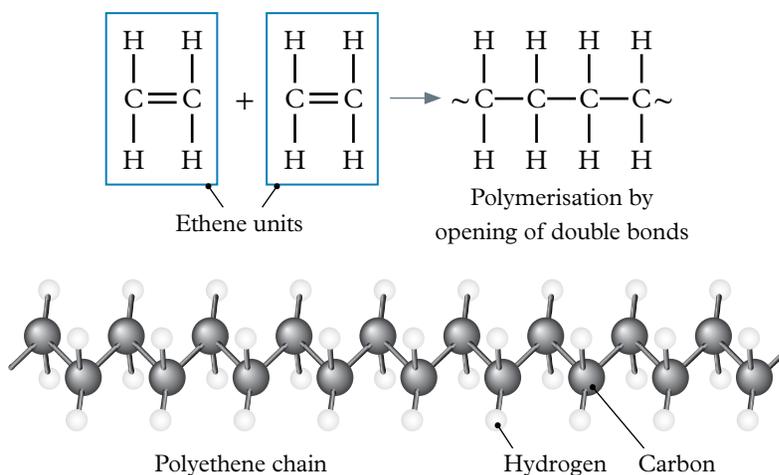
Figure 5 The formation of polyethene from ethene molecules

How we use polymers today

Many different polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Many tents are made from nylon, which produces a lightweight, tear-resistant fabric. Bigger tents are made of cotton polyester. The bases of the tents are made of polyurethane, another useful, waterproof polymer.

Many people have at least one piece of clothing made of polar fleece, which is warm yet lightweight. Polar fleece is a synthetic wool made from PET or PETE (polyethylene terephthalate). PET is a thermoplastic polymer and, for polar fleece, is sourced from recycled plastic bottles that have been processed into a clothing fabric. PET gives polar fleece its soft, warm, durable and fast-drying properties, which make it perfect for camping and other outdoor activities.

Figure 6 Thermoplastic paint is used to mark roads.

Check your learning 8.13

Check your learning 8.13

Retrieve

1 **Identify** the monomer unit of polyethene.

Comprehend

2 Use the structure of elastomers to **explain** their properties.

3 For each of the following applications, **explain** whether it would be better to make the object from a thermosetting polymer or a thermoplastic polymer.

   a Food wrap

   b Light switch

   c Disposable cup for soft drinks

   d Wash bottle for a science laboratory

   e Handles of barbecue tongs

Analyse

4 **Contrast** a linear polymer and a cross-linked polymer.

Apply

5 **Identify** the plastic you would expect to be a thermosetting polymer: a linear polymer or a cross-linked polymer. **Justify** your response.

6 **Discuss** the decision to use thermoplastic paint for painting markings on roads, instead of other types of paint.

Lesson 8.14
Experiment: Polymerisation of casein

Context

Milk contains a protein called casein. When milk is heated and mixed with an acid, such as the ethanoic acid in vinegar, the casein monomers bond with each other to form long polymers. Before the Second World War, casein plastic was used to make buttons, beads and jewellery.

Aim

To form polymers of casein monomers

Materials

- 100 mL full cream milk
- 5 mL vinegar (CH_3COOH)
- Bunsen burner
- Matches
- Tripod
- Thermometer
- Gauze mat
- Heatproof mat
- Spatula
- Filter paper
- Funnel
- 250 mL beaker
- Conical flask
- Heatproof gloves
- Timer

Chemistry

◄

Method

1 Place 100 mL of milk in a beaker and heat it over the Bunsen burner until it is above 49°C and no hotter than 80°C.

2 Remove the beaker of milk from the Bunsen burner and place it on the bench mat.

3 Add 5 mL of vinegar to the milk, stirring gently for 5 seconds. The milk will separate into curds.

4 Place the filter paper in the funnel and put it into the conical flask. Filter the casein polymer curds from the whey.

5 Weigh the casein polymer you obtained as a measure of the effectiveness of the reaction.

6 Mould the casein plastic into a shape of your choice.

Inquiry

Choose one of the following questions to investigate.

- What if low-fat milk was used?
- What if more vinegar was used?
- What if less vinegar was used?

Answer the following questions in relation to your inquiry.

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Record your observations and measurements in a table.

Discussion

1 **Identify** the reactants that were used.

2 **Identify** and **describe** the products that were produced.

3 **Describe** the type of reaction that has occurred.

4 **Identify** the polymer you created as a thermoplastic polymer or a thermosetting polymer. **Justify** your decision (by defining both terms and comparing the properties of the plastic you produced with the definition of the term you chose).

5 **Describe** a use for this polymer and **identify** the properties that make it suitable for that use.

Conclusion

Describe what you know about polymerisation.

Lesson 8.15

Surface area, concentration, temperature and stirring affect reaction rate

Key ideas

→ The speed at which a reaction occurs is called the rate of a reaction.

→ According to collision theory, reactants must collide in the correct orientation for a reaction to occur.

→ The rate of a reaction can be increased by increasing the surface area, concentration or temperature, or by stirring the reactants.

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Why reaction rates are important

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 m race. A runner can run fast or slowly; the only difference is how quickly the runner finishes the 100 m. 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.

reaction rate
how fast or slowly a reaction proceeds

Collision theory

For a chemical reaction to occur, the atoms, ions or molecules must collide at the right angle and with enough energy for that reaction to occur. This model is known as the 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 move around quickly. Each hydrogen iodide molecule must collide with another hydrogen iodide molecule in order to react.

Some collisions do not result in a reaction. If a collision is unsuccessful, the hydrogen iodide molecules bounce apart with no reaction, as shown in Figure 1.
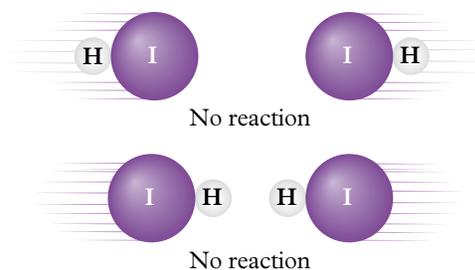
Figure 1 If collisions between HI molecules are unsuccessful, the HI molecules do not react with each other.

Chemistry

8.15

Only some collisions result in a reaction. The molecules must collide in the correct orientation for a reaction to occur. If the collision is successful, there will be a reaction (Figure 2, Figure 3 and Figure 4). A weak chemical bond forms between the iodide ions and the hydrogen ions. This intermediate substance is unstable and only exists for a short time before it breaks apart.

H_2I_2 is an intermediate complex.

Figure 2 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.

Figure 3 During the intermediate stage, H_2I_2 is formed. This molecule is unstable and short-lived.

Figure 4 The final products are formed and move apart (partly due to electrostatic repulsion).

Increasing the rate of collisions

To increase the rate of a reaction, you need to increase the number of successful 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 must 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 larger bits of material. The surface area is not the size of the pieces but the total area exposed to possible collisions (Figure 5).
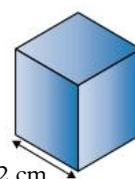
2 cm
Total surface area
= 2 cm × 2 cm ×
    6 sides
= 24 cm^2
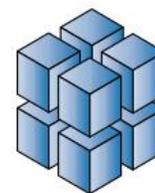
Total surface area
= 1 cm × 1 cm ×
    6 sides × 8 cubes
= 48 cm^2

Figure 5 The total surface area of many small particles is larger than that of 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
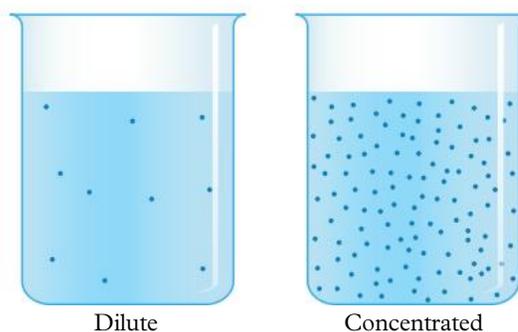
Figure 6 A concentrated solution contains more dissolved particles than a dilute solution.

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 vibrate faster than the particles in a cold substance (Figure 7).

Particles at a high temperature will collide more frequently and with more speed than particles at a low temperature. More frequent collisions between particles, plus an increased likelihood of each collision being successful, means that reactions happen faster at higher temperatures.

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, so their electrons can move to a different atom. Reactions involving catalyst are an exception.

Cold substance (particles have low kinetic energy)

kinetic energy the energy an object or particle has due to its motion
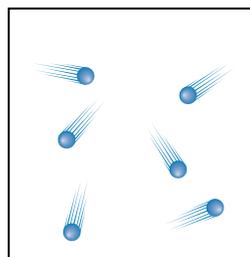
Hot substance (particles have high kinetic energy)

Figure 7 At higher temperatures, the average energy of the particles is increased and the particles vibrate faster.

Stir and mix

As a chemical reaction proceeds, the particles of the reactants get used up – when there are fewer particles of 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 particles of reactants. A basic way of doing this is by stirring or mixing the reactants.

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.

Mg metal

Initially, hydrogen ions react with magnesium.

Later, hydrogen bubbles cover the magnesium, stopping the ions from reacting.

Figure 8 Sometimes the presence of the product can slow down a chemical reaction.

Chemistry

Detoxifying cycad seeds

Aboriginal and Torres Strait Islander Peoples belonging to the Djabugay language group around northern Queensland detoxify cycad seeds or kernels for eating by using processes that speed up chemical reactions.

The cycad seeds are a rich source of energy, but they also contain a toxin called cycasin. The toxin can cause vomiting and nausea as well as long-term damage to the nervous system and liver. It is also a carcinogen, so removing this toxin is important before using cycad seeds as food.

Figure 9 Cycad seeds must be detoxified before they can be safely consumed.

The cycasin toxin will break down very slowly if it is soaked in running water for many weeks. To increase the rate of this breakdown, the Djabugay Peoples in northern Queensland developed a technique that involves grinding the cycad seeds into smaller pieces and heating the water slightly. Regular mixing allows the reactants (the plant material and water) to come into contact with each other and increases the rate of the detoxifying process.

If the Djabugay Peoples had not developed this knowledge of the detoxification process, food resources such as cycad seeds would have made many people sick and a potential food resource would have been overlooked.

Check your learning 8.15

Check your learning 8.15

Comprehend

1 **Describe** how products are formed when molecules of reactants collide.

2 **Explain** why increasing the surface area increases the rate of reaction.

3 **Explain** why diluting a solution decreases the rate of reaction.

4 **Explain** why a reaction occurs faster when the reactants are stirred together.

5 **Describe** how collision theory explains the dramatic increase in the rate of a reaction as reactants are heated.

Analyse

6 **Consider** the text under the subheading "Detoxifying cycad seeds".

   a **Identify** the techniques used that would increase the rate of the detoxification process.

   b Use what you have learnt in this chapter to **explain** how these techniques increase the reaction rate.

Apply

7 A scientist investigated the rate of a reaction between a magnesium ribbon and 1 mol/L of hydrochloric acid. They added both substances to a conical flask, which was connected to an inverted measuring cylinder in a trough of water (Figure 10). Then they measured the amount of hydrogen gas that was produced every 30 seconds. Their results are shown in Table 1.

   a **Construct** a graph of the scientist's results.

   b **Analyse** the data and **describe** any trends in terms of the independent and dependent variables in this experiment.

   c **Identify** the time point on your graph at which the reaction appears complete. **Justify** your decision.

   d **Propose** how the scientist might collect more precise data for their results table.

   e The scientist only conducted their test once to collect the data in Table 1. **Propose** one way they could make their results more reliable.

f Describe two ways that the scientist could increase the speed of the reaction.
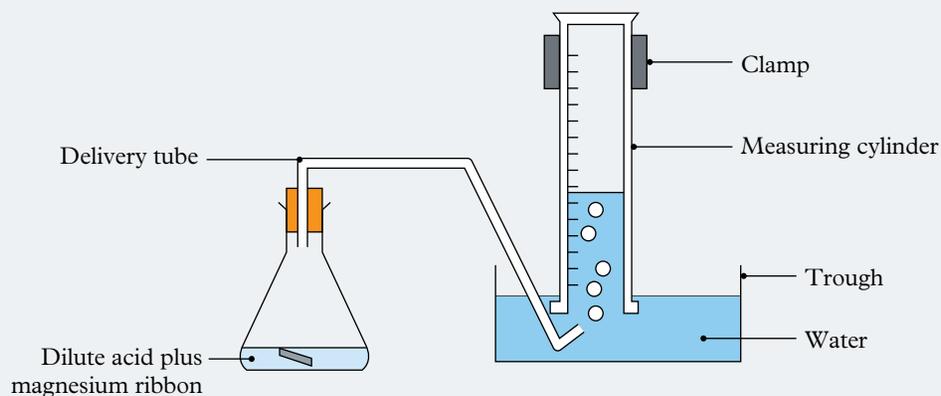
Figure 10 The scientist's experimental set-up

Table 1 Results from the scientist's experiment

Time (s)	Volume of gas (mL)
0	0
30	51
60	70
90	82
120	91
150	91
180	91
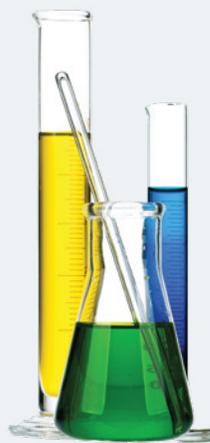
Figure 11 Stirring the reactants increases the rate of a chemical reaction.

Skills builder: Conducting investigations

8 Your teacher wants you to investigate the effect of reactant 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 not using the tare have on your results? Would the results be accurate?)

b **Assess** why using a conical flask is more appropriate than a beaker. (THINK: What would the difference in reaction be?)

Chemistry

Lesson 8.16
Experiment: Factors affecting reaction rate

- Wear protective gloves, a lab coat and safety glasses throughout this experiment.
- Avoid contact with the acid solutions because they are corrosive. If acid comes into contact with your skin, wash it with water immediately.

Aim

To investigate the rates of a reaction between hydrochloric acid and calcium carbonate

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 Identify a current Safety Data Sheet (SDS) for the reactants and products. Describe the precautions that you will take with these materials.
2 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.
3 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.
4 Record in your results table 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?
- What if the temperature of the acid was increased?

Answer the following questions in relation to your inquiry.

- Write a hypothesis (If … then … because …) for your inquiry.
- Identify the (independent) variable that you will change from the first method.
- Identify the (dependent) variable that you will measure and/or observe.
- Identify two variables that you will need to control to ensure a valid test. Describe how you will control these variables.
- Identify the materials that you will need for your experiment.
- Write down the method you will use to complete your investigation in your logbook.
- Identify the potential hazards in the experiment (e.g. heating the acid).
- Describe how you will remove or limit these risks.
- Draw a table to record your results.
- Show your teacher your planning for approval before starting your experiment.

Results

Copy and complete Table 1 and plot a graph of the mass loss by minutes.

Table 1 Results from the experiment

Experiment	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
Control (from the Method)									

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 **Compare** your hypothesis from your inquiry with the results you obtained.

4 **Identify** a random error and a systematic error in your experiment. **Describe** how you could prevent or minimise these errors to make this experiment more reliable.

5 **Describe** why the balance needed to read zero before you weighed the marble chips.

6 **Describe** how you could check the accuracy of the balance.

7 **Evaluate** the validity of this experiment (by describing a real-world example of this reaction, identifying other factors in the real world that might change this reaction, describing how these factors were controlled in this experiment, and deciding whether the experiment is valid).

8 **Design** an experiment that would test how temperature would impact the rate of displacement between zinc and dilute sulfuric acid. **Explain** how you would validate the results of this experiment.

Conclusion

Write a conclusion for your experiment that includes a general statement that summarises the evidence that supports the hypothesis from your inquiry.

Lesson 8.17

Catalysts increase the rate of a reaction

Learning intentions and success criteria

Check the next lesson for a linked practical activity or experiment.

Key ideas

→ Catalysts increase the rate of a chemical reaction without being permanently changed.

Introduction

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.

8.17

catalyst a substance that increases the rate of a chemical reaction without undergoing any permanent chemical change

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 car exhaust pipes. A honeycomb-like grid of metals provides a large surface area to increase the rate of reaction (Figure 2). As the exhaust gases pass through the converter, they react on the surface of the metals to form harmless gases. The catalytic metals absorb (hold on to) pollutant gases such as $CO(g)$ and $NO(g)$ and help to convert them into gases that are safer to release into the atmosphere, such as $CO_2(g)$ and $N_2(g)$. Catalysts are usually metals such as platinum, palladium and rhodium.

The overall reaction that occurs in the catalytic converter in a car's exhaust pipe is:

$$2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$$
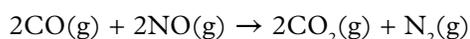
While catalysts can be reused many times, they can sometimes become contaminated after excessive use. Impurities in petrol can poison a car catalyst and prevent the catalyst from functioning properly.

Figure 1 Catalytic converters are used to reduce harmful pollution from exhaust gases.
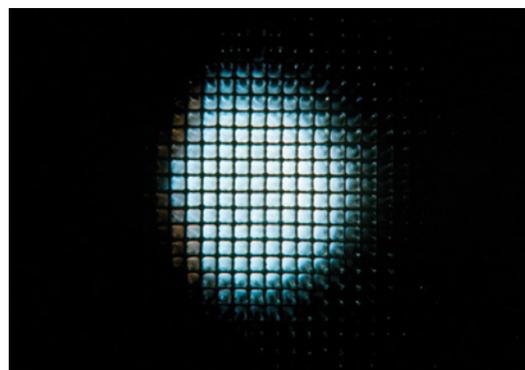
Figure 2 Catalysts are often in the form of a grid to maximise the surface area.

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, $O_3(g)$, by chlorofluorocarbons (CFCs).

The ozone layer is a region in the stratosphere between 10km and 50km high, with the greatest concentration at an altitude of 30km. Ozone in this region absorbs ultraviolet (UV) light, which would otherwise reach the Earth's surface and cause increased levels of skin cancers and eye problems.

The main destroyers of ozone are CFCs. CFCs are non-flammable, non-toxic, cheap to manufacture, easy to store and chemically stable. They were used in aerosol cans (Figure 3), fire extinguishers and asthma

Figure 3 Chlorofluorocarbons (CFCs) were used to pressurise the gas in aerosol cans before it was proved that CFCs damage the ozone layer.

inhalers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers, and as a refrigerant gas in refrigerators and air conditioners. Today, manufacturers use alternative gases where possible to avoid damaging the ozone layer.

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.

In this way, one chlorine atom from the original CFC can destroy up to 10,000 ozone molecules.

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. Figure 4 shows ozone levels over the southern hemisphere before and after the phasing out of CFCs.

1979

1999

2019

Ozone (Dobson units)

Ozone (Dobson units)

Ozone (Dobson units)

100   200 300   400   500

100   200 300   400   500

100   200 300   400   500
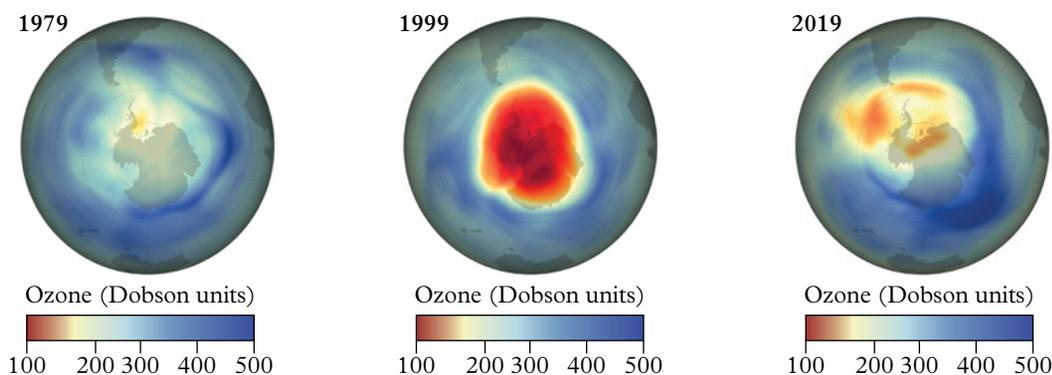
Figure 4 The darker colours show the growth of the "hole" in the ozone layer between 1979 and 1999, and its decrease after CFCs were banned.

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 called **substrates** and so will only catalyse certain reactions. The region in which reactants can bind to an enzyme is called the **active site**. This is shown in Figure 5.

Reactants

Active site

Products

Enzyme

Enzyme-substrate complex
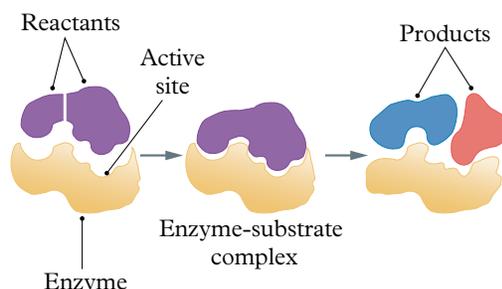
Figure 5 Enzymes only work with specific reactants that can bind to their active site.

enzyme a protein-based catalyst

substrate a molecule that reacts with an enzyme

active site the region of an enzyme that substrates can bind to

Chemistry

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8.17

Check your learning 8.17

Retrieve

1 **Define** the term "catalyst".

Comprehend

2 **Describe** two ways in which catalysts can work.

3 **Describe** a catalytic converter. **Explain** why they are used.

4 **Explain** why it is important that the amount of ozone in the atmosphere remains stable.

5 **Describe** what has caused the change in the amount of ozone in the atmosphere over time.

Apply

6 **Determine** which part of the CFC molecule destroys ozone. **Describe** how this atom becomes detached.

Skills builder: Planning investigations

7 **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?)

Lesson 8.18
Experiment: Using a catalyst

Context

The reaction used in this experiment is the decomposition of hydrogen peroxide:

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

Aim
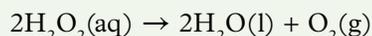
To investigate the effect of adding a catalyst to a reaction

Materials

- 3 per cent hydrogen peroxide (H_2O_2) solution (10 mL)
- Manganese dioxide (MnO_2) powder
- Test tubes and test-tube rack
- Spatula (small)
- 10 mL measuring cylinder

Method

1 Identify a current Safety Data Sheet (SDS) for the reactant and product. Describe the precautions that you will take with these materials.

2 Using a measuring cylinder, measure 5 mL of hydrogen peroxide solution into two separate test tubes.

3 Allow one of the tubes to stand; add a small amount of manganese dioxide to the other test tube using a spatula.

4 Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1 **Identify** whether your observations were quantitative or qualitative.
2 **Evaluate** the statement "There was no reaction in the test tube that had no manganese dioxide" (by defining the phrase "rate of a reaction" and comparing the decomposing rate of hydrogen peroxide with or without manganese dioxide).
3 **Describe** how manganese dioxide changed the rate of a reaction.
4 **Define** the term "catalyst".
5 **Identify** whether manganese dioxide is a catalyst. **Justify** your answer.
6 **Describe** two ways in which the rate of hydrogen peroxide decomposition could be increased further.
7 **Outline** the number of times you would need to repeat this experiment to identify that the results were valid.

Conclusion

Describe how a catalyst affects the rate of a reaction.
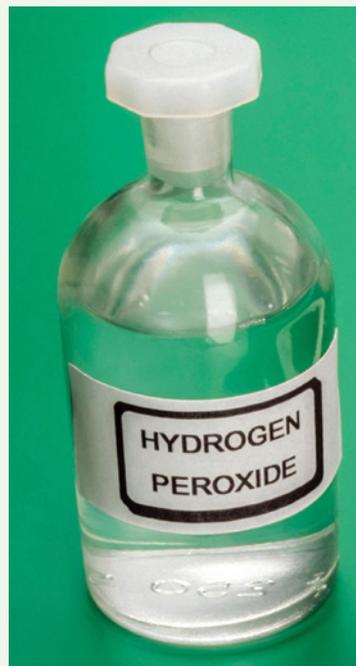
Figure 1 Hydrogen peroxide

Lesson 8.19

Science as a human endeavour: Reactions are used to produce a range of useful products

Key ideas

→ Polymers are used in water purification processes.

→ Bioplastics are polymers that are made from renewable living things.

→ Superalloys are complex structures containing multiple metals.

Learning intentions and success criteria

Introduction

Scientific research is an important endeavour as it moulds how we live our lives. It shapes what we eat, how we live, how we use transport and the technology that we use. In our world of food shortages, climate change, pollution, conflict and poor water quality, scientific research and the use of reactions to create innovative products has become even more important. Innovation in chemistry can be seen in reactions used to produce plaster, charcoal, polymers and superalloys.

Plaster of Paris

Plaster of Paris is a quick-setting white powder that has been used to make plaster casts for broken bones for decades. It was also used by Aboriginal and Torres Strait Islander Peoples to decorate bodies for ceremonies or, in the Lake Eyre region, to make balls for rolling or spinning games.

Plaster is made from a mineral compound called gypsum ($CaSO_4 \cdot 2H_2O$). The calcium sulfate molecule in gypsum is closely linked with two water molecules. Most of this water needs to be removed by calcination – heating to produce the plaster (which has two $CaSO_4$ molecules for every water molecule). Aboriginal and Torres Strait Islander Peoples knew that this process needed to be carefully controlled by gentle heating and mixing to prevent all the water from being removed.

Innovations in polymer chemistry

Polymer chemists are scientists who look at the synthesis, structure and properties of polymers. Polymers are large molecules that are made from the joining together of many smaller molecules (monomers). Synthetic polymers are used to manufacture 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.

Water quality

In Australia, most of our drinkable water comes from water catchments like the Wivenhoe Dam. However, due to drought and climate change, water levels have declined over the years. To help supplement the water requirements in South East Queensland, the Gold Coast Desalination Plant was built. Using scientific technologies such as reverse osmosis filtration, an additional 125 ML of water per day can be added to the water supply of South East Queensland.

Figure 1 Times of drought decrease the level of available water in the Wivenhoe Dam.

Seawater is drawn 1 km from the Queensland coast to the Gold Coast plant and filtered of particles. Reverse osmosis removes remaining impurities, including salt. Very high-pressure pumps then push pure water molecules through thousands of semi-permeable membranes, leaving the salt (and other impurities) behind on the other side of the membranes. The water passes through this system twice.

The membranes used in this process are made from polymers called polyamides. Polyamides are formed by a polymerisation reaction that links together many small organic molecules called amides. Once formed, the polyamides are then rolled into thin membranes able to filter water.

Figure 2 Reverse osmosis filtration for desalination plants

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 woodchips. Polylactic acid (PLA) is a common polymer bioplastic made from corn. Its properties are similar to fossil fuel–derived plastics such as polyethylene (PE).

Bioplastics are said to use less energy to manufacture compared to fossil fuel–derived plastics, and the manufacture of bioplastics also produces significantly less greenhouse gas. However, it is a major misconception that all bioplastics can be broken down naturally (biodegradable). A lot of research is currently being done in this area to minimise the environmental impact of bioplastics after their use.

Figure 3 Disposable cutlery made from a bioplastic that uses avocado seeds

bioplastic plastic produced from renewable biomass sources

Superalloys

superalloy high-strength complex metal alloy resistant to extreme temperature and stress

Superalloys are created by reactions that combine specific metals (often iron, nickel and cobalt) and metal alloys to produce an alloy with a highly complex structure. The complex structure and combined properties of metals provide superalloys with extremely high tolerance to heat, stress and corrosion. Being able to endure extreme temperatures (greater than 1,000°C) over long-term application has made the use of superalloys common in the aerospace engine industry. However, superalloys are now also being used across power industries, construction, to improve defence armour and even to create prosthetic limbs.

Some disadvantages of superalloy use include that most of these materials are costly and many also have poor **machinability**. This has limited the capacity for superalloys to be used in manufacturing. However, research today – including that by the CSIRO – is currently investigating how to improve the efficiency of superalloys and minimise costs involved with producing these materials.

machinability ability of a metal to be cut and shaped

Figure 4 The metal cobalt is commonly used to produce superalloys.

Test your skills and capabilities

Personal and environmental safety

One achievement of the Commonwealth Scientific and Industrial Organisation (CSIRO) was the development of a polymer called Elast-Eon™.

Research the polymer Elast-Eon™ and create an infographic that presents information on the following:

- What is the polymer?
- Who are the scientists/scientist credited to its discovery?
- What are the different applications and industries it is used in?
- When did the polymer become commercially available?
- What would be the impact if this polymer had not been discovered?
- What awards/accolades have been awarded to this research?

Lesson 8.20
Review: Chemical reactions

Summary

Lesson 8.1 Synthesis, decomposition and displacement reactions can be represented by equations

- Synthesis reactions combine multiple reactants to form a new compound.
- Decomposition reactions break down a reactant into multiple products.
- Displacement reactions involve an atom or group of atoms of a molecule being displaced by another atom or group of atoms.

Lesson 8.4 The solubility rules predict the formation of precipitates

- 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.
- 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.

Lesson 8.6 Acids have a low pH; bases have a high pH

- Acids taste sour and contain at least one hydrogen ion; bases taste bitter and feel soapy to touch.
- A pH scale is used to describe the strength of an acid (less than 7) or a base (more than 7).
- Indicators are used to determine the pH of a solution.
- Acids have a pH less than 7, and bases have a pH greater than 7.

Lesson 8.9 Acid reactions depend on strength and concentration

- A neutralisation reaction occurs when an acid reacts with a base to produce a neutral solution (pH 7).
- Acids react with metals to produce hydrogen and a metal salt.

- A concentrated acid has many acid molecules present with very little water.
- A strong acid readily donates a hydrogen ion to a base.

Lesson 8.11 Metals and non-metals react with oxygen

- Oxidation occurs when an element reacts with oxygen.
- Combustion reactions between non-metals and oxygen produce large amounts of energy in the form of heat and light.
- Combustion of hydrocarbons produces water and carbon dioxide.

Lesson 8.13 Polymers are long chains of monomers

- Polymerisation is the process of forming a long-chain polymer from smaller monomer molecules.

Lesson 8.15 Surface area, concentration, temperature and stirring affect reaction rate

- The speed at which a reaction occurs is called the rate of a reaction.
- According to collision theory, reactants must collide in the correct orientation for a reaction to occur.
- The rate of a reaction can be increased by increasing the surface area, concentration or temperature, or by stirring the reactants.

Lesson 8.17 Catalysts increase the rate of a reaction

- Catalysts increase the rate of a chemical reaction without being permanently changed.

Lesson 8.19 Science as a human endeavour: Reactions are used to produce a range of useful products

- Polymers are used in water purification processes.
- Bioplastics are polymers that are made from renewable living things.
- Superalloys are complex structures containing multiple metals.

Review questions 8.20

Review questions: Module 8

Retrieve

1 **Identify** the correct way to describe a decomposition reaction.
   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

2 **Identify** which of the following describes a catalyst.
   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

3 **Identify** the types of products that are formed when acids react with metals, carbonates or bases.

4 **Recall** four factors that will affect the rate of a chemical reaction.

Comprehend

5 **Describe** the differences between decomposition reactions and synthesis reactions.

6 A student mixed the following solutions together in a beaker: ammonium nitrate, sodium chloride, lead(II) nitrate, sodium sulfate. **Describe** what would be seen in the beaker. **Explain** your answer using a chemical equation.

7 **Describe** two different types of reactions that produce carbon dioxide.

8 **Describe** the link between CFCs and the ozone layer.

9 In terms of particles, **explain** what is required for a chemical reaction to take place.

10 **Describe** two ways that the rate of chemical reactions can be measured.

11 **Describe** one situation where it could be dangerous if a reaction occurs too quickly.

12 Polypropylene is a plastic that can be easily melted and formed into a range of products. **Describe** the likely structure of polypropylene and **explain** how its structure allows the plastic to be moulded into a range of shapes.

13 **Describe** two examples of catalysts used in the production of chemical products.

14 **Explain** how the particle model of matter helps us understand the rate of reactions.

15 **Describe** two applications of polymers in society.

Analyse

16 **Identify** the correct product for this synthesis reaction: $2Mg + O_2 \rightarrow$
   A $2MgO$
   B MgO_2
   C MgO
   D $2Mg_2O_4$

17 **Classify** each of the following reactions as either synthesis, decomposition, single displacement or double displacement. Add their states of matter.
   a $CaCO_3 \rightarrow CaO + CaO_2$
   b $Mg + Cu(NO_3)_2 \rightarrow Mg(NO_3)_2 + Cu$
   c $2CO + O_2 \rightarrow 2CO_2$
   d $HCl + NaOH \rightarrow NaCl + H_2O$
   e $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
   f $NH_3 + HCl \rightarrow NH_4Cl$

18 **Compare** thermosetting and thermoplastic polymers.

Apply

19 In many industrial environments, the presence of a fine dust is regarded as an explosion hazard. **Suggest** why coal dust is more likely to explode than chunks of coal.

Figure 1 Coal dust is a greater explosion risk than chunks of coal.

20 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 summer gave a low yield of that same product in winter, despite the reagents and concentrations being identical. **Propose** a possible explanation for the different yields.

21 Sodium metal was reacted with purified bauxite (Al_2O_3) to produce aluminium and sodium oxide (Na_2O).

  a **Identify** the type of reaction that occurred.

  b **Construct** a chemical equation for the process, ensuring that the law of conservation of mass is applied to the equation.

22 During an experiment, solid calcium carbonate ($CaCO_3$) was added to an aqueous solution of hydrochloric acid (HCl). The two substances reacted to produce calcium chloride ($CaCl_2$), water (H_2O) and carbon dioxide gas (CO_2).

The reaction was performed at two temperatures: 20°C and 30°C. The results of each trial were graphed together as shown in Figure 2.

  a Use the information provided to **construct** a title for the graph.

  b **Identify** which line (a or b) represents the trial at 20°C and which represents the trial at 30°C.

  c Use the information provided in the graph to **describe** the relationship between temperature and the rate of reaction.

  d Use the collision model to **provide** an explanation for the relationship identified in part **c**.

  e If a third trial was conducted at 35°C, **predict** how it might be graphed with the other trials (by sketching another line on the graph).

  f Write a balanced equation to **summarise** the chemical reaction taking place. (HINT: The information you need to start is in the question.)
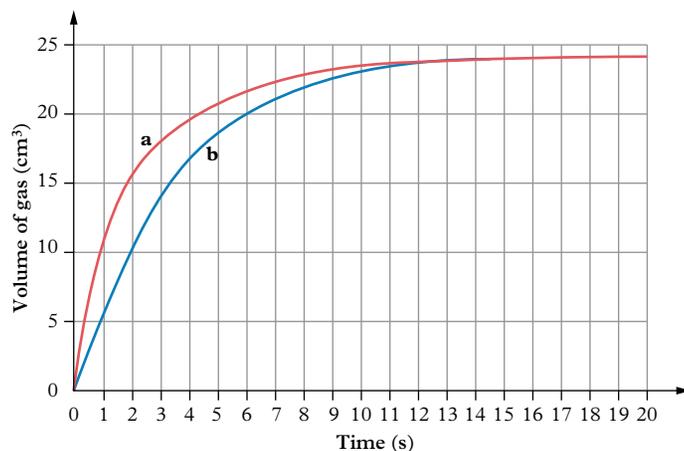
Figure 2 The results of each trial

23 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 as follows. 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

$2NO(g) + O_2(g) \rightarrow 2NO + 2(g)$
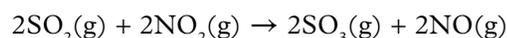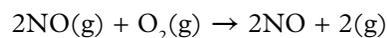
Propose two reasons why the nitrogen dioxide is regarded as a catalyst.

Social and ethical thinking

24 In the 1920s, the compound tetraethyl lead was developed to prevent "knocking" in car engines. ("Knocking" is where the spark plugs fire too early, resulting in loss of power and possible engine damage.) Adding tetraethyl lead saved the cost of additional refining of petrol, which reduced costs for consumers and motorists. However, some people were concerned about the use of a lead compound that was being released from the exhaust of cars. Imagine you had been part of the debate in the 1920s and **propose** two arguments you would make against the use of tetraethyl lead.

Critical and creative thinking

25 Some catalysts work by providing a surface on which reactions can occur. These surface catalysts work by allowing the reacting particles to interact together on the surface of the catalyst.

  a **Explain** why binding particles onto a surface of another chemical would encourage a chemical change to occur.

  b **Explain** why a substance that actually bonded chemically to the reacting particles would not make a good catalyst.

  c **Identify** an example of the use of a surface catalyst, describing in detail the chemical reaction.

  d Use your knowledge of collision theory to **discuss** why most catalysts are used in the form of a powder or fine mesh.

26 Pyrolysis is a process used by Aboriginal and Torres Strait Islander Peoples to produce the charcoal used in pigments and adhesives. The charcoal consists of mainly carbon with small amounts of hydrogen, oxygen, and minerals and is produced by gentle heating of wood with a limited oxygen supply to remove the water. As the temperature increases, the wood loses other molecules and becomes charcoal. This process requires careful control of temperature.

  a **Create** a diagram to represent the process of producing charcoal.

  b **Research** the process of current-day pyrolysis (production of charcoal) for use in the purification of metals from their ore.

  c **Compare** the modern process with that of Aboriginal and Torres Strait Islander Peoples.

Research

27 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

Rare metals

A range of rare metals is used in microelectronic devices. Many of these metals, such as tantalum and niobium, are sourced from Australia.

- Investigate where these metals are found in Australia.
- Identify in what form they occur naturally.
- Identify what chemical processes are used to extract the pure metals.

Figure 3 Tantalum wire scrap

Heat and cold packs

Chemical reactions involve the production of a new substance from reactants. This process of breaking and making new bonds involves the use and release of energy. This means a chemical reaction can be detected by a change in temperature.

- Identify a heat pack or cold pack that is used for sporting injuries.
- Describe how the pack is activated and used.
- Identify the reactants that are in the pack.
- Describe how the manufacturers prevent the reaction from occurring until it is required by the user.
- Identify the products produced in the pack.
- Describe if the reaction can be reversed and how this may be done.

Protective alloys

An understanding of metallic alloys has allowed the development of new materials with unique properties. Aluminium alloys have been used in the development of protective body armour. Steel alloys are used for added strength in building and construction.

- Select one alloy and investigate the elements used in the material.
- Describe the properties that are unique to the alloy.
- Explain how these properties determine how the alloy is used.

Figure 4 Rebars (reinforcement bars) are made of steel alloy and used in construction to reinforce concrete.

Module

9

Learning and memory

Overview

Neurons in our body send messages to the brain, helping us understand and react to the world. The brain is made up of different areas, each with its own role, like storing memories. Some behaviours are innate, meaning we are born with them, while others are learned through our experiences.

Learning can happen in different ways. When we link something we naturally do with something we experience, or when we learn from rewards or punishments, we form a memory. Our memories work in three steps: encoding (taking in information), storage (keeping it in our brain), and retrieval (getting it back when needed). Some things we remember better with the help of mnemonics, which are tricks to make it easier to recall information. These memory aids help us store and retrieve things more effectively.

Lessons in this module

oxford digital

Full lessons for this module are available on Oxford Digital.

[STEAM project 1]

How can we use technology so that we improve the lives of people in the world's poorest nations?

In Australia we are surrounded by technology every day. It is in the phones we use, the televisions we watch and the cars we drive. The term "technology" is used for any machinery or equipment that applies the scientific knowledge we have discovered. Wheels and computers are both examples of technology.

In high-income countries, emergency response teams often rely on technological data supplied by electronic sensors to respond to natural disasters such as storms, fires and plagues. Drones might be used to conduct search and rescue operations. Doctors can use technology to remotely diagnose people who are sick and to perform operations that save lives.

At the end of 2017, the number of high-speed mobile subscriptions in member countries of the Organisation for Economic Co-operation and Development (OECD) reached a milestone: more subscriptions than the number of people. These mobile phones have been used to alert people to natural disasters or to call for help in the event of floods and fires.

Technology is not just used for communication during natural disasters. It is also used to create medicine, improve farming practices and for education.

However, not everyone has access to technology.
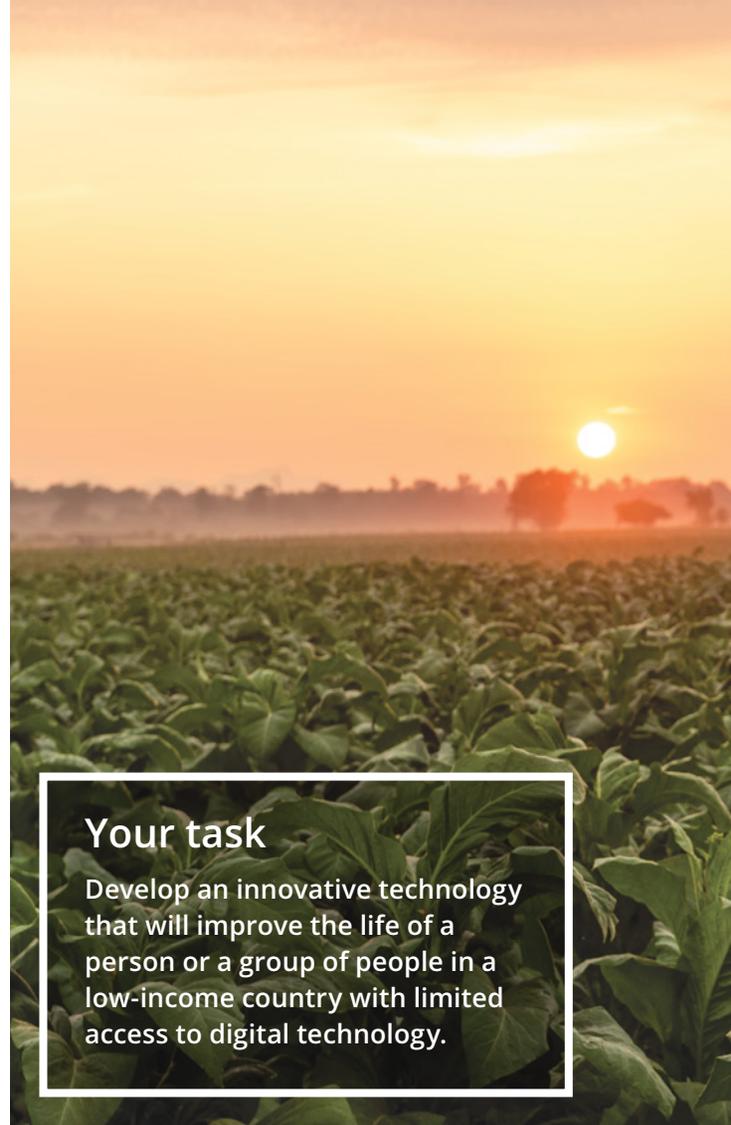
Your task

Develop an innovative technology that will improve the life of a person or a group of people in a low-income country with limited access to digital technology.

Figure 1 Technology can be used to enhance and improve agricultural practices.

The digital divide

The term "digital divide" is used to describe the gap between those who have access to digital technology – such as mobiles, computers and the internet – and those who do not. The Australian Bureau of Statistics has identified that almost 2.6 million Australians do not use the internet and cannot access technology in an emergency. Access is even lower in lower-income countries throughout Africa and Asia.

The OECD has identified that targeted innovation that uses technology can boost productivity, increase economic growth and help solve problems in society.

Figure 2 Technology has made attending a doctor's appointment easier and more accessible for people who may have difficulty attending in person.

HUMANITIES

In Geography this year, you will be learning about the spatial variations in human wellbeing globally. You will need to explore a range of factors that lead to inequalities, such as social, political, economic and technological differences. In Commerce, you will explore variations in living standards between countries and how living standards can be improved.

To complete this task successfully, you will need to research the initiatives of international governments and non-government organisations (NGOs) aimed at improving human wellbeing, particularly regarding health. You should consider how technology could be effectively accessed, resourced and used by a group of people to address their health concerns.

You will find more information on this in Module 4 "Inequalities in wellbeing" and Module 21 "The working environment" of *Oxford Humanities 10 Victorian Curriculum*.

MATHS

In Maths this year, you will extend your skills in representing, comparing and interpreting data. You will use digital technology to work with data but also perform calculations by hand.

To complete this task successfully, you will need to find data to quantify the problem, to cost your interventions and to calculate a quantitative, evidence-based estimate of the likely benefits of your interventions. You will need to use skills in performing proportionality and other calculations with very large numbers, using scientific notation.

You will find relevant mathematical and statistical concepts in Module 1 "Algebra" and Module 10 "Statistics" of *Oxford Maths 10/10A Victorian Curriculum*.

SCIENCE

In Science this year, you will learn how an understanding of evolution can contribute to the selection of desired traits (such as drought resistance) in plants and animals. You will also learn how genetic engineering can be used to develop medicines that will cure cancers and prevent disease.

To complete this task successfully, you will need to consider how the values and needs of different societies can influence the focus of scientific research. You will also need to consider the ethics of the technology that you will be offering to your selected individual or group of people.

You will find more information on this in Module 2 "Genetics" and Module 3 "Evolution" of *Oxford Science 10 Victorian Curriculum*.

[STEAM project 1]

The design cycle

To successfully complete this task, you will need to complete each of the phases of the design cycle.

discover

communicate

define

test

ideate

build

Discover

When designing solutions to a problem, you need to know who you are helping and what they need. The people you are helping, who will use your design, are called your end-users.

Consider the following questions to help you empathise with your end-users:

- Who am I designing for?
- What problems are they facing? Why are they facing them?
- What do they need? What do they not need?
- What does it feel like to face these problems? What words would you use to describe these feelings?

To answer these questions, you may need to investigate using different resources or conduct interviews or surveys.

Define

Before you start to design your innovative technology, you need to define the parameters you are working towards.

Define your version of the problem

Rewrite the problem so that you describe the group you are helping, the problem they are experiencing and the reason it is important to solve it. Use the following phrase as a guide.

"How can we help (the group) to solve (the problem) so that (the reason)?"

Determine the criteria

1 Describe the limitations in energy, communications, transport and support personnel that will need to be considered as part of the solution.
2 Describe how many copies of the solution prototype will need to be made to make a difference in the country you have chosen.
3 Identify who could pay for the construction of the solution prototypes.
4 Describe the social culture that is experienced by the individuals and groups who are affected by the problem. Why might some technologies be viewed as unwanted or even dangerous?

Ideate

Once you know who you're designing for and you know what the criteria are, it's time to get creative!

Outline the criteria or requirements your technological design must fulfil (e.g. cost, size and weight for transportation, and cultural appropriateness).

Brainstorm at least one idea per person that fulfils the criteria.

Remember that there are no bad ideas at this stage. One silly thought could lead to a genius innovation!

Build

Each group member should select one design to draw. Label each part of the design. Include the materials that will be used for its construction.

Include in the individual designs:

a   a detailed diagram of the design

b   a description of how it will change the life of your selected individual or group

c   an outline of any similar designs that are already available to buy

d   an outline of why your idea or design is better than others that are already available.

Present your design to your group.

Build the prototype

Choose one solution and build two or three prototypes. The prototype may be full size, or it may be a scale model (10 cm = 1 m).

Use the following questions as a guideline for your prototype solution.

- What materials or technology will you need to build or represent your prototype solution?
- What skills will you need to construct your prototype design? Does your group have these skills, or who can teach you these skills?
- How will you make sure your prototype design is able to be used by your selected individual or group? Will they need training?
- How will you display or describe the way the prototype design will work?

Test

Prototype 1

Use the scientific method to design an experiment that will test the effectiveness and strength of your first prototype solution.

You will test the prototype more than once to compare results, so you will need to control your variables between tests.

What criteria will you use to determine the success of your prototype? Conduct your tests and record your results in an appropriate table.

Prototype 2

If your prototype will be used to help an individual, then you will need to generate a survey to test whether the prototype is appropriate for their use. (How would they use it? Would it make their work easier or harder? Would they consider buying it?)

Prototype 3

Use the information you have obtained from testing the first two versions to adapt your last prototype to be more effective and usable for the group you are helping. You may want to use the first two prototypes to demonstrate how the design has been improved over time.

Communicate

Present your design to the class as though you are trying to get your peers to invest in your designed solution.

In your presentation, you will need to:

- outline the situation of the country in which your selected individual or group lives
- outline the challenges faced by your selected individual or group
- include a working model or a detailed series of diagrams with a description of how the prototype of the solution will be used
- include a description of how you changed your design prototype as a result of testing or feedback
- include a description of how the design prototype will improve the lives of your selected individual or group.

Online resources:

Student booklet
This helpful booklet will guide you step-by-step through the project.

What is the design cycle?
This video will help you to better understand each phase in the design cycle.

How to manage your project
This "how-to" video will help you to manage your time throughout the design cycle.

How to pitch your idea
This "how-to" video will help you with the "Communicate" phase of your project.

STEAM PROJECT   409

[STEAM project 2]

How can Australia reduce its reliance on fossil fuels so that we protect the environment and the economy?

Fossil fuels such as coal, oil and gas are made from fossilised, decomposed organisms that aged over millions of years in the Earth's crust. They contain carbon, which can be burned for energy. Due to the length of time it takes for these fuels to form as part of the carbon cycle, they are classified as long-term renewable sources of energy, sometimes called non-renewable.

Australia is a major user, producer and exporter of fossil fuels. Nearly 80 per cent of Australia's electricity is generated from coal and gas. Seventy-five per cent of coal mined in Australia is exported, making Australia the largest net exporter of this fuel in the world. In 2019, it was reported that Australia was the world's third-largest exporter of fossil fuels. Economically, the production and export of fossil fuels contributes hugely to Australia's GDP, and the mining industry is an important employer.

Coal emits higher amounts of CO_2 than oil or gas when used to produce energy. Measuring fossil fuel exports according to their potential to emit CO_2 makes Australia's carbon footprint per capita one of the largest in the world. This is contentious globally, particularly for nations most affected by a changing climate.
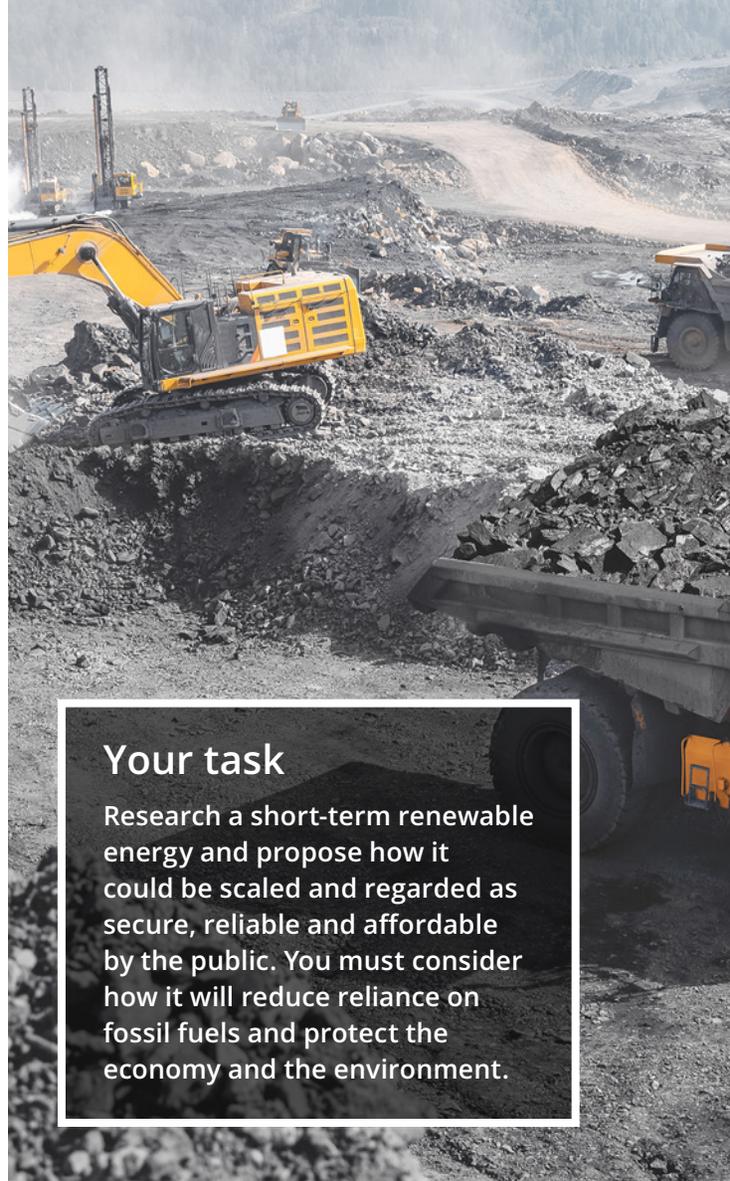
Your task

Research a short-term renewable energy and propose how it could be scaled and regarded as secure, reliable and affordable by the public. You must consider how it will reduce reliance on fossil fuels and protect the economy and the environment.

Figure 1 Most of Australia's energy is generated from coal. Almost 80 per cent of the coal produced in Australia is from open-cut mines.

Renewable alternatives

To protect both the environment and the economy, Australia needs to focus more on short-term renewable energy. When deciding on energy alternatives, it is important that energy supply be secure, reliable and affordable.

Short-term renewable energy sources include hydropower, solar power, wind power, bioenergy and ocean energy. Australia's landscape is suitable for many of these alternatives, but large investments in technology are required. As we invest more in the technology that makes short-term renewable energy possible, the better we get at making it, the more affordable it becomes and the more demand for renewable energy grows (a cyclical process).

Figure 2 A solar farm in Canberra. Solar energy is a source of renewable energy.

HUMANITIES

In Geography this year, you will learn about environmental change and management. You will explore the environmental, technological and economic factors that have influenced the change and the consequences of human actions on the sustainability of the environment.

In Commerce, you will investigate how the performance of Australia's economy is measured and how Australia's economic growth has depended on natural resources. You will explore the impact that environmental policies can have on Australia's economy and living standards.

To complete this task successfully, you will need to understand how stakeholders such as governments, communities and businesses can work together to initiate environmental change and management plans that protect both the environment and the economy.

You will find more information on this in Module 2 "Changing and managing the environment", Module 19 "Economic growth" and Module 20 "Living standards" of *Oxford Humanities 10 Victorian Curriculum*.

MATHS

In Maths this year, you will extend your skills in representing and interpreting data, including univariate, bivariate and multivariate data sets. This will include critical consideration of media reports that use statistics and present graphs. You will use digital technology to work with data but also perform calculations by hand.

To complete this task successfully, you will need to find data to quantify the problem, to cost your interventions and to calculate a quantitative, evidence-based estimate of the likely benefits of your interventions. You will need to have skills in performing proportionality and other calculations with very large numbers, using scientific notation.

You will find relevant mathematical and statistical concepts in Module 1 "Algebra" and Module 10 "Statistics" of *Oxford Maths 10/10A Victorian Curriculum*.

SCIENCE

In Science this year, you will learn about the impacts of fossil fuel combustion reactions in the production of carbon dioxide and carbon monoxide. You will also examine how increased reliance on this form of energy has affected the way carbon cycles through Earth's spheres, and how the resulting increase in greenhouse gases (including carbon dioxide) has led to enhanced global warming, which is contributing to melting sea ice and permafrost, rising sea levels and an increased number of extreme weather events.

To complete this task successfully, you will need to consider how energy that is generated can be used efficiently.

You will find more information on this in Module 4 "Climate change" of *Oxford Science 10 Victorian Curriculum*.

Oxford University Press

[STEAM project 2]

The design cycle

To successfully complete this task, you will need to complete each of the phases of the design cycle.

discover

communicate

define

test

ideate

build

Discover

When designing solutions to a problem, you need to know who you are helping (your end-users) and what they need.

Consider the following questions to help you empathise with your end-users:

- Who am I designing for? Will I be helping the government or members of the public?
- What problems are they facing? Why are they facing them?
- What do they need? What do they not need?

To answer these questions, you may need to investigate using different resources or conduct interviews or surveys.

Define

Before you start to design your solution for the potential replacement of fossil fuels, you need to define the parameters you are working towards.

Define your version of the problem

Rewrite the problem so that you describe the group you are helping, the problem they are experiencing and the reason it is important to solve it. Use the following phrase as a guide.

"How can we help (the group) to solve (the problem) so that (the reason)?"

Determine the criteria

1   What type of energy source are you trying to replace? How much of it is currently used and how is it used?
2   How will the renewable energy be used? Will it be easy for the user to access?
3   Will the renewable energy require many changes in the vehicles or equipment being used? Who will pay for this change in infrastructure? How much will it cost?
4   How long will it take to generate the resources needed to make this renewable energy resource accessible and affordable for most people?

Ideate

Once you know who you're designing for and you know what the criteria are, it's time to get creative!

Outline the criteria or requirements your design must fulfil (e.g. type of equipment, number and amount of materials, area that needs to be covered).

Brainstorm at least one idea per person that fulfils the criteria.

Remember that there are no bad ideas at this stage. One silly thought could lead to a genius innovation!

Build

Each team member should draw one individual design. Label each part of the design. Include the materials that will be used to construct a model of the design. Also include descriptions of:

a what you see as the biggest problem with the energy source that you are replacing

b the renewable energy that you propose could be used instead

c how this renewable energy could be scaled up so that it can be used more effectively.

Present your design to your group.

Build the prototype

As a group, choose one design and plan how to model or build it. You may need to produce two or three to-scale prototypes for your group's design. Keep each iteration so that you can show the progress of your ideas.

Use the following questions as a guideline for your prototype.

- How will you replicate or model the renewable energy source?
- How will you model how the renewable energy will be used?
- What are the limitations of the renewable energy source? Will it produce enough energy for the equipment that currently uses fossil fuels?
- Calculate the number, density or requirements of energy sources in your area. How will your model provide for these demands?

Test

Use the scientific method to design an experiment that will test the limitations of your renewable energy prototype idea. You will need to model and test more than one prototype to compare results, so you will need to consider all variables between tests.

What criteria will you use to determine the success of your renewable energy prototype?

If your prototype will be used by a particular group of individuals, then you will need to generate a survey to test whether the prototype is appropriate for their use. (How would they use the alternative energy source? Would it make their life easier or harder? Would they consider buying it? How much would they be prepared to pay to access this form of energy?)

Conduct your tests and record your results in an appropriate table.

Communicate

Present your design to the class as though you are trying to get your peers to invest in your alternative energy design.

In your presentation, you will need to:

- outline the energy needs of the selected individual or group you are supporting
- outline the energy challenges faced by your selected individual or group
- create a working model or a detailed series of diagrams, with a description of how the design prototype will be used to replace the current energy demands
- describe how you changed your design prototype as a result of testing or feedback
- describe how the renewable energy prototype will improve the life of your selected individual or group
- estimate the cost of production for each element of your energy design
- estimate the number of each element of your energy design required in your local government area
- estimate the total implementation cost to individuals or to local, state or national government bodies
- compare how this energy system could be implemented in developed and developing countries.

Online resources:

Student booklet
This helpful booklet will guide you step-by-step through the project.

What is the design cycle?
This video will help you to better understand each phase in the design cycle.

How to manage your project
This "how-to" video will help you to manage your time throughout the design cycle.

How to define a problem
This "how-to" video will help you to narrow your ideas down and define a specific problem.

Glossary

A

absolute dating

a method of determining the age of a fossil, by measuring the amount of radioactivity remaining in the rock surrounding the fossil

absolute magnitude scale

a scale for measuring the brightness (luminosity) of objects from the same distance

absorption spectrum

a spectrum with dark bands missing from the pattern, where the element has absorbed characteristic light wavelengths; the opposite of an emission spectrum

acceleration due to gravity

acceleration of an object due to a planet's gravitational field; on Earth, $g = 9.8$ m/s; the approximate value of 10 m/s^2 is sometimes used

accurate

how carefully, correctly and consistently data have been measured or processed; in science, how close a measured value is to the true value

achondroplasia

a genetic (inherited) disorder of bone growth resulting in abnormally short stature and short limbs

acid

a hydrogen-containing substance that has the ability to donate a proton

active site

the region of an enzyme that substrates can bind to

adaptation

a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

alkali

a base that dissolves in water

alkali metal

an element in group 1 of the periodic table

alkaline earth metals

elements with similar properties found in group 2 of the periodic table

alkaline solution

a solution that consists of a base dissolved in water

allele

a version of a gene; a person inherits two alleles for each gene, one coming from each parent

amino acids

small molecules that make up proteins

amygdala

a part of the brain responsible for encoding the emotional part of a memory

analogous structures

structures in organisms of different species that have the same function but are structurally different, because they evolved independently; for example, wings in birds and bats

anion

a negatively charged ion formed when an atom gains electrons

apoptosis

programmed cell death

apparent magnitude scale

a scale for measuring the brightness of an object when viewed from Earth

artificial selection

when humans breed organisms that have desirable traits, increasing the likelihood of that trait occurring in the next generation

atomic number

the number of protons in an atom

autosome

a chromosome that does not determine the sex of an organism

B

base

a substance that has the ability to accept a hydrogen proton

bias

discrimination against ideas, against people or in the collection and interpretation of information

Big Bang theory

the theory that the universe began as a hot, dense, single point at some time in the past, and since then has expanded and will continue to expand into the future

binary fission

a form of asexual reproduction used by bacteria; the splitting of a parent cell into two equal daughter cells

biochar

a lightweight residue containing carbon and ash that is formed from the slow burning of biomass

biodiversity

the variety of life; the different plants, animals and microorganisms and the ecosystems they live in

bioplastic

plastic produced from renewable biomass sources

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 strong that nothing, not even light, can escape from it

blind study

when the participants do not know if they are receiving the treatment or a placebo

blue shift

the apparent increase in frequency (towards the blue end of the spectrum) of light from galaxies that are moving towards the Earth

Bohr model

a model of the atom in which electrons orbit the nucleus in a series of defined orbits known as shells

C

carbon nanotube

a very small tube of carbon atoms, made synthetically

carrier

a person who has the allele for a recessive trait that does not show in their phenotype

catalyst

a substance that increases the rate of a chemical reaction without undergoing any permanent chemical change

categorical data

information that can be divided into groups or categories

cation

a positively charged ion that results from an atom losing electrons

cerebellum

a small lobe at the lower rear of the brain responsible for fine motor movement, balance and coordination

cerebral cortex

the outer layer of the brain that is responsible for conscious thought

chromatid

one side of the X-shaped chromosome that contains a double helix of DNA

chromosome

the form of DNA that is tightly wound around proteins before replication

classical conditioning

a learned behaviour that is linked to a previously neutral stimulus

climate

the weather conditions at a particular place, averaged over a long period of time, based on the collection and analysis of large amounts of data

climate change

periodic change in the Earth's climate

climate change adaptation

coping adjustments made in response to the effects of climate change

climate change mitigation

efforts that aim to reduce or prevent greenhouse gas emission

co-dominant

two different alleles that can both appear in the phenotype at the same time; both can appear with a single allele

codon

a group of three nucleotides on mRNA

cognition

mental processes that are involved in acquiring, storing, manipulating and retrieving information

column graph

vertical bars used to compare data

command term

a "doing word" that requires you to perform a specific thinking task

complementary base

a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand; adenine pairs with thymine, cytosine pairs with guanine

concentration

the number of active molecules in a set volume of solution

conclusion

a statement that "answers" the aim of an experiment

confirmation bias

when a scientist selects a method that will support the outcome they want

constellation

a group of stars that form a pattern or picture

continental drift

the continuous movement of the continents over time

continuous data

information that can be any value, including decimals and fractions that are measured

convergent evolution

the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

Coriolis effect

the influence of the Earth's rotation on the direction of movement of air or water

corrosion reaction

a chemical reaction that produces a metal oxide due to a metal reacting with oxygen

corrosive

a substance that can damage or destroy other materials

cosmic microwave background radiation

remnant electromagnetic radiation left from early stages of the universe

Country

a term used by Aboriginal and Torres Strait Islander Peoples to describe the connections between land, water, sky, animals, plants, people, stories, songs, cultural practices and spiritual beliefs that make up a traditional area

covalent bond

a bond formed when two or more atoms share electrons

cultural norm

the expectation that you should behave according to the values of the people around you

cytokinesis

the splitting of a replicating cell into two cells

D

decomposition

a reaction that involves the breakdown of a compound into simpler substances

delocalised electron

an electron in a molecule that can easily move between atoms

diatomic molecule

a molecule that consists of two atoms

dilute

containing a small number of solute particles in the volume of solution

diploid

containing two complete sets of chromosomes

direct imaging

directly measuring the amount of light emitted from a star

discrete data

information that can only take on specific and distinct values, such as whole numbers

displacement

the change of position of a moving object in a particular direction

displacement reaction

a reaction resulting in the displacement of an atom or group of atoms

distance

the length of the path travelled by an object

diverge

in relation to two species: to become more different over time due to different selection pressures, possibly becoming reproductively isolated

DNA (deoxyribonucleic acid)

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

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

double displacement reaction

when two reactants exchange ions to form new products during a chemical reaction

double-blind study

when neither the participants nor the treating doctors know if they are receiving the treatment or a placebo

E

early detection and predictive testing for adults

the testing of chromosomes for the presence of alleles that increase the probability of cancers forming

echoic memory

auditory memory that decays after a few seconds

elaborative rehearsal

a memory technique that involves thinking about the meaning of the term to be remembered

elastomer

long chains of polymers occasionally linked together like a ladder

electron configuration

a numerical way of showing the number of electrons in each electron shell around a particular atomic nucleus

electron shell

a defined area of space in which electrons move around an atom's nucleus

emission spectrum

the pattern of wavelengths (or frequencies) that appear as coloured lines in a spectroscope; it is unique to each element

encoding

the conversion of sensory memory into a usable form so that it can be represented and stored in memory

enzyme

a protein-based catalyst

equipment

items used in the laboratory to conduct experiments

ethics

a set of principles that provide guidance to determine what is morally right and wrong

event horizon

the boundary around a black hole at which no light or matter can escape

evolution

the gradual change in the genetic material of a population of organisms over a long period of time

evolutionary relationship

the way in which two species or populations are related with respect to their evolutionary descent

exoplanet

a planet that orbits a star outside of our solar system

exothermic

a chemical reaction that releases energy as heat (and sometimes light)

experiment

an investigation used to test a hypothesis, solve a problem or find an answer to a question

extrapolation

estimating unknown values from trends in known data

F

fossil

the remains or traces of an organism that existed in the past

fossilisation

the process of an organism becoming a fossil

frameshift mutation

a type of mutation in which a nucleotide is added or deleted, causing a shift in the reading frame of codons; usually results in a deformed protein

functional magnetic resonance imaging (fMRI)

the use of magnetic fields to show high blood flow in areas of the brain

G

gamete

a haploid cell that combines with that of the opposite sex as part of sexual reproduction

gene

basic unit of genetic material passed on from parents to offspring

gene cloning

the production of identical copies of a gene

gene flow

the flow of genes from one generation to the next, or from one population to the next, as different families or groups in the population choose partners and mate

gene pool

all the genes or alleles in a population

gene therapy

inserting a new healthy allele into an organism to treat a genetic disease

genetic code

the sequence of nucleotides in DNA, inherited from parent organisms

genetic engineering

the deliberate engineering of change in the DNA of an organism

genetically modified organisms (GMOs)

an organism that has had its DNA changed in a laboratory

genotype

the combination of alleles for a particular trait

Goldilocks zone

the area around a star where it is not too hot or too cold for liquid water to exist on a planet

greenhouse gases

a gas (carbon dioxide, water vapour, methane) in the atmosphere that can absorb heat

group

a vertical list of elements in the periodic table that have characteristics in common

H

half-life

the time it takes the radioactivity in a substance to decrease by half

halogens

the group of elements in group 17 of the periodic table

haploid

containing one complete set of chromosomes in each cell; an example is gametes

Hertzsprung–Russell diagram

a graph displaying star data, with the star's spectral class (temperature) on the x-axis and its absolute magnitude (luminosity) on the y-axis

heterozygous

having two different alleles for a particular trait; a carrier for a recessive trait

high-pressure system

area of high pressure in the Earth's atmosphere

hippocampus

a central part of the brain responsible for encoding explicit memories

homologous structure

structure that is similar in different species, because those species evolved from a common ancestor, but do not necessarily have the same function now; an example is forelimbs in different mammal species

homozygous

having two identical alleles for a particular trait

horizontal transfer

the transfer of genetic material (usually containing antibiotic resistance) from a bacterium to another bacterium that is not its offspring

hydrocarbon

a molecule that contains only carbon and hydrogen atoms

hydrogen bond

a type of weak chemical bond between two groups of atoms; the bond between two nitrogen bases in the DNA helix

hydrostatic equilibrium

in relation to the Earth's atmosphere: a state of stability, with upward forces balanced by downward forces

hypothesis

a proposed explanation for a prediction that can be tested

I

iconic memory

visual memories that decay in less than 1 second

imprinting

a form of learning where a baby rapidly encodes a memory that identifies a parent or object

indicator

a substance that changes colour in the presence of an acid or a base

Indigenous science

a system of knowledge developed by Aboriginal and Torres Strait Islander Peoples over tens of thousands of years that combines careful observation and testing of the natural world with cultural understanding to explain how things work and are connected in nature

inertia

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

inference

a conclusion based on evidence and reasoning

innate behaviour

a common behaviour that all members of a species are born with

interphase

a phase of cell life where normal functioning occurs

interpolation

determining a value from existing values

intrusion

when upwelled waters do not reach the surface

inversely proportional relationship

when one quantity decreases the other quantity increases, or vice versa

ion

an atom that is charged because it has an unequal number of electrons and protons

ionic bond

a bond between a negatively charged anion and a positively charged cation

ionic compound

a substance made up of a negatively charged anion and a positively charged cation

isobar

a line drawn on a weather map that joins places of equal air pressure

isolation

the division of a population into two groups

K

karyotype

a way of representing a complete set of chromosomes, arranged in pairs, in order of decreasing size

kinetic energy

the energy an object or particle has due to its motion

L

Law of Conservation of Momentum

a scientific rule that states that the total momentum in an isolated system does not change during a collision

learning

when an animal gains new knowledge, skills, or behaviours based on experiences

light-year

the distance that light travels in 1 year

line graphs

individual data points that are connected and that change over time

line of best fit

a straight line that goes through the middle of all the scatter points to minimise the distance between the line and the scatter points

linear polymer

long single chains of polymers

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 detailed recording of observations and data from a scientific investigation

long-term memory (LTM)

a memory store that holds information for an unlimited period of time

low-pressure system

area of low pressure in the Earth's atmosphere

luminosity

the actual brightness of a star (amount of energy it radiates); measured using the absolute magnitude scale

M

machinability

ability of a metal to be cut and shaped

magnetic resonance imaging (MRI)

the use of magnetic fields and radio waves to produce detailed images of organs and tissues of the body

magnitude

the size or extent of something

mass number

the total number of protons and neutrons in the nucleus of an atom

maternal serum screening (MSS)

the genetic testing of foetal DNA found in the mother's blood

maturation

the process of becoming an adult

mean

the average of a data set

median

the middle value for data arranged from smallest to largest

meiosis

the process that results in the formation of gametes with half the genetic material of the parent cell

metals

elements on the left-hand side of the periodic table; they are malleable, lustrous, ductile and highly conductive

mitosis

the process of cell division that results in genetically identical daughter cells; allows growth and repair

mnemonic

a learning strategy of using a song, rhyme or visual image to help in the encoding, storage and recall of a memory

mode

the value that appears the most in a data set

molecular compound

a molecule that contains two or more different atoms bonded together

molecule

group of two or more atoms bonded together (e.g. a water molecule)

momentum

the product of an object's mass and velocity

monomer

a small molecule from which polymers are made

mutagen

a chemical or physical agent that causes a change in genetic material such as DNA

mutation

a permanent change in the sequence or amount of DNA

N

nanotechnology
the manipulation of individual atoms to form structures

natural selection
when the natural environment selects for or against a physical characteristic

nebula
a cloud of gas and dust in space (plural: nebulae)

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

neural pathway
a number of connected neurons that transmit signals in the brain and body

neuroimaging
the creation of an image of brain structures or brain activity

neuron
a nerve cell

neuroscience
the study of how the brain works to improve learning and memory

neutral
having a pH of 7, so neither an acid nor a base; an example is water

neutral stimulus
sensory information from the environment (sound, smell, feel) that can start a behaviour

neutralisation
a reaction in which an acid and a base combine to produce a metal salt and water

neutron star
a small, highly dense star made mostly of neutrons

newborn screening
the testing of chromosomes in a baby's white blood cells for the presence of a genetic disease

noble gases
the stable gaseous elements in group 18 of the periodic table

non-disjunction
the failure of one or more chromosomes to separate during meiosis; can result in an abnormal number of chromosomes in the daughter cells

non-metals
elements on the right-hand side of the periodic table

nuclear fusion
a reaction in which two lighter atomic nuclei fuse to form a heavier nucleus, releasing energy

nucleotide
a subunit of a nucleic acid

numerical data
information in the form of numbers

O

objective
uninfluenced by personal opinions and interests

observational learning
when an animal learns from watching others

operant conditioning
a way of learning that some behaviours result in a reward and other behaviours result in a punishment; the consequence of the behaviour determines the likelihood of it occurring again

outlier
a data point that differs significantly from the main group of data

oxidation
a chemical process where a substances loses electrons (gains oxygen or loses hydrogen)

P

pattern
a repeated sequence or arrangement of numbers or data points

pedigree
a chart showing the phenotypes for an individual and their ancestors, usually over several generations; also known as a family tree diagram

peer review
a process in which experts evaluate the findings of a report before it is published

period
in chemistry: a horizontal list of elements in the periodic table

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

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

phylogenetic tree
a branching tree-like diagram showing relationships between different taxonomic groups

placebo
a substance or treatment that is designed to have no effect

planetary nebula
a glowing shell of gas formed when a star dies

polyatomic ion
a charged ion that consists of two or more atoms bonded together

polymer
a long-chain molecule formed by the joining of many smaller repeating molecules (monomers)

polymerisation
the process of joining smaller units (monomers) to form a long-chain molecule (polymer)

positive reinforcement
a desired/pleasant result or consequence of a behaviour

positron emission tomography (PET)
the use of radioactive glucose to produce an image of the highly active areas of the brain

precipitate
a solid, insoluble compound formed in a precipitation reaction

precipitation reaction
a reaction used to produce solid products from solutions of ionic substances

prediction
an outcome that is expected based on prior knowledge or observation

protein
a chain of amino acids; an essential part of cells

pseudoscience
a claim that has not been tested using the scientific method

punishment
a negative result or consequence of a behaviour

Punnett square
a diagram used to predict the outcome of breeding organisms

R

random error
when an unpredictable variation in measurement occurs, resulting in an outlier result

randomised
when people or objects are selected at random

reaction force
the force acting in the opposite direction to an initial force

reaction rate
how fast or slowly a reaction proceeds

recessive trait

a characteristic that is only expressed in the phenotype when two identical alleles are inherited

red giant

a star that has become large and bright with a cool surface, because it has run out of hydrogen fuel

red shift

the apparent decrease in frequency (towards the red end of the spectrum) of light from galaxies that are moving away from the Earth

reflex response

a behaviour that does not have to be learnt

reforestation

the process of replanting trees and vegetation to restore natural habitat

relative dating

a method of determining the age of an object relative to events that occurred before and after

reliable

consistency of a measurement, test or experiment

repeatable

when an experiment can be repeated by the same scientist using the same materials

reproducible

when the experiment can be repeated by another scientist in another laboratory

results

the measurements and observations made in an experiment; often presented in a table or graph

retrieval

the act of processing and recovering memory information from storage

risk

exposure to danger

risk assessment

the process of identifying and evaluating potential risks, including how they can be mitigated and what to do if there is exposure to the risk

S

safety data sheet (SDS)

a document that details health and safety information about a material, including safe handling and its properties

sampling bias

a bias where a group of test subjects do not represent the larger sample group

scalar

having only magnitude (a numeric quantity)

scatter plot

a type of graph that displays the relationship between two sets of numerical data

selection pressure

the environmental factors that affect an organism's ability to survive

semantic networks

a framework that links information in our brain

sensory memory

the ability of our senses to temporarily store a specific memory

sex chromosome

a chromosome that determines the sex of an organism

shell diagram

a diagram that shows the number of electrons in each electron shell around a particular atomic nucleus

short-term memory (STM)

a type of memory store where we can consciously hold information while we use it or before we transfer it to long-term memory

single displacement reaction

a reaction in which a more reactive element displaces a less reactive element on a molecule

solar radiation

radiant electromagnetic energy from the Sun

solution

a mixture of a solute dissolved in a solvent

somatic cells

the body cells except gametes (egg and sperm)

speciation

the process that results in the formation of a new species

species-specific behaviour

a behaviour that is unique to a single species

spectator ion

an ion that does not take part in a chemical reaction

speed

the distance travelled per unit of time

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 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 many types of cells

stimulus

any information that the body receives that causes the body to respond

storage

the ability to keep encoded information in the brain

strength

how easily an acid releases a hydrogen ion in a chemical reaction; also describes the bond between different atoms

substitution mutation

a form of mutation where one nucleotide is substituted for another; may or may not result in a deformed protein

substrate

a molecule that reacts with an enzyme

superalloy

high-strength complex metal alloy resistant to extreme temperature and stress

supernova

the explosive death of a star

synthesis

a reaction that involves the building up of compounds by combining simpler substances, usually elements

systematic error

a repetitive error that is not removed by repeating the experiment

T

thermoplastic polymer

a polymer that softens and forms new shapes when heated

thermosetting polymers

polymers that do not melt or change shape when heated

transcription

the process of copying the DNA that makes up a gene to messenger RNA

transgenic organism

an organism that has a gene from another organism inserted into its own chromosomes

transition metals

the elements in groups 3–12 of the periodic table

transitional fossil

a fossil or an organism that shows an intermediate state between an ancestral form and its descendants; also known as a "missing link"

translation

the formation of a protein from RNA; occurs on a ribosome

trend

represents the overall direction of the data points

U

unbiased

impartial and free from preconceived ideas

universal indicator

a solution that is used to determine the pH (amount of acid or base) of a solution

upwelling

a process in which deep, nutrient-rich cold water moves up towards the surface

V

valence shell

the outermost electron shell in an atom that contains electrons

valid

when the design of the experiment will produce a result that answers the scientific question

variable

something that can affect the outcome or results of an experiment

vector

having magnitude and direction

velocity

the vector quantity that measures speed in a particular direction

vestigial structure

a structure in an organism that no longer has an obvious purpose

W

weather

the temperature, humidity, rainfall and wind on particular days at a particular place

Western science

a system of knowledge based on careful observation, measurement, testing and experimentation (known as the scientific method) to develop and test hypotheses to explain how things work

white dwarf

a small, hot star that forms when a star (e.g. our Sun) runs out of fuel and slowly fades and cools

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Acknowledgements

Periodic table

Key:

```
6        — Atomic number
C        — Chemical symbol
12.01    — Atomic mass
Carbon   — Name of element
```

Group																	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.0 Hydrogen																	2 **He** 4.0 Helium
3 **Li** 6.9 Lithium	4 **Be** 9.0 Beryllium											5 **B** 10.8 Boron	6 **C** 12.0 Carbon	7 **N** 14.0 Nitrogen	8 **O** 16.0 Oxygen	9 **F** 19.0 Fluorine	10 **Ne** 20.2 Neon
11 **Na** 23.0 Sodium	12 **Mg** 24.3 Magnesium											13 **Al** 27.0 Aluminium	14 **Si** 28.1 Silicon	15 **P** 31.0 Phosphorus	16 **S** 32.1 Sulfur	17 **Cl** 35.5 Chlorine	18 **Ar** 39.9 Argon
19 **K** 39.1 Potassium	20 **Ca** 40.1 Calcium	21 **Sc** 45.0 Scandium	22 **Ti** 47.9 Titanium	23 **V** 50.9 Vanadium	24 **Cr** 52.0 Chromium	25 **Mn** 54.9 Manganese	26 **Fe** 55.8 Iron	27 **Co** 58.9 Cobalt	28 **Ni** 58.7 Nickel	29 **Cu** 63.5 Copper	30 **Zn** 65.4 Zinc	31 **Ga** 69.7 Gallium	32 **Ge** 72.6 Germanium	33 **As** 74.9 Arsenic	34 **Se** 79.0 Selenium	35 **Br** 79.9 Bromine	36 **Kr** 83.8 Krypton
37 **Rb** 85.5 Rubidium	38 **Sr** 87.6 Strontium	39 **Y** 88.9 Yttrium	40 **Zr** 91.2 Zirconium	41 **Nb** 92.9 Niobium	42 **Mo** 96.0 Molybdenum	43 **Tc** (97) Technetium	44 **Ru** 101.1 Ruthenium	45 **Rh** 102.9 Rhodium	46 **Pd** 106.4 Palladium	47 **Ag** 107.9 Silver	48 **Cd** 112.4 Cadmium	49 **In** 114.8 Indium	50 **Sn** 118.7 Tin	51 **Sb** 121.8 Antimony	52 **Te** 127.6 Tellurium	53 **I** 126.9 Iodine	54 **Xe** 131.3 Xenon
55 **Cs** 132.9 Caesium	56 **Ba** 137.3 Barium	57 to 71	72 **Hf** 178.5 Hafnium	73 **Ta** 180.9 Tantalum	74 **W** 183.8 Tungsten	75 **Re** 186.2 Rhenium	76 **Os** 190.2 Osmium	77 **Ir** 192.2 Iridium	78 **Pt** 195.1 Platinum	79 **Au** 197.0 Gold	80 **Hg** 200.6 Mercury	81 **Tl** 204.4 Thallium	82 **Pb** 207.2 Lead	83 **Bi** 209.0 Bismuth	84 **Po** (210) Polonium	85 **At** (210) Astatine	86 **Rn** (222) Radon
87 **Fr** (223) Francium	88 **Ra** (226) Radium	89 to 103	104 **Rf** (267) Rutherfordium	105 **Db** (270) Dubnium	106 **Sg** (269) Seaborgium	107 **Bh** (270) Bohrium	108 **Hs** (270) Hassium	109 **Mt** (278) Meitnerium	110 **Ds** (281) Darmstadtium	111 **Rg** (281) Roentgenium	112 **Cn** (285) Copernicium	113 **Nh** (286) Nihonium	114 **Fl** (289) Flerovium	115 **Mc** (290) Moscovium	116 **Lv** (289) Livermorium	117 **Ts** (294) Tennessine	118 **Og** (294) Oganesson

— Metals —

Rare earth elements — Lanthanide series

57 **La** 138.9 Lanthanum	58 **Ce** 140.1 Cerium	59 **Pr** 140.9 Praseodymium	60 **Nd** 144.2 Neodymium	61 **Pm** (145) Promethium	62 **Sm** 150.4 Samarium	63 **Eu** 152.0 Europium	64 **Gd** 157.3 Gadolinium	65 **Tb** 158.9 Terbium	66 **Dy** 162.5 Dysprosium	67 **Ho** 164.9 Holmium	68 **Er** 167.3 Erbium	69 **Tm** 168.9 Thulium	70 **Yb** 173.1 Ytterbium	71 **Lu** 175.0 Lutetium

Actinide series

89 **Ac** (227) Actinium	90 **Th** 232.0 Thorium	91 **Pa** 231.0 Protactinium	92 **U** 238.0 Uranium	93 **Np** (237) Neptunium	94 **Pu** (244) Plutonium	95 **Am** (243) Americium	96 **Cm** (247) Curium	97 **Bk** (247) Berkelium	98 **Cf** (251) Californium	99 **Es** (252) Einsteinium	100 **Fm** (257) Fermium	101 **Md** (258) Mendelevium	102 **No** (259) Nobelium	103 **Lr** (260) Lawrencium

Metals
- Alkali metal
- Alkaline earth metal
- Lanthanide
- Actinide
- Transition metal
- Post-transition metal

Non-metals
- Diatomic non-metal
- Polyatomic non-metal
- Noble gas

Other
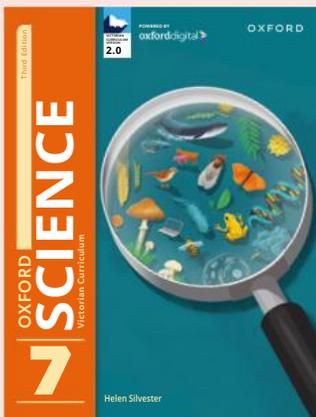- Metalloid
- Unknown chemical properties

DNA is like a blueprint, or set of plans, for every structure and function in an organism. Every cell in your body (except red blood cells) contains the same identical DNA molecules. Each molecule of DNA is a double helix consisting of two linked strands connected by hydrogen bonds.

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