NEW SOUTH WALES CURRICULUM

POWERED BY oxforddigital

Science

OXFORD SCIENCE Stage 5

Melinda Mestre
Lily Okati
Timothy Sloane
Mora Soliman
Helen Silvester

NSW Curriculum

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Warning
Aboriginal and Torres Strait Islander readers are advised that this book (and the resources that support it) may contain the names, images, stories and voices of deceased persons.

Non-Indigenous readers should be aware that for some Aboriginal and Torres Strait Islander communities, showing the names and photographs of deceased persons may cause sadness or distress and, in some cases, be contrary to cultural protocols.

Contents

Introducing *Oxford Science Stage 5 NSW Curriculum*

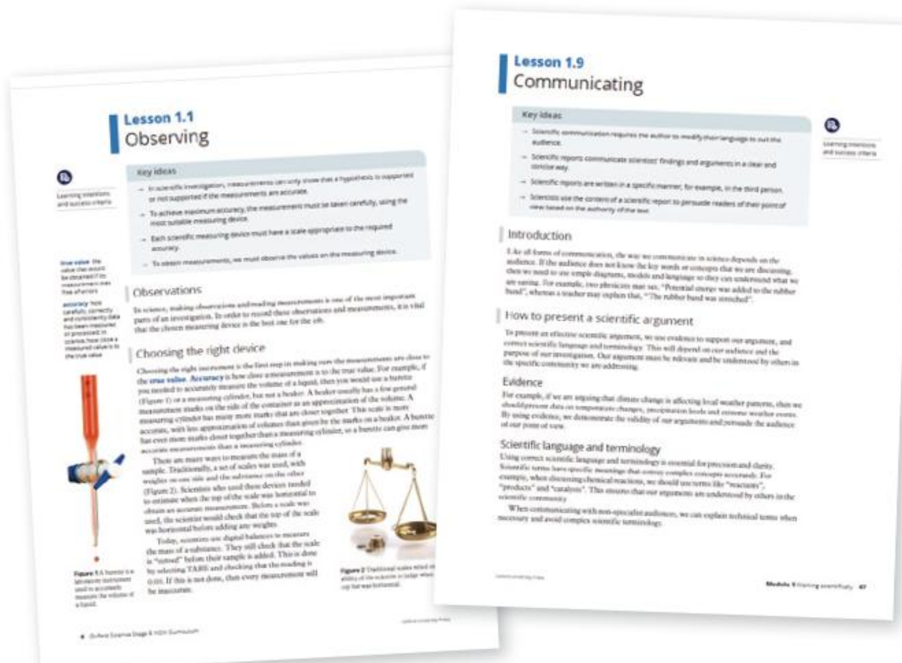
Congratulations on choosing *Oxford Science Stage 5 NSW Curriculum* as part of your studies this year!

Oxford Science Stage 5 NSW Curriculum has been purpose-written to meet the requirements of the Science 7–10 Syllabus (2023). It includes a range of flexible print and digital products to suit your school and incorporates a wide variety of features designed to make learning fun, purposeful and accessible to all students!

Key features of Student Books

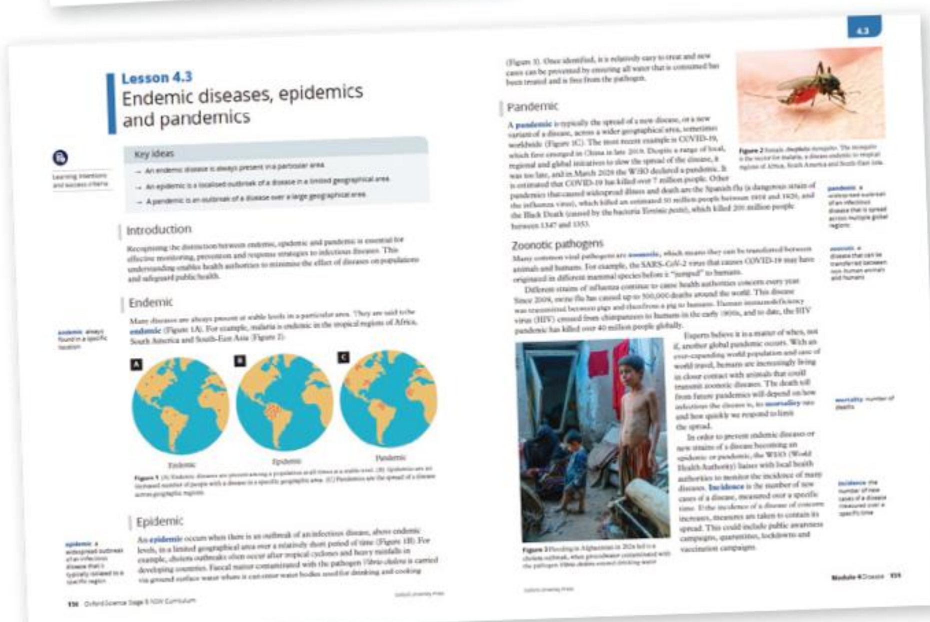
The **Working scientifically** is a standalone module that explicitly teaches important Science inquiry skills.

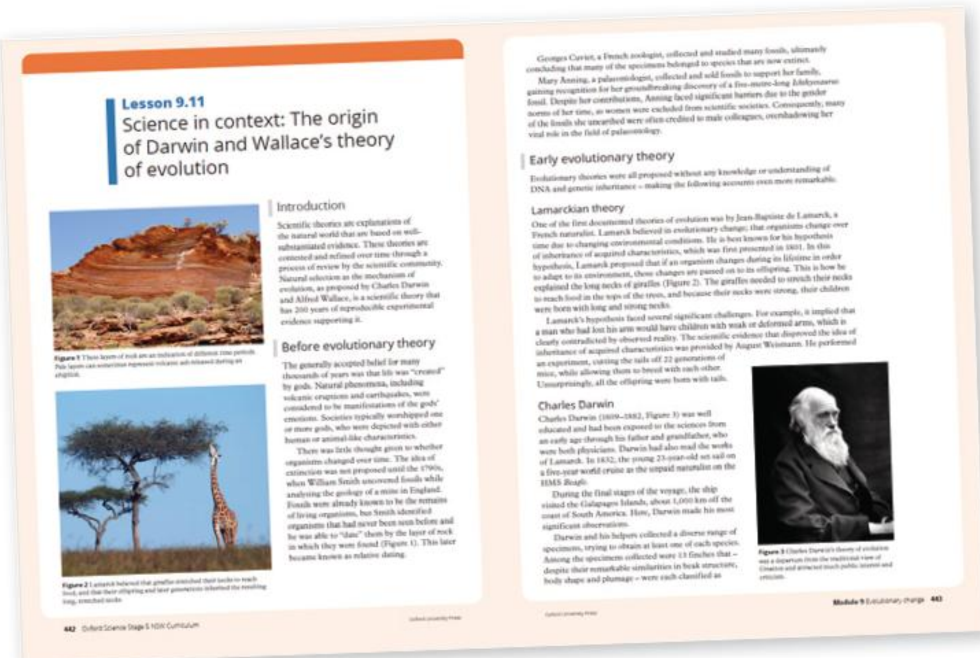
The **Aboriginal and Torres Strait Islander Histories and Cultures** cross-curriculum priority is addressed in both standalone lessons and within other lessons.



In each core lesson:

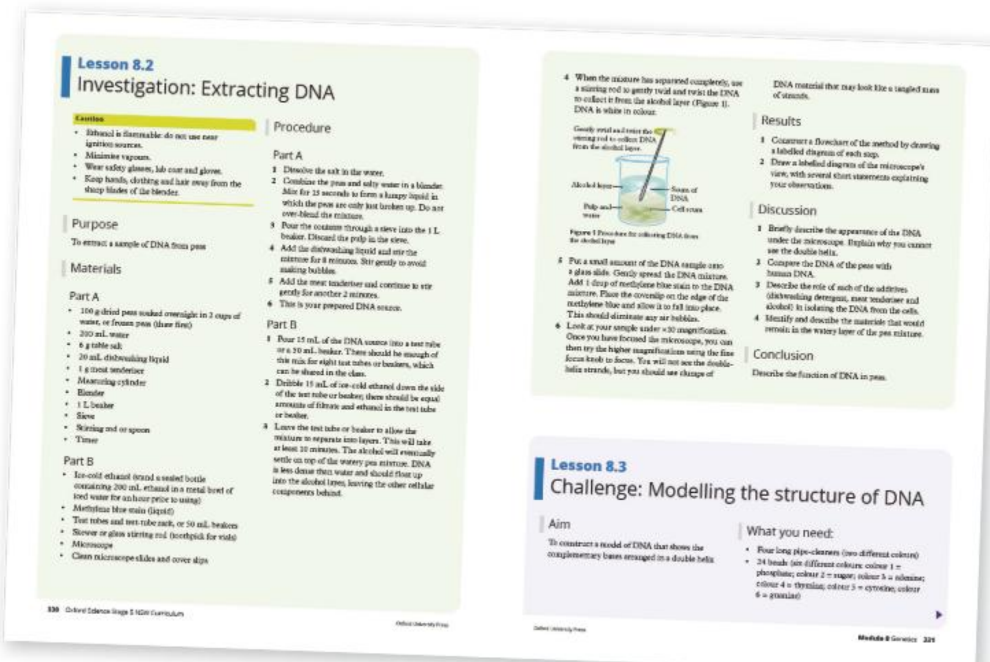
- a concept statement summarises the key concept in one sentence
- key ideas are summarised in succinct dot points
- key terms are bolded in blue text, with a glossary definition provided in the margin
- a set of check your learning questions are aligned to the learning intentions for the lesson.





Science in context lessons explore real world examples and case studies, allowing students to apply science understanding.

The **Test your skills and capabilities** section provides scaffolded opportunities for students to apply their science understanding while developing skills and capabilities.



Practical activities appear within each module, directly after the core lesson they relate to. Additional activities are provided through Oxford Digital.

Challenges, Skills labs and **Investigations** provide students with opportunities to use problem-solving and critical thinking, and apply science inquiry skills.

Find out more

For a complete overview of all the features and benefits of this Student Book:

> activate your digital access (using the instructions on the inside front cover of this book) and click on "Introducing *Oxford Science Stage 5 NSW Curriculum*" in the "About this course" menu.

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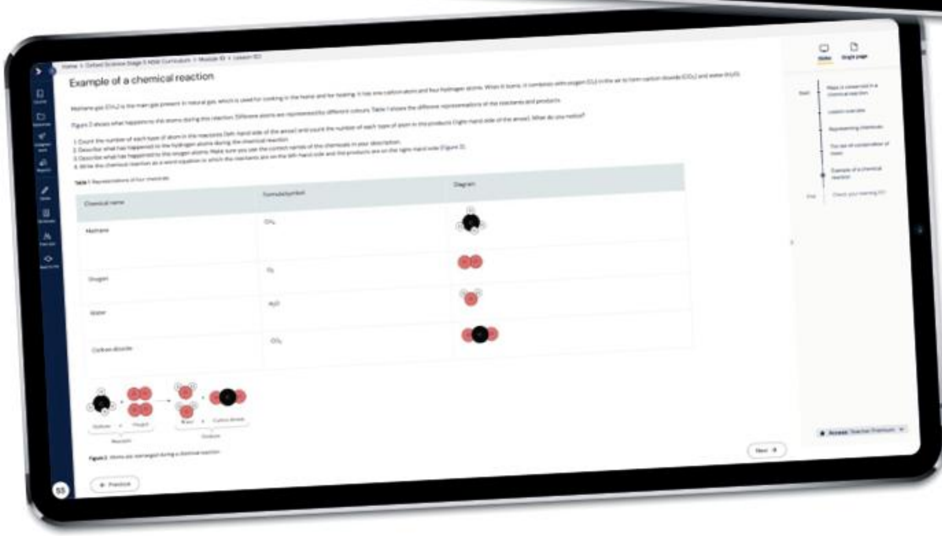
There's also a range of unique features designed to improve learning outcomes.



As a student, you can:

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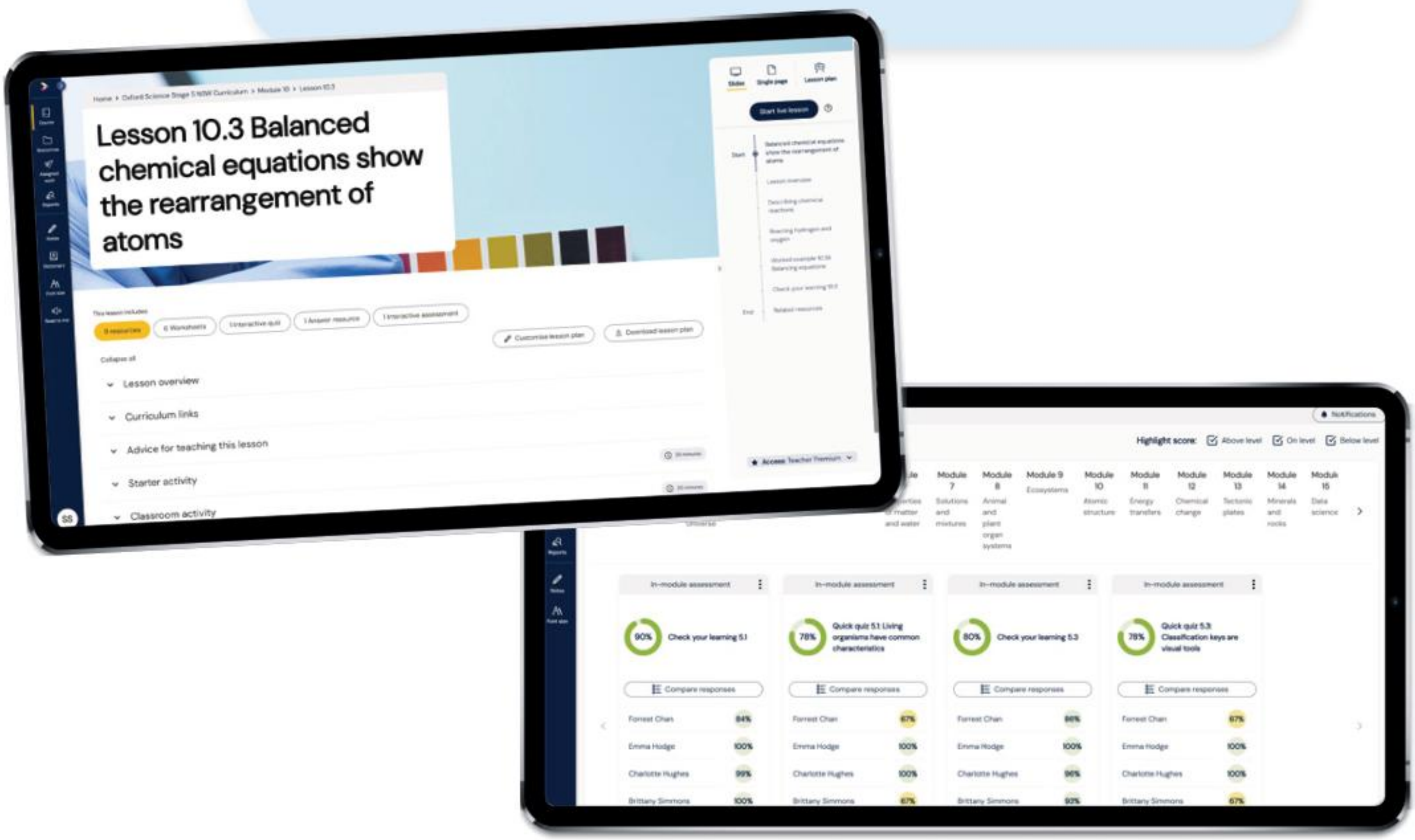

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Meet the authors & reviewers

Melinda Mestre

Author

Melinda is currently the Head of Science in the independent school's sector. She has a Master of Educational Leadership (with Excellence) and holds degrees in science, chemistry and education. Melinda is also employed by various educational organisations and universities in a variety of roles including a unit convenor and sessional academic, teaching units relating to secondary education and science. Melinda sits on the Science Professional Learning Advisory Committee with the AIS, presenting at various science workshops throughout the last several years. Melinda is a passionate educator who is driven by supporting teachers in their understanding of how to teach science to promote student academic growth.

Lily Okati

Author

Lily Okati has over a decade of experience teaching science, physics, and chemistry across Stages 4–6. She holds a Bachelor of Science, a Master of Physical Chemistry and a Master of Education. In addition to her classroom teaching, she has contributed to the development of physics trial examination papers for the Catholic Secondary Schools Association. Her professional interests lie in curriculum development and fostering deep scientific understanding among secondary students.

Timothy Sloane

Author

Timothy Sloane is the Head Teacher of Science at Concord High School, with over 20 years of experience teaching HSC biology in NSW schools. Before teaching, he was a published research scientist in cardiovascular disease. He holds a Master of Education, focusing on ICT in science education to boost student engagement.

His profile within the science teaching community and expert knowledge of assessment, curriculum content and best practice delivery of that content has led to multiple high-profile leadership and resource development opportunities within the profession. He has presented at numerous conferences and workshops, including HSC Meet the Markers, the BEEST conference and the Centre for Professional Learning, where he has shared his expertise in syllabus programming, and the development of Stage 4 and 5 student research projects, and Stage 6 depth studies and associated marking criteria. Timothy has a keen interest in improving students' scientific literacy, focused on the use of A.L.A.R.M (A Learning and Responding Matrix) to enhance students' writing.

Additionally, he has conducted HSC student study workshops at UNSW, USYD and local community libraries, demonstrating his commitment to enhancing student learning and professional development in education.

Mora Soliman
Author

Mora completed a Bachelor of Technology in Biotechnology as her undergraduate degree and was a microbiologist before completing a Graduate Diploma in Education and starting her teaching career in 2003. She completed a Master of Education Leadership in School Education in 2013 and has been working in independent and Catholic schools in NSW over the last 20 years. She is currently Head of Science at St Vincents College in Ashfield and has taught chemistry, biology and physics for both the old syllabus and current syllabus. She is currently teaching chemistry and Science Extension. She has been a committee member and presenter for Association of Independent Schools and Science Teachers Association NSW. She has also been on exam committees for chemistry and Science Extension and has been a senior HSC marker for both chemistry and Science Extension. She worked with Oxford University Press on the Skills and Activity Book for the previous edition and is an author of the Data Science modules in this new edition.

Helen Silvester
Author

Helen Silvester is a neuroscientist by training and an experienced science educator with a passion for fostering scientific understanding. With over 20 years of experience in education, she has taught science to students ranging in age from 3 to 18 years. Helen is dedicated to science communication in all its forms, including teaching, presenting, curriculum design and textbook writing. She draws on her extensive experience and current research to develop innovative curriculum resources for both students and educators. Helen currently serves as the Learning Area Manager (Science) at the Australian Academy of Science, where she leads the development of the *Primary Connections and Science Connections* resources.

Jarrah Cain
First Nations reviewer

Jarrah is a proud Aboriginal woman who descends from the Gomeroi and Darkinyung nations. She is passionate about science and believes that through a culturally inclusive environment, we can learn best practices in environmental sustainability and management. Jarrah is a teacher inspired by her culture and connection to Country. She strongly believes that through sharing, advocating and leading Aboriginal education, we can make a difference and pave a path to a reconciled Australia. Jarrah is the recipient of the Deadly Science STEM Teacher Award for 2024 and is a role model for other Aboriginal women and girls who want to embrace a career in education and science.

Module 1

Working scientifically

Overview

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

This module builds on the skills covered in ***Oxford Science Stage 4 NSW Curriculum*** and explores new aspects of the scientific method and ways to communicate findings. These skills should be used while studying all focus areas in this course.

Lessons in this module

Lesson 1.1
Observing

Learning intentions and success criteria

Key ideas

- → In scientific investigation, measurements can only show that a hypothesis is supported or not supported if the measurements are accurate.
- → To achieve maximum accuracy, the measurement must be taken carefully, using the most suitable measuring device.
- → Each scientific measuring device must have a scale appropriate to the required accuracy.
- → To obtain measurements, we must observe the values on the measuring device.

true value the value that would be obtained if its measurement was free of errors

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

Observations

In science, making observations and reading measurements is one of the most important parts of an investigation. In order to record these observations and measurements, it is vital that the chosen measuring device is the best one for the job.

Choosing the right device

Choosing the right instrument is the first step in making sure the measurements are close to the **true value**. **Accuracy** is how close a measurement is to the true value. For example, if you needed to accurately measure the volume of a liquid, then you would use a burette (Figure 1) or a measuring cylinder, but not a beaker. A beaker usually has a few general measurement marks on the side of the container as an approximation of the volume. A measuring cylinder has many more marks that are closer together. This scale is more accurate, with less approximation of volumes than given by the marks on a beaker. A burette has even more marks closer together than a measuring cylinder, so a burette can give more accurate measurements than a measuring cylinder.

There are many ways to measure the mass of a sample. Traditionally, a set of scales was used, with weights on one side and the substance on the other (Figure 2). Scientists who used these devices needed to estimate when the top of the scale was horizontal to obtain an accurate measurement. Before a scale was used, the scientist would check that the top of the scale was horizontal before adding any weights.

Today, scientists use digital balances to measure the mass of a substance. They still check that the scale is "zeroed" before their sample is added. This is done by selecting TARE and checking that the reading is 0.00. If this is not done, then every measurement will be inaccurate.

Figure 1 A burette is a laboratory instrument used to accurately measure the volume of a liquid.

Figure 2 Traditional scales relied on the ability of the scientist to judge when the top bar was horizontal.

Depending on the scale, the measurements may be accurate to two, three or four decimal places. It is important to write down all the significant figures provided by the measuring devices.

Not only is accuracy important, so is **precision**. This relates to whether the measurements recorded in an experiment could be repeated if the experiment was conducted again (trials) or at another time (Figure 3).

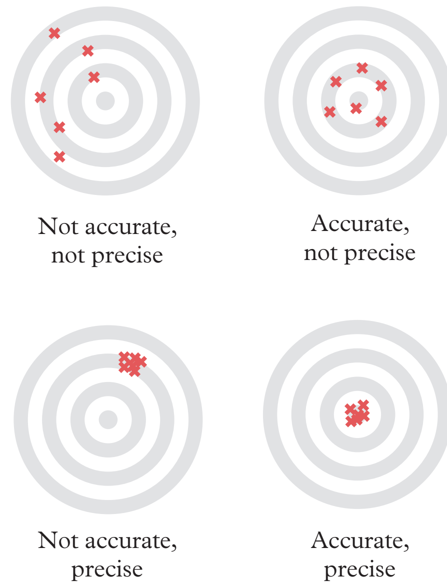


Figure 3 The accuracy and precision of data depends on the measuring devices used and the measurements observed.

precision the state of measurements being consistent and repeatable

Uncertainty

Sometimes, the amount being measured is between two values and this can happen when measuring the volume of a liquid in a measuring cylinder. In Figure 4, the liquid level is between 4.4 and 4.6 mL.

While most people would estimate the volume as 4.5 mL, a scientist needs to show the level of **uncertainty** in the value. When this occurs, the volume should be recorded as 4.4 mL (the bottom of the **meniscus** at eye level). A scientist then needs to show the level of uncertainty in the value. The uncertainty value is determined by halving the smallest increment of the measuring device. Since the measuring cylinder increases by increments of 0.1 mL, half of 0.1 is 0.05. This makes the uncertainty ± 0.05 mL.

Writing it as 4.4 ± 0.05 mL means that the volume could be any value between 4.35 and 4.45 mL.

uncertainty the range of possible values where the true measurement lies

meniscus the curve at the surface of a liquid in a container

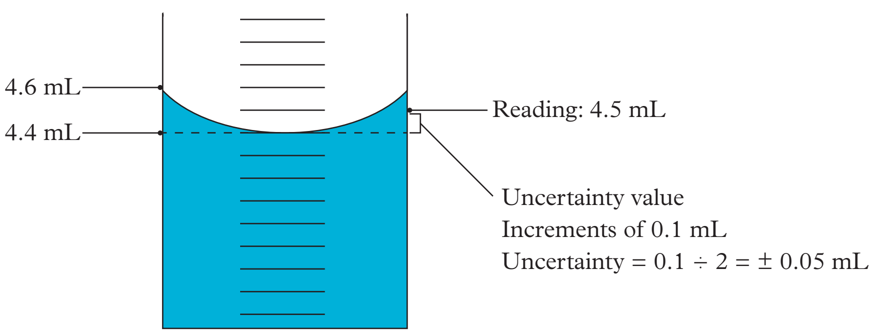


Figure 4 How the uncertainty of a measuring device is determined

Errors

When making observations using measuring devices, errors can occur. They are categorised as:

1. **systematic errors**, such as mis-calibrated equipment, environmental factors and following the wrong method
2. **random errors**, such as unpredictable changes in the environment, instrument limitations and difficulty reading the measuring instruments.

More information can be found in Lesson 1.4 Conducting investigations (page 21).

systematic error a consistent and predictable difference in measurements

random error variability in a measurement in either direction by an unknown cause or causes

Worked example 1.1A Adding uncertainties

A student measured the volume of a liquid in a measuring cylinder as 5.5 ± 0.05 mL. Calculate the range of the final volume of the liquid.

Solution

Steps	What to do	Working out
a.	The ± means there are two values: • where you add the value • where you subtract the value.	5.5 + 0.05 mL = 5.55 mL 5.5 − 0.05 mL = 5.45 mL
b.	Answer the question, with the smallest value first.	The range is 5.45–5.55 mL

Combining uncertainties

The level of uncertainty can also be shown when there are many measurements taken during an experiment. For example, an experiment that measured the time taken for a ball to fall to the floor and bounce back may have two measurements: the time taken for the ball to fall to the floor may be 3.35 seconds with an uncertainty of 0.005 seconds, and the time taken to bounce back may be 3.20 seconds with the same uncertainty. When the different measurements are combined, the amount of uncertainty is also combined.

Worked example 1.1B Calculating uncertainties

A student measured the volume of two liquids as 10.34 ± 0.005 mL and 5.12 ± 0.005 mL respectively. Calculate the range of the final volume of the two liquids if they were combined.

Solution

Steps	What to do	Working out
a.	Calculate the final volume by adding the volume of the two liquids.	10.34 mL + 5.12 mL = 15.46 mL
b.	Calculate the final uncertainty by adding the uncertainties of the two volumes.	0.005 mL + 0.005 mL = 0.01 mL
c.	Calculate the range of the final volume by adding and subtracting the final uncertainty to and from the final volume.	15.46 mL + 0.01 mL = 15.47 mL 15.46 mL – 0.01 mL = 15.45 mL
d.	Answer the question.	The range of the final volume could be 15.45–15.47 mL.

Check your learning 1.1

Check your learning 1.1

Retrieve

1 Define the term “uncertainty”.

2 Define the term “accuracy”.

Comprehend

3 Explain why a measuring cylinder or burette should be used to measure a volume instead of a beaker.

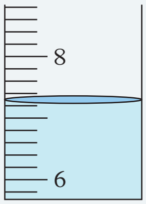


Figure 5 Water in a measuring cylinder

Analyse

4 Calculate the volume and uncertainty of the volume shown in Figure 5.

5 Calculate the value and uncertainty of the final volume when solution A (23.8 ± 0.05 mL) is added to solution B (13.2 ± 0.05 mL).

6 Calculate the mean and uncertainty of the following values: 19.6, 12.9, 21.8, 11.2.

Lesson 1.2
Questioning and predicting

Key ideas

→ Before we begin a scientific investigation, we need to come up with a question first.

→ The question we come up with must have measurable parts.

→ A hypothesis is the predicted outcome of the investigation and links the dependent and independent variable.

→ The hypothesis is written as an "If … then … because …" statement.

Learning intentions and success criteria

Introduction

Science is a way of asking and answering questions about biological, chemical, physical and technological worlds. It allows us to explore the unknown and use our knowledge to solve problems.

Questioning and predicting

All scientific investigations start by asking a question. There are many types of questions that can be asked. 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?").

Big questions often need to be broken down into a series of smaller questions that can be answered over time (Figure 1). For example, the question: "How did the Universe start?", could be broken down into the following questions.

- What is a Universe?
- What makes up our Universe?
- What is the state of our current Universe?
- How is our Universe changing?
- Can we measure these changes?
- Have these changes always occurred?
- What is causing these changes?

Figure 1 Scientists might ask: "How did the Universe start?". To investigate this, they also need to ask questions that can be tested and measured.

Another example is the broad question: "How does climate change affect ecosystems?", which 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?"

Forming a hypothesis

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

hypothesis a proposed explanation for a prediction that can be tested

Once the question is testable, the scientist can predict the outcome of the test and state the reason for their **prediction**. A **hypothesis** is then 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 of hydrogen peroxide, then more gas will be produced because more yeast suspension increases the rate of reaction" (Figure 2).

This hypothesis includes the variables to test (amount of yeast suspension used), the predicted outcome (more gas produced) and the reasoning behind the prediction (scientific knowledge about rates of reaction). Hypotheses like this guide investigations and help scientists focus on gathering the right data to draw conclusions.

Independent variable	IF 6 drops of yeast suspension (instead of 3 drops) was added to 2 mL of hydrogen peroxide
Dependent variable	THEN twice as much gas would be produced in the same time
Possible explanation	BECAUSE increasing the amount of catalyst will increase the rate of a reaction.

Figure 2 How a hypothesis is developed using the measurable variables of the investigation

Using data to support or refute questions and hypotheses

refute prove a statement to be false or incorrect using evidence

When we perform experiments or carry out research, we often start with a hypothesis: a statement or idea we think might be true based on what we know. Data collected from an investigation is then used to support or **refute** a hypothesis. For example, if our hypothesis is: "If a plant has more access to sunlight, then the plant will grow taller because more sunlight means the plant can undergo photosynthesis", we could gather data by measuring the height of plants grown in different light conditions. If the plants in brighter light grow taller, the data supports our hypothesis, but if the plants do not grow or do not grow as high as the plants in sunlight, the data doesn't match what we predicted, and we may need to revise or refute our hypothesis. This process of testing ideas with data helps us understand the world more accurately and make better decisions.

Check your learning 1.2

Check your learning 1.2

Retrieve

1 Define what it means to "operationalise a question". Give an example to support your definition.

2 State the purpose of a hypothesis in a scientific investigation.

3 State two testable questions scientists might ask.

Comprehend

4 Describe the steps needed to operationalise a question in a scientific investigation.

5 Explain why breaking a big question into smaller, testable questions is important in science.

6 Explain why it is necessary to specify the variables when forming a hypothesis.

Analyse

7 A student conducted an experiment to test how the amount of sunlight affects plant growth. They used three identical plants.

a Analyse the data and identify the relationship between sunlight exposure and plant growth.

b Predict what might happen if the experiment was repeated using different plant species.

» Plant A was placed in full sunlight for 8 hours a day.

» Plant B was placed in partial sunlight for 4 hours a day.

» Plant C was kept in the shade with no direct sunlight.

After 2 weeks, the plants had the following growth measurements.

- Plant A: 12 cm taller
- Plant B: 6 cm taller
- Plant C: 1 cm taller

8 Consider the following statement:

"If participants in Group A use brand A toothpaste for 6 weeks, then they will have whiter teeth than participants in Group B, who used brand B toothpaste for 6 weeks."

a Identify what is missing from this statement to make it a hypothesis.

b Identify the independent and dependent variables being tested.

c Identify one controlled variable in the experiment. Explain why it is important for this variable to be controlled.

Apply

9 A student wanted to demonstrate that heating a chemical reaction will cause it to happen faster. They wanted to test it using a dissolvable Alka-Seltzer tablet.

a Create an operationalised question for this investigation.

b Construct a hypothesis for this investigation.

10 Describe how a hypothesis that is shown to be wrong can still be useful. Justify your answer (by providing an example that matches your description).

Lesson 1.3
Planning investigations

Learning intentions and success criteria

Key ideas

→ Investigations must be valid and reliable.

→ Bias can affect the outcome of an investigation.

→ Controlled investigations need to have control groups and may have positive and negative controls.

→ Types of scientific investigation include case studies, modelling or simulations, quantitative analysis and controlled experiments.

→ Data can be qualitative or quantitative.

→ The following variables must be considered in an investigation: controlled, independent, dependent and confounding.

→ Data should be kept in a paper-based or digital logbook.

→ Before performing an investigation, all risks should be identified in a risk assessment.

→ When considering whether or not to undertake an investigation, scientists must ensure their investigation is ethical.

Purpose of an investigation

The purpose or 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.

For example, if we are investigating how the concentration of an acid affects the rate of a chemical reaction, the purpose of our 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 we aim to learn and what variables to measure, such as the time it takes for the magnesium to dissolve.

Types of data

When conducting a scientific investigation, one of the most important steps is determining what data we need to collect. The type of data depends on the kind of investigation we are doing. For example, if we are testing how temperature affects the rate of a chemical reaction, we will need to collect data about temperature and the time it takes for the reaction to occur. On the other hand, if we are investigating the effect of light on plant growth, we will need to collect data about the amount of light, plant height and the number of leaves.

qualitative data information that is descriptive and cannot be represented by numbers

There are two main types of data that are collected in investigations.

1 **Qualitative data**: This type of data is descriptive and deals with qualities or characteristics that cannot be measured with numbers easily. For example, in a plant

growth investigation, we might describe the colour of the leaves or how healthy the plant looks. This type of data helps us observe trends, but is not as precise as quantitative data.

2 **Quantitative data**: This is numerical data that is measured and counted. It involves things like counting how many bubbles are produced in a chemical reaction, measuring the temperature at different times or determining the mass of a substance. Quantitative data is important for comparing results and making evidence-based conclusions.

quantitative data information that can be counted or measured; numerical values

When planning an investigation, we should also consider how we will collect and organise the data. Will we measure the temperature every minute or only at the beginning and end? Do we need to record qualitative observations, like the colour change in a solution, along with quantitative data, like the amount of acid used? Understanding the type of data we need will help us plan our experiment effectively, ensuring we collect the right information to answer our research question.

Planning an investigation

There are many ways to plan an investigation. The type of investigation used is called the **methodology**. This is different to a **procedure** (the step-by-step process of an investigation, also known as the method). The methodology that a scientist uses will depend on the type of question and the equipment that is used.

methodology the overall approach to a scientific investigation

procedure a series of clear steps that are followed when conducting a scientific investigation; also called a method

Bias

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. Biased observations only tell one side of a story, so they can sometimes cause inaccurate data and leave a false impression. There are many ways bias can affect a scientific investigation.

bias leaning towards or against an idea by being prejudiced or unfair

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

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

Types of bias

Confirmation bias

When a researcher has a hypothesis that they are certain is correct, they may shape their investigation so that the data supports this hypothesis. We call this **confirmation bias**, and it involves favouring information that "confirms" a hypothesis.

Sampling bias

Sampling bias occurs when an experiment tests a small group of subjects (either people or objects) that do not represent the larger group (Figure 1). For example, during pre-election surveys, people were asked who they would vote for via landline phone surveys in city regions. These surveys often missed people who were not home during the day or who did not have a landline phone because they only used their mobile phone. This meant the prediction of who would win the election was biased because the sample only represented people who owned landline phones.

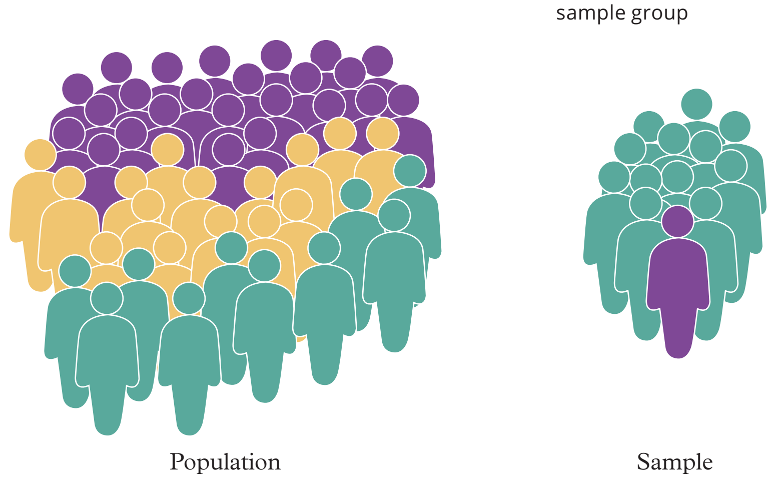


Figure 1 Sampling bias exists when the population of the sample doesn't reflect the actual population.

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.

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.

randomised when people, objects or similar are selected at random

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

Instead, the two groups should be **randomised** (randomly assigned to a group), and both groups should appear to receive the same treatment. For example, both groups should be given a pill 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 are so convinced that the treatment will work that a placebo makes 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. Some of 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**.

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

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 the real 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 decide 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**.

Investigation methods

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

Fieldwork

In fieldwork, scientists collect data directly from the natural environment, rather than in a laboratory. Data collected from fieldwork 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 fieldwork, scientists can collect accurate data from the environment.

Laboratory experimentation

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

Other investigation methods

Other types of investigation methods include:

- simulations
- modelling
- surveys
- case studies
- comparative studies
- longitudinal studies.

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

Variables

One of the most important parts of a scientific investigation is identifying the variables that affect the outcome of the experiment.

Most investigations will have many factors or variables that could change the results. For example, an investigation that tests how to improve the growth of a plant is affected by the following variables: type of soil, amount of water, amount of sunlight, temperature of the environment, amount of air and concentration of different gases in the air. A good experiment will keep these variables the same, except for one. The variables that are kept the same throughout an investigation are called the **controlled variables**.

The **independent variable** is the only variable that is deliberately changed by the scientist. Using the example of the plant experiment in Lesson 1.2 Questioning and predicting (page 7), the scientist should keep the soil, temperature and amount of sunlight and air the same for all plants. The only thing that may change is the amount of water the plants receive. Then the scientist will know if the amount of water causes a change in the **dependent variable**. The dependent variable is the variable that is measured at the end of the investigation and it is "dependent" on any change in the independent variable.

Confounding variables are a third type of variable that impact both the independent and the dependent variables. For example, weather is a confounding variable in an investigation examining the relationship between the level of sunburn and the number of ice creams sold. While it might appear as if there is a direct correlation between sunburn in individuals and the number of ice creams sold, one variable does not cause the other. Instead, the confounding variable is the weather and the amount of sunlight, which causes the changes in the other two variables.

controlled variable a variable that is kept constant and unchanged throughout an investigation

independent variable a variable that is changed in an investigation

dependent variable a variable in an investigation that may change as a result of changes to the independent variable

confounding variable a variable that is not measured but may impact the results of an investigation

Materials and technologies

Selecting suitable materials and technologies is a critical aspect of successfully conducting scientific investigations. When choosing tools and materials, it is important 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. The correct technology must be used as well, such as digital probes to record temperature or pH more accurately (Figure 4).

Figure 4 (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.

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

Valid investigations

valid where a test investigates what it sets out to investigate

The dependent variable must be selected carefully to make sure the investigation is **valid**. An investigation is valid if it measures what it claims to measure. The scientific validity can be checked by asking three questions.

- Does the investigation relate to what happens in the real world?
- Does the investigation measure a dependent variable that is relevant to the aim?
- Does the investigation control all the other factors that might affect the outcome?

For example, if a scientist wants to test the growth of a plant, they need to consider what variables they want to investigate. Growth can mean the height of the plant, the number of leaves, the size of the leaves, the length of the roots or the number of roots. A valid experiment would identify which of these dependent variables would apply in the real world and would not be affected by the other factors (such as how tightly packed the soil may be).

An example of a poorly designed investigation is one based on the scientific question: “Does eating eggs cause your hair to grow faster?” The researchers compared the hair length and egg intake of two groups of people. They found that everyone had different diets, but the people who had a faster hair growth rate ate more eggs than people who had a slower hair growth rate. The researchers could have concluded that eggs made hair grow faster, but they knew that the experimental comparison was not valid because there were too many uncontrolled variables. This meant that there were many other factors (health factors or supplements) that could have contributed to the results. The experiment also assumes that eating eggs is what causes hair to grow. This means the experimental comparison fails the valid test for both method and measurement.

reliable consistency of a measurement, test or experiment

repeatable the same results and observations can be made under the same conditions and using the same method

reproducible the ability to repeat and replicate a test exactly

Reliable investigations

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 affect the dependent variable need to be identified and controlled for.

Control groups

Controlled investigations keep all the variables the same except for the independent variable. If the independent variable is changed, then it needs to be compared to a **control group**. The control group is a second group of organisms, chemical reactions or physical conditions for which the independent variable has not been changed (Figure 5).

control group a group of organisms, chemical reactions or physical conditions that can be compared to the group that has had the independent variable changed

In biology, the effect of the amount of water on plants might be investigated, where the independent variable is the amount of water. The control group and the experiment group would contain identical plants with the same soil, temperature, sunlight and air conditions. The control group would then receive a standard amount of water, while the experiment group would receive a different amount of water.

In chemistry, a control group might be a set of chemical reactions that occur at a standard temperature, while the experiment group's reactions occur at an increased temperature.

In physics, an experiment group of model cars might have a mass added compared to the control group.

In psychology, the control and experiment groups must contain the same number of people of the same ages and general health. They should differ only in regard to the independent variable being tested.

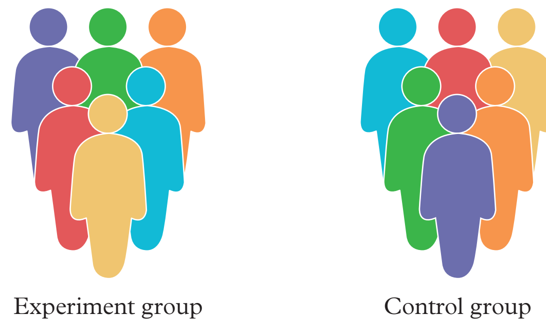


Figure 5 An experiment to determine the effectiveness of increased sleep on exam results requires matching participants' age, sex, food intake, amount of exercise, amount of sleep and general health. Having similar characteristics in each group reduces the number of variables when comparing results.

Positive control

The **positive control** is an individual test that makes sure that a positive result is possible. For example, in a test to determine if a soap can kill bacteria, a positive control is one where a soap known to kill bacteria is used in the same method (Figure 6).

positive control an individual test that checks that a positive result is possible in an experiment

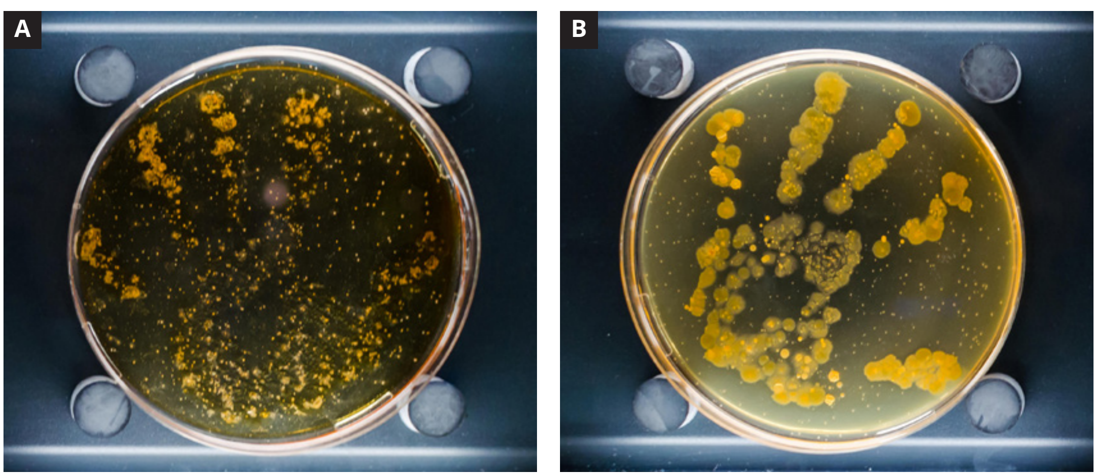


Figure 6 When testing the effectiveness of hand-washing with soap in killing bacteria, the positive control (A) will see a known soap that can kill bacteria used when washing your hands, whereas the negative control (B) will just involve washing your hands with water.

Negative control

A **negative control** is an individual test to check that the different materials will not affect the dependent variable. For example, in a test to determine if a soap can kill bacteria, a negative control would be to use water (without soap) to wash your hands.

negative control an individual test that checks that a negative result is possible in an experiment

Modifying an investigation

When conducting an investigation, it is important to stay flexible and be willing to modify our approach if new evidence or unexpected results emerge. For example, if we discover that the temperature is affecting our experimental results in a way we did not anticipate, we might decide to control the temperature more carefully or conduct the experiment in a more temperature-stable environment.

Modifying our investigation based on new evidence allows us to refine our methods, ensure more accurate results and address any issues that might affect the outcome. Being open to change also encourages a deeper understanding of the problem, leading to more reliable conclusions. This process of adjusting our methods helps improve the investigation and ensures that the data we collect is valid and meaningful.

Using a logbook

logbook a book used to record all the details of experiments or research projects

All scientists, whether conducting fieldwork or laboratory experiments, keep a **logbook** to record their research, observations and data. Logbooks can be paper-based or digital (with regular back-ups to prevent data loss).

A well-maintained logbook should contain both expected and unexpected results. These observations are crucial, as they might indicate new patterns or raise questions that lead to further inquiry. If we make any modifications to our investigation method, these changes should be recorded carefully. For example, if we decide to adjust the amount of a chemical used or change the time interval between measurements, we should note these changes and describe how they affect the results. By documenting these modifications, we can track how each change influences the outcome, which can be invaluable when analysing the data or revising our experimental approach.

Before starting any investigation, we should always write down the name of the investigation and the date at the top of the page. This helps us stay organised and ensures we can easily reference our investigation when writing formal reports, preparing for tests or reviewing our work in the future. Properly recording this information keeps our research structured and allows us to reflect on the progress of our experiments over time.

Setting up a logbook

All scientists have basic rules when using a logbook.

1. A logbook should be a bound notebook specifically for laboratory work or research. If you use loose sheets of paper, you might lose them, and using a computer is only successful if you make continuous back-ups of your data.
2. Your logbook should include your name, your school and your teacher's name. This way, if you misplace your logbook, you reduce the risk of losing all your data.
3. The logbook should contain a table of contents on the second page. This will help you navigate your way through experiments and research when it comes time for your Student research project. An example of a table of contents is shown in Table 1.
4. Use a consistent style for recording notes and data.
5. Every entry in your logbook should be dated.
6. You should record everything in your logbook in pen. If you make a mistake, simply cross it out. Never use liquid paper or white-out tape; this ensures that everything is true and not forged (including results!)
7. Entries should be clear and concise. You don't need to use full sentences.
8. If you do use any loose paper or images, glue them down or sticky tape them so they can't be lost.

9 If you change anything about your research or an experiment, write it down. This will help you see where you might have gone wrong and how you fixed it.

10 Record any observations during an experiment. This will help you write your final report.

Table 1 Example of a table of contents for a logbook

Science area	Experiment title	Page number
Chemistry	Rates of reactions	4
Biology	Factors affecting plant growth	7
Physics	Newton's first law	9

Risks: anticipate, recognise and eliminate

As scientists, we work with many hazardous materials when completing experiments. As a result, we need to be aware of **risks**; anything that might affect our health or safety in the laboratory. The laboratory is a safe place, provided hazards are anticipated, recognised, eliminated or controlled.

risk the potential for harm

safety data sheet (SDS) a document providing information about how to minimise the risk associated with the use, handling and storage of hazardous chemicals

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 7).

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 Section 8 - Exposure control and personal protection. 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.

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.

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 10.

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.

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.

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.

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

Figure 7 Example of a safety data sheet (SDS) from a manufacturer or certified provider

Figure 8 The hazards identified in an SDS are displayed by many industries, including the mining industry.

The SDS can contain a lot of information, including the type of protective equipment that must be worn (Figure 8 and Figure 9) and the specific hazards of chemicals (Figure 10). The SDS can also include the following.

- How to dispose of the chemical safely. This section should include the disposal containers which can be used, the effects of sewage disposal and the special precautions needed to ensure the safety of individuals and the environment.
- How to transport the chemical. This section should include any special precautions for transporting the chemical. This may include the hazchem code (the code provided by the government for each class of chemical).
- An Australian telephone number from which information about the chemical can be obtained in an emergency.
- The date the SDS was last reviewed. The hazards identified in the SDS are often used by industries to create safety signs which they display around the work environment (Figure 8).

Writing a risk assessment

risk assessment the determination of quantitative or qualitative estimate of risk related to a well-defined situation and a recognised threat (also called hazard)

Writing 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 affect the safety and risks associated with the experiment. An example of a risk assessment table is shown in Table 2.

Figure 9 Emergency workers in sealed positive-pressure protective suits communicating with each other

Table 2 A risk assessment table for an experiment involving a reaction between a magnesium ribbon and hydrochloric acid

Chemical	Risk	Precaution	Management
200 mL of 1 M 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 are 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 case of a fire, use a fire extinguisher to handle any ignition of gas.

Ethics

Ethics are a set of principles that provide a way to think when making decisions. Sometimes when we make a decision, we use the rules that are written down, such as the school rules or the laws of the government. Other times we use the rules that are not written down. Some rules are set according to what is normal for the people around us. For example, the unwritten rules in a 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 is written down; however, everyone in the class will know them and behave accordingly. The expectation that we should behave according to the values of those around us is called the **cultural norm**.

Figure 10 Pictograms such as these are often seen on the labels of chemicals to communicate specific hazards.

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 (Figure 11).

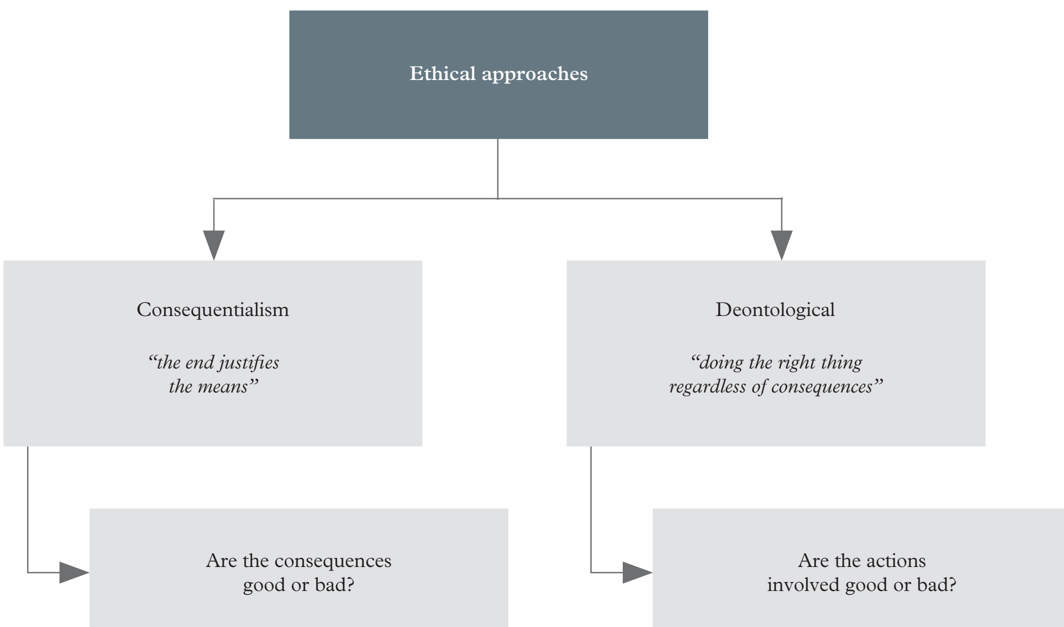


Figure 11 A consequentialist approach to ethics considers the consequences. A deontological approach considers duties and rules.

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

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

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 invention of dynamite (patented in 1867) was bad because it had been used to kill many people, and that the science should 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" despite the outcome.

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

Check your learning 1.3

Check your learning 1.3

Retrieve

1 Define the term "SDS".

2 Define the term "bias".

3 Define the term "placebo".

Comprehend

4 Compare the terms "valid" and "reliable".

5 Explain why a control group should have participants with similar or comparable characteristics to those of the experiment group.

6 Explain why it is important to review an SDS before starting an experiment.

7 Explain why it is important to have all the names of a chemical on an SDS.

Analyse

8 Identify the variables that need to be controlled in an experiment that tests the following hypothesis. Describe how you could control each variable.
Hypothesis: If the speed of a car is increased from 60 km/h to 80 km/h, then the distance taken to stop will increase from 27 m to 36 m because the car will travel further before the driver reacts and the braking distance will also increase.

9 Identify a positive control and a negative control for an experiment where an electric circuit is set up to determine whether a crystal is able to conduct electricity.

10 Contrast repeatable experiments and reproducible experiments.

Apply

11 Discuss how a scientist can avoid confirmation bias when designing an experiment to test the effectiveness of adding phosphorus to soil to improve plant growth.

12 Your class is investigating whether adding coffee grounds to soil helps a plant grow faster. One of your classmates suggests adding tea leaves to the soil of a plant as a negative control. Evaluate this suggestion (by defining a negative control, comparing the definition to the student's suggestion and deciding whether adding tea leaves would act as a negative control).

13 Determine the name and contact details of the government body in your state that regulates chemicals.

14 Using different ethical approaches can lead to different opinions about what is right and wrong. When this occurs, there is not always a single correct answer to the ethical dilemma. Instead, the consequentialist and deontological approaches can be used to understand the reasons for the different opinions and to provide a common base to discuss the ethical decision that each person would make.

a Is it ethical to:

- **i** dissect humans post-mortem to determine the cause of their death
- **ii** test vaccines on animals to determine the safety of the vaccines
- **iii** test new drugs on humans to determine the safety of the drugs
- **iv** use foetal cell lines in the development of vaccines
- **v** dissect animals in science classes
- **vi** develop new flexible plastic moulds (to make ceramic false teeth) that do not degrade
- **vii** use Aboriginal and Torres Strait Islander Peoples' knowledge to develop a commercial product without their permission?

b For each problem:
- **i** describe the issue using consequentialist ethics
- **ii** describe the issue using deontological ethics
- **iii** identify any conflicts between the two approaches
- **iv** describe the decision you would make
- **v** explain the reasons for your decision.

Lesson 1.4
Conducting investigations

Key ideas

→ When conducting an investigation, follow the procedure and wear appropriate safety equipment.

→ Data should be presented in an easy-to-read format, such as a table, to help minimise any data collection errors.

→ If using secondary sources in your report, use a referencing method to identify where you found the information.

Learning intentions and success criteria

Safety in the laboratory

When completing investigations, follow the laboratory rules and work in a safe manner. Before starting your investigation, put on protective equipment, including safety glasses, lab coat and gloves. When setting up your work bench, ensure there is sufficient work space. As you perform your procedure, keep in mind any safety risks identified on your risk assessment. Store equipment and any chemicals in a safe manner on your bench to minimise chemical spills and equipment damage and breakage.

Equipment

The ability to set up and operate your equipment safely and effectively will determine how accurate and reliable your data is.

For example, when investigating the relationship between voltage, current and resistance in physics, a circuit diagram will show the layout of the circuit (Figure 1). Once in the laboratory, you must understand how to set up the circuit correctly using the wires, power supply and ammeter/voltmeter, and also how to manipulate the equipment if the circuit doesn't work.

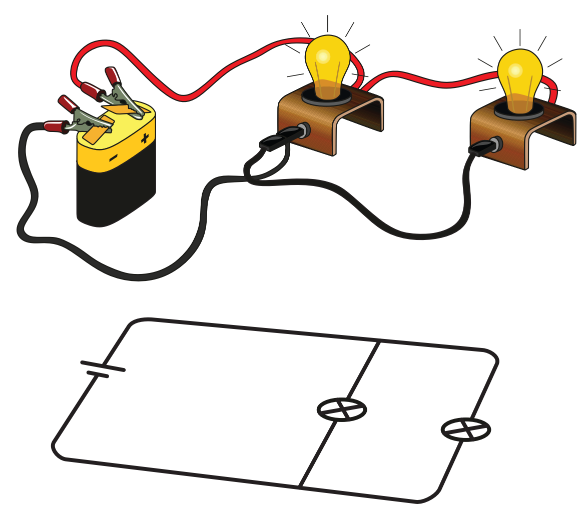


Figure 1 Constructing an electrical circuit from a circuit diagram may require problem-solving skills if the circuit doesn't work once connected.

Following the procedure

Following a planned procedure accurately ensures the reliability and validity of the investigation. If errors occur along the way, you can restart that part of the investigation (time permitting) and make a note of the errors in your logbook, or you can continue with the investigation and discuss the impact of the errors on your final results and how the investigation could be improved.

For example, during a chemistry experiment to investigate the effect of concentration on reaction rates, you might realise that you accidentally used an incorrect volume of a solution. In response, you could restart that part of the experiment with the correct measurements (if time permits and extra materials are available), noting the mistake in your logbook.

Collecting and recording data

During the investigation, you will collect and record qualitative and quantitative data in your logbook 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 accurately collect data and minimise errors, measurements should be double-checked before they are recorded, and the data should be presented in a clear and structured manner, such as in a table (Table 1). Qualitative data can also be recorded in the table or as a list in your logbook.

When recording the results of your experiments, your data should be neatly presented in a table, using the following four steps.

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.

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

The change in water temperature over time

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.

Errors

There are many variables that can affect the outcome of an experiment. Something as simple as breathing on the scales can change the measurement of an object's mass, 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.

Another error that can occur is a **systematic error.** These 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 2) or carefully checking that there are no other variables in the method that will affect the outcome will minimise these errors.

Other ways to reduce errors include:

- using equipment that is more accurate and sensitive in taking readings. For example, using a digital thermometer instead of an alcohol thermometer.
- recording your results immediately once observed so they are not forgotten or a mistake is made.
- controlling all the variables except the independent variable.
- following the method carefully and consistently, as well as practicing using the equipment correctly.

Figure 2 Checking the accuracy of scales will minimise errors in data.

Reliable secondary sources

A reliable secondary source is one that provides accurate, well-researched and credible information 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.

Referencing secondary sources

If you use a secondary source in your investigation report, you must reference the material to acknowledge the original creators. This allows those reading your report to trace the sources of information for further research and adds credibility to your work. Failing to reference properly can lead to accusations of plagiarism (copying).

The most common referencing methods are listed below and have specific formatting rules:

- Harvard
- Oxford
- American Psychological Association (APA)
- Modern Language Association (MLA)
- Chicago/Turabian.

Today, there are online referencing generators that will create your references after you input all the required information. Your teacher will tell you which referencing method they would like you to use.

Check your learning 1.4

Check your learning 1.4

Retrieve

1 Explain why data should be recorded in a table.
2 Describe the way you can determine if secondary sources are valid.
3 Identify three things you need to include in a reference.

Comprehend

4 Explain why an experiment should have a clear and detailed method.
5 Describe the factors that contribute to the validity of an experiment.
6 Explain why you may not get exactly the same outcome twice if you repeat an experiment.

Apply

7 Evaluate the claim that "an increased sample size makes an experiment more reliable". Justify your answer by:
- defining the terms "sample size" and "reliable"
- explaining the effect of increasing the sample size in an experiment
- deciding whether increasing the sample size makes an experiment more reliable.

8 Scientists often have to present their findings to the public in order to get action taken. Sometimes this is difficult, so they need to be sure that their findings are valid and reliable. Discuss how the scientific method ensures that the findings are valid and reliable by:
- defining the terms "independent variable" and "dependent variable"
- describing the importance of controlling all other variables
- identifying why it is important for the method to be repeatable and reproducible.

Lesson 1.5
Processing data and information

Learning intentions and success criteria

Key ideas

→ There are two types of data: primary data and secondary data.
→ Data can be represented in numerous ways, including graphs, keys, models, diagrams, tables and spreadsheets.
→ The type of graph used will depend on the type of data collected.
→ The mean, median and mode (measures of centre) are used to analyse data mathematically.
→ Data can be extracted from texts, diagrams, flowcharts, databases and multimedia resources.
→ Data is analysed and used to support or refute a question or hypothesis. This data can be used to solve problems that occur in the real world.

Introduction

There are two types of data: primary data and secondary data. **Primary data** is data that you collect from your own experiments. This data relies on the careful planning of the experiment to make sure it is a valid experiment that produces reliable results. The second form of data is collected by other people. This data is called **secondary data**.

When analysing secondary data, it is important to ask a series of questions. These questions might be as simple as:

- Is the data trustworthy?
- Where did the data come from?
- Why did the person collect the data?
- Is the data biased?

primary data data collected by the person writing the report

secondary data data collected by someone else

Representing data

Once data is collected from an investigation, knowing how to effectively organise and represent the data is crucial for interpreting and communicating scientific findings. Representations such as graphs, models, diagrams, tables (covered in Lesson 1.4 Conducting investigations, page 21) and spreadsheets 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.

Choosing the right representation

Each representation has strengths and is useful in different situations. The key to effectively organising data is knowing when and how to use each type of representation.

- Graphs are best for showing trends or relationships between sets of data.
- Models are used to simplify and visualise complex systems or processes.
- Diagrams are great for showing structures, processes or systems.
- Tables are useful to organise large amounts of data for easy comparison.
- Spreadsheets are ideal for storing, calculating and analysing data quickly and efficiently.

By using the right tools to organise data, we can make sense of the information we collect, draw meaningful conclusions and communicate our findings clearly.

Keys

A key is a tool used in diagrams to help identify and differentiate objects or organisms based on their features. Keys are used in biology to classify plants or animals. They typically use a series of yes/no questions or choices that lead to the identification of a particular item.

For example, a key might ask: “Is the leaf shape broad or narrow?” or “Does the plant have flowers or not?”

Using a key and working through the questions helps us identify the correct species or object.

Models

Models are representations of systems, structures or processes, and are 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 flowchart). Models help us understand how things work by simplifying complex ideas into something easier to study and experiment with. For example, a model of the water cycle helps us understand how water moves through the environment without needing to observe the entire process first hand.

Diagrams

A diagram is a drawing or chart that shows the parts of something and how they are related. Diagrams are commonly used to explain processes or systems. For example, a food chain diagram shows the flow of energy from one organism to another in an ecosystem, or a circuit diagram shows how electrical components are connected in a circuit. Diagrams help us visualise the structure and function of complex systems, making it easier to grasp key concepts.

Spreadsheets

spreadsheet a digital tool that allows you to organise, calculate and analyse data displayed in rows and columns

A **spreadsheet** is a digital tool that allows us to organise, calculate and analyse data in rows and columns. Programs like Microsoft Excel or Google Sheets are popular examples of spreadsheets. Spreadsheets offer several advantages over traditional paper-based tables because they allow us to perform calculations, create graphs and sort or filter data easily.

For example, if we are tracking the growth of plants over several weeks, we could use a spreadsheet to enter the plant heights and automatically calculate the average height, generate graphs or track the changes over time.

Measurements and units

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

Although the SI unit for mass is the kilogram, this is not always the most suitable unit to use. Some objects are too heavy or too light for this to be the most convenient unit. The measurement would have too many zeroes in it. For example, masses of 0.00000000743 kg or 850,000,000 kg are very inconvenient to write. So scientists and mathematicians choose a unit that requires as few zeroes as possible. They show this by using a system of prefixes before the basic measurement unit, as shown in Table 2.

Notice that when the number is larger than the basic measurement, the prefix is a capital letter. When it is only a fraction of the basic measurement, the prefix is a small letter (i.e. lower case). For example, a megalitre, which is a million litres, is written as ML, whereas a millilitre, which is one-thousandth of a litre, is written as mL. Kilograms is an exception to this general rule. A kilogram is 1,000 grams, and its symbol is kg.

Table 1 SI system of units

Physical quantity	SI unit	Abbreviation or symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K
Amount of a substance	mole	mol
Electric current	ampere	A

Table 2 Standard prefixes and meanings

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

Graphs

There are many tools that are used to analyse the data of an experiment. One important tool is a graph of the data. All graphs should have:

- the independent variable on the horizontal x-axis
- the dependent variable on the vertical y-axis
- a descriptive title
- units of measurement.

The type of data – whether discrete or continuous, qualitative or quantitative – affects how we organise and represent it because different data types highlight different patterns or relationships (Table 3).

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

Table 3 Summary of data types and how they are represented

Type of data	Description	Representation
Discrete data	Distinct, separate values like the number of students in a class	Bar graph, table or pie chart
Continuous data	Values within a range, such as height or temperature	Line graph or histogram (to show fluctuations over time or a range of values)
Qualitative data	Description of characteristics like colour or texture	Categorical table or bar chart
Quantitative data	Numerical values like weight or time	Line graph, scatter graph or histogram (to allow for precise measurement and analysis)

discrete data data where the numbers can be separated into different groups

continuous data data that is measured and can be any value, such as height, mass, speed, temperature and distance

Line graphs

line graph a graph used to display continuous data that is connected by a line; typically used to demonstrate trends in data

Line graphs are used when both the independent variable and the dependent variable are continuous data (Figure 1). 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.

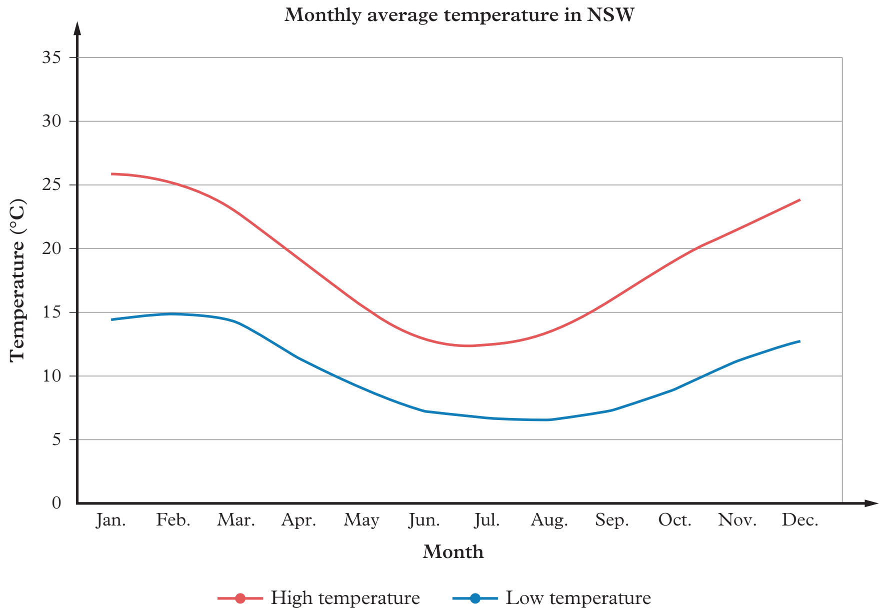


Figure 1 A line graph plots continuous data. In this graph, two data sets are included and are represented by different colours to make it easier to interpret.

Scatter graphs

scatter graph a graph used to represent continuous data; it consists of discrete data points

line of best fit the line on a scatter graph that passes through, or nearly through, as many data points as possible to show any overall trends in the data

Scatter graphs 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, showing the positive or negative relationship (correlation) between two variables (Figure 2).

Figure 2 A scatter graph with a line of best fit

Qualitative data, describing characteristics like colour or texture, is best displayed as a bar graph or column graph. These graphs are used when either the independent variable or the dependent variable has discrete data. The main difference between a bar graph and a column graph is that a column graph has vertical bars (Figure 3), while a bar graph has horizontal bars.

Common features of graphs

There are four features all graphs have in common:

1 a descriptive title of what the graph shows
2 a grid that is used to plot the points or data
3 the independent variable on the horizontal axis
4 the dependent variable on the vertical axis.

Units should be included on each axis, in brackets, when relevant.

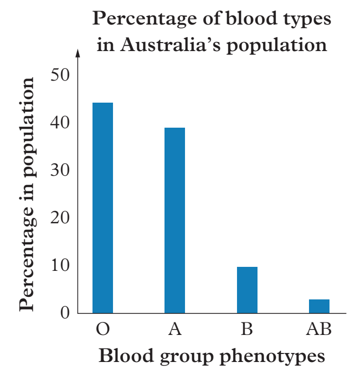


Figure 3 A column graph is used to represent discrete data.

Extrapolating graphs

Graphs are used to show data and also to analyse data and 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 (data points that are very different to the rest of the data).

Extrapolation occurs when data is estimated outside the known values. To extrapolate a graph, 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 4).

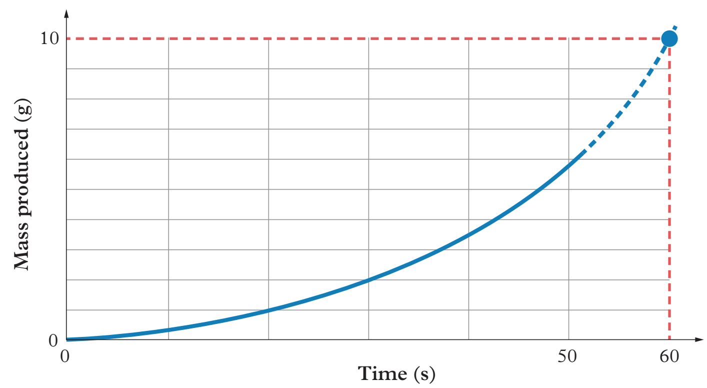


Figure 4 The data was only collected for 50 seconds. Extrapolating the data to 60 seconds (blue dotted line) can introduce errors.

extrapolation estimating unknown values from trends in known data

interpolation an estimation of a value within the original range of the data

Interpolation and making predictions

While extrapolation involves estimating values outside the known data, **interpolation** estimates values within the range of the data 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 a graph, you simply use the existing data points 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 and reading the value (Figure 5).

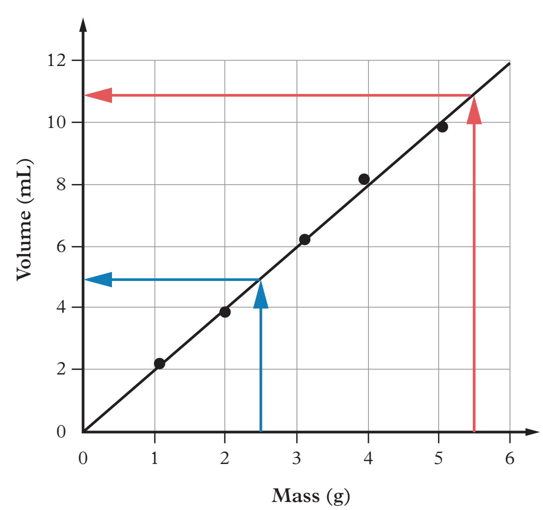


Figure 5 Interpolation uses existing data points to estimate unknown values and is more accurate than extrapolation.

Reliability of predictions

Both extrapolation and interpolation allow us to make predictions based on trends shown in graphs. Extrapolation should be done cautiously, however, 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 is important to consider the reliability of the predictions and whether additional data could improve the accuracy of our results.

Extracting information

Texts

When extracting information from texts, we should summarise the main ideas and note any supporting evidence. For example, while reading an article on climate change, we might highlight data on temperature trends and summarise the findings about the impact of human activities.

Diagrams

Diagrams visually represent information, making complex data easier to understand. We should focus on interpreting labels, symbols and relationships between components. For instance, in a water cycle diagram, we would identify processes like evaporation, condensation and precipitation, and demonstrate how they are interconnected.

Flowcharts

Flowcharts illustrate sequences of steps or processes, using arrows and boxes to indicate the progression and decision points. For example, a flowchart explaining the steps of photosynthesis would help us visualise the process more easily (Figure 6).

Databases

Databases store large amounts of data that can be queried and analysed, using search functions and filters to find specific information. For example, using a database of animal species might help to extract data on the population trends of endangered species over the past decade (Figure 7).

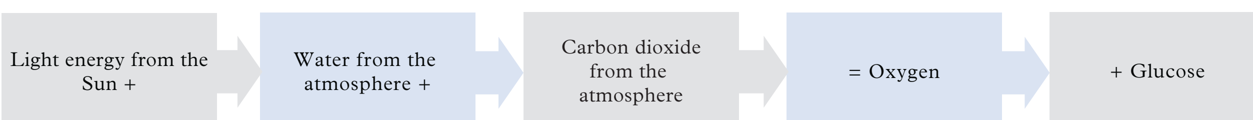


Figure 6 A flowchart can make it easier to follow a process than a diagram.

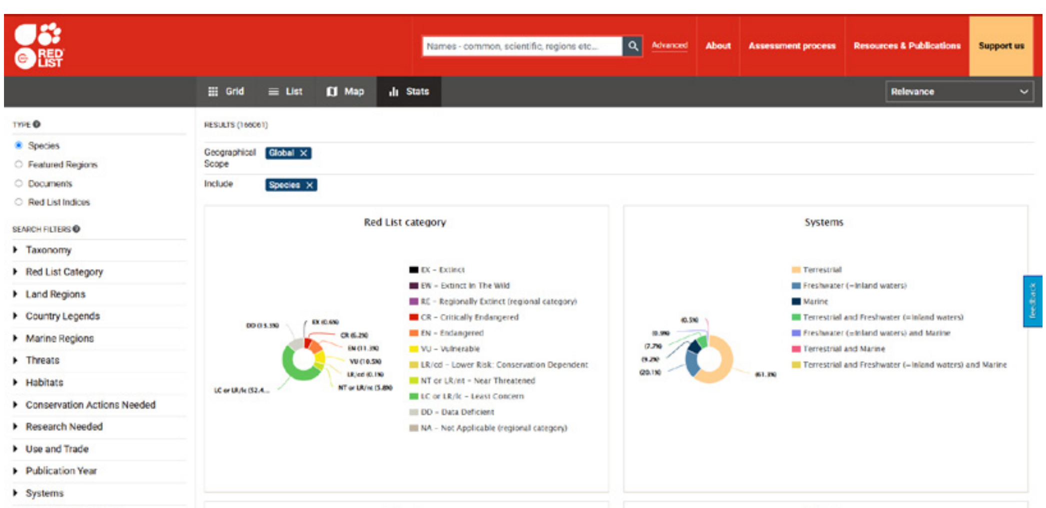


Figure 7 The International Union for Conservation of Nature (IUCN) Red List is a database of threatened species around the world.

Multimedia resources

Multimedia resources include videos, animations and interactive tools, and use key visuals and audio cues to display relevant information. For instance, if we watch a video on volcanic eruptions, we might note the types of eruptions, the effects on the environment and how they are detected.

Analysing numerical data

There are many ways to use mathematics to represent data. The measures of centre of a data set are outlined in Table 4. Worked example 1.5A shows how to find the measures of centre of a data set.

Table 4 How to determine the measures of centre of a data set

Measure	Description
Mean	• The expected or average value of a data set. • It is calculated by the formula: $\text{mean} = \frac{\text{sum of all values}}{\text{the number of values}}$
Median	• The middle value of a data set. • 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 of a data set. • It is calculated by tallying how many times each number appears. The number that appears the most is the mode.

mean the average of a set of numbers calculated by adding the numbers and dividing by the total number of values

median the middle value in a sorted data set

mode the value that appears most frequently in a data set

Significant figures

Calculations with significant figures are essential in science to ensure precision and accuracy in measurements and results. Following the rules for determining the number of significant figures in results avoids overstating its precision.

With multiplication and division, the number of significant figures should match the number of the least precise measurement in the calculation.

For example, when multiplying 4.56 (which has three significant figures) by 1.4 (which has two significant figures), the product is 6.384. Since the least precise measurement (1.4) has only two significant figures, the final result should be rounded to two significant figures, which is 6.4.

This rule is similar when adding or subtracting values, but in this case, we look at the number of decimal places.

For example, when adding 12.345 (which has three decimal places) and 7.12 (which has two decimal places), the sum is 19.465. Since the least precise measurement (7.12) has two decimal places, the final result should be rounded to 19.47.

Outliers

Occasionally, the data that scientists collect contains a value that is far away from the main group of data. These values are called **outliers** and may be due to inaccurate measurements or experimental errors. 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 5).

outlier a data point that does not fit with the rest of the data

From the table, it is clear 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 5 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

Worked example 1.5A 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:

a mean **b** median **c** mode.

Solution

Steps	What to do	Working out
a.	To calculate the mean for part **a**, all values must be in the same unit (seconds).	3 minutes × 60 = 180 seconds
b.	Calculate the mean by adding all the values, then dividing by the number of values.	mean $= \frac{278 + 167 + 180 + 208 + 180}{5}$ $= \frac{1,013}{5}$ = 202.6 seconds Therefore, the mean is 203 seconds.
c.	To determine the median for part **b**, all the values must be placed in increasing order.	167 s, 180 s, 180 s, 208 s, 278 s
d.	The median value is the middle value.	Median = 180 seconds
e.	The mode is the most common value in the data set.	Mode = 180 seconds (appears twice in the data set)

Data which supports or refutes

To identify data that supports or refutes questions and hypotheses, the data must first be analysed. This includes determining whether the independent variable affects the dependent variable.

For example, we are investigating the effectiveness of fertilisers on crop yield. The hypothesis might be, "if Brand A of fertiliser is used, then there will be a higher yield of crops because it contains more nitrogen". We would need to fertilise separate plots and measure the crop yield. If the data shows Brand A consistently produces a higher yield, then the hypothesis is supported. If the yields are similar or lower, then the data refutes (disagrees with) the hypothesis.

Proposed solutions

Data also helps to provide solutions to real-life problems. Whether we're trying to solve problems like pollution, health issues or traffic jams, data is key to finding out what works. For example, if a city wants to reduce traffic, they might collect data on how many cars travel on different roads at different times. Based on this data, they might propose solutions like building new roads or adding bus lanes. After the solution is implemented, the city can collect more data to see if traffic has improved. If the data shows traffic is still bad, it might mean the solution didn't work, and they may need to try something else. This is why data is so important: it helps us test ideas, solve problems and improve the world around us.

Check your learning 1.5

Check your learning 1.5

Retrieve

1 Identify the symbol for:
   - **a** millionths of a gram
   - **b** billions of litres
   - **c** thousandths of an ampere
   - **d** thousands of metres.

2 Recall what an outlier is.

3 In your own words, define:
   - **a** mean
   - **b** median
   - **c** mode.

4 Recall which variable is located on the horizontal axis of a graph.

Comprehend

5 Explain why it is best to present our data in table form.

6 Explain why graphs are used in scientific reports.

7 Describe how data helps us determine if our hypothesis is supported or needs to be changed. Provide an example from an experiment.

8 Explain why is it important to use data when proposing solutions to real-world problems, like traffic congestion or pollution. Provide an example of where data might help improve a solution.

9 Describe what to do next if your experiment shows data that refutes (disagrees with) your hypothesis. Explain how this process helps scientists learn more about the world.

10 Explain why extrapolating a graph can lead to errors.

Analyse

11 Identify the number of significant figures in each of the following measurements.
   - **a** 45.22 mL
   - **b** 9.0 s
   - **c** 8,000 L
   - **d** 3.005 m

12 A student took the following measurements for an experiment:
V = 5.6 volts, I = 2.97 amperes, t = 3,000 seconds.
Using $E = VIt$, determine how many significant figures should be in the final answer. Justify your answer.

13 A student measured the amount of hydrogen gas produced from an acid and metal reaction. They repeated the experiment five times to make sure the experiment was reliable. The amount of gas collected in each attempt is shown in Table 6. Calculate the mean, median and mode for the hydrogen gas produced.

Table 6 The amount of gas produced from an acid and metal reaction

Attempt	Amount of hydrogen gas (mL^3)
1	1.68
2	2.54
3	2.05
4	1.69
5	2.05

Apply

14 The speed of a car travelling down an entry ramp onto the freeway is recorded for 10 seconds. Using the Figure 8, determine the speed of the car at:

a t = 6 seconds

b t = 14 seconds.

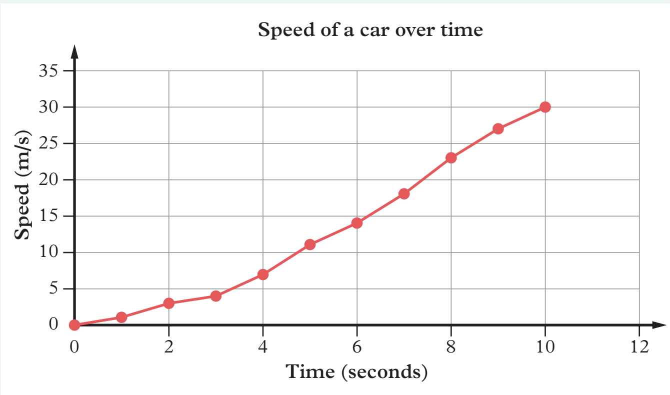


Figure 8 Graph showing the speed of a car over time

15 Justify if the speed determined in question **14b** is reasonable. (Hint: Multiply your speed by 3.6 to convert it to km/h.)

16 Figure 9 shows a graph drawn by a student. Identify all the errors on the graph.

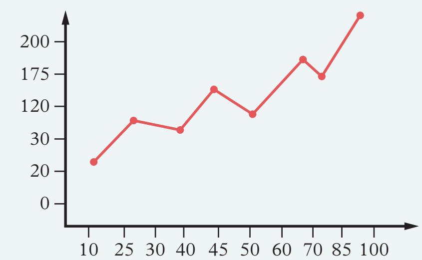


Figure 9 Graph drawn by a student

17 Construct a graph to best represent the data in Table 7. Explain what has happened during each month.

Table 7 The number of accidents that occurred at a local shopping centre each month.

Month	Number of accidents
January	3
February	4
March	5
April	5
May	8
June	13

Lesson 1.6
Analysing data and information

Learning intentions and success criteria

Key ideas

→ Describing trends in graphs helps define the relationship between variables.

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

→ Investigations must include a conclusion, identifying whether the hypothesis is supported or refuted using evidence.

→ Sources of uncertainty should be considered as well as alternative explanations for the observed results.

→ Information from secondary sources may not be true. Check who wrote it, where it is published and if it is current.

Describing relationships between variables

In science, we often look for **relationships** between different variables. For example, if we are 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, we 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. Other times, the relationship might be more complex or less obvious, and we'll need to collect more data or look for other factors that could be influencing the result.

relationship an association between two or more variables; observed when a change in one variable causes a change in another

Interpreting graphs

Line graphs are the most common graphs in scientific reports. These graphs show the relationship between the independent variable and the dependent variable. The shape of the graph gives a hint as to how the two variables are related (Figure 1).

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).

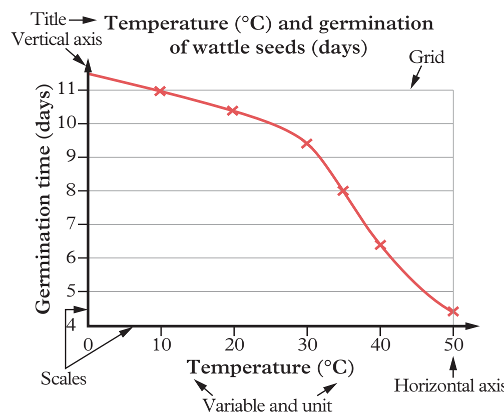


Figure 1 A line graph of the germination time of wattle seeds versus temperature

inversely proportional relationship a relationship between two variables in which the dependent variable decreases as the independent variable increases

Occasionally a graph is curved. These 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.

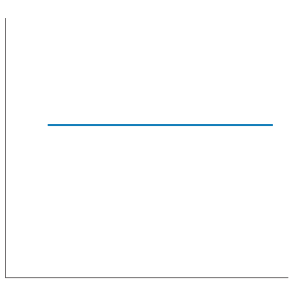


Figure 2 A horizontal line on a graph means the dependent variable is not affected by the independent variable

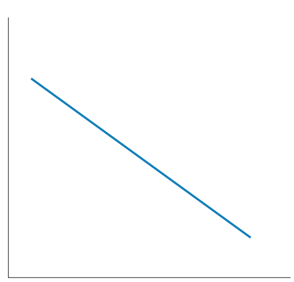


Figure 3 An inversely proportional relationship

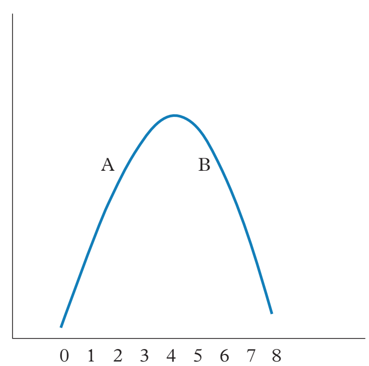


Figure 4 A curved graph is divided into sections that show different relationships.

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.

pattern when a set of data repeats in a predictable way

trend the general tendency of a set of data to move in a certain direction

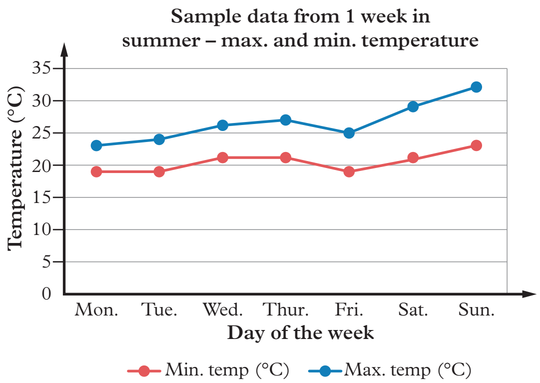


Figure 5 This graph shows a clear trend, with the temperature rising towards the end of the week.

For example, if we are looking at how the temperature changes throughout the day, we 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 allows us to predict what might happen next. It is also important to look for inconsistencies in the data; these are points that don't fit the general pattern. For instance, if the temperature drops suddenly during the afternoon when the trend suggests it should continue rising, it could be an inconsistency (or an outlier) that needs further investigation.

Assessing first-hand data

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

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.

Reliable and unreliable data

Reliable data

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 we measure the reaction speed at 25°C multiple times and get similar results each time, the data is reliable.

Unreliable data

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.

Drawing conclusions

After completing an investigation, we can draw a **conclusion** that aligns with the data and observations collected, ensuring it is based on accurate and reliable evidence. We explain whether our hypothesis was supported or refuted (using data to support our findings) as well as highlight the significance of the results.

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

For example, if testing whether 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."

Synthesising data and information

Synthesising data involves integrating information from various sources to create a well-supported argument. This allows us to draw strong conclusions based on a wide range of evidence. By combining data from studies, observations and resources, we can develop arguments that are logical and evidence-based.

For example, when researching the impact of deforestation on local ecosystems, we might use these sources for data and other evidence:

- climate data
- satellite images
- scientific studies
- surveys.

Integrating multiple sources of evidence presents a more comprehensive and convincing argument, highlighting the importance of using a range of sources to support scientific conclusions.

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.

Sources of uncertainty in an investigation can include the following.

- 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.

Alternative explanations

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

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

Validity of secondary sources

On social media you may find people making big claims about the latest scientific research. These claims cannot be trusted unless they pass validity and credibility tests. There are a number of things to look for before we accept a claim as valid.

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 an article written?

Some articles are written by or paid for by companies that want us to buy their products. Cosmetic companies claim that their skin cream will make us look younger, while car companies claim that their new suspension system will make our car drive more smoothly. Companies may write articles quoting scientific data to make their products look the best and ignore data that disagrees with their claim. Always consider why an article was written and whether it is biased towards a particular view.

Figure 6 (A) Peer-reviewed articles in science journals are valid secondary sources because they have been checked by other scientists. (B) Posts and articles on social media are not always valid sources because they may not have been checked for credibility, and posts can be sponsored by companies with their own agendas.

Is it current?

A current claim does not just mean the most recently written article. While the date on the article is important, it is worth checking if the data matches other available data.

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 is reproduced by other scientists. Does it fit with current research or is it from the same group of people using a 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 are actually "pay to publish" sites. These websites publish any article that is written as long as the authors pay the company. In 2005, Massachusetts Institute of Technology (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.

Check your learning 1.6

Check your learning 1.6

Revise

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 Describe what is meant by the phrase "pay to publish".

4 Explain what reliable data is.

5 Recall two places where we would find reliable research. Explain why these sources are reliable.

Analyse

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

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

8 Look at the following set of data showing the temperature at different times during the day.
   Describe the trend you notice in the temperature data. Identify any inconsistencies and explain what could cause them.
   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

9 The following data is from an experiment measuring the growth of plants in two different soil types.
   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.
      » 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

Apply

10 Describe the relationship between the independent variable and dependent variable in Figure 7.

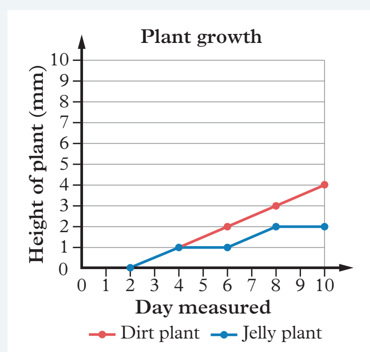


Figure 7 Height of plant versus day measured

11 Identify which of the following doctors could be trusted to comment on vaccines. Justify your decision (by describing the qualifications of each doctor and comparing these to the qualifications needed to understand vaccines).
   – PhD of English literature
   – Veterinarian
   – Epidemiologist

12 Explain how data is used to draw evidence-based conclusions.

Lesson 1.7

Investigation: What if the absorbency of different paper towels was compared?

Purpose

To measure and compare the absorbency of different brands of paper towel, which vary in their cost per square centimetre

Materials

- Three brands of paper towel
- Ruler and pencil
- Scissors
- 100 mL measuring cylinder
- Small beaker of water with a dropper
- Stopwatch
- 250 mL beaker
- Calculator
- Tweezers

Procedure

1. For one brand of paper towel, record the brand, price, number of sheets and the dimensions of each sheet in centimetres.
2. Cut a 20 cm × 20 cm square from one sheet from the brand of paper towel being tested.
3. Fill the measuring cylinder with water to the 100 mL mark, using the dropper for the last 2 to 3 mL. Ensure that your eyes are level with the scale to avoid parallax error.
4. Use tweezers to immerse the square of paper towel in the water in the measuring cylinder for 10 seconds. Use the stopwatch for timing. Hold the paper towel above the measuring cylinder, without squeezing the towel, for another 10 seconds, then remove it and place it in the 250 mL beaker.
5. Record the level of water left in the measuring cylinder and, hence, the volume of water absorbed by the paper towel in 10 seconds.
6. Complete two more trials by repeating steps 2 to 5.
7. Repeat steps 1 to 6 for the other brands of paper towel.

Results

- Calculate the total surface area and the cost per square centimetre for each paper towel, and record your results in a table.
  - The total surface area of the paper towel roll is calculated as follows:
    $A = l \times w \times$ number of sheets of paper towel
  - The cost of paper towel per square centimetre is calculated as follows:

$$\text{cost of paper towel} = \frac{\text{cost of roll}}{\text{total area of roll}}$$

- Calculate the average volume of water absorbed per 20 cm square of paper towel and record your results in a table.
  - The average volume of water absorbed per 20 cm square is calculated using the results from the three trials as follows:

$$\text{average volume of water} = \frac{\text{volume 1} + \text{volume 2} + \text{volume 3}}{3}$$

- Draw a bar graph to show the average volume of water absorbed for each brand.
- In your graph, place the brands in order from least expensive to most expensive. On each bar, state the price per square centimetre of that brand.

Discussion

1 State the reasons for the following.
  a Three readings were taken each time and then averaged.
  b The same-sized square was used each time.
  c The cost of the paper towel per square centimetre was calculated and used instead of the total cost of the roll.
  d Each square of paper towel was allowed to drip for precisely 10 seconds before removing it from the water.
2 Compare the absorbency of the different brands to the predictions you made in your hypothesis.
3 Evaluate the validity (by identifying any variables that might not have been controlled) and reliability (by describing whether you or other scientists will achieve the same results) of this investigation.
4 Identify the limitations of these results (by describing how testing with other solutions may achieve different absorbency).
5 Explain if the data supports or refutes your purpose and hypothesis.
6 Explain if the measurements you recorded for each brand of paper towel were precise.
7 Describe any problems you may have encountered when collecting the data and how the data collection process could be improved.
8 Identify how an investigation could be modified based on the data collected and if the purpose or hypothesis was refuted.
9 Predict, using your data, what volume of water would be absorbed if the paper towel was a:
  a 10 cm square
  b 40 cm square.

Conclusion

From your graph, identify any apparent relationship between the cost of the paper towel per square centimetre and its absorbency. Provide evidence (by mentioning values) from your results to support your answer.

Lesson 1.8
Problem solving

Key ideas

→ Problem solving uses various strategies, such as trial and error, brainstorming and algorithms.

→ When developing evaluation criteria for solving a problem, the criteria must be clear and measurable and must align with the goals of the problem.

→ Cause-and-effect relationships and models are used to make predictions based on observations and existing data.

→ There are many approaches that are used to solve problems, including investigations, fieldwork, “pros and cons” lists, and “strengths, weaknesses, opportunities and threats (SWOT)” analysis.

→ In the media, claims are regularly made about products or ideas. It is important to assess these claims before making an informed decision.

Learning intentions and success criteria

Introduction

Solving problems is not just about finding any solution; it is about selecting the right strategies, evaluating different approaches and using evidence to support conclusions. Whether we are investigating how to reduce pollution, increase plant growth or improve a product, the steps we take in solving a problem are crucial.

Strategies to solve a problem

A strategy is a plan of action designed to achieve a specific goal. There are a variety of problem-solving strategies used to investigate problems. These include the following.

- Trial and error: Trying multiple solutions until one works, but this can take a long time
- Algorithms: Using a procedure or mathematical formula
- Brainstorming: Collaborating with peers to generate a wide range of ideas and solutions
- Simulation and modelling: Using computer simulations and models to predict future patterns based on current data
- Comparative analysis: Comparing different data sets or case studies to identify patterns and draw conclusions
- Hypothesis testing: Forming a hypothesis and conducting an investigation to test it
- Root cause analysis: Identifying the underlying cause of a problem to solve it
- Decision matrix: Using a grid to evaluate and compare multiple options based on specific criteria.

Evaluation criteria

When developing evaluation criteria for solving a problem, it's important to ensure that the criteria are clear and measurable and that they align with the goals of the problem. Some suggested criteria include the following.

- Define the problem and its goals: What do you aim to achieve?
- Identify relevant variables: What factors (e.g. environmental, economic) will affect the solution's success?
- Make criteria specific and measurable: Use clear, quantifiable terms (e.g. "increase plant growth by 5 cm in 2 weeks").
- Accuracy, reliability and validity: Is the data precise and correct? Will the results be consistent when repeated? Does the method measure what it intended to measure?
- Effectiveness: How well will the solution work once the problem is solved?
- Consider different perspectives: Think about social, ethical, environmental and economic factors.
- Assess feasibility: Can the solution be implemented realistically within the available time and resources?
- Safety: What risks need to be considered?
- Refer to industry standards: Use established guidelines or expert recommendations.

Worked example 1.8A Evaluation criteria for investigating plant growth

A student aims to investigate which natural fertiliser – compost or manure – promotes the best plant growth. The investigation involves selecting fertilisers, applying them to identical plants and then measuring the growth over a set period.

Solution

Define the problem and its goals	Problem: Which natural fertiliser promotes the best growth in plants? Goal: To determine which of the two natural fertilisers (compost or manure) produces the greatest increase in plant height and overall health over 4 weeks
Identify relevant variables	Type of fertiliser: Compost or manure Amount of fertiliser: Measured in teaspoons or tablespoons Application frequency: Every 2 days or once a week Watering schedule: How much water the plant gets and how often Type of plant: Plants must be the same species to avoid variations in growth due to species differences
Make criteria specific and measurable	Effectiveness: Measure plant height at the start and end of the 4 weeks. The fertiliser that increases the plant height by the most (in centimetres) is considered the most effective.
Consider different perspectives	Ethical: Are the fertilisers eco-friendly and safe for the plants and environment? Does one fertiliser include harmful chemicals? Economical: Is the solution cost-effective in a small-scale experiment?
Assess practicality	Compost: Feasible and easy to get, requires little effort to apply Manure: Feasible but may require more careful handling and is less convenient for indoor use Cost: Total cost of the fertiliser should be under $10 for the duration of the experiment
Evaluate risks	Compost: No significant risks but may attract pests if not applied properly Manure: Risk of over-fertilising if applied incorrectly; the smell could be unpleasant
Refer to industry standards	Compare results: Compare your results to other research or similar experiments involving fertilisers.

Cause-and-effect relationships and models

We often use cause-and-effect relationships to explain how one event leads to another. For example, if you increase the temperature of a substance (cause), the particles move faster, which increases the rate of reaction (the effect). Higher temperatures provide more energy to the particles, allowing them to collide more frequently and with greater force, leading to a faster reaction. Understanding cause-and-effect relationships helps scientists make predictions.

Models are also useful in explaining these relationships. A model is a simplified version of something that helps us understand complex ideas. For example, a particle model shows how particles behave in solids, liquids and gases, helping us understand how matter changes in different conditions. Mathematical models are used to simulate the interactions of particles in complex systems, allowing us to understand the complex nature of the moving particles.

In the real world, models are tools that make predictions about future events. Meteorologists use computer models to predict conditions based on current atmospheric data (Figure 1). When we check the weather for the day or week, we receive information about temperature, humidity, windspeed and rain.

Figure 1 The Bureau of Meteorology uses models to make predictions about the weather based on data (website accessed May 2025).

By using cause-and-effect relationships and models, scientists make informed predictions about what might happen in similar situations in the future. These predictions guide experiments and lead to new discoveries.

Approaches used to solve problems

A scientific approach is a method that is used to solve a problem, and there are various approaches that are used. Comparing different methods helps to 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 (see Lesson 1.3 Planning investigations, page 10)
- fieldwork (see Lesson 1.3 Planning investigations, page 10)
- modelling and simulations
- comparative analysis
- writing a pros and cons list
- conducting a SWOT analysis
- creating cause-and-effect diagrams.

Pros and cons list

A **pros** and **cons** list is a simple tool used to evaluate the positive and negative aspects of a problem. By listing the pros and cons, we can weigh the advantages and disadvantages and make an informed decision (Table 1).

pro an advantage where the outcomes are favourable

con a disadvantage that is a risk or unfavourable outcome

Table 1 A pros and cons list on whether to investigate the effects of a new fertiliser on crop yield

Pros	Cons
Increased crop yield	Cost
Improved soil health	Environmental impact
Economic benefits	Uncertain results
Scientific advancement	Resistance to change

SWOT analysis

A SWOT analysis looks at the strengths, weaknesses, opportunities and threats of a solution to a problem (Figure 2). The strengths of a solution are the things that can be solved well, whereas the weaknesses are things that cannot be solved well with the suggested solution. Opportunities are the benefits of the solution. Threats are external; for example, government restrictions.

Figure 2 A SWOT analysis grid

Cause-and-effect (fishbone) diagram

A cause-and-effect diagram (also known as a fishbone diagram or Ishikawa diagram) focuses on identifying the problem; for example, climate change. It then identifies the main causes of the problem; for example, human activities. Once the main causes are identified, sub-causes are determined; for example, human reliance on fossil fuels and deforestation. These are often drawn as a fishbone diagram.

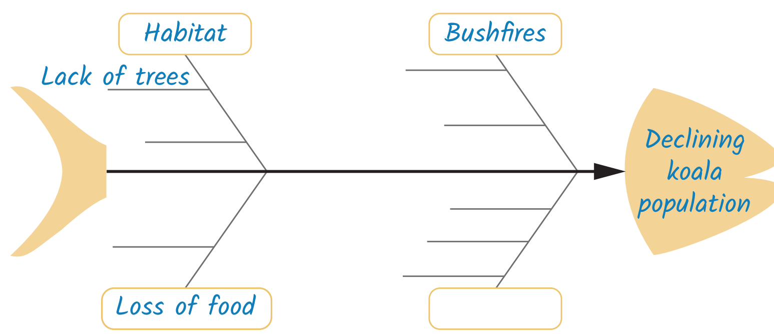


Figure 3 A cause-and-effect diagram

Evaluating claims using scientific knowledge and evidence

When we hear claims, whether in the news, from advertisements or from our family and friends, it is important to assess whether those claims are scientifically valid before making an informed decision. To do this, we should use scientific knowledge and evidence from investigations to determine whether the claim is credible. This involves recognising the limitations of the study, assessing the reliability of the data and considering alternative explanations.

For example, when evaluating a claim about the effectiveness of a new medication, we should review who conducted the trials, how the trials were run, the sample size, control groups and any biases, as well as the type of data collected. By using scientific knowledge and investigating the claim, we can make a more informed judgement about whether the claim is based on evidence or if it is misleading.

Check your learning 1.8

Check your learning 1.8

Retrieve

1 Name three strategies scientists use to solve problems.

2 Explain what the term "cause-and-effect relationship" means in science.

3 Describe what a SWOT analysis is and what it stands for.

Comprehend

4 Describe how a cause-and-effect diagram might help solve a problem in an experiment.

5 Explain how models are used to make predictions in scientific problem solving.

6 Identify the strengths and limitations of the following problem-solving approaches.

- **a** Fieldwork
- **b** Modelling and simulations
- **c** Pros and cons list
- **d** SWOT analysis
- **e** Cause-and-effect diagrams

Analyse

7 A scientist is testing the effectiveness of two different cleaning agents. They use a SWOT analysis to evaluate the two options. The analysis for cleaning agent 1 lists the strengths as "cost-effective" and "works quickly", but a weakness as "harsh chemicals". Cleaning agent 2 has the strength of "natural ingredients", but the weakness of "higher cost". Based on this analysis, explain which cleaning agent the scientist might choose and why.

8 Global warming is a current issue that is having an impact on weather patterns and ecosystems. Use Table 2 to:

- **a** identify any trends or patterns in the data
- **b** predict the monthly average maximum temperatures for 2025 and justify your reasoning.

Apply

9 Water pollution is a significant environmental issue that affects ecosystems and human health. Investigate the various causes of water pollution in a local river and create a cause-and-effect (fishbone) diagram to illustrate your findings.

10 Select and propose solutions to evaluation criteria designed to investigate air pollution, knowing that air pollution affects people's health and lifespan.

Table 2 Monthly average maximum temperatures (°C) in NSW in 2023 and 2024

Month	2023	2024
January	29.5	30.1
February	29.0	29.8
March	27.5	28.2
April	24.0	24.5
May	21.0	21.5
June	18.0	18.3
July	17.5	17.8
August	19.0	19.4
September	22.0	22.5
October	25.0	25.5
November	27.0	27.6
December	18.5	29.0

Lesson 1.9
Communicating

Key ideas

→ Scientific communication requires the author to modify their language to suit the audience.

→ Scientific reports communicate scientists' findings and arguments in a clear and concise way.

→ Scientific reports are written in a specific manner; for example, in the third person.

→ Scientists use the content of a scientific report to persuade readers of their point of view based on the authority of the text.

Learning intentions and success criteria

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 we are discussing, then we need to use simple diagrams, models and language so they can understand what we are saying. For example, two physicists may say, "Potential energy was added to the rubber band", whereas a teacher may explain that, "The rubber band was stretched".

How to present a scientific argument

To present an effective **scientific argument**, we use evidence to support our argument, and correct scientific language and terminology. This will depend on our audience and the purpose of our investigation. Our argument must be relevant and be understood by others in the specific community we are addressing.

scientific argument an explanation based on evidence rather than belief or opinion

Evidence

For example, if we are arguing that climate change is affecting local weather patterns, then we should present data on temperature changes, precipitation levels and extreme weather events. By using evidence, we demonstrate the validity of our arguments and persuade the audience of our 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, we should use terms like "reactants", "products" and "catalysts". This ensures that our arguments are understood by others in the scientific community.

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

Writing a scientific report

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

Table 1 Sections of a scientific report

Section	Description
Title	The title is a statement that includes the independent variable and the dependent variable.
Abstract	• The abstract is presented on its own page at the start of a report. • It offers a brief summary (no more than 250 words) about the aim, results and conclusion of an experiment. (Hint: We can read this to determine if the research is relevant to our topic.)
Introduction	• The introduction summarises any previous experiments that you have completed. • It describes the key concepts being examined and how they are related to your hypothesis.
Aim	• The aim is a statement of what you are trying to achieve in the experiment.
Hypothesis	• The hypothesis is a prediction of how the independent variable will affect the dependent variable and the reasons for the outcome. • If … <how the independent variable will change> … then … <how the dependent variable will change> … because … <reason for the change>.
Method	• The method is a list of materials, containing the concentrations and brands. • It provides step-by-step instructions or a brief description (in the past tense) that enables someone to repeat the experiment. • Safety advice or a risk assessment is included. • Relevant labelled diagrams are included where necessary.
Results	• The results data is presented in a table, graph or diagram. • A written summary of the results (stating facts without conclusions) is also included.
Discussion	The discussion section analyses 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 apply in the real world.
Conclusion	The conclusion answers the aim of the experiment by: • comparing the conclusion 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	• The references include any sources that you used to research the scientific concepts or definitions. • 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). For example: Silvester, H. (2023). *Oxford Science 10 Australian Curriculum* (2nd ed.). Oxford University Press.

unbiased showing no prejudice for or against something

objective without bias or prejudice

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

Scientific reports and papers are written in the third person so that the communication remains objective, rather than it 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.

Examples of the differences between scientific language and common language are given in Table 2.

Table 2 Scientific language compared to 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°C. (Past tense)	Heat the beakers to 50°C. (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 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.

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.

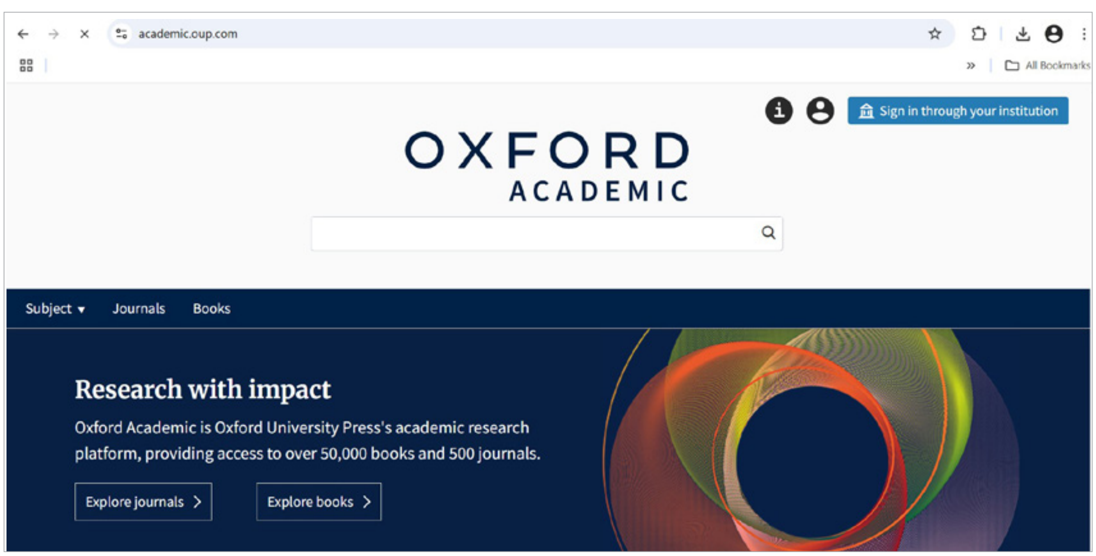


Figure 1 Scientific texts are available from publishing companies, universities and journals, and their credibility helps build trust with readers.

The descriptive sentence tells us what happened, but it does not give a scientific explanation for the behaviour of the flower. The scientific description offers a summary of what happened to the flower and why the flower reacted. It is important to be concise when writing scientifically and not include irrelevant information.

The role of scientific texts

Scientific texts present information that is logical, evidence-based and authoritative (Figure 1). By understanding the techniques used in these texts, we can critically evaluate the arguments and determine their validity.

Scientific texts cite reputable sources, use precise language and follow established scientific conventions, while also appealing to our logic and values. This builds trust and credibility, and makes their arguments relatable and persuasive.

Check your learning 1.9

Check your learning 1.9

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

Comprehend

3 Explain why scientists avoid using the first person to describe the results of an experiment.

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

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

6 Rewrite the following statements using scientific language.
- **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.

7 Explain why Wikipedia is not a credible source for scientific texts.

Analyse

8 Contrast the common meaning and the scientific meaning of the word “significant”.

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

10 Read the following two sentences. Assess which sentence uses scientific writing, and explain why it is scientific.
- **a** At 40°C, icy poles were softened in their packets and vanilla ice cream was melted.
- **b** On a very hot summer day, Sally noticed her delicious vanilla ice cream was completely melted and was almost like a milkshake. She also noticed that her fingers were sticky holding onto a lemonade icy pole for her brother.

Lesson 1.10
Review: Working scientifically

Summary

Lesson 1.1 Observing

- In scientific investigation, measurements can only show that a hypothesis is supported or not supported if the measurements are accurate.
- To achieve maximum accuracy, the measurement must be taken carefully, using the most suitable measuring device.
- Each scientific measuring device must have a scale appropriate to the required accuracy.
- To obtain measurements, we must observe the values on the measuring device.

Lesson 1.2 Questioning and predicting

- Before we begin a scientific investigation, we need to come up with a question first.
- The question we come up with must have measurable parts.
- A hypothesis is the predicted outcome of the investigation and links the dependent and independent variable.
- The hypothesis is written as an "If … then … because …" statement.

Lesson 1.3 Planning investigations

- Investigations must be valid and reliable.
- Bias can affect the outcome of an investigation.
- Controlled investigations need to have control groups and may have positive and negative controls.
- Types of scientific investigation include case studies, modelling or simulations, quantitative analysis and controlled experiments.
- Data can be qualitative or quantitative.
- The following variables must be considered in an investigation: controlled, independent, dependent and confounding.
- Data should be kept in a paper-based or digital logbook.
- Before performing an investigation, all risks should be identified in a risk assessment.
- When considering whether or not to undertake an investigation, scientists must ensure their investigation is ethical.

Lesson 1.4 Conducting investigations

- When conducting an investigation, follow the procedure and wear appropriate safety equipment.
- Data should be presented in an easy-to-read format, such as a table, to help minimise any data collection errors.
- If using secondary sources in your report, use a referencing method to identify where you found the information.

Lesson 1.5 Processing data and information

- There are two types of data: primary data and secondary data.Data can be represented in numerous ways, including graphs, keys, models, diagrams, tables and spreadsheets.
- The type of graph used will depend on the type of data collected.
- The mean, median and mode (measures of centre) are used to analyse data mathematically.
- Data can be extracted from texts, diagrams, flowcharts, databases and multimedia resources.
- Data is analysed and used to support or refute a question or hypothesis. This data can be used to solve problems that occur in the real world.

Lesson 1.6 Analysing data and information

- Describing trends in graphs helps define the relationship between variables.
- To determine the validity and reliability of data, the investigation must measure the intended variable and the data must be consistent across trials.
- Investigations must include a conclusion, identifying whether the hypothesis is supported or refuted using evidence.
- Sources of uncertainty should be considered as well as alternative explanations for the observed results.
- Information from secondary sources may not be true. Check who wrote it, where it is published and if it is current.

Lesson 1.8 Problem solving

- Problem solving uses various strategies, such as trial and error, brainstorming and algorithms.
- When developing evaluation criteria for solving a problem, the criteria must be clear and measurable and must align with the goals of the problem.
- Cause-and-effect relationships and models are used to make predictions based on observations and existing data.
- There are many approaches that are used to solve problems, including investigations, fieldwork, "pros and cons" lists, and "strengths, weaknesses, opportunities and threats (SWOT)" analysis.
- In the media, claims are regularly made about products or ideas. It is important to assess these claims before making an informed decision.

Lesson 1.9 Communicating

- Scientific communication requires the author to modify their language to suit the audience.
- Scientific reports communicate scientists' findings and arguments in a clear and concise way.
- Scientific reports are written in a specific manner; for example, in the third person.
- Scientists use the content of a scientific report to persuade readers of their point of view based on the authority of the text.

Review questions 1.10

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 is described in the method section of a scientific report.
 C Data is analysed in the results section of a scientific report.
 D A safety data sheet (SDS) should include the personal protective equipment (PPE) 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 Master of botany
 D PhD in epidemiology

4 Identify the main steps used when conducting an experimental investigation using 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.

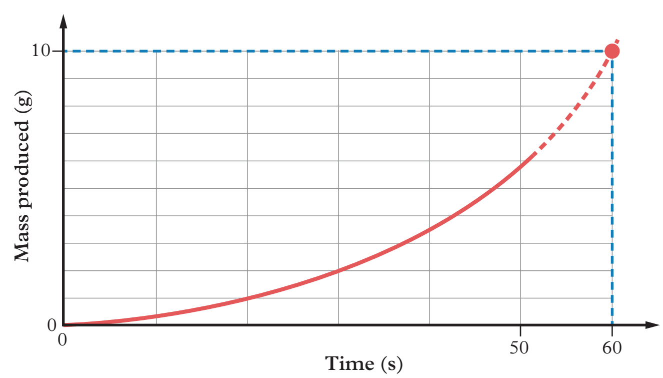


Figure 1 A graph created by a student

8 Identify three types of information that should be included on an SDS.

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 an 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 precise 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 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.

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

19 A student used a measuring cylinder to measure two volumes of 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

20 A 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. Then they decided to conduct more tests, so they 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 results. Justify your answer (by comparing the reliability of the test with 20 teenagers to that of 120 teenagers and deciding which is more reliable).

21 A scientist was commissioned by a jeans manufacturer to test various denims. The manufacturer wanted a more durable (long-lasting) 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?

22 A make-up manufacturer claims that their brand of tinted lip gloss will stay on for at least 6 hours, even while eating and drinking (Figure 3).
- **a** Create an experiment based on the scientific method to test this claim.
- **b** State your hypothesis.
- **c** Identify the variables you will be testing.
- **d** Describe the measurements you will take and how you will ensure that they are accurate.
- **e** Predict the results you would expect to obtain if your stated hypothesis was correct.

Figure 3 What results would be expected for the hypothesis of the tinted lip gloss investigation?

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

23 An investigation was conducted where the time taken to cover a distance was recorded for a runner in training (Table 1).
a Calculate the average speed for each segment of the run using:
$$\text{average speed} = \frac{\text{distance}}{\text{time}}.$$
b Discuss what the values calculated in part **a** mean, with reference to the runner.
c Explain if these results would be accurate and precise.
d Explain if the method would be reproducible.

Table 1 Data from one training sprint

Distance (metres)	Time (seconds)
0	0
50	10
100	22
150	28
200	40
250	55

Social and ethical thinking

24 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 or pictures were not used.
d Evaluate whether using the phrases or pictures disadvantage the person viewing the advertisement.
e Decide whether the phrases or pictures of scientists should be allowed in advertising.

Critical and creative thinking

25 One source of information for consumers is *Choice* magazine. The magazine reports the results of testing of consumer products.
a If a 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

26 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.

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 with at least 10 points, detailing any 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 4 People of all ages use mobile phones.

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?

- 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 (e.g. do they depend on where you live).

Figure 5 Why do people drink bottled water?

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.

- 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

Energy

Overview

The law of conservation of energy states that energy is always conserved during transfers and transformations, meaning the total energy stays the same. Not all energy transfers are 100% efficient, however, and some energy is wasted as heat or sound. A Sankey diagram shows how energy is transferred and transformed. We can use our understanding of energy efficiency to examine Aboriginal and Torres Strait Islander ground ovens. We will also compare different sources of energy which are used to generate electricity, such as coal, hydropower and solar.

Lessons in this module

Lesson 2.1
Energy cannot be created or destroyed

Learning intentions and success criteria

Key ideas

→ The law of conservation of energy states that energy cannot be created or destroyed.

→ When energy is transformed, waste energy is produced.

→ Efficient energy transformations produce less waste energy.

Law of conservation of energy

energy the capacity to do work

closed system a system that does not allow matter to enter or leave but does allow energy to be transferred in or out

matter anything that has space and volume; it is made up of atoms

isolated system a system that does not allow matter or energy to enter or leave

Humans have been fascinated with **energy** for thousands of years, from the heat energy released in the earliest human-generated fires to the energy that allows us to reach the Moon and beyond. There are different types of energy, such as heat, sound, electricity and light. One law is consistent across all forms of energy: energy cannot be created or destroyed.

Closed and isolated systems

A **closed system** is one where **matter** cannot enter or leave, but energy can be transferred into or out of it (Figure 1). This means it exchanges energy with its surroundings. The amount of energy lost by the system must be equal to the amount of energy gained by the surroundings and vice versa. The total amount of energy of the system and its surroundings remains constant, even if the energy is transformed (converted to a different form).

An **isolated system** is one where neither energy nor matter can enter or leave (Figure 1). This means there is no exchange of energy or matter between the system and its surroundings. The total amount of energy in an isolated system remains constant.

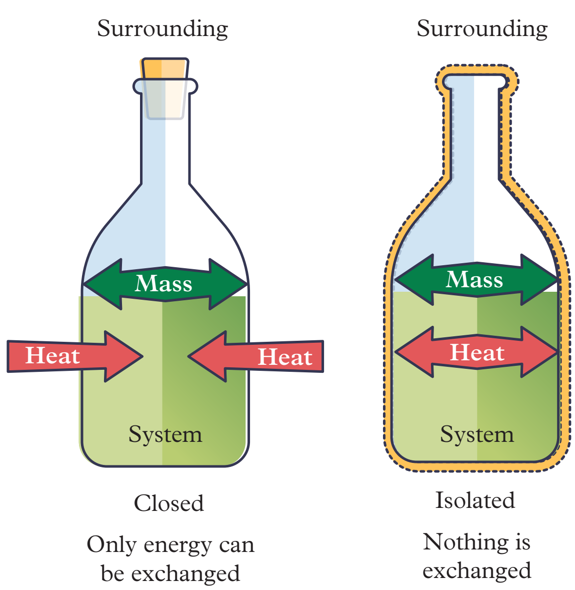


Figure 1 A closed system is one where matter cannot enter or leave, but energy can. An isolated system is one where neither energy nor matter can enter or leave.

In both closed and isolated systems, the total energy at the end must be equal to the total energy at the beginning. This principle is known as the **law of conservation of energy**. No energy can be created or destroyed, but it can be transferred (from one object to another) or **transformed**.

law of conservation of energy a scientific rule that states that the total energy of a closed system and its surroundings is always constant and cannot be created or destroyed

transformed describes energy that has changed into a different form

When we lift an object up in the air, we add gravitational potential energy. This energy did not just appear. The kinetic energy provided by our hand was conserved and transformed into the gravitational potential energy of the object. When the object is dropped, the energy is not destroyed. The gravitational potential energy is once again transformed into kinetic energy as it falls.

Energy efficiency

If a device transforms most of its input energy into the most useful output energy, like a trampoline, then it is considered to be a very energy-efficient device. Energy is said to be "wasted" if it is in a form that cannot be used, such as heat or sound. The less "wasted energy", the more energy-efficient the device. **Energy efficiency** is a measure of the percentage of useful energy transformed.

energy efficiency a measure of how much input energy is transformed, rather than lost (via sound or heat)

Theoretically, the total amount of energy is constant when you jump on a trampoline. In reality, there may be a small amount of heat energy produced as you fall due to air resistance. This "loss" of energy is not really a loss but rather just a transformation of energy to a non-usable form. The efficiency can be calculated by comparing how high above the trampoline you started and the height you reached on the rebound (usable final energy). Any difference in height is a result of heat and sound energy.

$$\text{Efficiency (\%)} = \frac{\text{useful energy output}}{\text{energy input}} \times 100$$

Take the trampoline example in Figure 2. The input energy was 500 **joules (J)** and the useful output energy was 400 J. This means that the trampoline is 400 ÷ 500 × 100 = 80% efficient.

joule (J) the unit of energy; its symbol is J

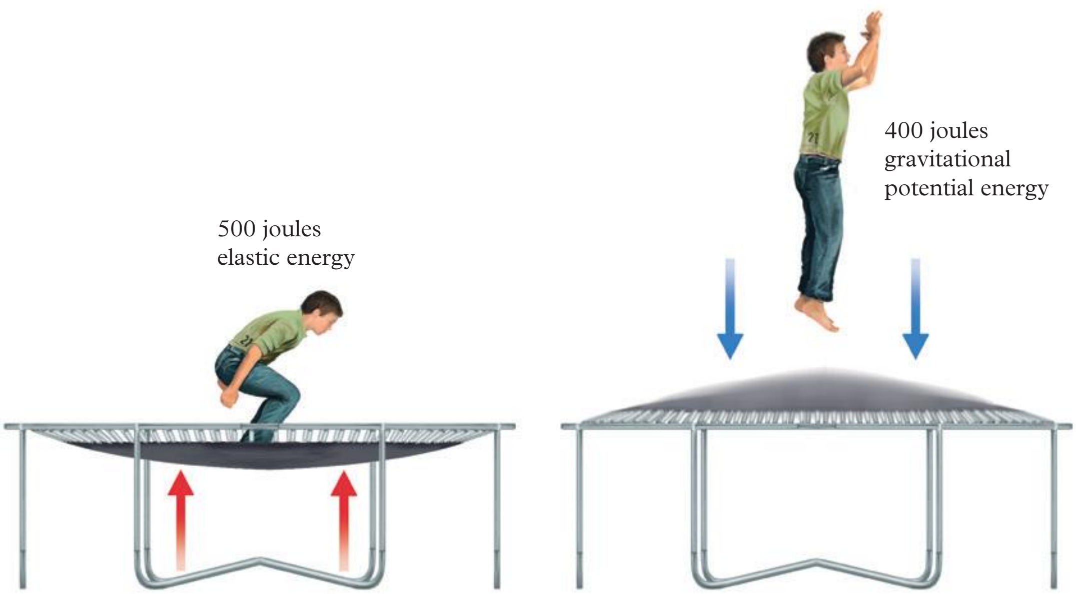


Figure 2 There is 500 J of energy stored in the springs of the trampoline. At the highest point, the jumper has 400 J of gravitational potential energy. Where have the 100 "missing" units gone?

Most energy transformations for everyday appliances aren't as efficient as trampolines. Scientists are constantly trying to design the best appliances possible with the highest efficiency ratings. This would make them better for the environment and cost less to power. Do you and your family always buy the most efficient appliances? Are you familiar with the star ratings on appliances? More stars mean that the appliance is more energy efficient. Not only is it good to know that less energy is being wasted, but it also means that when you pay your electricity and gas bills you are paying for energy that is being used rather than for energy that is being wasted.

Worked example 2.1A shows how to calculate energy efficiency.

Worked example 2.1A Calculating energy efficiency

Calculate the efficiency of a device if its input energy is 150 J and its waste energy is 60 J.

Solution

Steps	What to do	Working out
a.	Calculate the component of useful energy.	Useful energy = input energy − waste energy = 150 − 60 = 90 J
b.	Calculate the energy efficiency by substituting the values into the formula.	$\text{Efficiency (\%)} = \frac{\text{useful energy output}}{\text{energy input}} \times 100$ $= \frac{90}{150} \times 100$ = 60%
c.	State the efficiency of the device.	The device has an energy efficiency of 60 per cent.

Figure 3 When we drop a basketball on the ground, gravitational potential energy is transformed into kinetic energy.

Heat and sound waste energy

If no system is 100 per cent efficient, but the energy cannot be destroyed, then where does the energy go? In most cases, the energy is transformed into heat and sound energy. Think what happens when we drop a ball on the ground. The ball starts with gravitational potential energy which is transformed into kinetic energy when we drop it. When the ball hits the ground, it makes a noise. The louder the noise, the more sound energy it generates. If we bounce a ball many times in a row, we might feel the ball warm up. Heat energy has been generated. Both the heat and sound energy disperse into the air. They are not lost or destroyed. We cannot reuse them. They are by-products of the main energy transformation.

Figure 4 Dropping a glass bottle onto the ground generates and releases sound energy, producing a large shattering noise.

Pendulums

A pendulum is a mass that is attached by a string to a pivot point. When the mass is drawn upwards, it gains gravitational potential energy. When the mass is let go, the force of gravity pulls it back to its original position, converting the gravitational potential energy to kinetic energy. The momentum built up by the moving mass causes the mass to then swing in the opposite direction. This means all the kinetic energy is converted back into gravitational potential energy. Pendulums (like a swing in a playground) are a good example of how energy efficiency can be measured. Some kinetic energy is always lost as waste energy when it is transformed to heat and sound. This is evident when the pendulum does not quite reach the height at which it started.

Figure 5 A swing will not reach its original height because it loses energy as heat and sound energy.

Check your learning 2.1

Check your learning 2.1

Retrieve

1 Recall the law of conservation of energy.

2 Define "energy efficiency".

Comprehend

3 Give an example of a closed system in everyday life and explain why it fits this definition.

4 Explain what it means if a machine is 80 per cent energy efficient.

5 Determine why a pendulum eventually stops swinging if no energy is added.

Analyse

6 Explain why a rubber band that had 10 units of elastic energy cannot produce 12 units of kinetic energy.

7 For the rubber band in question **4**, calculate its percentage efficiency if 7 units of kinetic energy were produced. Describe where the remaining 3 units of energy have gone.

8 Identify and describe the by-product energy transformations for a car.

Apply

9 "Energy was lost when I bounced a ball." Do you agree or disagree? Think about the types of energy the ball had before, during and after the bounce. Explain how the law of conservation of energy applies in this situation and whether energy has truly been lost.

Skills builder: Questioning and predicting

10 Turning a scientific question into a hypothesis helps to structure an investigation. You are presented with the research question: "What happens to the amount of stored energy as a rubber band is stretched?"

- **a** Rewrite this question as a scientific question. (THINK: How can I make this measurable?)
- **b** Identify the dependent variable and the independent variable in your question. (THINK: What am I measuring? What am I changing?)
- **c** Develop a hypothesis for stretching a rubber band. (THINK: Have I included both variables? Have I included a potential result?)

Lesson 2.2
Sankey diagrams can represent energy efficiency

Learning intentions and success criteria

Key ideas

→ The conservation of energy can be represented in a Sankey diagram.

Drawing energy efficiency

A hair dryer has two basic components: a fan and a heating element. When plugged in and switched on, the fan motor spins and the heating element heats up. This means that a hair dryer converts electrical energy into thermal (heat) energy and kinetic energy. The air blown by the fan is directed over the heating element, passing the heat energy to the air which flows out of the hair dryer. Some hair dryers have different speed and heat settings that control the amount of electrical energy flowing to each part of the device. Processes such as these can be represented using a **Sankey diagram**.

Sankey diagram a flow chart that represents movement or change in resources, such as the transfer or transformation of energy

Sankey diagrams

A Sankey diagram is a type of flow diagram. Sankey diagrams are used to represent the efficiency of energy transfers and transformations. The diagram visually demonstrates how energy moves through a system, whether it is transferred from one object to another or transformed from one form to another. Each Sankey diagram has a series of arrows of different widths. The widths of the arrows represent the amount of energy that flows in and out of a system.

Let's look at the transfer and transformation of energy in toasters. Toasters use heating elements to convert electrical energy into thermal energy. Heating elements are made of wires that heat up without melting when electricity flows through them. These wires are poor **conductors** of electricity. If the wires resist the flow of charged particles and make it more difficult to move, then more electrical energy is transformed into thermal energy. The thermal energy is then passed to the air, which then passes the heat to the bread, toasting it. This transfer of energy can be represented in a Sankey diagram (Figure 1).

conductor a material or substance that electrons can flow through; the flow of electrons through a conductor is electrical current

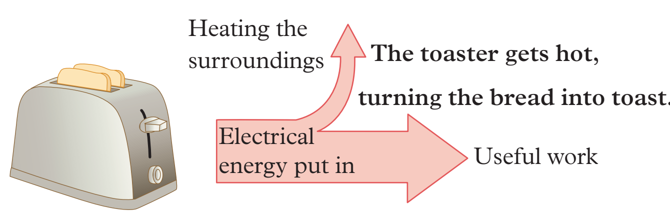


Figure 1 A Sankey diagram of energy transfer in a toaster

Drawing a Sankey diagram

Sankey diagrams have three main parts: the input energy, the output energy and the waste energy. The input energy is shown at the start of the arrow on the left-hand side of the diagram. The useful output energy is shown with an arrowhead travelling straight on to the right-hand side. The waste energy is usually shown by another arrowhead, travelling either up or down on the diagram. Sankey diagrams are usually drawn on graph paper so that the width of the arrow can accurately represent the amount of energy (Figure 2).

Sankey diagrams are also used to represent complex energy transitions. Worked example 2.2A shows the process of drawing a Sankey diagram.

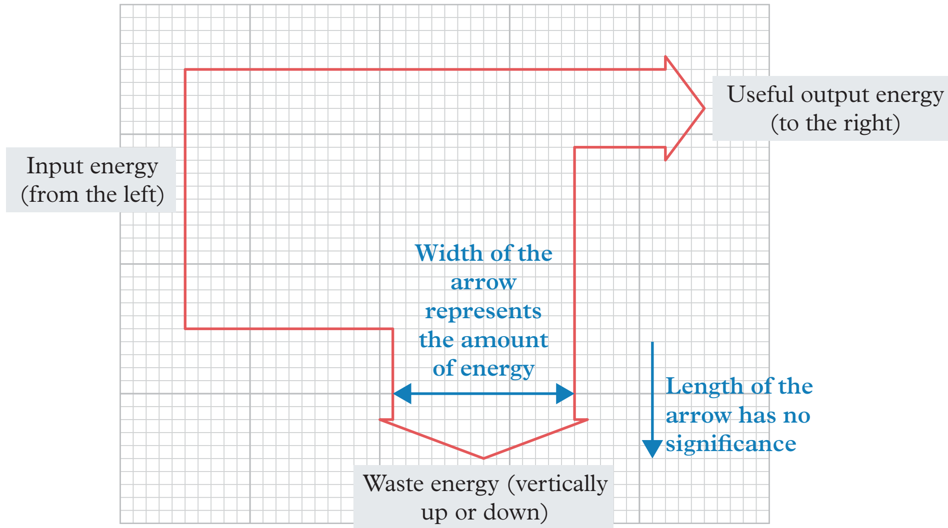
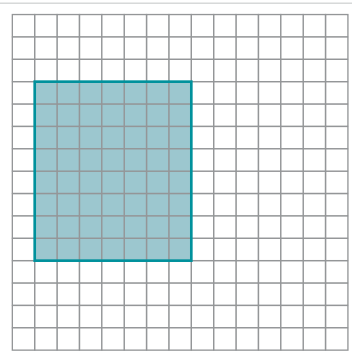
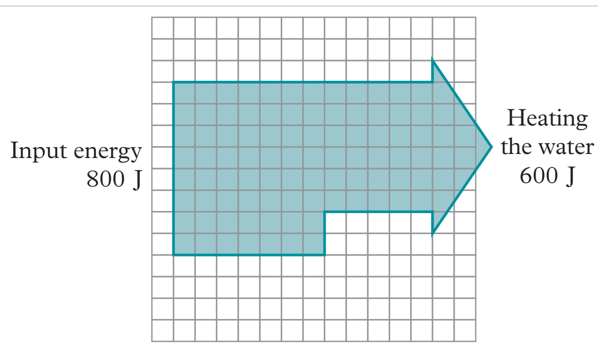


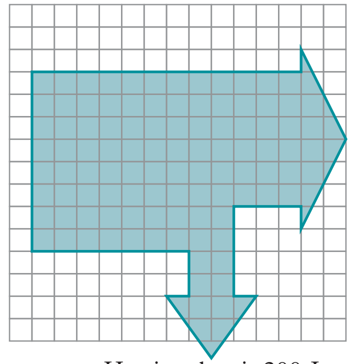
Figure 2 Key steps of a Sankey diagram

Worked example 2.2A Drawing a Sankey diagram

A kettle has an input of 800 J of electrical energy. Heating the water uses 600 J of thermal energy while 200 J of thermal energy heats the surrounding air. Draw a Sankey diagram to represent this energy transfer.

Solution

Steps	What to do	Working out
a.	Before starting your diagram, you will need to decide on a scale for the graph paper. It is usually easiest for one square to equal a simple number. In this case, one square = 100 J.	–
b.	As the input energy is 800 J, this will be equal to eight squares down on the graph paper. Colour across a number of squares. Add a label to show the input energy.	
c.	The useful thermal energy that heats the water is 600 J. To show this, colour six squares down the graph paper from the top right of your input energy block. Colour across until you reach a few squares from the right edge of the graph paper. Add an arrowhead to the right side and a label to show the output energy.	

Steps	What to do	Working out
d.	The waste energy (heating of the surrounding air) is 200 J. To show this, draw a block, two squares wide, extending down from the right of the input energy block. Add an arrowhead and label to show the waste energy. This is now a Sankey diagram of the energy input and output of the kettle.	

Check your learning 2.2

Check your learning 2.2

Retrieve

1 Identify the three key parts of a Sankey diagram.

Comprehend

2 Describe how a Sankey diagram can help identify energy losses in a system.

Apply

3 Draw a Sankey diagram to represent the energy transfers and transformations of a rubber band that starts with 10 units of elastic energy and produces 6 units of kinetic energy and 4 units of waste heat.

4 Using a Sankey diagram, compare the energy efficiency of two appliances: a kettle and a microwave. The kettle uses 2,000 J and delivers 1,800 J of useful energy. The microwave uses 2,000 J and delivers 1,200 J of useful energy.

Analyse

5 The Sun provides 400 J of light energy to a plant. The plant uses the light to store 100 J of chemical energy. Calculate the amount of waste energy from this process.

6 A student claimed a fan heater was inefficient due to energy lost as sound.

a Explain why thermal energy and kinetic energy is considered "useful" in a fan heater.

b Use Figure 3 to calculate the amount of sound energy generated.

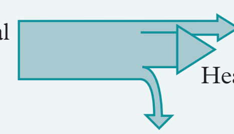


Figure 3 Sankey diagram for a fan heater

7 Calculate the amount of electrical energy required by the television in Figure 4.

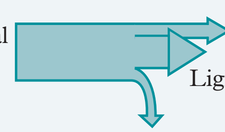


Figure 4 Sankey diagram for a television

Oxford University Press

Lesson 2.3
Investigation: What if you bounced a ball?

Purpose

To investigate the energy efficiency of a bouncing ball

Materials

- Tennis ball
- Metre ruler
- A selection of other types of balls
- Blu-Tack or masking tape

Procedure

1 Hold the tennis ball 1 metre above the ground next to the vertical ruler.
2 Drop the ball (do not throw it) on a hard surface.
3 Use the metre ruler to measure how high the ball bounces back. Be careful to avoid parallax error by ensuring your eye is level with the ball.
4 Determine the percentage energy efficiency by using the formula below:

$$\text{efficiency (\%)} = \frac{\text{height of bounce}}{\text{starting height}} \times \frac{100}{1}$$

Inquiry

Choose one of the following questions to investigate.

- What if another ball was bounced on the same surface? (Does it have the same efficiency?)
- What if the same ball was bounced on a different surface? (Does it have the same efficiency?)

Answer the following questions in relation to your inquiry.

1 Write a prediction or hypothesis 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 fair test. Describe how you will control these variables.
5 Write down the method you will use to complete your investigation in your logbook.
6 Draw a table to record your results.
7 Show your teacher your planning for approval before starting your experiment.

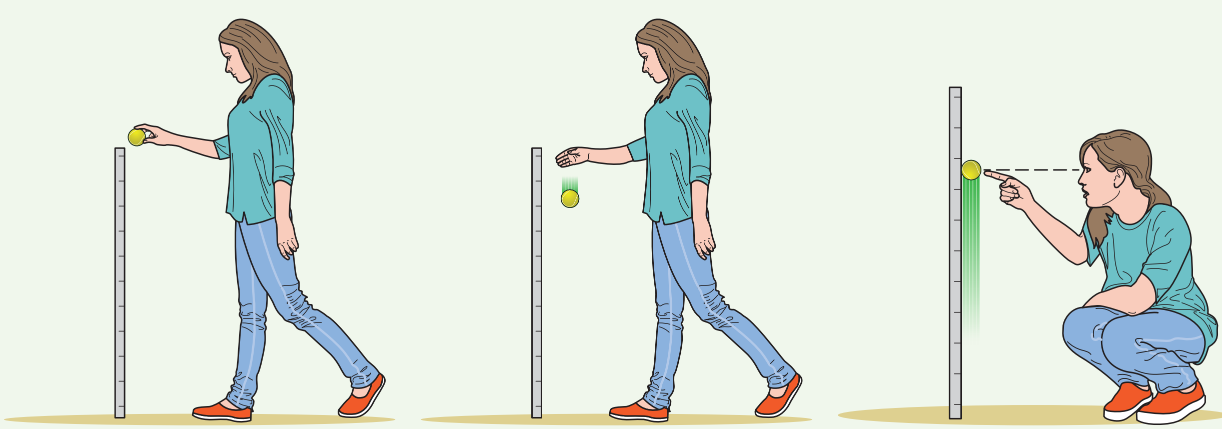


Figure 1 Experimental set-up

Results

1 Copy and complete Table 1.
2 Draw a column graph showing how the energy efficiency of the balls changed with your independent variable.

Discussion

1 Describe the results of your experiment by describing how you changed the independent variable and how this affected the dependent variable.
2 Compare (the similarities and differences between) the results of your experiment and your hypothesis.
3 Identify the type of energy the ball had:
   – before it was dropped
   – just before it hit the ground
   – as it touched the ground.
4 Identify the waste energy.
5 Draw a flow diagram of the energy transformation.
6 Draw a flow diagram of the energy transfer.

Conclusion

Describe how the independent variable affected the dependent variable.

Table 1 Bouncing ball experiment

Independent variable (surface/ball)	Height of bounce (cm)			Average height of bounce (cm)	Efficiency (%)
	Attempt 1	Attempt 2	Attempt 3		

Lesson 2.4
Electricity can flow through circuits

Learning intentions and success criteria

electric charge a property of subatomic particles (electrons and protons) that results in electric energy; electric charge can be positive or negative

electron a negatively charged particle that moves around in the space outside the nucleus

Key ideas

→ A closed circuit occurs when the positive and negative charges can be separated and reunited.

→ An electrical conductor allows the charges to flow easily.

→ An electrical insulator restricts the movement of the charges.

Introduction

"Electricity" is a general term related to the presence and flow of charged particles. An **electric charge** can be either positive or negative. It is produced by subatomic particles (parts of atoms), such as **electrons**, which carry a negative charge, or **protons**, which carry a positive charge.

Electrostatic charge

Objects are normally uncharged; that is, their atoms usually have equal numbers of positive protons and negative electrons. But when two objects are rubbed together, some of the electrons on the surface may be transferred from one object to the other. This causes the object with fewer electrons to become positively charged and the object with extra electrons to become negatively charged. This is called an **electrostatic charge**.

electrostatic charge an electric charge between two objects caused by a deficiency or excess of electrons (negative charges)

You can see examples of electrostatic charge when you rub a balloon against a woollen jumper and your hair stands up when you bring the balloon close to your head, or if you walk across a synthetic carpet and you get a small shock when you touch a door handle. In both these cases, the positive or negative electric charge stays on the charged object without moving. If the charges on two objects are the same (both positive or both negative), then they are described as "like charges". If the charges are different (one positive and one negative), then they are described as "unlike charges".

The following are important rules to learn about electrostatic charges (Figure 1).

- Like charges repel.
- Unlike charges attract.
- Charged objects attract neutral objects.

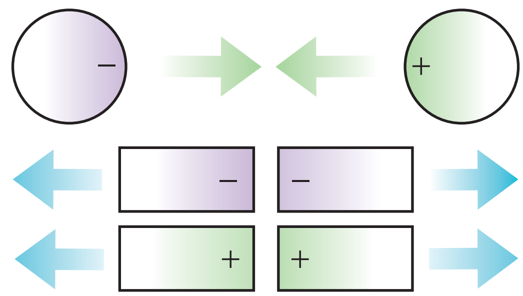


Figure 1 Like charges repel, unlike charges attract.

When charged objects are close to each other, the small negative electrons are attracted to the positively charged object (unlike charges attract). If these two objects are brought close enough, the electrons will try to jump across the gap as a spark. This is what happens when the air particles in a cloud rub against each other and become charged. If the charges build up enough, a large spark (lightning) will move between the charges in the clouds or towards the neutral ground (charged particles and neutral objects are attracted to each other).

The **Van de Graaff generator** is a machine that produces an electrostatic charge by rubbing a belt (Figure 2). The surface of the dome can lose electrons and become positively charged. Anything that touches the top of the dome also becomes positively charged. If a person touches the surface of the dome, their hair can become positively charged, causing the strands of hair to stand on end and move away from each other. This happens because the positive charges in the hair strands repel one another (like charges repel).

Van de Graaff generator a machine that produces an electrostatic charge

Similar generators are used to accelerate particles in X-ray machines and food sterilisers, and in nuclear physics demonstrations.

Figure 2 Placing a hand on the Van de Graaff generator causes negatively charged electrons to move from a person's hair to the dome. The positive charges that are left in their hair strands cause the strands to repel each other.

Electrical potential energy and circuits

When positive and negative electric charges are separated, they gain electrical potential energy, much like how an object gains gravitational potential energy when lifted against gravity. If you drop the object, it moves from a higher gravitational potential energy to a lower point, and this difference in potential energy is converted into kinetic energy. Similarly, when electric charges move from a point with higher electrical potential energy to one with lower potential energy, the difference in electrical potential energy transforms into kinetic energy, causing them to move.

It is difficult to continually rub things together to separate charges and give them electrical potential energy. An energy source, such as a **dry cell** (e.g. a torch battery) or a **wet cell** (e.g. a car battery), uses a chemical reaction to continually separate charges, resulting in a potential difference (voltage) between the two terminals that makes electric charges flow through wires.

The flow of electric charges from one place to another along a pathway made from an electrical conductor is called an **electric current**. An electric current comes from the movement of negatively charged electrons along a closed conducting pathway called an **electric circuit**. For historical reasons, the direction of the current is given as the flow of positive charges from the positive terminal of the energy source to the negative terminal. This flow of positive charges is referred to as a **conventional current** (Figure 3). As electrically charged particles move around an electric circuit, they carry energy from the energy source (such as a battery) to the device that transforms the energy (such as a light globe, motor or heater). An example of the movement of electrical energy in a simple circuit is shown in Figure 4.

Electric circuits must have an energy source, wires to carry the charges and a load that transforms the electrical energy into heat, light or kinetic energy. Many devices have “gaps” called switches to control the flow of electricity in a circuit. If the switch is open, the pathway is broken and no electricity flows. Circuits must therefore be closed for electricity to flow through them.

dry cell contains dry substances and uses a chemical reaction to produce electrical energy; commonly used for portable devices such as a torch battery

wet cell contains wet substances and uses a chemical reaction to produce electrical energy (e.g. a car battery)

electric current the flow of electrical charge through a circuit

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

conventional current the flow of positive charges in a circuit

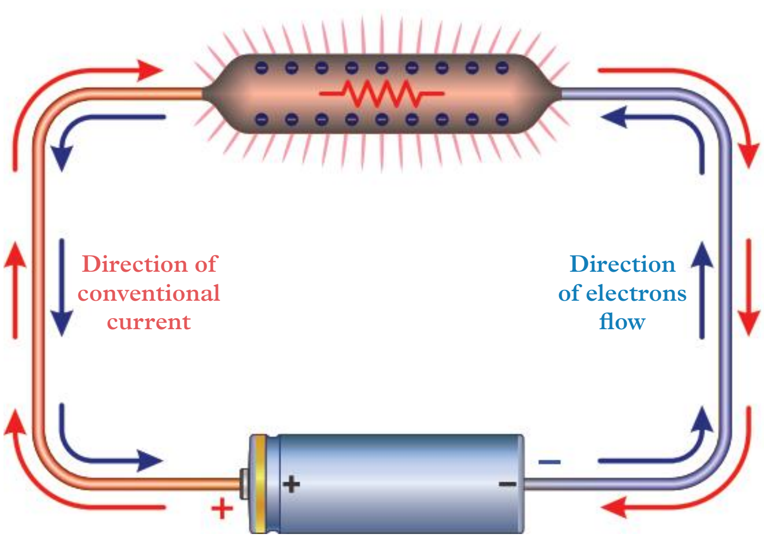


Figure 3 The direction of conventional current is from the positive terminal to the negative terminal, opposite to the direction of electron flow in a circuit.

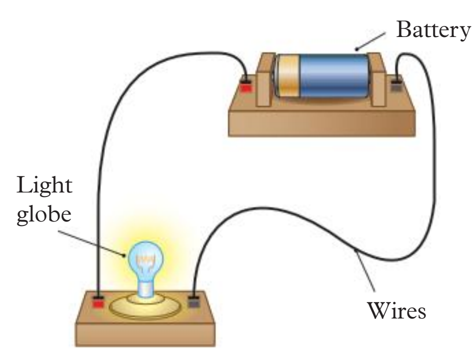


Figure 4 A simple circuit: electric charges move from the battery through the wires to the light globe

Drawing circuit diagrams

We use **circuit diagrams** to represent electric circuits. Each component of an electric circuit is represented by a symbol, as shown in Figure 5 and Figure 6.

In a circuit diagram, wires are usually drawn as straight lines that are joined at right angles (though there are exceptions to this). In Figure 5, the longer line on the battery symbol indicates the positive terminal, and the shorter line indicates the negative terminal. Each terminal is where the wires are connected. When you draw a circuit diagram, use a ruler and a pencil, and make sure all lines are connected to indicate there are no breaks in the circuit.

circuit diagram a diagrammatic way to represent an electric circuit

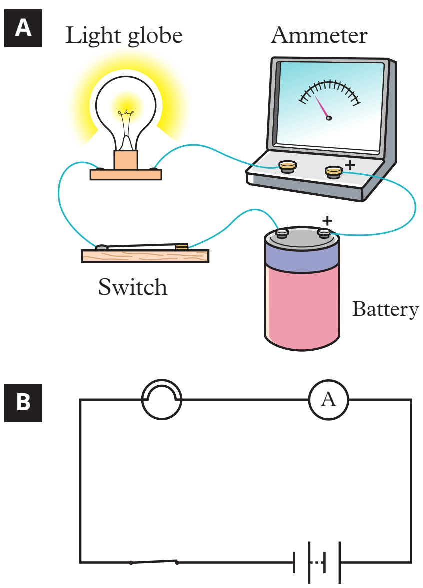


Figure 5 (A) An electric circuit and (B) the circuit diagram to represent this circuit

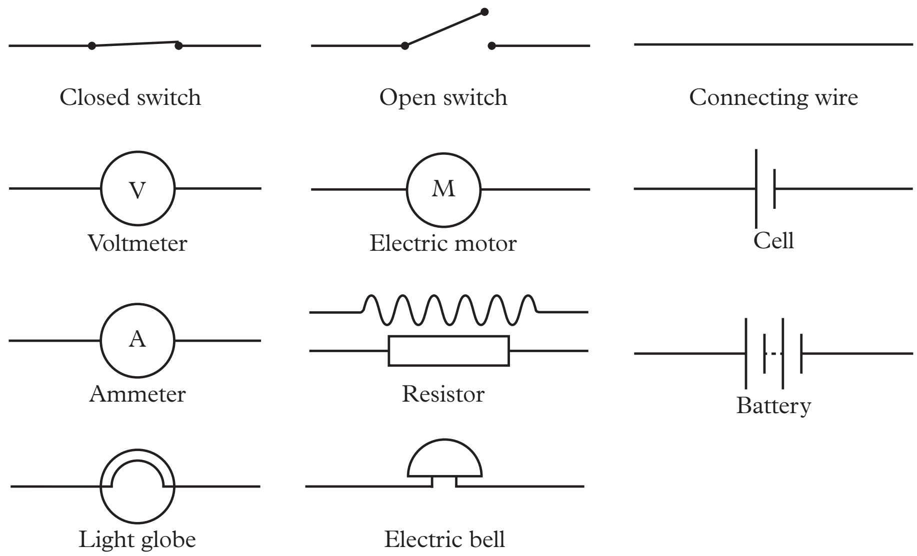


Figure 6 Common symbols used in circuit diagrams

Measuring electric current

Electric current (symbol I), or the flow of charge over time, is measured by counting the number of electrons that go past a point in the circuit in 1 second. The unit of measurement for current is amperes (symbol A). An ampere is a large unit of current, so smaller units, such as the milliampere (1,000 mA = 1 A), are often used. Traditionally, an ammeter (Figure 7A) has been used to measure the current passing a particular point in an electric circuit. The ammeter is connected into the circuit so that the current flowed through it. A more accurate device called a multimeter (Figure 7B) is used to measure many different aspects of a circuit, including the current.

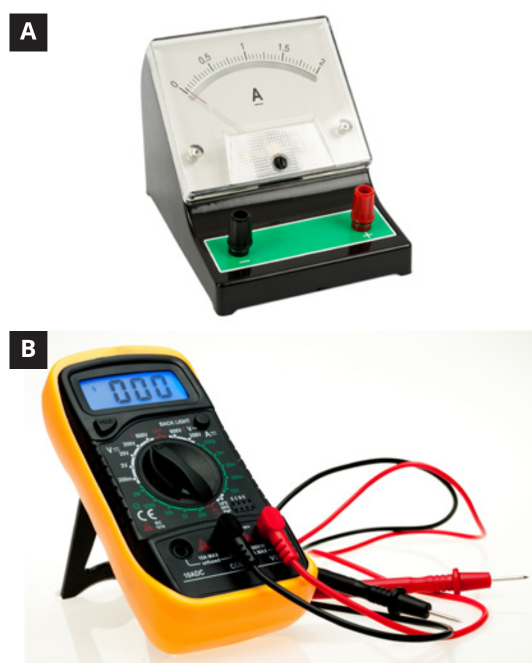


Figure 7 (A) An ammeter or (B) a multimeter is used to measure electric current.

Electrical conductors and insulators

electrical conductor a material through which charged particles are able to move

electrical insulator a material that does not allow the movement of charged particles

insulator a substance that prevents the movement of thermal or electrical energy

semiconductor a material that has properties between conductors and insulators; its conductivity increases by adding some impurities to it

An **electrical conductor** is a material through which charged particles are able to move. An **electrical insulator** is a material that does not allow the current of charged particles to move. Most wires are made of copper, a metal, with a plastic coating around the outside. Copper is an electrical conductor – electrons are able to move through it easily. Plastic, however, is an electrical insulator. The wires are coated in plastic to prevent the current being "lost" to the surroundings as it passes through the wires.

Some substances are better **insulators** or better conductors than others. It depends on how easily they allow electrons to move through them; that is, whether they offer more or less resistance to the movement of charges. Air is a good resistor because it is difficult for charged particles to move freely.

Some substances, such as germanium and silicon, are insulators in their pure form, but become conductors if they are combined with a small amount of another substance. These materials are called **semiconductors**.

Within a single silicon chip, very thin layers of silicon are combined with other substances to make that layer a conductor. Complex microcircuits used in computing are made in this way.

Check your learning 2.4

Check your learning 2.4

Retrieve

1 Identify the charge on the following particles.
- a Protons
- b Electrons

2 Define the term "current".

Comprehend

3 Describe how objects can become electrostatically charged.

4 Explain the purpose of a battery in a circuit.

5 Describe an electric circuit.

6 Describe why silicon is called a semiconductor.

7 Compare a conductor and an insulator.

Analyse

8 Compare the flow of electric current in a circuit made with copper wire to one made with rubber wire.

Apply

9 If living organisms are good conductors and air is a good resistor, discuss why it would be dangerous to stand out in an open area during a lightning storm.

10 Draw a circuit diagram containing a battery, a switch and two light bulbs connected one after the other.

11 You are given a plastic rod and a metal rod. Design a simple experiment to test which rod is a better conductor of electricity.

Lesson 2.5

Skills lab: Understanding resistor colour codes

Aim

To use the coloured banding of a resistor to determine its value

Materials

A selection of coloured resistors

Method

Carbon resistors typically have four colour-coded bands on their case (Figure 1). These bands are part of a code that allows you to work out their approximate value and tolerance. The fourth band is the tolerance band, which indicates the amount that the resistance may vary by (the relative accuracy of the resistor). Gold means 5 per cent tolerance, silver means 10 per cent tolerance and no fourth band means 20 per cent tolerance. The lower the percentage tolerance, the more accurate (or closer to the true value) the resistor is.

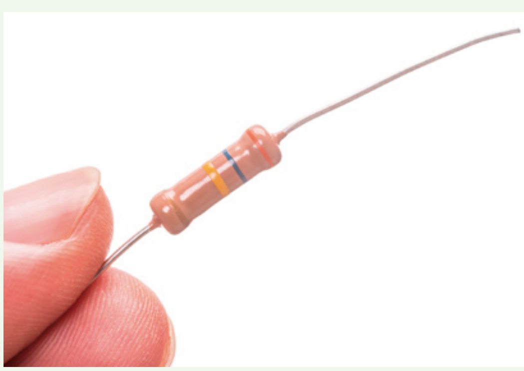


Figure 1 A resistor with colour-coded bands

To read the other three bands, put the tolerance band on the right and start at the other end. The first two bands form a two-digit number according to their colour (see Table 1). The third band tells you how many zeroes to put after the number.

Table 1 Resistor colour codes

Colour	Value	Colour	Value
Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Grey	8
Yellow	4	White	9

Look at the resistor in Figure 2. What does its code mean?

1. The tolerance band is gold, so the resistor has 5 per cent tolerance.
2. The first band is blue, so it has a value of 6.
3. The second band is red, so it has a value of 2. The number is now 62.
4. The third band is also red, so this means 2 zeroes need to be added to the number. The number is now 6,200.
5. Resistor values are always coded in ohms, so the value of this resistor is 6,200 ohms or 6.2 kilo-ohms.

Collect a resistor from your teacher and use the coloured bands to determine its value.

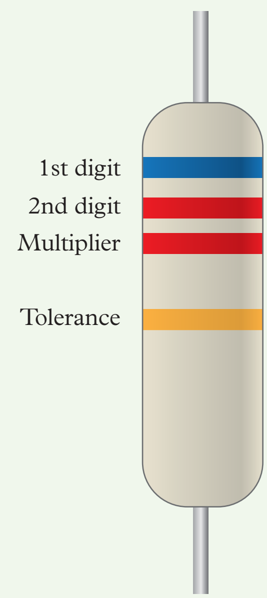


Figure 2 Calculate the value of this resistor.

Questions

1. Define the electrical term “resistance”.
2. Explain why different resistors are used in different circuits.
3. Explain what is meant by the term “tolerance”.

Lesson 2.6

Investigation: Demonstrating electrostatic electricity

Purpose

To model and explain electrostatic electricity

Materials

- Plastic comb
- Woollen cloth
- Rice Bubbles
- Large plastic bag with tie
- Plastic rod or pen
- Small pieces of paper
- Balloons
- Balloon pump
- Felt-tipped pens
- String
- Tape

Procedure

Part A

1. Place some of the Rice Bubbles in the plastic bag. Blow air into the bag and seal it with the tie.
2. Rub the woollen cloth over both the plastic bag and the comb.
3. Bring the plastic bag and comb together.
4. Record what happens.
5. Explain your observations, using the idea of electrostatic charge.

Part B

1. On a piece of paper, draw four positive and four negative charges. Show what happens to these charges when the positively charged woollen cloth is brought close to them.
2. Rub the plastic rod or pen with the woollen cloth
3. Bring the paper and the plastic rod or pen together.
4. Record what happens and explain your observations, discussing the movement of charges.

Part C

1. Using the balloon pump, blow up a balloon and carefully draw a face on it.
2. Tie the balloon onto a string and suspend it from a doorway or ceiling using tape, so that it is level with your head.
3. Rub the balloon face with the woollen cloth and walk towards it.
4. Record what happens.
   - Identify the distance you have to be from the "balloon face" before it is attracted to you.
   - Describe what happens if you put a piece of paper between you and the balloon.
5. Blow up another balloon and draw a face on it.
   - Describe what happens when you bring it close to your suspended balloon.

Figure 1 Can you explain the attraction of the balloon?

Discussion

1. Describe your observations in part A using the terms "like charges", "unlike charges" and "neutral or no charge".
2. Describe your observations in part B using the terms "like charges", "unlike charges" and "neutral or no charge".
3. Describe your observations in part C using the terms "like charges", "unlike charges" and "neutral or no charge".

Lesson 2.7

Current can flow through series and parallel circuits

Key ideas

→ In a series circuit, the loads are connected one after the other, and the current is the same throughout the circuit.

→ In a parallel circuit, the loads are parallel to one another, and the current is shared between them.

→ A short circuit occurs when the electrical energy can move through an easier path with less resistance.

Learning intentions and success criteria

Series and parallel circuits

When two or more **loads**, such as globes, are connected in a circuit, two different types of connection are possible. In a **series circuit**, the loads are connected one after the other so that the current goes through one load and then through the second load (Figure 1A). In a **parallel circuit**, the circuit has two or more branches and the current splits between the branches (Figure 1B) and comes back together afterwards.

Comparing circuits

If two globes are connected in a circuit in series, then all the current (moving electrons) passes through both globes (Figure 1A). This means the current is always the same at all points in a series circuit.

If two globes are connected in parallel, however, the current splits (Figure 1B). This means that when the electrons reach the point where the wire splits, the electrons will travel along one path or the other. Part of the current passes through each globe and then joins together again after passing through the globes. This means the currents going through each globe must be added together to determine the total amount of current coming from the battery.

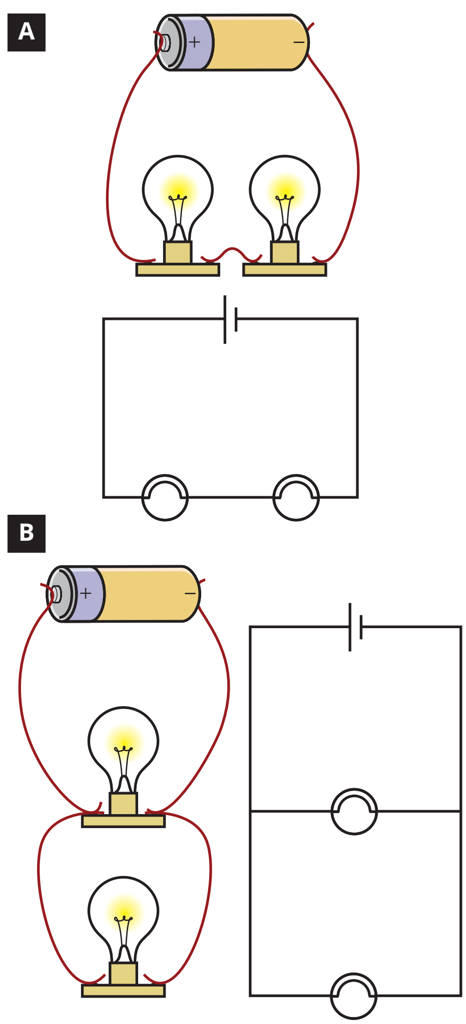


Figure 1 (A) In a series circuit, the current is the same anywhere in the circuit. (B) In a parallel circuit, the sum of the current going through globe A and globe B is equal to the total current.

load a device that transforms electric potential energy into other forms of energy such as heat or light

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

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

Figure 2 Traditionally, party lights were a series circuit. This meant that when one light broke, all the lights went out. Now, most modern party lights are arranged in a parallel circuit.

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

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

- some appliances can be on while others are off (achieved by inserting switches)
- if one appliance fails, the others will still work (Figure 2).

Worked example 2.7A Calculating currents

If the current leaving a battery is 6 amperes (A), calculate the current travelling through two identical lamps if they are connected:

a in series **b** in parallel.

Solution

Steps	What to do	Working out
a.	For part **a**, you need to remember that is the lamps are connected in series, then the electrons will flow through each lamp.	The current in each lamp is 6 A.
b.	For part **b**, you need to remember that if the lamps are connected in parallel, the electrons are divided equally between the lamps.	6 A ÷ 2 light bulbs = 3 A in each light bulb

Batteries in series and in parallel

Batteries may be connected in series or in parallel, in a similar way to globes. When batteries are connected in series, each electron picks up a certain amount of energy as it passes through the first battery and then an additional amount as it passes through the second battery. This arrangement allows electrons to be given larger amounts of energy. For instance, a simple torch normally has two 1.5 V batteries connected in series. As each electron passes through both batteries, it collects the total amount of energy provided by both batteries, which is 3 V.

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

Short circuit

A **short circuit** occurs when a conductor with very low **resistance** is connected in parallel to a component in the circuit. This causes the current (moving electrons) to flow along a different path from the one intended. This can be caused by damaged insulation that usually surrounds the wires or by another shorter conductor, such as water, providing an easy path for the electrons. Electric charges will always take the path of least resistance. This means that large currents can flow through any short path or conductor that allows the electrons to move most easily. Short circuits are dangerous because they can also lead to wires heating up from the fast flow of electrons, causing damage or even fire.

short circuit a condition in an electrical circuit that allows the current to flow along an unintended path

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

Fuse

A **fuse** is an electrical safety device designed to protect a circuit from excessive current. It consists of a thin wire or filament that melts when the current flowing through it exceeds a certain limit. This causes a break in the circuit so that the electrical energy stops flowing, preventing damage to other components. Fuses are commonly used in household appliances and electrical systems to prevent damage from overloads or short circuits.

fuse a switch or wire that stops the flow of current if it starts moving too fast

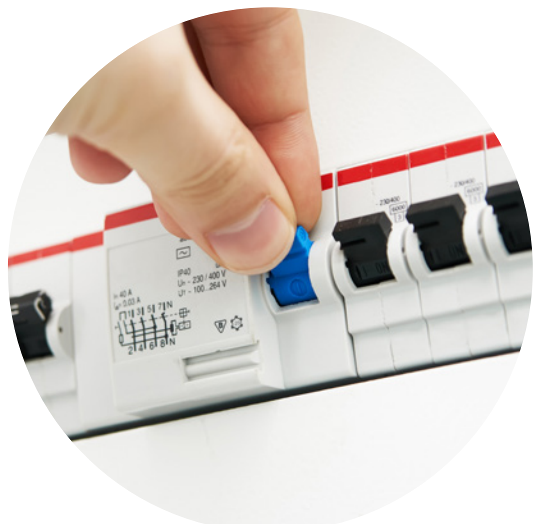


Figure 3 A sudden increase in current will cause a fuse or safety switch to break the circuit. This stops the current from flowing and may prevent electrocution.

Check your learning 2.7

Check your learning 2.7

Retrieve

1 Identify the advantages of having a safety switch or fuse in the electric circuits of your house.

Comprehend

2 Describe how you could determine whether the globes in a set of party lights are connected in series or in parallel. (Hint: How does current flow through a series circuit and a parallel circuit?)

Analyse

3 Contrast the movement of current in a series circuit and a parallel circuit.

4 Three identical lamps were connected in series to a battery that produced a 12 A current. Calculate the current flowing in each lamp.

Apply

5 Infer how the household appliances are connected in your house (in series or in parallel). Justify your answer (by explaining how series and parallel circuits behave and providing an example that matches your explanation).

6 Double adaptors and power boards enable you to connect additional appliances to a power point. Explain whether the double adaptors or power boards are more likely to be series or parallel connections. Justify your answer.

7 An electrician wanted to connect four identical lamps to a 6 A source so that two lamps had a current of 6 A and the other two lamps had a current of 3 A. Create a circuit diagram to show a possible arrangement of the lamps the electrician could use.

8 Draw a series circuit diagram using Figure 4.

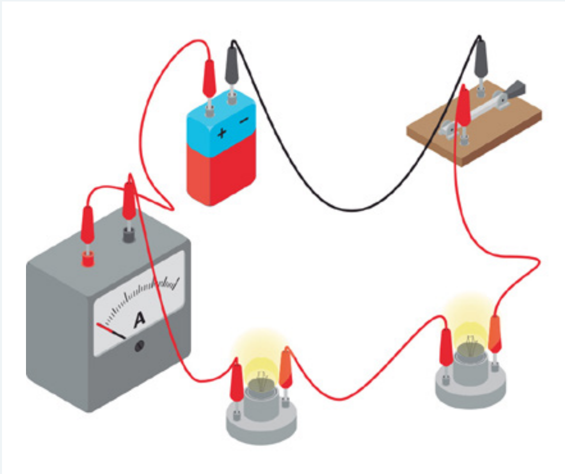


Figure 4 A series circuit

Skills builder: Planning investigations

9 Electricians and scientists use diagrams to explain how something needs to be set up. You have been asked to plan an investigation into the wiring of the apartment in Figure 5. Apply your understanding and create a circuit diagram for one of the following apartment floor plans. (THINK: How does each light bulb receive electricity? Have I drawn this scientifically? What are the correct symbols to use?)

You need to include the following:

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

Figure 5 An apartment floor plan

Lesson 2.8
Investigation: Making series and parallel circuits

Purpose

To compare the current in series and parallel circuits

Materials

- Two 1.2 V globes and holders
- 1.5 V battery and holder
- Eight connecting wires (with banana plugs or alligator clips)
- Switch
- Ammeter or multimeter

Procedure

1. Construct four circuits, placing the switch so that it controls:
   - **a** both globes, with both either on or off at the same time
   - **b** one globe only, with the other on all the time
   - **c** the other globe only, with the first globe on all the time
   - **d** both globes, with one globe on when the other is off and vice versa.

Complete step 2 before you disconnect each circuit.

2. Draw the circuit diagram to show where the switch was placed in each circuit.
3. Connect an ammeter at different places in each circuit and measure the current at each point.

Discussion

1. Describe the effect of changing the location of the switch in a simple circuit.
2. Describe how an ammeter should be connected to measure the current in a circuit.
3. Describe how the current did or did not change when the ammeter's location was changed.

Lesson 2.9
Voltage, current and resistance

Key ideas

→ Voltage is a measure of the difference in electrical potential energy carried by charged particles between different points in a circuit.

→ Voltage can be measured using a voltmeter or multimeter in parallel to the circuit.

→ Resistance is a measure of how difficult it is for the current to flow through part of the circuit.

Learning intentions and success criteria

Voltage

voltage a measure of the amount of energy in joules given to a unit of charged particles passing through a battery

potential difference the difference in electrical potential energy between two points of a circuit for each unit of charged particle; also known as voltage drop

Each charged particle has electrical potential energy as it moves in an electric circuit. This energy is given to the charged particles by the battery. The potential difference (**voltage**) across a battery is a measure of the amount of energy, in joules, given to a unit of charged particles passing through it. This electrical potential energy can be transformed into sound as it moves through a speaker, or into light and heat if it moves through a globe. This means the energy of a charged particle (electron) decreases as it passes through the speaker or globe. The difference in electrical potential energy between two points of a circuit for each unit of charged particle is called **potential difference** (also known as voltage drop). A component of a circuit that transforms electrical potential energy into other forms of energy and across which a potential drop occurs is called a load.

Voltage is measured by a voltmeter or a multimeter in the unit volts (symbol V). To measure the potential difference or voltage between any two points of a circuit, voltmeters are set in parallel across the two points in the circuit that you want to measure (Figure 1).

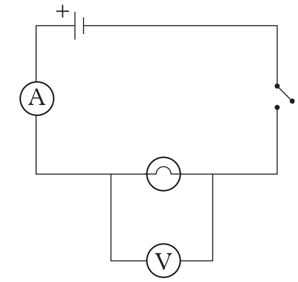


Figure 1 A voltmeter is used to measure voltage in a circuit.

Figure 2 Each unit of charge in this battery has 1.5 J of energy.

Batteries add energy to charged particles. The amount of energy added by the battery can be determined by connecting a voltmeter in parallel to the battery. The electrical potential of a charge travelling through a 1.5 V battery changes from 0–1.5 V, meaning the charge gains energy from the battery and its electrical potential energy increases. As the charge moves through the circuit, its energy is converted into other forms, such as light, heat or mechanical energy, depending on the components in the circuit. The charge then returns to the battery where it gains energy again, and this process continues as long as the circuit is functioning.

In a series circuit, the potential energy contained by each electron must be divided between the different loads. This means a 12 V battery connected to two identical light bulbs in series may transform 6 V of energy to each bulb. If the two globes are connected in parallel, each electron moving in a light bulb is able to transform all the 12 V into light and heat.

Worked example 2.9A Calculating voltage

If a 6 V battery is connected to two identical light bulbs, calculate the voltage drop across each lamp if they are connected:

a in series **b** in parallel.

Solution

Steps	What to do	Working out
a.	For part **a**, you need to remember that if the light bulbs are connected in series, the electrons must divide the voltage (potential energy) between the bulbs.	6 V ÷ 2 lamps = 3 V in each lamp The voltage drop across each lamp will be 3 V.
b.	For part **b**, you need to remember that if the bulbs are connected in parallel, the electrons will separate at the fork in the wires and carry all the energy to each bulb.	The voltage drop (potential difference) will be 6 V across each bulb.

Resistance

The amount of current flowing in a circuit is determined by the resistance (symbol *R*) of the circuit. The electrical resistance of a material is a measure of how difficult it is for charged particles to move through. Electrons collide with the atoms in the wires and the various other components of a circuit, and some of their electrical energy is converted or transformed into heat. Most connecting wires are thick and made of good conductors. They have very low resistance, and so hardly any energy is lost by the electrons. The wires in a toaster, however, are designed so that a lot of the electrons' energy is transformed into heat – so much so that the wires glow red-hot and brown our toast.

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

resistor a device that has opposition to an electric current

A rheostat is a variable resistor, used to control the amount of current in a circuit. It consists of a coil of wire, a slider and two terminals: one fixed and one moving. Some rheostats have three terminals, but only two are typically used. When using the fixed terminal, A, and the moving terminal, B, the resistance of the rheostat decreases as the slider moves closer to point A (Figure 3 and Figure 4).

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

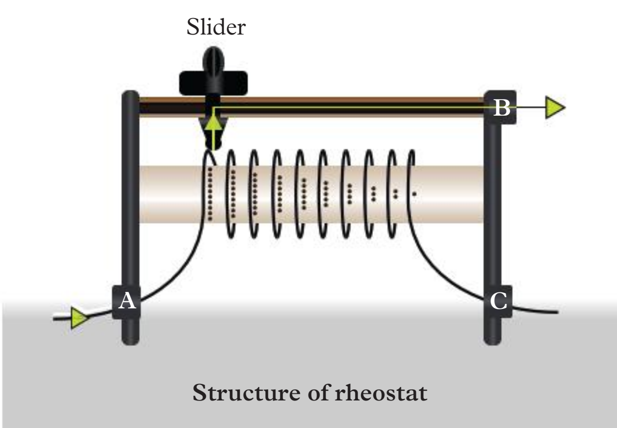


Figure 3 A rheostat with three terminals

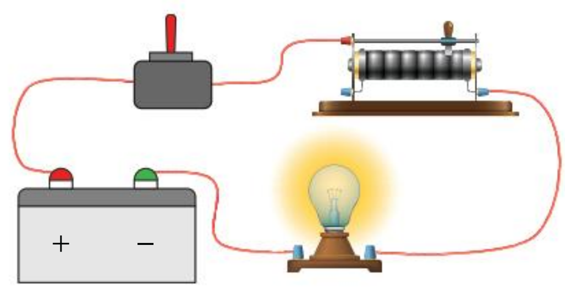


Figure 4 A rheostat in a circuit

Figure 5 Metal wires have low resistance while the plastic coating has high resistance.

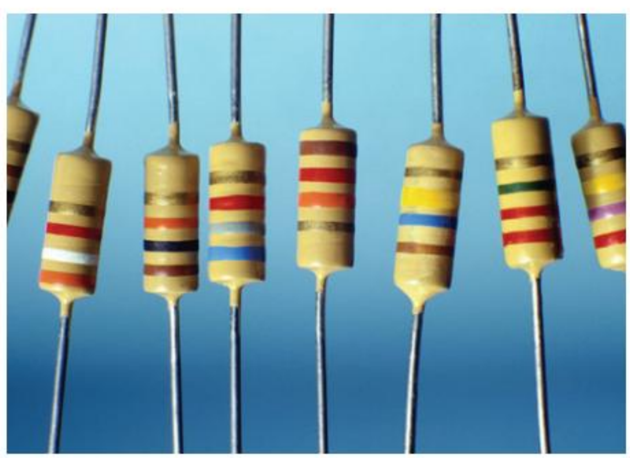


Figure 6 Many types of resistor are available. The resistance of carbon resistors is indicated by the coloured bands on their plastic case.

Ohm's law

Georg Ohm, a German physicist, discovered the relationship between voltage, current and resistance. Ohm found that the voltage drop across a fixed-value resistor is always directly proportional to the current through the resistor. This means that, as the voltage goes down, the current will also go down. This relationship is known as **Ohm's law** and is written as:

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

$V = IR$

where V is voltage in volts (V), I is current in amps (A) and R is resistance in ohms (Ω).

To help us remember Ohm's law, we can use the Ohm's law triangle (Figure 7). To find resistance (Ω), cover the R and the two letters show you the formula to use. So $R = \frac{V}{I}$. The same method is used to find current (I) which gives $I = \frac{V}{R}$. To find voltage, cover V, which gives $V = IR$.

If you plot a graph of current versus voltage, the graph is a straight line. Resistance equals one divided by the gradient of the current–voltage graph (Figure 8). Resistors that have a constant resistance are called ohmic resistors because they obey Ohm's law.

Some resistors do not obey Ohm's law. These resistors are called non-ohmic resistors. The resistance of a non-ohmic resistor, such as a light globe, changes with temperature. Ohm's law applies only to ohmic resistors. The current–voltage graph of a non-ohmic resistor is not linear (Figure 9).

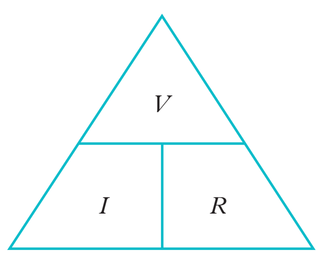


Figure 7 The Ohm's law triangle is used to remember the equations for Ohm's law.

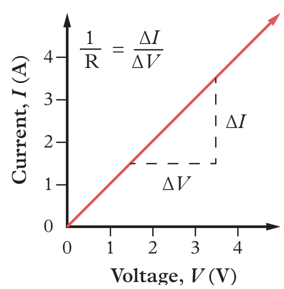


Figure 8 Graphical representation of Ohm's law

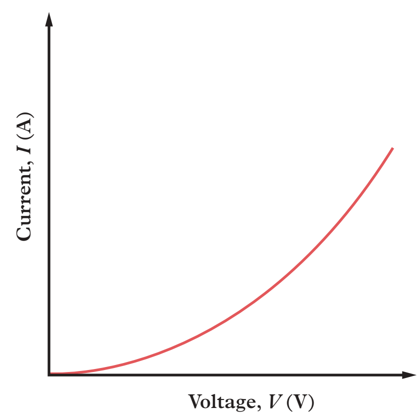


Figure 9 Current versus voltage graph of a non-ohmic resistor

Worked example 2.9B Calculating resistance

If a 9 V battery produces 6 A of current, calculate the resistance of the circuit.

Solution

Steps	What to do	Working out
a.	State the known and unknown information.	V = 9 V, I = 6 A, R = ?
b.	Substitute the values into $R = \frac{V}{I}$ and solve for R, including units.	$R = \frac{9V}{6A}$ = 1.5 Ω The resistance in the circuit is 1.5 Ω.

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Check your learning 2.9

Check your learning 2.9

Retrieve

1 Define the terms:
 a voltage
 b rheostat
 c resistance.

2 Complete the information in Table 1.

Table 1 Symbols and units for electric circuit terms

Term	Symbol	Unit
Current	*I*	
Voltage		V
Resistance		

Comprehend

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

Analyse

4 Identify the three equations that can be obtained by rearranging the Ohm's law triangle.

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

6 Calculate the change in voltage across a 25 Ω resistor when a current of 50 mA (0.05 A) flows through it.

7 Calculate the value of a resistor that has a voltage drop of 8 V across it when a current of 0.4 A flows through it.

Apply and create

8 A group of students performed an experiment to determine the value of an unknown ohmic resistor. They made a simple circuit and measured the amount of current for different values of voltage. Their results are shown in Table 2.
 a Determine the independent, dependent and controlled variables.
 b Draw a current–voltage graph for the data in Table 2.
 c Calculate the resistance using the gradient of the graph.
 d Another group of students performed the same experiment but each time they changed the voltage and thickness of the connecting wires. Evaluate the validity of their experiment.

Table 2 Experimental results for an electric circuit

Voltage (V)	Current (A)
0	0.0
2	0.1
4	0.2
6	0.3
8	0.4
10	0.5

Skills builder: Conducting investigations

9 When you conduct investigations around electricity, there are different risks to consider compared with investigations involving chemicals. It is particularly important that your equipment is set up and assembled safely.
 a Identify risks associated with connecting the power source before you have set up your circuit. (THINK: What risks exist when wires aren't connected correctly?)
 b Explain why it is important that you check wires before commencing an investigation. (THINK: Would your results be impacted?)

Lesson 2.10

Investigation: Investigating Ohm's law

Purpose

To investigate the voltage drop across a resistor and the current flow through a resistor, and to calculate the average value of the resistance

Materials

- 10 Ω resistor
- Voltmeter
- Ammeter
- 2–12 V power supply
- 3 other resistors with masking tape over their coloured bands
- Connecting wires

Procedure

1 Identify the 10 Ω resistor. It should be colour-coded brown, black, black.

2 Connect the circuit as shown in Figure 1. Connect the voltmeter around the resistor. Use the DC terminals of the power supply and start with the dial on 2 V.

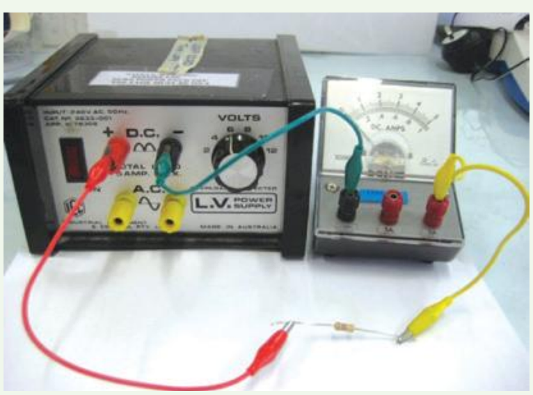


Figure 1 Circuit set-up

3 Switch on the power supply, take the readings on the ammeter and voltmeter, and switch the power off again straight away (so you don't overheat the resistor).

4 Repeat step 3 three times and record your measurements in Table 1.

5 Change the dial on the power supply to 4 V and repeat steps 3 and 4. Then change the dial to 6 V and repeat steps 3 and 4 again.

6 Repeat the experiment for the other three resistors, without reading their coloured bands.

7 Complete the results table for each of the three masked resistors and calculate their resistance.

8 Determine the average resistance of each resistor.

9 Remove the masking tape and determine the resistance values from the coloured bands of the resistors.

Results

Copy and complete Table 1.

Discussion

1 From your results table, calculate the values in the last column.

2 For the three masked resistors, compare the accuracy of the values you obtained to the values indicated by their coloured bands.

3 Use the formula below to calculate the difference (error) between the two values as a percentage of the marked value.

$$\%\ \text{error} = \frac{\text{marked value} - \text{average calculated value}}{\text{marked value}} \times 100$$

4 Identify which value – the one obtained by reading the coloured bands or the one obtained from your calculations – provides the most useful measure of a resistor's resistance. Justify your answer (by explaining how each value is obtained, describing which value is most relevant to use in a circuit and deciding which value provides the most useful measure).

Conclusion

Describe what you know about Ohm's law.

Table 1 Experiment results

Resistor	Voltage (V) (volts, V)	Current (I) (milliamps, mA)	Volts ÷ amps

Lesson 2.11
How is power measured?

Key ideas

→ The unit of measurement for power is the watt (W), which is the amount of energy used per second.

→ To determine how much you pay for electricity, a power meter is installed and read, then a bill sent out.

→ The energy star rating system is a visual guide to show consumers how energy efficient an appliance is. The more stars, the more energy efficient.

Learning intentions and success criteria

Introduction

The electrical potential energy of charged particles in an electric circuit decreases as they move through loads such as light bulbs, toasters and fans. These devices transform electrical energy into other forms of energy, such as light, heat or kinetic energy. Different electrical devices convert energy at different rates. For example, a 100 watt light bulb running for 10 hours would use 1 kilowatt-hour of energy. A 1,000 watt microwave would use 1 kilowatt-hour of energy in just 1 hour.

Energy consumption

The rate at which energy is transformed is called **power** (P), and its unit of measurement is the **watt** (W). If an electrical device uses 1 W of power, it means it consumes 1 J of energy per second. For example, a 100 W light bulb uses 100 J of energy every second.

The amount of energy used by appliances in your home determines how much you pay on your electricity bill. To measure energy usage, electricity companies use a unit of measurement called the **kilowatt-hour** (kWh). This is the amount of energy a 1-kilowatt appliance uses in 1 hour. There are 1,000 W in 1 kilowatt (kW), so if you have a 1,000 W appliance running for 1 hour, it uses 1,000 W × 1 hour = 1,000 watt-hour, or 1 kWh.

power the rate at which energy is transformed in a circuit

watt unit of power; 1 watt is equal to 1 joule per second

kilowatt-hour unit used by electricity companies to measure electricity usage; it is equal to the amount of energy used (in kilowatts) in one hour

Figure 1 Plug power meters show how many watts a device uses.

Electricity companies typically charge a certain rate per kWh, which is listed on your electricity bill. For instance, if the cost is $0.10 per kWh, running a 1 kW appliance for 1 hour would cost you 10 cents.

A power meter is a device that measures the power used by an electrical device. Using a power meter can help you monitor how much electricity an appliance uses, which can help you save energy and reduce electricity costs. Power meters are easy to use; you simply plug the power meter into an electrical outlet and then plug the electrical device into the power meter (Figure 1). The power meter will show you how many watts the device uses.

Calculate kWh by following these steps.

1 Divide the power in W by 1,000 to convert them to kW.
2 Multiply the kW calculated in step 1 by the number of hours the device was used.

To work out how much the electricity costs, multiply the kWh (calculated in step 2) by the cost of electricity per kWh on your electricity bill.

Worked example 2.11A Energy consumption

a Calculate the energy in kWh that a 3,500 W air conditioner uses in 2 hours.
b If the cost of electricity is $0.20 per kWh, calculate the cost of running the air conditioner for 2 hours.

Solution

Steps	What to do	Working out
a.	For part **a**, to convert W to kW, divide the power in W by 1,000.	3,500 W ÷ 1,000 = 3.5 kW
b.	To calculate the energy used in kWh, multiply the kW by the number of hours the device was used.	3.5 kW × 2 h = 7 kWh
c.	For part **b**, to calculate the cost of running the air conditioner for 2 hours, multiply the kWh by the cost of electricity per kWh.	7 kWh × $0.20 = $1.40

Energy star rating

Scientists are constantly trying to design the best appliances possible with the highest efficiency ratings. This makes the appliances better for the environment and less costly to power. Do you and your family always buy the most efficient appliances? Are you familiar with the star ratings on appliances?

The energy star rating labels provide two important pieces of information about the device: a star rating and the energy consumption per year. A device can have between 1 and 6 stars. The more stars, the more energy-efficient the appliance is, meaning it uses less energy than a model of similar size and features. Not only is it good to know that less energy is being wasted, but it also means that, on your electricity and gas bills, you are paying for energy that is being used rather than for energy that is being thrown away. The other information on an energy star rating label is the energy consumption of the device. It shows how much electricity a device uses in kWh per year (Figure 2).

Figure 2 Appliances with a higher star rating are considered more energy efficient.

Check your learning 2.11

Check your learning 2.11

Retrieve

1 Define the term "power".

Comprehend

2 Explain the purpose of the energy star rating labels.

3 Explain why two appliances with the same power rating might have different energy star ratings.

Analyse

4 Calculate:

a the electrical energy (in kWh) used by a 300 W refrigerator in 24 hours

b the cost of using the refrigerator for 24 hours if each kWh costs $0.20.

5 Calculate:

a the energy in kWh that a 100 W laptop uses in 8 hours

b the cost of running the laptop for 8 hours if the cost of energy is $0.20 per kWh.

Apply

6 For three days in a row, record the reading on your family's electricity meter at exactly the same time each day (e.g. 6 pm).

a Calculate the number of kWh your family used in the first 24-hour period (subtract the second reading from the first). Then calculate the number of kWh your family used in the second 24-hour period.

b Calculate the approximate cost of each 24-hour period's electricity, assuming that each kWh costs $0.20. (What information do I have? Where do I need to place this in an equation?)

c List all the electrical appliances your family used during this time (e.g. electric hot water, kettle, electric stove and/or oven, computers, TV).

d Identify the items in part c that you think used the most energy during this time, using the information from their energy star rating.

e Compare the energy efficiency of the items in part c using their energy star rating.

Lesson 2.12
Investigation: Comparing the energy transformed over time

Purpose

To investigate energy transformation over time

Materials

- 30 cm nichrome wire
- Wires
- Alligator clips
- Power supply
- Ammeter
- Voltmeter
- Calorimeter
- Thermometer
- Stirring rod
- 100 mL measuring cylinder
- Stopwatch

Procedure

Part A: Prepare the heating coil

1 Wrap the nichrome wire around a pencil to form a coil shape. Ensure the coils do not touch each other.

Part B: Set up the circuit

2 Use alligator clips and wires to connect the two ends of the nichrome wire (heating coil) to the power supply.
3 Place an ammeter in series with the circuit to measure the current.
4 Place a voltmeter parallel to the heating coil to measure the voltage drop.

Part C: Prepare the calorimeter

5 Fill the calorimeter cup with 100 g (100 mL) of cold water.
6 Insert the thermometer into the water. Make sure it doesn't touch the sides or bottom of the cup.
7 Record the initial temperature of the water.

Part D: Placing the heating coil in the calorimeter

8 Gently place the nichrome heating coil into the calorimeter cup. Ensure the coil is fully submerged in the water and is not touching the bottom of the calorimeter cup.
9 Secure the coil in place by either of the following methods.
   - Attach the coil to a small piece of string or thread, which can be tied to the top of the calorimeter. This keeps the coil from touching the bottom of the cup or the sides of the calorimeter.
   - Use a small clamp or stand to hold the coil just above the bottom of the cup while ensuring it is still submerged in water. If you use a clamp, make sure it does not touch the wire directly to avoid any unwanted energy loss.

Part E: Start the experiment

10 Set the voltage of the power supply to 2 V.
11 Turn on the power supply and start the stopwatch immediately.
12 Set the current to 1 A by adjusting the voltage. Make sure the current is maintained at 1 A.
13 Record the voltage at 1-minute intervals throughout the experiment.
14 Monitor the temperature of the water using the thermometer.
15 Continue the experiment until the water's temperature increases by about 10°C.
16 Turn off the power supply.
17 Stir the water gently to ensure uniform temperature distribution.
18 Record the final temperature of the water.

Calculations

Calculate input energy

1 Calculate the power used in each 1-minute time interval by multiplying the current by the voltage drop ($P = I \times V$). Record this in the results table.
2 Multiply the power value for each interval by 60 seconds to calculate the energy used in each time interval (energy = power × time).
3 Add together the energy used in all time intervals to calculate the total electrical energy used during the experiment.

Calculate the heat absorbed by the water

4 Calculate the heat absorbed by the water (q) using the formula:

q = mass of water (g) × 4.18 × (final temperature – initial temperature)

Results

1 Note the initial and final temperatures.
2 Copy and complete Table 1.

Table 1 Experiment results

Time (mins)	Voltage (V)	Current (A)	Power (W) = voltage × current	Input energy (J) = power × 60
1				
2				
3				
...				
Final (10°C) increase				

Discussion

1 What type of energy transformation occurred in this experiment?

2 Compare the heat absorbed by the water (q) to the total energy input of the circuit.

3 Explain any discrepancies between the calculated energy and the heat absorbed by the water.

Lesson 2.13
Energy efficiency can reduce energy consumption

Key ideas

→ When cooking food, you do not want to lose heat energy to the surroundings or else it will take longer for the food to cook.

→ Insulation prevents the transfer of thermal (heat) energy.

→ The use of traditional ground ovens by Aboriginal and Torres Strait Islander Peoples demonstrates their understanding of energy efficiency, ensuring that heat energy is retained during the cooking process.

Learning intentions and success criteria

Being energy efficient

For thousands of years, Aboriginal and Torres Strait Islander Peoples have used their understanding of the way energy is transferred and transformed to develop energy-efficient ways to generate heat and to cook food and not lose the heat energy to the surroundings.

Cooking food

One role of archaeologists is to develop an understanding of traditional methods used by Aboriginal and Torres Strait Islander Peoples to cook food. With the permission of the Barengi Gadjin Land Council Aboriginal Corporation, which represents the Traditional Owners of the Jadawadjali language group in Western Victoria, archaeologists set out to recreate a traditional ground oven. They dug a large pit, 25 cm deep, in the earth and lined the base of the pit with spheres made of clay and sand. On top of the spheres, a fire was slowly built up until it burned strongly for 1 hour (Figure 1a–e). When the fire died down to glowing coal, half the coals and spheres were removed (Figure 1f). Wet reeds were placed on top of the remaining coals and clay spheres (Figure 1g) before the edible roots of *Microseris scapigera* (yam daisy) were placed on top of the reeds. The remaining hot coals and spheres (Figure 1h) were placed on top of the roots before being covered with large sheets of stringy bark (Figure 1i) and sand (Figure 1j). The food was cooked overnight. This process of using the reeds, stringy bark and sand to insulate the heat, reduced the loss of heat and increased the efficiency of the ground oven.

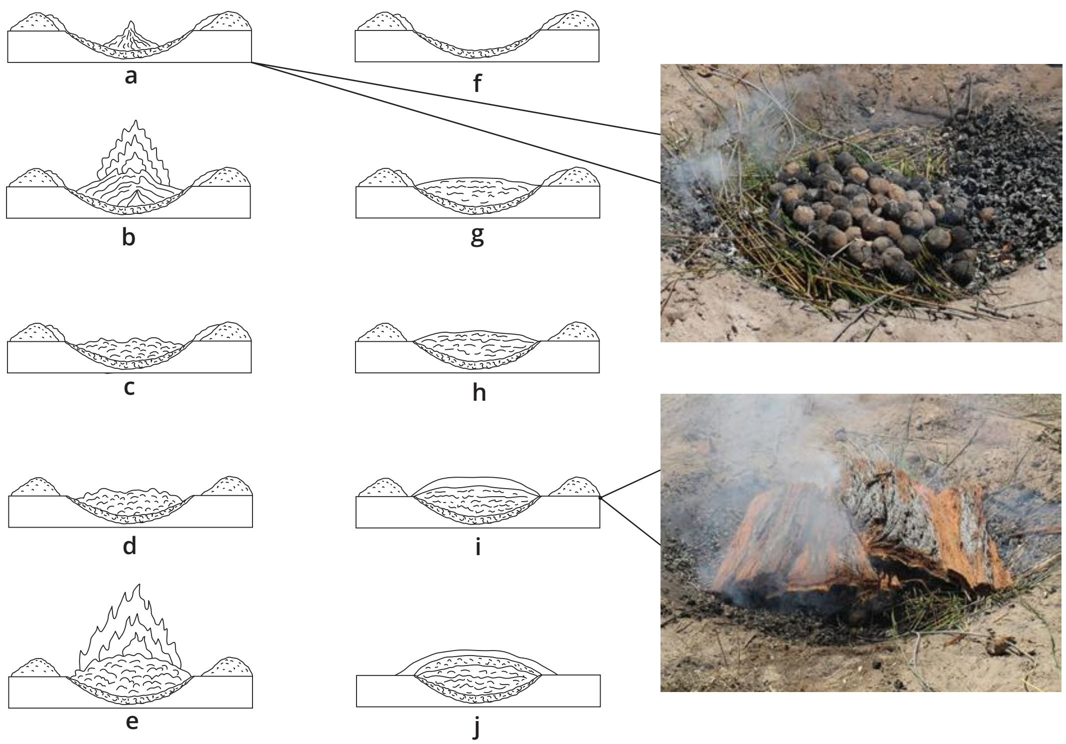


Figure 1 Recreation of a traditional ground oven

Heating and cooling your house

You probably use electricity or gas to run heating or cooling systems at home. In a hot environment, energy is needed to remove the heat from inside your home, allowing it to cool down.

The warm air inside the house is moved over cool pipes in an air conditioner. The thermal energy of the house air is passed to the refrigerant inside the pipes and is then carried outside the house. If the house is well designed, thermal energy remains outside and the house stays cool.

Home design features

Architects design homes to help control the flow of thermal energy. They can add a variety of features that help limit the amount of heating or cooling your house needs.

Figure 2 Insulation prevents heat energy from being transferred between the inside and outside of the house.

Insulation

Lining the inside of the walls, floors and roof of your house can ensure that heat is not transferred between the outside air and the inside of the house. This keeps the heat inside on a cold day and outside on a hot day.

Reducing window heat

One of the main places that heat is transferred is through windows. On a hot day, light and heat from the Sun can easily penetrate a window. This transfers heat into the house.

An awning on a window can limit this. Limiting the number of windows facing the Sun can also help to prevent the heat being transferred into the house.

Double-glazed windows have two panes of glass, separated by an air gap (Figure 3). Air does not transfer heat very well (it is a good insulator). A home with double-glazed windows will not gain much heat during a hot day or lose heat on a cold night.

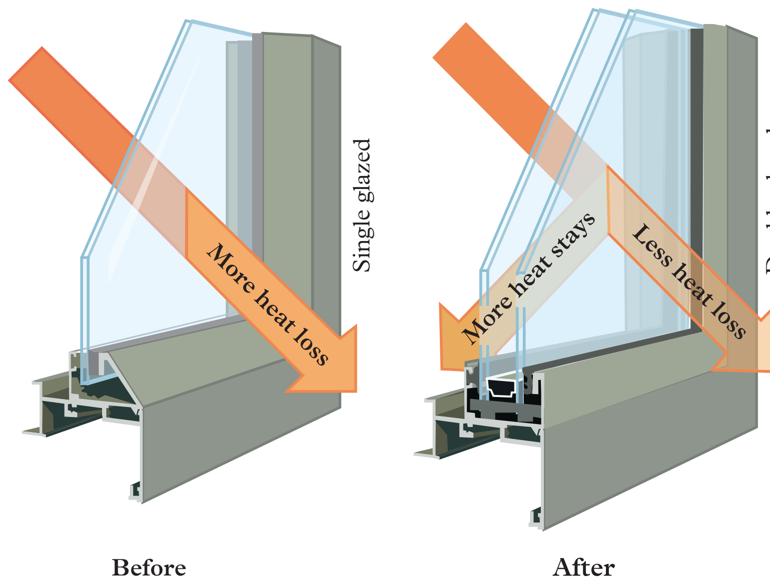


Figure 3 Double-glazed windows use two panes of glass to reduce the transfer of heat in and out of a house.

Verandas

Verandas work much like awnings, but also prevent heat and light from the Sun from shining on walls. This stops heat from being transferred to the walls and then to the air inside.

Figure 4 A veranda prevents heat from being transferred from the Sun to the walls of a house.

Check your learning 2.13

Check your learning 2.13

Comprehend

1 Explain how insulation reduces the need for artificial heating and cooling.

2 Describe how window awnings and verandas keep a house cool in summer.

Apply

3 Summarise how architects use their knowledge of energy efficiency to minimise the energy used in a house.

4 The temperature inside and outside a house was measured over 4 days and displayed in Figure 5.

 a Determine from the graph whether the house was insulated.

 b Justify your answer (by using numbers from the graph as evidence).

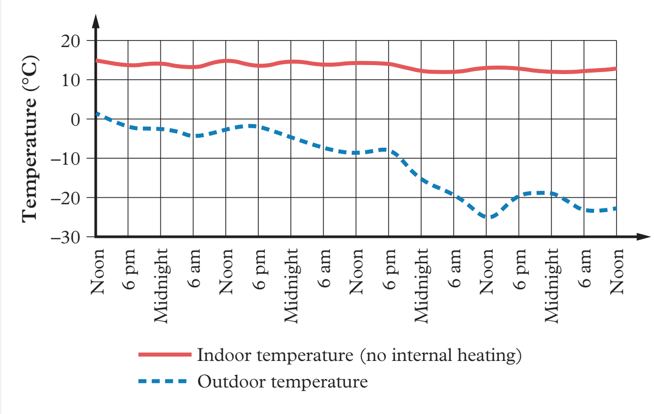


Figure 5 A graph showing the temperature inside and outside a house

Lesson 2.14

Challenge: Design an energy-efficient house

Design brief

Design and build two identical model houses out of cardboard or wood. Add a feature to one of the houses that will make it more efficient in staying cool. Test your design feature by exposing both houses to an energy source (a strong light) and determine the rate of temperature increase for each house.

Criteria

- Only one feature may be added to the second house.
- The feature must represent a design feature that is currently available to homeowners.
- The feature must be proportionate in size to the house.

Questioning and predicting

1 Identify the feature you will add.

2 Identify the materials you will use.

3 Use your knowledge of heat energy to explain why your added feature will keep the house cool.

Planning and conducting

1 Explain how you will measure the temperature of the two houses.
2 Draw a table that you will use to collect your data. Include headings and units of measurement.
3 Describe how long you will expose the houses to the energy source.

Processing, analysing and evaluating

1 Create a graph to compare the data from both houses.
2 Describe the rate of temperature increase in both houses.
3 Calculate how efficient your feature was at preventing the transfer of thermal energy by comparing the difference in temperature of the two houses.
4 Describe the limitations of your design (when it will not prevent thermal transfer).
5 Explain how you could create a large-scale version of your design for a real house.
6 Evaluate your design and explain how you would modify it if you were doing this experiment again.

Communicating

Present the various stages of your investigation in a formal scientific report.

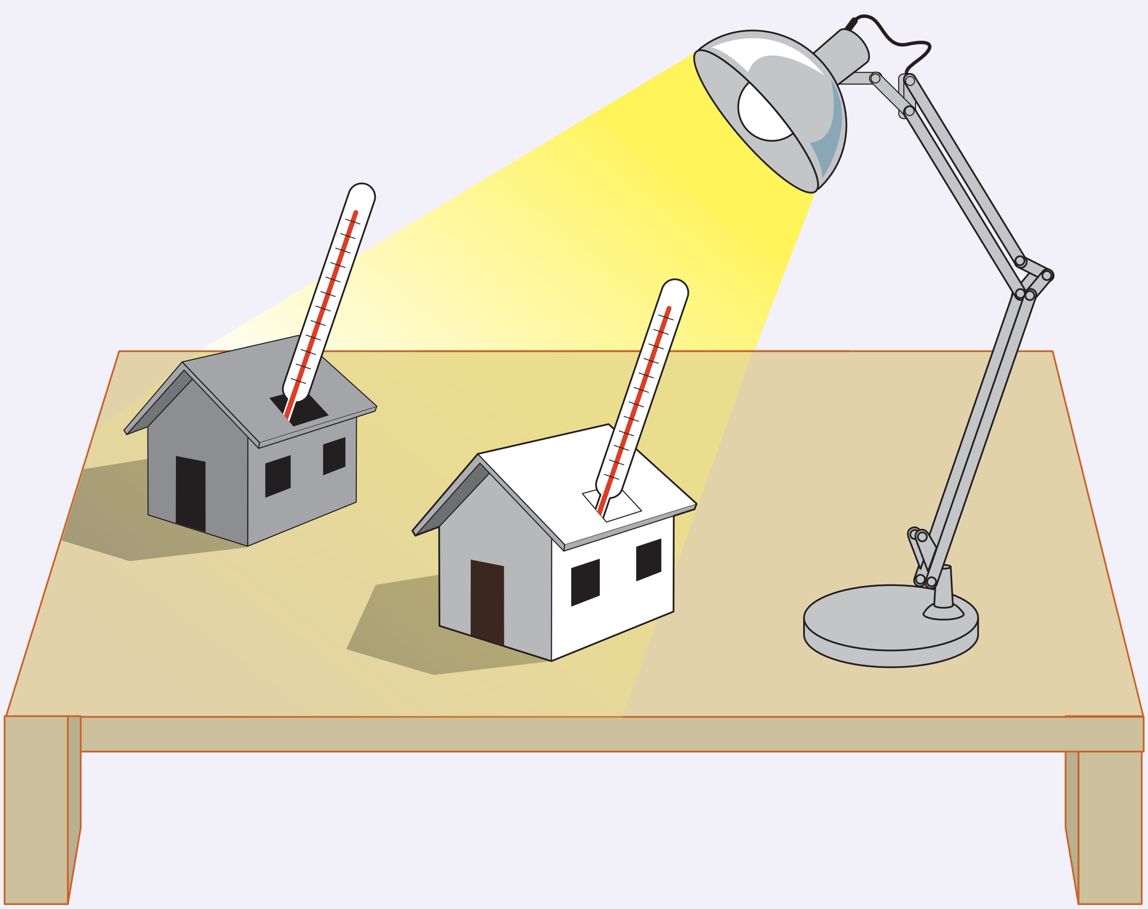


Figure 1 General set-up of the experiment

Lesson 2.15
Electricity is generated from different energy sources

Learning intentions and success criteria

Key ideas

→ Global energy consumption has increased since 1900.

→ The world is moving towards a greater reliance on electrical energy.

→ Electrical generators transform kinetic energy into electrical energy.

Introduction

The world's energy consumption is increasing as populations grow and people become wealthier. This global rise in energy demand has prompted efforts worldwide to develop alternative sources of energy and to become more energy-efficient.

Global energy consumption

Global energy consumption has increased almost every year since 1900 (Figure 1). Until the mid-1800s, the main sources of energy were renewable, such as wood and waste from agriculture (e.g. animal dung and excess plant material), which were burned for heating and cooking. These sources of energy are called "traditional biomass" (Figure 1). After the mid-1800s, the use of fossil fuels rapidly expanded. Since 1900, the majority of energy has come from coal, oil and natural gas, which are non-renewable energy sources. Today, fossil fuels remain the dominant energy source worldwide, although the use of renewable sources is growing.

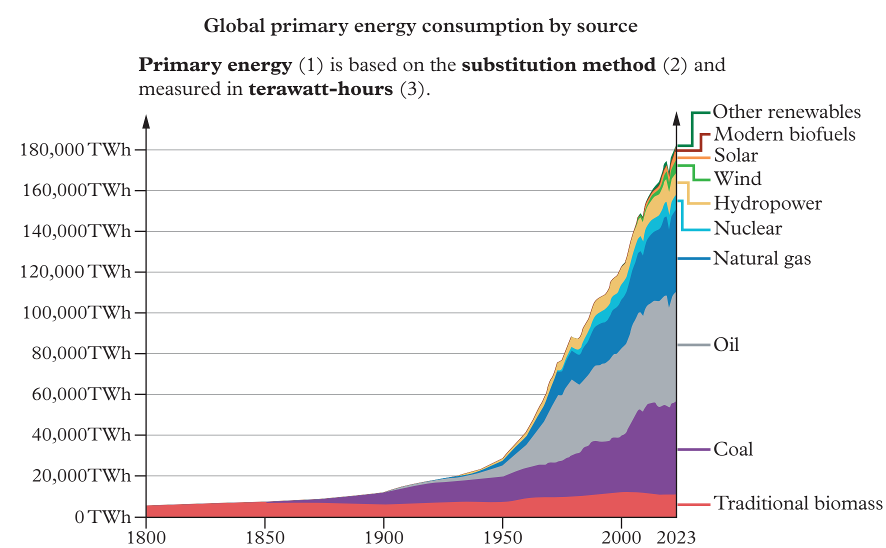


Figure 1 Global primary energy consumption

Primary energy (1): raw energy sources (like coal or solar) before conversion, including both usable energy and losses. **The substitution method (2):** adjusts non-fossil energy to match fossil fuel inefficiencies for fair comparison, using a standard efficiency factor (~0.4). **A watt-hour (3):** a unit of energy equal to 1 watt used for 1 hour (3,600 joules), often measured in kWh, MWh, etc.

Australia has abundant fossil fuels, and coal is its main energy source (Figure 2). There is increasing awareness of the environmental impact of continually burning fossil fuels, and pressure is being put on politicians to consider climate change when managing the use of these energy sources. Reducing Australia's dependency on fossil fuels would decrease the environmental damage caused by their combustion and the effects of climate change.

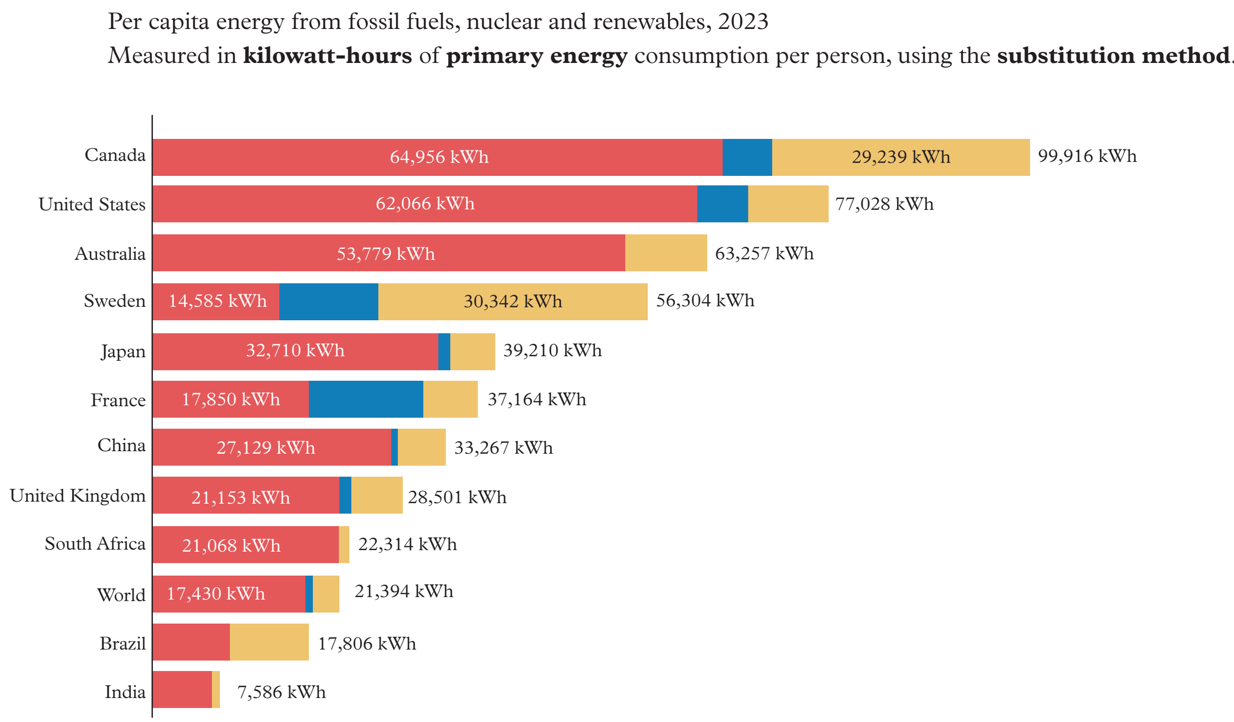


Figure 2 Energy use (kWh) per person in different countries

The rate of growth in electricity generation has outpaced the growth in total energy consumption by 25 per cent. This suggests that the world is shifting towards greater reliance on electrical energy, highlighting the need to explore alternative energy sources for electricity generation.

There are many ways to generate electricity. Electrical generators convert kinetic energy into electrical energy. **Turbines**, which consist of a series of blades mounted on a pole, drive electricity generators. Different sources of energy, such as water, steam and wind, can be used to rotate a turbine's blades. The turbine is attached to a **generator**, and the kinetic energy of the turbine is transferred to the generator. The generator then converts this energy into electrical energy.

turbine a large wheel with angled sections called vanes, like a propeller, that is used to generate electricity

generator a machine that uses the electromagnetic effect to separate charges and produce electricity

Generating electricity using renewable sources of energy

Solar energy

Solar energy is the most abundant source of energy. The Sun emits solar radiation as light. Solar energy technologies, such as solar panels, take this light energy and transform it into electrical energy. This process is called photovoltaic effect. Solar panels are also called photovoltaic panels.

Wind energy

Wind energy is the kinetic energy of moving air. Wind turbines transform this kinetic energy into electrical energy. A wind turbine is the opposite of an electric fan which transforms electrical energy into kinetic energy. Wind turbines consist of large blades mounted on a tower. As the wind blows, it causes the blades to spin which turns a generator to produce electricity. Wind farms, which are collections of wind turbines, can be found both onshore and offshore.

Hydropower

hydropower energy produced by falling water that turns turbines to generate electricity

Hydropower uses the gravitational potential energy of water moving from a higher elevation to a lower point. As the water flows to the lower level, its gravitational potential energy decreases and is converted to kinetic energy, according to the law of conservation of energy. The kinetic energy of the water is used to turn a turbine and generate electricity. Hydropower plants can be found in various forms, including large dams, run-of-the-river systems and pumped storage systems. These plants provide a significant portion of the world's renewable energy.

Snowy Hydro 2.0 is the largest renewable energy project in Australia, located in NSW. It links two dams at different heights: the Tantangara and the Talbingo. Water will be pumped from the lower dam to the upper dam when there is less demand for electricity. When more electricity is needed, the water from the upper dam will be released back down to the lower dam, transforming gravitational potential energy into kinetic energy. The kinetic energy of water turns a turbine which generates electricity by converting kinetic energy into electrical energy. This project will help provide reliable, renewable energy.

Geothermal energy

geothermal energy energy that comes from heat beneath Earth's surface

Geothermal energy is heat energy from under the Earth's surface. Steam turbines are used to transform this heat energy into electrical energy. Geothermal power plants typically use steam produced from reservoirs of hot water found a few miles or more below Earth's surface. The steam is brought to the surface through wells and used to drive turbines connected to generators.

Biomass

biomass organic matter (material from organisms such as plants and animals); a renewable resource that can be used to generate energy

biofuel a renewable energy source derived from organic materials, including plants and animal waste

Biomass is an organic energy source. It can come from a variety of sources, such as wood, crops and animal waste. When biomass is burned, it releases energy that is used for heating, electricity generation and transportation. These **biofuels** can be used in place of fossil fuels.

Generating electricity using coal

Fossil fuels are burned to heat water and generate electricity using steam turbines. Coal, a non-renewable energy source, is still widely used in Australia for electricity generation. The energy stored in coal is converted into electrical energy in a power station. Since coal is inexpensive and readily available in Australia, there has been resistance to adopting emerging renewable technologies, such as solar power, hydropower and wind energy. Despite this reluctance, scientists are working to encourage the use of these renewable sources and to find more sustainable methods of using coal. Many people in today's society, particularly younger generations, increasingly seek renewable energy sources and adopt more sustainable lifestyles. While the transition to renewable energy is important, some scientists are exploring methods to reduce the environmental impact of using coal.

Coal washing

Coal washing removes impurities from the coal. In this process, coal is crushed and mixed with liquid, allowing contaminants to separate. The coal is then burned, and the harmful gases produced are treated with limestone and water to remove sulfur dioxide. Nitrogen oxides can also be reduced, using burners that limit the oxygen involved in the combustion process.

coal washing the process of "cleaning" coal with water and chemicals to remove sulfur and other impurities before it is burned at a coal power plant

Coal gasification (IGCC)

Another technique is the Integrated Gasification Combined Cycle (IGCC) system, which transforms coal into gas for energy production. The IGCC process uses steam and pressurised hot air to break apart the carbon molecules in coal. This method is more energy-efficient than directly burning coal to generate heat for turning a turbine.

Carbon capture and storage (CCS)

When carbon dioxide is emitted from power plants, it can be captured and stored through carbon capture and storage (CCS). Several methods have been developed to capture carbon dioxide, including the following.

- Flue-gas separation captures carbon dioxide using steam, which is then condensed into a concentrated stream.
- Oxy-fuel combustion is a process in which coal is burned in pure oxygen, creating a gas composed mostly of carbon dioxide and water vapour, without sulfur dioxide or nitrogen oxides. The carbon dioxide is then stored in containers, either deep underground or under the ocean, where it dissolves.

Figure 3 Mount Piper is a coal power station near Lithgow in NSW.

Individual choices and future developments

In our daily life, the energy choices we make – such as which appliances to purchase – can have an impact on energy consumption. Some appliances are more energy efficient than others, helping to reduce overall energy demand. Scientists, including engineers, biologists, chemists and physicists, are collaborating to develop new, more sustainable energy sources. Their work will play a crucial role in creating a future where energy consumption is both environmentally responsible and efficient.

Figure 4 Coal provides a form of non-renewable energy.

Check your learning 2.15

Check your learning 2.15

Retrieve

1 Identify the two waste gases other than carbon dioxide that result from burning coal.

2 List three renewable sources of energy used to generate electricity.

Comprehend

3 Summarise the environmental benefits of using solar power over coal.

4 Explain how hydroelectric power stations convert kinetic energy into electrical energy.

Analyse

5 Use the graph in Figure 1 to identify past trends in energy use and predict future energy demands at global levels.

6 Compare the environmental impact of electricity generation from coal, wind and solar.

Apply

7 Predict the impact on electricity output if wind speed decreases on a wind farm.

8 The use of coal in Australia is widely debated. Coal has negative environmental impacts, and people sometimes suggest Australia should use renewable energy sources, specifically nuclear energy. This is suggested because Australia has one of the largest uranium stores on Earth.
   a Research nuclear power as a source of energy.
   b Evaluate nuclear energy and coal energy, considering ethical issues and how sustainable they are.

Skills builder: Conducting investigations

9 Research two sources of information related to the use of coal in Australia. Then investigate two sources of information related to renewable energy in Australia.
   a List the references for each source.
   b Discuss whether one source was better than the other.

10 Scientists assess strategies that are identified as possible solutions to a problem. An example of a problem and a possible solution is coal and coal washing. Evaluate the method of coal washing by writing a pros and cons list. (THINK: What is the value of coal washing? What are the outcomes of coal washing? Are there better alternatives?)

Lesson 2.16
Solar cells transform the Sun's light energy into electrical energy

Learning intentions and success criteria

Key ideas

→ Solar energy is converted into electrical energy using solar cells.

→ Solar energy is stored in a battery as chemical potential energy, which can be used when needed.

Introduction

A solar cell is any device that transforms the Sun's light energy into electrical energy. The number of households using the Sun's light energy to heat water or power heating and cooling devices is growing rapidly every year.

Using solar energy in Australia

Australia is often known as the sunburnt country. This is a reference to the large number of hours each day that the Sun shines. Australia is a big country, however, and the number of hours the Sun shines varies greatly, depending on the location and the time of year. **Solar energy** is often measured as the number of peak sunlight hours every day (Figure 1). This is then averaged out over the whole year. For example, in the Hunter Valley in NSW, the number of peak hours can be as low as 4.0 hours/day in winter and as high as 6.5 hours/day in summer. Over a year, this averages out to 5.6 hours/day. In Tasmania, the average number of peak hours is 3 hours/day. In Queensland, the Northern Territory and Western Australia, the average number of peak hours each day is 6.

solar energy the energy from sunlight that can be converted into electrical or heat energy

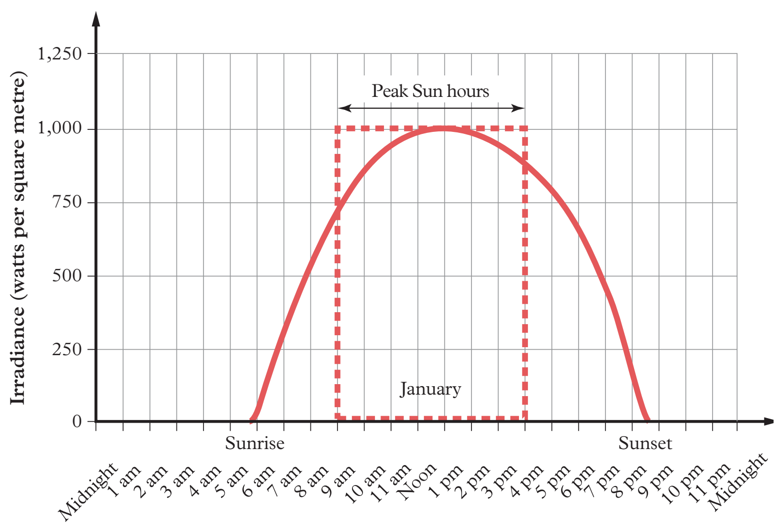


Figure 1 Graph showing the peak sunlight hours over a day

Converting energy from the Sun

Using energy from sunlight to power a house has its problems. The most common time people use electrical energy is when sunlight is least available. This means that the light energy from the Sun needs to be stored so it can be used at night. This light energy is transformed into potential chemical energy in a battery so it can be used to heat water, provide light or supply energy for cooking (Figure 2).

Figure 2 The Tesla Powerwall is a rechargeable battery system that is used to store solar-generated electricity for use in homes and businesses.

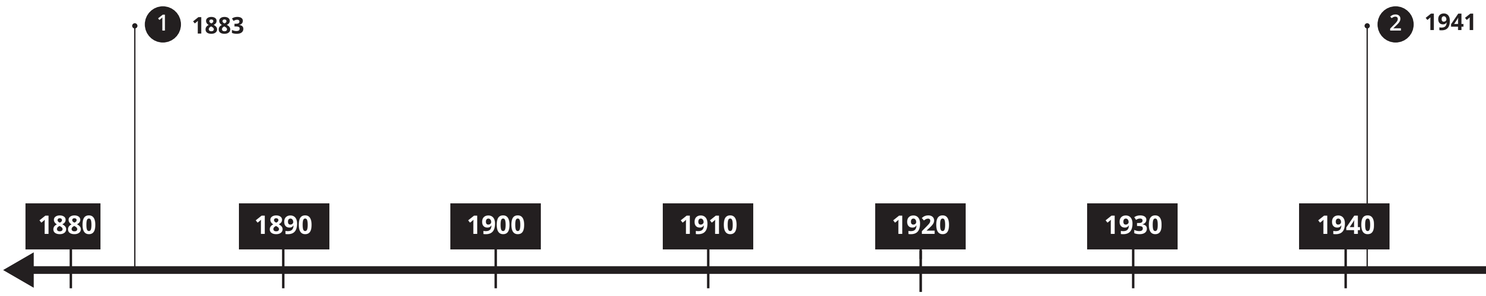


Figure 3 History of solar cars; the following parts are labelled:

1. 1883: The first solar cell was invented by Charles Fritts. A solar cell is selenium (a semiconductor) with a thin layer of gold.
2. 1941: The silicon solar cell was invented by Russel Ohl and had an efficiency of 1 per cent.
3. 1954: Gerald Pearson, Calvin Fuller and Daryl Chapin improved the efficiency of the silicon solar cell to 6 per cent. Silicon strips were used to create the first solar panels.
4. 1955: The first solar car invented was a tiny 35 cm vehicle created by William G. Cobb of General Motors.
5. 1962: International Rectifier Company designed the first solar car that could be driven. They converted a vintage 1912 Baker electric car to run on approximately 10,640 PVCs.
6. 1977: Alabama University professor Ed Passerini constructed his own solar-powered car called “Bluebird”.
7. 1980: Englishman Alain Freeman road-registered a three-wheeler solar car with a solar panel on the roof.
8. 1980: Arye Braunstein and colleagues at Tel Aviv University (Israel) designed a solar car with a solar panel on the roof and hood of the car. The car was recorded reaching 65 km/h with a maximum range of 80 km.
9. 1982: Australian brothers Larry and Garry Perkins designed and hand-built the “Quiet Achiever”, the first vehicle driven across a continent using only solar power. Larry and Hans Tholstrup drove the Quiet Achiever from the east coast of Australia to the west coast. Their feat is recognised in the World Solar Challenge, a solar car race that allows designers to compete in a race across Australia every 2 years.
10. 1987: GM Sunraycer completed a 3,010 km trip in California with an average speed of 67 km/h.
11. 2014: A solar-powered family car (with four seats) called “Stella” was driven 613 km from Los Angeles to San Francisco.

Capturing the light energy

photovoltaic cells (pv cells) solar cells that transform solar energy into electrical energy; also known as pv cells

Solar panels are a collection of solar cells called **photovoltaic cells (PV cells)**. When light shines on the surface of PV cells, the light energy is transformed into electrical energy. The most efficient PV cells currently convert 30 per cent of the energy they receive from the Sun.

Alternatives to fossil fuel cars

Since the beginning of the 1900s, people have relied on cars to move from one place to the next. Cars rely on the chemical energy in fossil fuels (petrol and diesel) to generate the kinetic energy to move. This energy transformation from chemical energy to movement energy has contributed to the carbon dioxide that is warming the atmosphere. As a result, scientists and engineers are working to develop alternative forms of energy transformation.

Hybrid cars combine combustion engines that use fossil fuels with electric motors that use energy stored in a battery. The car uses the electric motor at low speeds and the combustion engine when accelerating and travelling at faster speeds. Hybrid cars cannot be plugged into the energy grid to charge the battery.

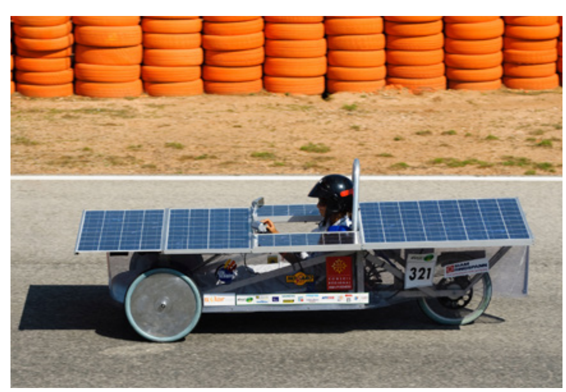
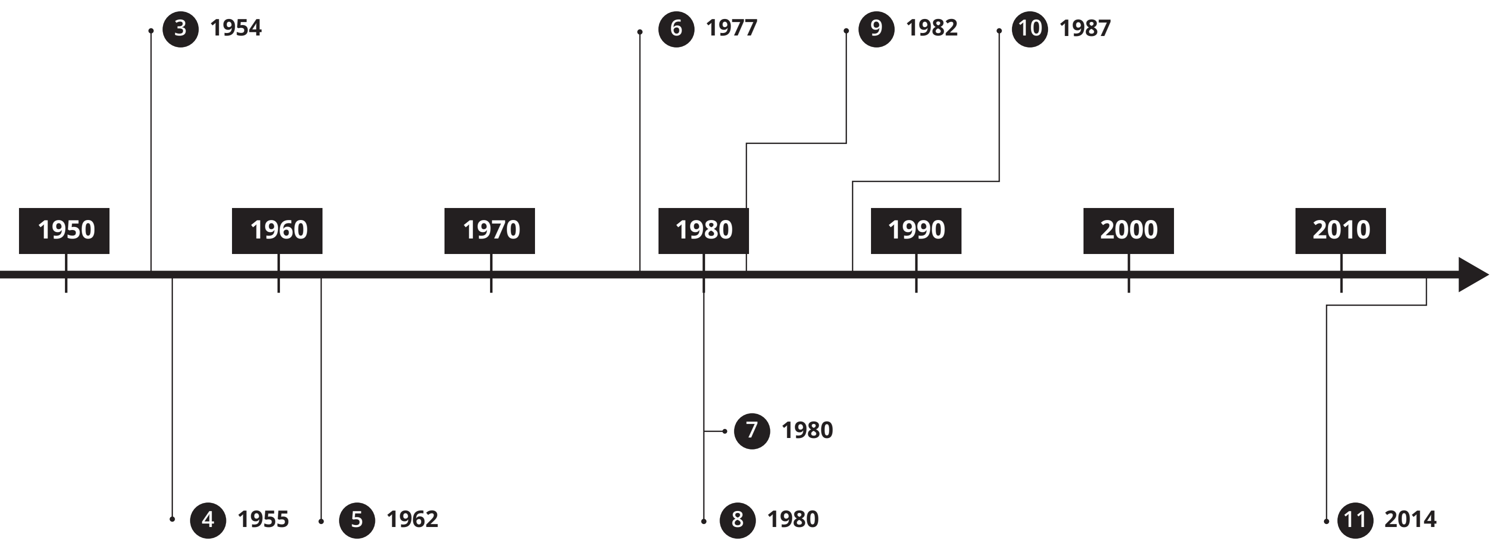


Figure 4 A three-wheeled solar car with a solar panel on the roof



Instead, the battery is recharged by converting kinetic energy (from when the car brakes or coasts) into electrical energy and storing it in the battery.

Electric cars use the chemical energy in batteries to generate kinetic energy. The batteries can be charged through the same electrical grid that powers your house. They can also use solar panels to transform sunlight into electrical energy, which can be stored as chemical potential energy in the battery.

Solar cars use a variety of solar panels to transform light energy into kinetic energy. Most current solar-powered vehicles only carry one person (Figure 4). They are lightweight (approximately 600 kg) so that they are more energy efficient.

Check your learning 2.16

Check your learning 2.16

Retrieve

1 Define the following terms:
   a Tesla Powerwall
   b photovoltaic cell.

2 Recall why Australia is known as the sunburnt country.

Analyse

3 Explain why it is important to store solar energy.

4 Compare the carbon footprint of fossil fuel cars, hybrid cars and electric cars.

Apply

5 Investigate the challenges electric cars face in terms of battery life and charging infrastructure.

Figure 5 A 1970s electric CitiCar

6 Imagine your family needs to buy a car and asks your opinion on choosing between a fossil fuel car, a hybrid or an electric car. Which option would you suggest? Explain your choice in terms of cost and environmental impacts.

Skills builder: Processing and analysing data

7 The amount of (photovoltaic) sunshine available across Australia changes according to the time of the year (Figure 6). Photovoltaic data is collected by a number of Australian research groups to track the effectiveness of energy transformation from light energy to electrical energy.

Analyse the graphs by answering the questions below.

a Identify the variable on the horizontal x-axis.

b Identify the variable on the vertical y-axis.

c Identify Queensland's maximum percentage of photovoltaic capacity from the graphs.

d The data was collected at different times of the year. Evaluate the energy efficiency of the different seasons by answering the following.

i Identify which graph has the highest value.

ii Explain how the different seasons affect the level of sunshine available in Queensland.

iii Decide which season produces the highest percentage of photovoltaic capacity.

e Evaluate which state is capable of transforming the most light energy into electrical energy through the use of PV cells by answering the following.

i Identify which state has high percentages of photovoltaic capacity in both seasons.

ii Explain why transforming light energy across the whole year is more important than transforming the most light energy in just one season.

iii Decide which state is capable of transforming the most light energy into electrical energy.

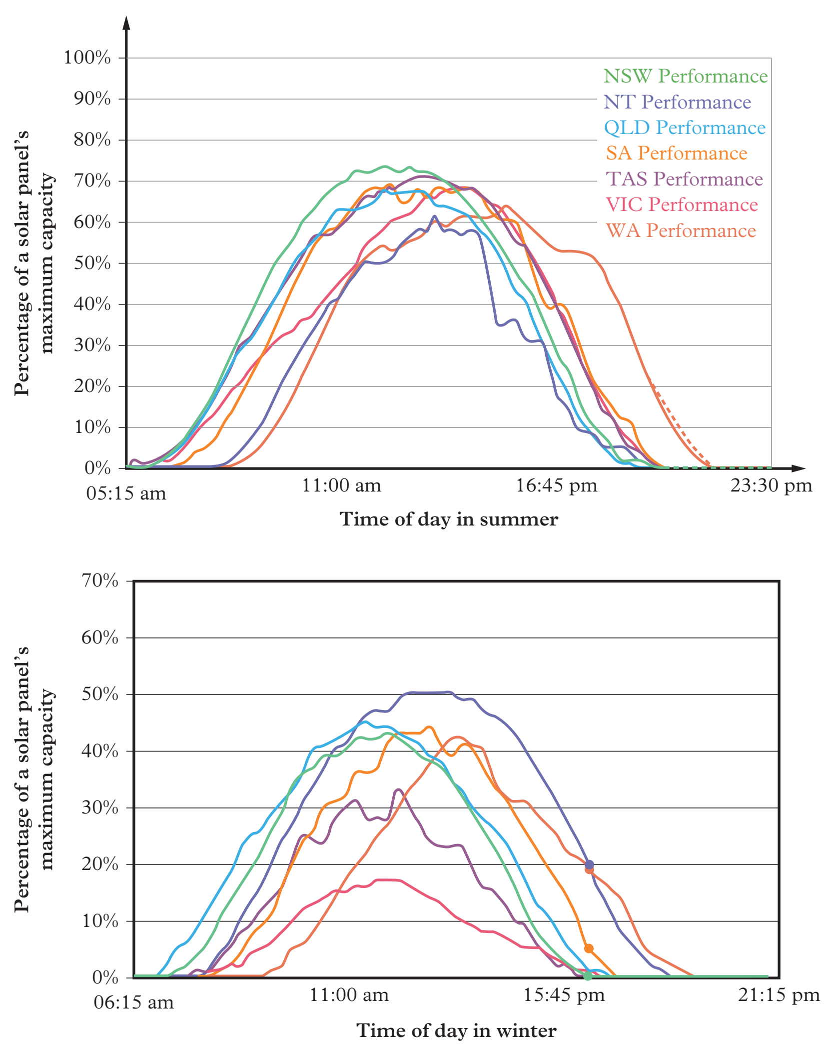


Figure 6 Estimated output of a solar panel as a percentage of its maximum capacity in each state at different times of the year

Lesson 2.17
Review: Energy

Summary

Lesson 2.1 Energy cannot be created or destroyed

- The law of conservation of energy states that energy cannot be created or destroyed.
- When energy is transformed, waste energy is produced.
- Efficient energy transformations produce less waste energy.

Lesson 2.2 Sankey diagrams can represent energy efficiency

- The conservation of energy can be represented in a Sankey diagram.

Lesson 2.4 Electricity can flow through circuits

- A closed circuit occurs when the positive and negative charges can be separated and reunited.
- An electrical conductor allows the charges to flow easily.
- An electrical insulator restricts the movement of the charges.

Lesson 2.7 Current can flow through series and parallel circuits

- In a series circuit, the loads are connected one after the other, and the current is the same throughout the circuit.
- In a parallel circuit, the loads are parallel to one another, and the current is shared between them.
- A short circuit occurs when the electrical energy can move through an easier path with less resistance.

Lesson 2.9 Voltage, current and resistance

- Voltage is a measure of the difference in electrical potential energy carried by charged particles between different points in a circuit.
- Voltage can be measured using a voltmeter or multimeter in parallel to the circuit.
- Resistance is a measure of how difficult it is for the current to flow through part of the circuit.

Lesson 2.11 How is power measured?

- The unit of measurement for power is the watt (W), which is the amount of energy used per second.
- To determine how much you pay for electricity, a power meter is installed and read, then a bill sent out.
- The energy star rating system is a visual guide to show consumers how energy efficient an appliance is. The more stars, the more energy efficient.

Lesson 2.13 Energy efficiency can reduce energy consumption

- When cooking food, you do not want to lose heat energy to the surroundings or else it will take longer for the food to cook.
- Insulation prevents the transfer of thermal (heat) energy.
- The use of traditional ground ovens by Aboriginal and Torres Strait Islander Peoples demonstrates their understanding of energy efficiency, ensuring that heat energy is retained during the cooking process.

Lesson 2.15 Electricity is generated from different energy sources

- Global energy consumption has increased since 1900.
- The world is moving towards a greater reliance on electrical energy.
- Electrical generators transform kinetic energy into electrical energy.

Lesson 2.16 Solar cells transform the Sun's light energy into electrical energy

- Solar energy is converted into electrical energy using solar cells.
- Solar energy is stored in a battery as chemical potential energy, which can be used when needed.

Review questions 2.17

Review questions Module 2

Retrieve

1 The units of voltage, current and resistance, respectively, are:
- **A** amps, ohms and volts
- **B** ohms, volts and amps
- **C** volts, amps and ohms
- **D** volts, ohms and amps.

2 A 50 Ω resistor is connected to a 10 V battery. The current flowing through it is __________.
If the voltage is doubled, then the current will be __________.
- **A** 5 A, 2.5 A
- **B** 0.2 A, 0.1 A
- **C** 5 A, 10 A
- **D** 0.2 A, 0.4 A

3 A voltmeter is connected in __________ in a circuit, and an ammeter is connected in __________ in a circuit.
- **A** series, series
- **B** parallel, parallel
- **C** series, parallel
- **D** parallel, series

4 Identify the circuit in Figure 1 as either parallel or series.

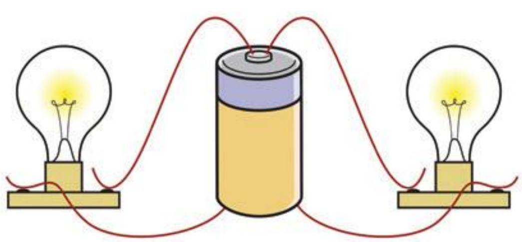


Figure 1 Identify the circuit.

5 Identify each symbol (ammeter, cell, globe or switch) in Figure 2.

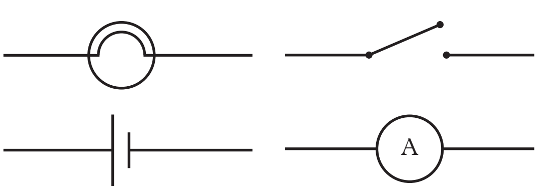


Figure 2 Circuit symbols

6 Define the term “resistance”.

7 In your own words, describe Ohm’s law.

8 Identify the correct labels for A, B and C in Figure 3.

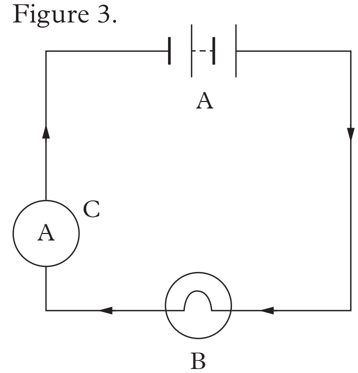


Figure 3 Circuit diagram

Comprehend

Figure 4 A block of ice melting

9 Describe how current moves in a parallel circuit.

10 Figure 4 shows a block of ice melting.
- **a** Describe what is happening to the molecules as the ice melts. Draw a diagram to illustrate your answer.
- **b** Explain where the energy to melt the ice comes from. Explain how the energy is transferred to the molecules of ice.

Analyse

11 Draw a circuit diagram showing a battery and a switch, with a globe on either side of the switch.
- **a** Does it matter where in the circuit the switch is placed?
- **b** Show the direction of electron flow and the direction of conventional current.

12 Calculate the current flowing through a 30 Ω resistor when it has a voltage drop of 12 V across it.

13 Calculate the voltage drop across a 50 Ω resistor when a current of 25 mA flows through it.

14 Calculate the value of a resistor that has a voltage drop of 18 V across it when a current of 0.3 A flows through it.

15 Draw a circuit diagram showing a battery, three globes and a switch that turns off the whole circuit. Two globes are in series, while the third globe is in parallel with the other two globes.

16 Explain why your home is wired in parallel.

17 Consider why it is scientifically incorrect to say that the fridge passed on its cold energy to you.

18 Compare current and voltage.

Apply

19 Assess the use of coal in Australia to generate electricity.

20 Explain why your home is wired in parallel.

21 Aboriginal and Torres Strait Islander Peoples have used possum, kangaroo and wallaby skin coats to keep themselves warm. Traditionally, the skin was worn with the fur facing towards the body to reduce heat loss. Use your understanding of the transfer of thermal energy to discuss the effectiveness of this strategy.

22 Rubber and wood have very high resistance to the flow of electricity. Propose how this will affect the current and voltage in a circuit.

Critical and creative thinking

23 A storm has blown a tree over on the main power line to your neighbourhood. The electricity supply is cut. Describe your day without electricity.

24 Investigate two sources of information related to the use of coal in Australia. Then investigate two sources of information that provide an alternate energy source in Australia.

- **a** Write down references for each source.
- **b** Discuss whether one source is better than the other.

25 Construct a fair experiment to investigate the effect of increasing resistance on the current.

- **a** Write a hypothesis for the experiment.
- **b** Determine independent, dependent and controlled variables.
- **c** Write a method for performing the experiment.
- **d** Draw a labelled scientific diagram of the equipment set-up.

26 The use of coal in Australia causes debate among people. Coal has negative environmental impacts, and people sometimes suggest Australia should use renewable energy sources, specifically nuclear energy. This is suggested because Australia has the largest uranium stores on Earth.

- **a** Investigate nuclear power as a source of energy.
- **b** Create a table to compare nuclear energy and coal energy.

27 Use your understanding of current and voltage to create a model of the flow of electricity through a circuit. You might use people or even an animation as your model.

Research

28 Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

Incandescent light globes

Incandescent light globes are traditional light globes. You are likely to see them around homes. What does “incandescent” mean? What are incandescent light globes made of? Why must the filament be contained in an inert gas like argon? What temperature does the filament need to be heated to so that it gives off light? How efficient are incandescent light globes?

Generating electricity

Australia is powered via coal energy, which is created at coal power stations. Why do they need to burn coal? What is water steam used for? How can wind energy or any other renewable resources be used instead of coal?

Energy-efficient housing

In previous societies, energy efficiency was important because people had limited access to the types of energy supplies and their applications that we have today. Research how civilisations in tropical areas designed their homes to keep them cool and damp-free. What different types of energy-efficiency practices have humans used through the ages?

Imagine your family needs to buy a car and asks your opinion on choosing between a fossil fuel car, a hybrid or an electric car. Which option would you suggest? Explain your choice in terms of cost and environmental impacts.

Module 3

Homeostasis

Overview

The nervous and endocrine systems work together to help the body respond to changes and keep everything in balance. They help control the body's reactions to temperature, light, danger, hunger or thirst by sending electrical signals (nervous system) and hormones (endocrine system) from one part of the body to another. The body's ability to respond to internal changes and ensure conditions are stable is called homeostasis. Our systems use feedback loops to adjust and fix things when needed, including keeping body temperature or blood sugar levels steady. Diseases like diabetes can cause problems with these systems, showing how important balance is for health. Understanding these feedback loops has helped create treatments such as insulin for diabetes.

Lessons in this module

Lesson 3.1
Homeostasis regulates through negative feedback loops

Learning intentions and success criteria

Key ideas

→ The body needs to detect and correct changes in its levels of nutrients, water and temperature to stay healthy.

→ Homeostasis is the process whereby the body regulates and maintains a stable, balanced condition inside the body

→ Negative feedback loops occur when the body responds in a way that removes the initial change (stimulus).

homeostasis the process by which the body detects and responds to stimuli to ensure a stable internal state is maintained

negative feedback loop a regulatory mechanism in which the stimulus causes a response that acts in the opposite direction to whatever is being regulated

stimulus any information that the body receives that causes it to respond

response the action or change in behaviour or physiology that occurs as a result of a stimulus

receptor a specialised cell that detects a stimulus or change in the normal functioning of the body

hypothalamus the region at the centre of the brain that produces hormones and regulates important body functions such as sleep, body temperature and heart rate

effector a cell, tissue or organ that responds to a stimulus

Homeostasis

Humans can only survive in very specific environments. Our bodies have particular requirements, including the right amount of nutrients, water and oxygen. Conditions must be kept within a very narrow range to maintain normal cell function. If fluctuations occur outside the "normal range", it can lead to serious ill health.

The body's ability to detect and respond to internal changes to ensure conditions stay within this normal, stable state is called **homeostasis**. The monitoring and adjusting of body conditions to maintain homeostasis occurs via **negative feedback loops** (or negative feedback mechanisms). These mechanisms are called negative feedback loops because a **stimulus** (change in the body or environment) causes a **response** that acts in the opposite direction to the change.

Body temperature

In Australia, the average life expectancy is 83 years. For that entire time, the core body temperature must be maintained at 37°C. If you were lost in a desert or in freezing temperatures, your body would try to maintain this temperature at all times to keep all cells working efficiently. An increase or decrease by as little at 3°C can be fatal.

To maintain body temperature, our body uses a mechanism that is similar to a thermostat in a heater. When temperature **receptors** on our skin and in the **hypothalamus** of our brain detect our core body temperature decreasing (a stimulus), a message is sent to a variety of **effectors** around our body. Effectors are cells, tissues or organs that cause a change in the way our body functions. This may include muscles to make us shiver (to warm up) or blood vessels to redirect the flow of warm blood to the important organs in our body (heart, liver and brain).

Figure 1 Homeostasis is your body's ability to regulate and maintain a stable condition (balance) inside your body, regardless of changes to the external environment.

Figure 2 (A) When your body gets too hot, homeostasis ensures you cool down by sweating. (B) When your body temperature begins to fall, homeostasis causes shivering to raise your body temperature.

If the temperature receptors detect that we are too hot (a stimulus), then the effectors include our sweat glands and blood vessels. Our body responds by sending more blood, which is carrying heat, to our skin, where sweat is evaporating. The evaporation of the sweat carries the heat away and cools us down. The body always responds to return the body temperature to 37°C (Figure 2).

Hormones at work

The rate of **hormone** production and secretion is often regulated by a negative feedback loop. If a stimulus is received that indicates something in the body is happening "too much", the body has receptors to detect it. The body responds by producing a hormone to remove the stimulus and return the body to normal.

hormone a chemical messenger that travels through blood vessels to target cells

Blood glucose

As we eat, food gets broken down into smaller nutrients. All carbohydrates get broken down into simple sugars, including glucose. These glucose molecules travel through our blood and provide energy for cellular respiration (the reaction of glucose with oxygen to produce energy, carbon dioxide and water).

hyperglycaemia a condition resulting from too much glucose in the blood

High blood glucose

Too much glucose in the blood (**hyperglycaemia**) is not healthy because it causes water to be lost from cells through osmosis. Our body uses a negative feedback loop to control the amount of glucose in our blood. If the concentration of glucose in our blood is too high (stimulus), then receptors in the pancreas detect it (Figure 3). The pancreas then releases a hormone called insulin into the blood. Insulin travels throughout the body to insulin receptors on the target muscle and liver cells. These cells then act as effectors and remove glucose from the blood. This causes the blood glucose to decrease, removing the original stimulus (high blood glucose) (Figure 4).

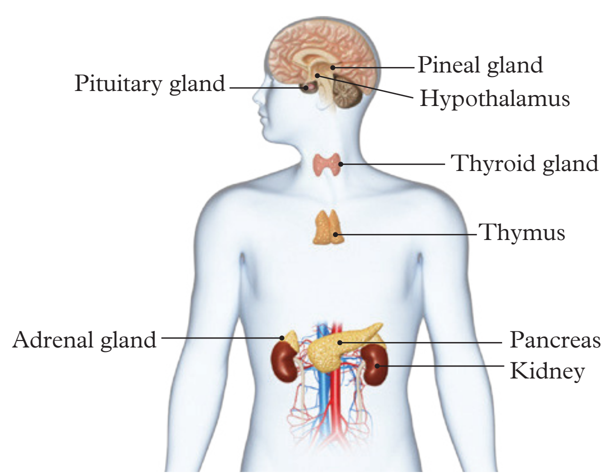


Figure 3 The pancreas is the endocrine organ responsible for the regulation of blood glucose levels.

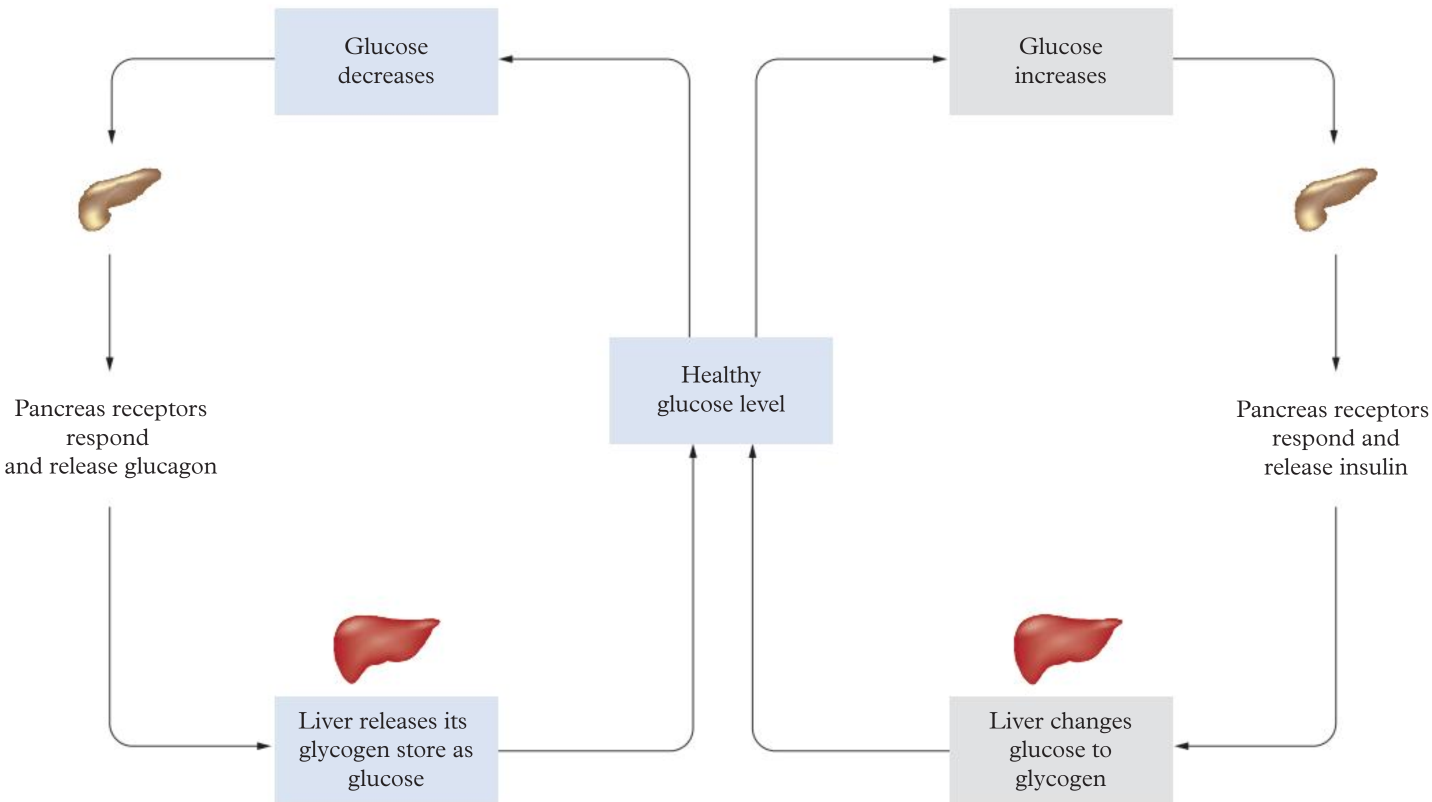


Figure 4 Eating a meal will increase blood glucose levels, while heavy exercise will decrease blood glucose levels. The pancreas and the liver work together to maintain healthy glucose levels in the body using negative feedback loops.

Low blood glucose

hypoglycaemia a condition resulting from too little glucose in the blood

If blood glucose levels are too low (**hypoglycaemia**), our body will use negative feedback loops to restore levels to a homeostatic state. Low glucose levels are detected by receptors in the pancreas (stimulus). This time, the hormone glucagon is released into the blood. Receptors for glucagon are also found on the effector cells in the liver and muscles. Glucagon binds to the receptors, causing the muscle and liver cells to release stored glucose into the blood (response), increasing the amount of blood glucose and removing the original stimulus (low blood glucose; Figure 4 and Figure 5).

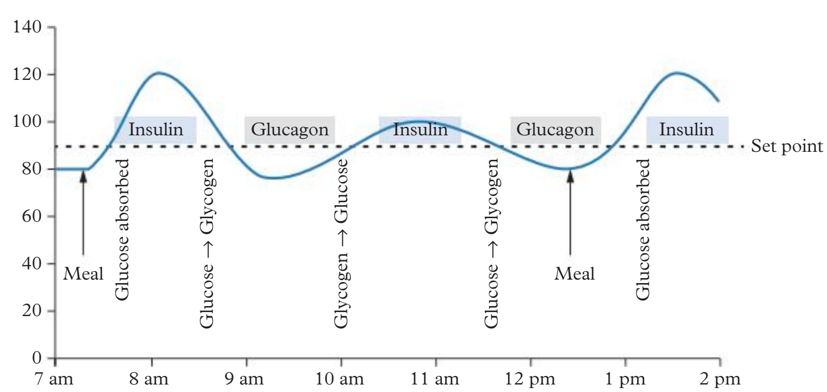


Figure 5 To maintain homeostasis, the body releases insulin when blood glucose levels are high and releases glucagon when blood glucose is low.

Water regulation

You may have noticed that when you drink a lot of water, you need to visit the bathroom in the next hour. Your body uses homeostasis to control the balance of water in your body. Water is needed to control all the chemical reactions that occur in the cells. If there is too much or too little water, these chemical reactions will be affected, and the cells can become damaged.

The water balance in your body is tightly controlled by the hypothalamus in your brain (Figure 3). If it has been a hot day or you have been doing physical exercise and sweating, then your body may have lost a lot of water. Receptors in the hypothalamus detect changes in fluid levels in your blood and send a message to the **pituitary gland** at the base of your brain. The pituitary gland releases a chemical messenger called **antidiuretic hormone (ADH)** into your blood.

This hormone travels all around your body until it reaches target effector cells in your kidney. The ADH binds to the receptors on the effector cells, causing them to reabsorb extra water from your urine. This makes your urine more concentrated or darker in colour. The extra water that was reabsorbed goes back into the blood, keeping the blood volume high. This is a form of negative feedback because the response (reabsorbing water from the urine and returning it to the blood) results in a decrease of the stimulus (improving water levels in the blood).

Figure 6 Water controls the chemical reactions that occur in cells.

pituitary gland a small gland at the base of the brain that produces hormones

antidiuretic hormone (ADH) a hormone that regulates the amount of water in the body

Drinking a lot of water causes the blood volume to increase. This is also detected by receptors in the hypothalamus. This time, the message to the pituitary gland is "Stop producing ADH". The lack of ADH is detected by the effector cells in the kidney and they stop reabsorbing water from the urine. This means the urine has more water in it, and it becomes very clear and diluted (Figure 7).

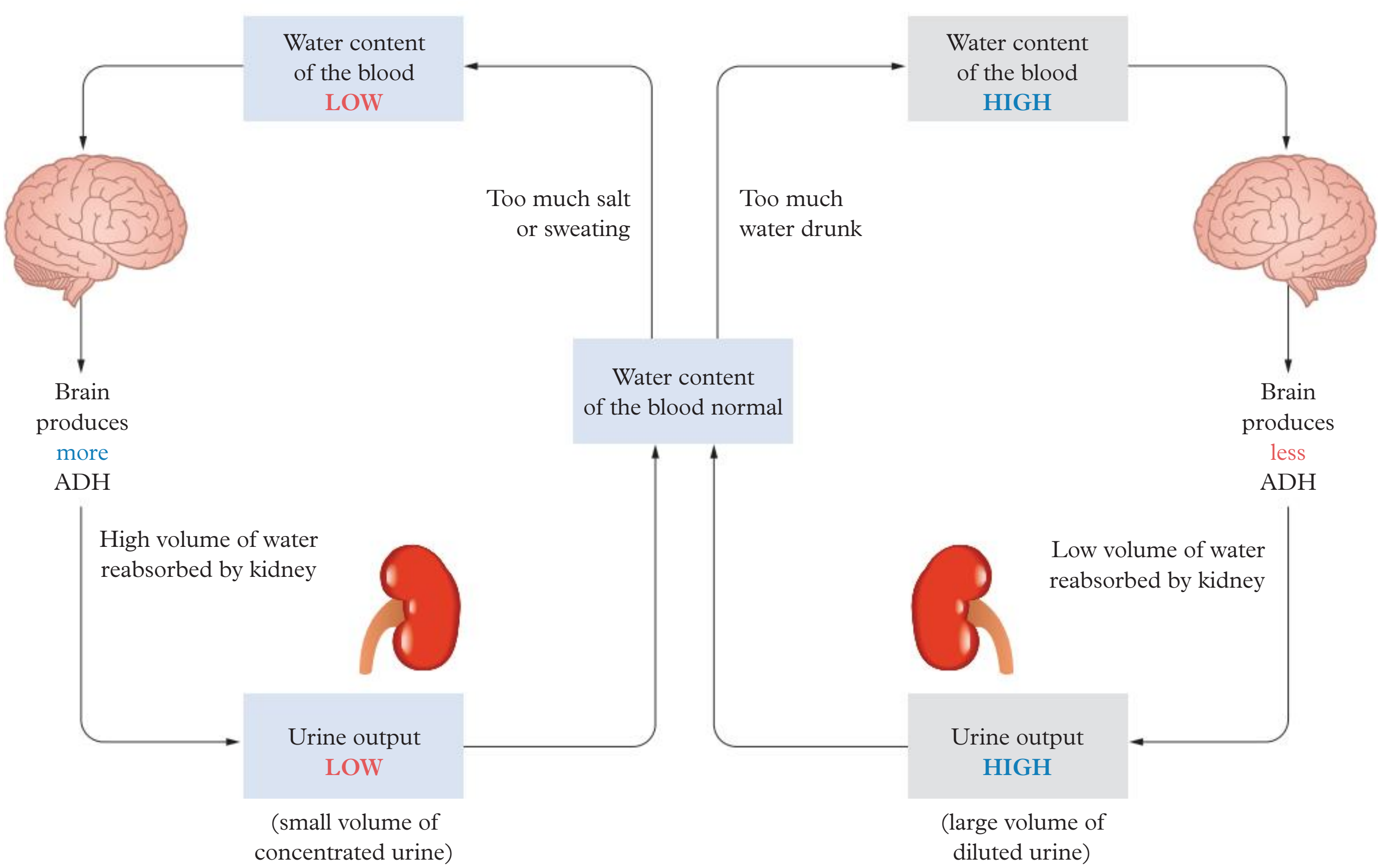


Figure 7 Negative feedback loops regulate water in the human body.

Figure 8 You may feel out of breath after running a race.

Figure 9 When you meditate, the carbon dioxide levels in your body decrease.

Oxygen and carbon dioxide homeostasis

Have you ever wondered why you feel out of breath when running a race? Oxygen and carbon dioxide in the blood are under strict homeostatic control. You need the oxygen for cellular respiration in a cell. Carbon dioxide is the waste product of this reaction.

Sprinting during a race causes the muscle cells in your legs to use a lot of glucose and oxygen and to produce a lot of carbon dioxide. The muscle cells release the carbon dioxide into the blood, where it forms carbonic acid. This is not good for your body. The acid content of the blood is measured by receptors in the medulla in the brain stem. If the level is too high from excess carbon dioxide, a message is sent through the nervous system to the muscles that control your breathing. This causes the diaphragm to move faster, increasing the rate of your breathing and making you feel out of breath. The message also goes to the heart to make it beat faster. This makes the blood move around the body faster, carrying the carbon dioxide to the lungs where it can be removed by breathing out. These two responses act as negative feedback, removing the stimulus of high levels of carbon dioxide in the blood.

Meditation often involves sitting or lying down and relaxing. This means the level of cellular respiration in muscles is low. Little oxygen is used and little carbon dioxide is produced. As a result, the levels of carbon dioxide in the blood decrease. The receptors in the medulla once again detect the change from the homeostatic state and signal the heart to slow its beat and the lungs to slow their breathing.

Positive feedback loops

A positive feedback loop (which are rare) is the opposite of a negative feedback loop where a temporary response leads to more of a hormone being released, amplifying the effect until the outcome is achieved, after which a negative feedback loop takes over to return to homeostasis.

An example of this is when a baby is ready to be born.

- The baby pushes against the cervix during labour.
- Oxytocin is released from the pituitary gland because of impulses sent to the brain.
- The uterus contracts and as more pressure is applied, more oxytocin is released.
- The positive feedback loop ends once the baby is born as it is no longer pushing on the cervix.

Check your learning 3.1

Check your learning 3.1

Retrieve

1 Define the term "homeostasis".

2 Identify the stimulus, location of receptors, effectors and response related to high body temperature.

Comprehend

3 Explain how your body responds to cold weather.

4 Describe how your blood sugar level changes when you eat.

5 Describe how your body responds to low blood sugar levels.

Analyse

6 If a negative feedback loop reduces the effect of a hormone, infer what a positive feedback loop should do. Can you think of any examples?

Apply

7 Discuss how and why your body responds to the following:
 a drinking a bottle of water
 b swimming 15 m under water
 c swimming in the ocean on a cold day.

8 In type 1 diabetes, cells in the pancreas are unable to produce insulin. Predict what effect this would have on blood glucose levels.

9 Construct a negative feedback loop to show how body temperature is regulated.

Skills builder: Planning investigations

10 To investigate homeostasis in humans, scientists may need to test body responses, including temperature and heart rate.
 a Identify what equipment you would need to measure temperature in humans. (THINK: What is the best device to use?)
 b Explain whether taking someone's pulse with your fingers would be as successful as using a device, such as a smart watch. (THINK: What could go wrong measuring a pulse with fingers? Are the results from a device more accurate?)
 c Recall why it is important to use the appropriate device to measure a body response. (THINK: How might the wrong device impact your results?)

Figure 10 What is the best device to measure a body response?

Lesson 3.2

Investigation: Experiencing homeostasis

Purpose

To demonstrate how homeostasis maintains control of our heart rate during and after exercise

Materials

- Stopwatch
- Heart rate monitor (optional)

Procedure

1 While sitting down, find your pulse and count the number of times your heart beats in 15 seconds.

2 Multiply this number by 4 to determine the number of beats every minute (i.e. your heart rate in beats per minute).

3 Measure your breathing rate by counting the number of breaths you take in 1 minute.

4 Do repeated step-ups or star jumps for 2 minutes. (Make sure you are wearing appropriate shoes.)

5 Measure your heart rate and breathing rate immediately after you stop exercising.

6 Measure your heart rate and breathing rate every 2 minutes for 10 minutes.

Results

1. Record the data by copying and completing Table 1.
2. Draw a line graph showing how your heart rate varied after exercise.
3. Draw a line graph showing how your breathing rate varied after exercise.

Table 1 Heart rate and breathing rate before and after exercise

Time (minutes)	Heart rate (beats/minute)	Breathing rate (breaths/minute)
0 (before exercise)		
2		
4		
6		
8		
10		

Discussion

1. Describe how your breathing rate changed during exercise and in the 10 minutes after exercise.
2. Describe how your heart rate changed during exercise.
3. Describe what happened to your heart rate during the 10 minutes after exercise.
4. Use the concept of homeostasis to explain why your heart rate was different before, during and after exercise.
5. Describe how you could ensure that the way you measured your heart rate and breathing rate was accurate.
6. Explain any changes you noticed in your breathing rate and heart rate.
7. Compare your results to others in your class. Determine the mean heart rate before the exercise started and immediately after finishing the exercise. Compare this to the median and mode values at these times.
8. Identify any outliers of the mean heart rate after exercise. Explain how these affected the mean value.
9. Identify any random or systematic errors that could explain the outliers and how this could be improved if the experiment was repeated.
10. Use the concept of homeostasis to explain why your heart rate was different before, during and after exercise.

Conclusion

Describe how homeostasis ensures that our muscles get enough nutrients and that wastes are removed during exercise.

Figure 1 Heart rate monitor on a smart watch

Lesson 3.3
Human and animal responses to stimuli

Key ideas

→ Humans and animals have receptors that detect changes (stimuli) in the environment.

→ The five main external receptors detect light, sound, touch, and chemicals in the mouth (taste) and the air (smell).

Learning intentions and success criteria

Introduction

Humans and animals use five senses to detect changes in the environment; these senses are sight, hearing, taste, smell and touch. The degree to which the senses are used depends on the environment and the adaptations that humans and animals have developed to survive those conditions. Each sense is associated with specialised receptors that will detect changes and bring about a response.

Human responses to stimuli

Responding to change

Our bodies are constantly responding to internal and external changes. A stimulus is any information our body receives that might cause it to respond. Responding to a stimulus can prevent major changes to the internal environment that might otherwise cause us to become ill or possibly die.

Figure 1 We often respond to hot weather by drinking more water.

The easiest stimuli to identify are those we detect with the major sense organs (the eyes, ears, tongue, nose and skin). What makes you aware that you're hungry or thirsty? Something in your body is communicating with your brain to tell you to find food or water (Figure 1). A similar process occurs when you feel tired or have a headache. What is the source of these stimuli?

Other examples of stimuli are less obvious. We are surrounded by bacteria, viruses and fungi. Although many of them are too small to see, our bodies are constantly monitoring their numbers and fighting off harmful microorganisms that could make us sick (Figure 2).

Figure 2 The human papillomavirus (seen here under a microscope) stimulates an immune response in the human body.

Your body is an amazing combination of cells, tissues, organs and systems, all working together. Each plays a part in detecting stimuli and passing on the information to other parts of the body. The cells that detect stimuli or changes in the environment are called receptors. There are different receptors for different purposes; for example, cells that detect light are called photoreceptors, while those that detect smell are called olfactory receptors.

The sense organs

photoreceptor a cell in the eye that detects light

Our body can detect five main signals: light (sight), sound (hearing), chemicals in our mouth (taste) and in the air (smell) and touch. These are external senses because they tell us about the world outside our body. The sense organs – the eyes, ears, tongue, nose and skin – are highly specialised to receive stimuli from the environment.

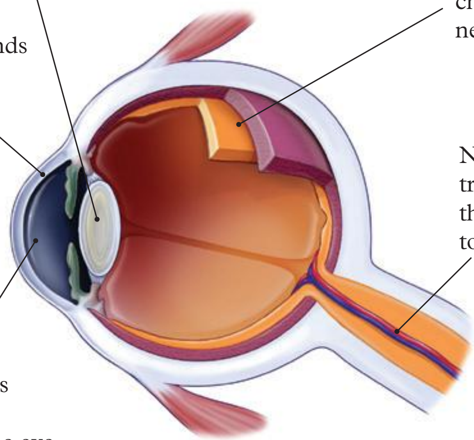


Figure 3 Photoreceptors in the human eye transform light into nerve signals.

Sight

Sight tells us more about the world than any other sense. When light enters the eye, the **photoreceptors** convert the light into electrical signals. Two messages are sent; one message is to the iris (the coloured part of your eye), telling it to constrict and close the pupil, and the other message is to the brain via the optic nerve. The message sent along the optic nerve is interpreted by the brain, which then tells you what you are looking at (Figure 3). You can observe the eye responding to light by pairing up with a partner and watching what happens to their pupils when they open and close their eyes.

Hearing

The strumming of a guitar causes the particles in the air to vibrate. This causes your eardrums to vibrate. The vibrations are transferred along the bones of the middle ear – the smallest bones in your body – into your cochlea to be converted into nerve impulses (Figure 4). The brain then interprets the information, telling you what you are hearing.

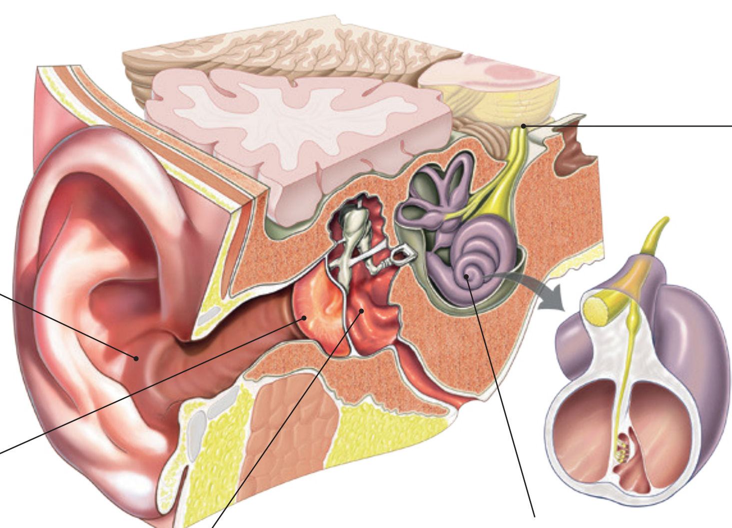


Figure 4 The human ear transfers vibrations to the middle ear.

Taste

Your tongue is covered in thousands of tiny taste buds (Figure 5). You can see this in a mirror. Taste buds contain special receptor cells that react to chemicals in foods. These chemical receptors recognise basic kinds of taste molecules, such as sweet, sour, salty, bitter and umami (savoury). When you eat or drink, the information from the taste receptor cells is sent to your brain through nerves. It is the mix of chemical molecules that your brain detects as the flavours you are tasting.

Figure 5 The idea that the human tongue has different regions that detect different tastes has been debunked, as it was a misinterpretation of a paper from 1901 which showed differences in sensitivity.

Smell

Like taste, our perception of smell depends on chemical (olfactory) receptors. The receptors in our nostrils detect chemicals in the air and then send messages to the brain, which interprets the messages and tells us what we are smelling (Figure 6). Smell is closely linked to taste. If this seems strange, think about the last time you had a bad cold that caused a blocked nose. Did it affect your ability to taste? A lot of what people think is taste is actually smell.

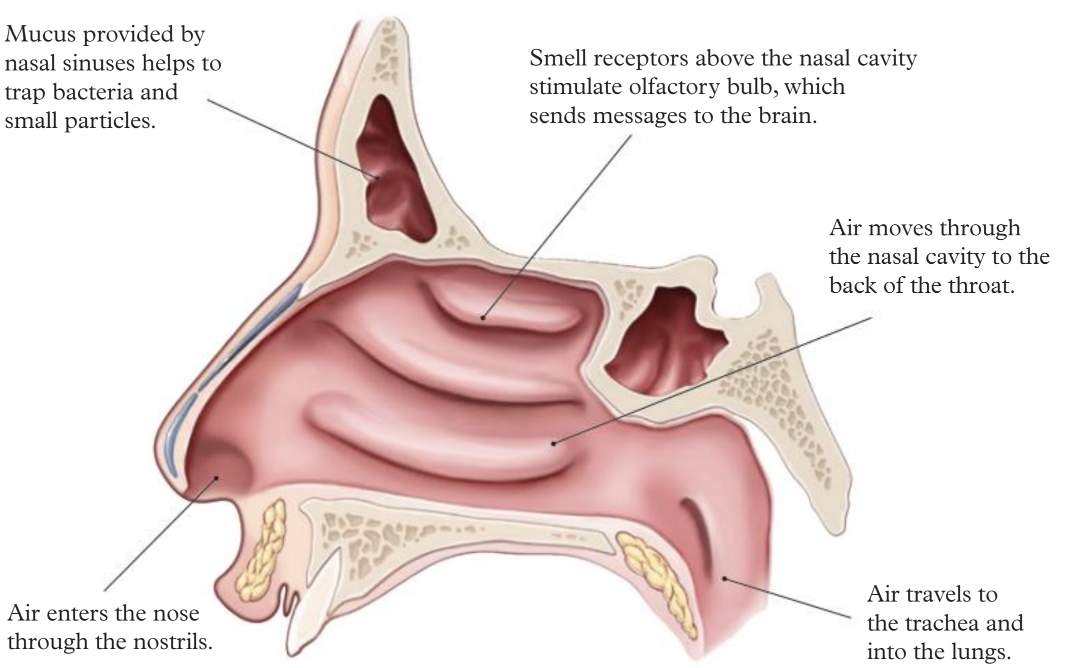


Figure 6 Smell receptors in human nostrils detect chemicals and send messages to the brain.

Touch

thermoreceptor a nerve cell that detects temperature

mechanoreceptor a nerve cell that detects pressure or touch

While the other four senses are in specific locations, touch is felt all over the body through the skin (Figure 7). The inner layer of skin, called the dermis, contains many nerve endings that can detect temperature (**thermoreceptors**), pressure (**mechanoreceptors**) and pain (pain receptors). Information is collected by the different receptors and sent to the brain for processing and reaction.

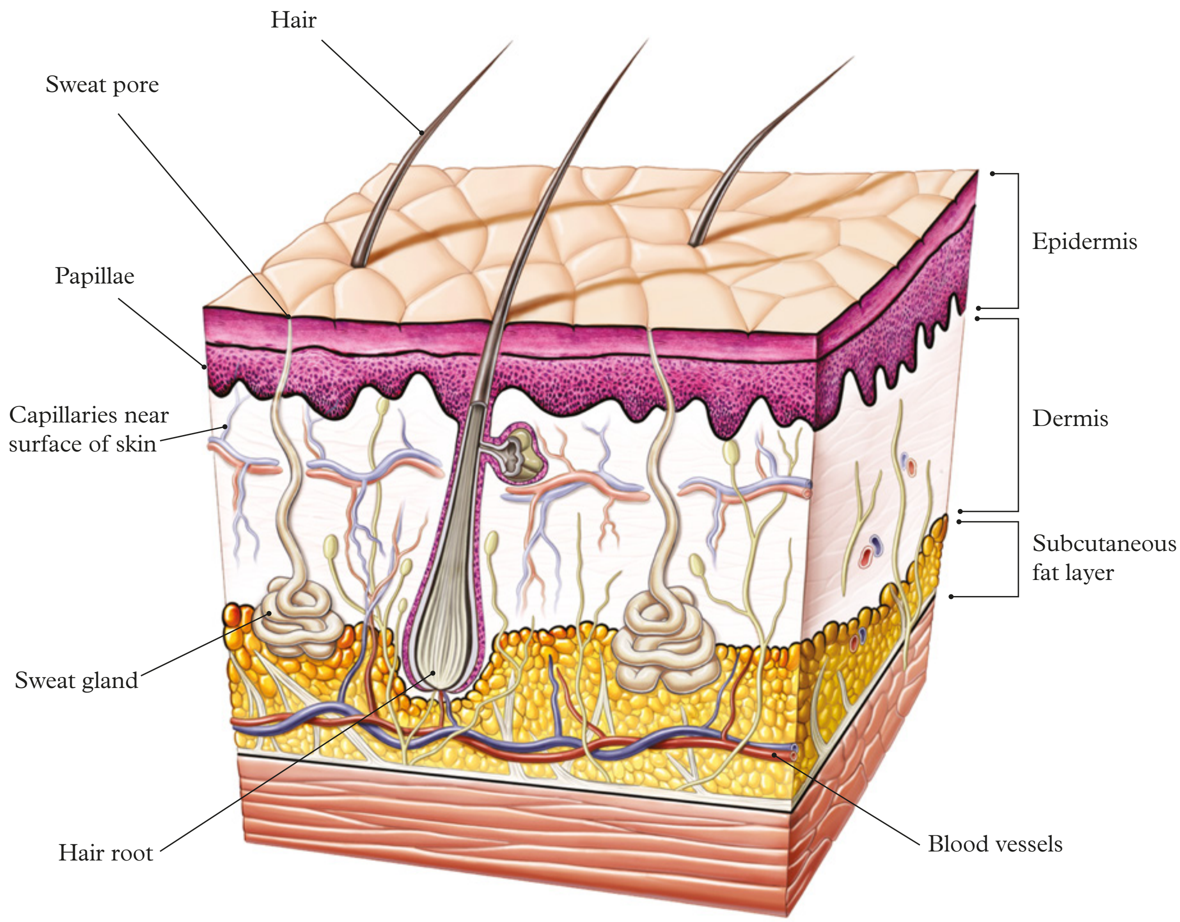


Figure 7 A cross-section of human skin

Animal senses

magnetoreception the ability to sense Earth's magnetic fields

While most animals use the same five senses as humans, some have additional senses that help them detect different stimuli and respond accordingly. For example, **magnetoreception** is the ability of migratory animals to sense the Earth's magnetic fields, which they use to guide their movement. Some migratory birds can even find the same nest site they used the previous year after travelling thousands of kilometres, and homing pigeons can find their way home (Figure 8A).

Some animals, including the platypus and echidna, use **electroreception** to detect prey. When prey move, their muscle contractions generate an electrical impulse that is detected by specialised receptors called electroreceptors. This can be observed by watching a platypus hunt a small shrimp in murky waters (Figure 8B).

electroreception the ability to sense electric fields generated by other animals

Dolphins and bats use **echolocation** to interpret and respond to their environment. Echolocation involves the animal emitting a pulse of sound that creates an echo when it bounces off an object or prey. When the returning sound is detected, the animal can determine the distance and location of the object (Figure 8C).

echolocation the ability to use sound to navigate and hunt

Figure 8 Different sensory systems are found in the animal kingdom. (A) Magnetoreception is used by homing pigeons to find their way home. (B) Platypuses use electroreception to locate prey. (C) Dolphins use echolocation to navigate and locate prey.

Different animal responses to temperature

Ectotherms are animals that are unable to regulate their own body temperature; examples are amphibians, reptiles and invertebrates. If the external temperature increases, then their internal temperature increases, and if the external temperature decreases, then their internal temperature decreases. For example, when a lizard's thermoreceptors detect a decrease in body temperature, the lizard will seek out a warm rock to lie on (Figure 9). This will bring its body temperature back up. The lizard needs to leave the rock eventually so that it doesn't overheat.

ectotherm an animal that is unable to regulate its own body temperature

Figure 9 Ectotherms are unable to regulate their own body temperature. They are dependent on the temperature of their environment for heating and cooling.

endotherm an animal that regulates its own body temperature

Endotherms are animals that regulate their own body temperature; examples of endotherms are mammals (including humans) and birds. An endotherm's internal body temperature remains constant throughout their life, regardless of the external temperature. For example, a polar bear living in the Arctic region at −50°C or a camel living in the Gobi Desert at 42°C will both maintain an internal body temperature of 37°C (Figure 10).

Figure 10 (A) A polar bear living in the Arctic region. (B) A camel in a desert. Both animals are endotherms and maintain an internal body temperature of 37°C no matter what the external temperature is.

Migration

migrate the movement of an animal from one region to another, typically in response to changing seasons

hibernation an extended period of inactivity, typically in response to colder conditions

Many animals **migrate** in response to changes in their environment. For example, birds often fly south during North America's winter. The Arctic tern (Figure 11) has the longest migration of any animal, travelling up to 70,000 km per year depending on the route chosen. They follow the summer sun, travelling from their Arctic breeding grounds to enjoy the summer feeding grounds of Antarctica before returning to start the cycle again.

Bird migration occurs in response to environmental stimuli, including changes in day length and temperature. These environmental cues cause hormonal changes in the birds which instinctively prompt the birds to migrate.

Figure 11 The Arctic tern can migrate over 70,000 km per year.

Figure 12 The great wildebeest migration occurs every year as millions of wildebeest move to find more food and water.

The great wildebeest migration in Africa occurs each year with up to 2 million wildebeest, zebra and gazelle travelling over 3,000 km (Figure 12). The migration is instinctive and occurs in response to environmental stimuli, primarily rainfall. Some scientists have suggested that the animals respond by moving towards distant lightning and thunderstorms because they are associated with rainfall and more readily available water and food.

Hibernation

Migration is only one solution to the changing seasons. **Hibernation** is an alternative solution, in which some animals will enter an extended period of inactivity for the winter. During hibernation, animals will have a slower heart rate, slower breathing and slower metabolic rate. These responses make the animal better equipped to survive winter when food sources may be low (Figure 13). Environmental stimuli, such as shorter day length and cooler temperatures, trigger hormonal changes in the animal that instinctively cause them to enter the hibernation period.

Figure 13 A brown bear hibernating to escape winter

Check your learning 3.3

Check your learning 3.3

Retrieve

1 Define the term "stimulus".

2 Identify the five major sense organs.

3 Distinguish between an ectotherm and an endotherm.

Comprehend

4 Stimuli can be changes in our immediate environment or changes within our body. Describe two examples of each.

5 Describe two situations in which each of the five major sense organs would need to respond.

6 Explain why there are no reptiles in Antarctica.

Analyse

7 Compare the way you detect smell and the way you detect taste.

8 Identify a likely response to the following stimuli:

- **a** walking on hot sand
- **b** seeing something running straight towards you
- **c** realising you've put salt on your cereal instead of sugar
- **d** hearing a loud bang.

Apply

9 "A person has more than five senses." Evaluate this statement by:

- – describing the five senses that are being referred to
- – describing what happens to your balance when you spin around quickly (sense of balance)
- – describing how your body reacts when you are sick (sensing bacteria)
- – deciding whether the statement is correct.

10 Research five different animals and describe how each one can be observed responding to a specific stimuli.

Skills builder: Planning investigations

11 A student wants to know if the receptors sensitive to umami are distributed evenly on the tongue or concentrated in particular areas. They use the following foods to test their theory: sour hard sweets, gummy bears, sea salt crisps, grapefruit and mi goreng.

- **a** Identify what experimental method they could use to test their theory. (THINK: What are they trying to test? How many repeats would they need to measure?)
- **b** List any additional materials they might need. (THINK: How could they make this experiment safe? How would the flavours be tasted?)
- **c** Select two risks associated with the test. (THINK: Do they need to use people in this experiment? Would allergies be an issue?)
- **d** Explain how the risks you identified in part c could be managed. (THINK: What would the student need to know about the participants? How could they avoid making people sick?)

Lesson 3.4
Plant responses to stimuli

Learning intentions and success criteria

Key ideas

→ Like humans and animals, plants also detect and respond to changes in their environment.

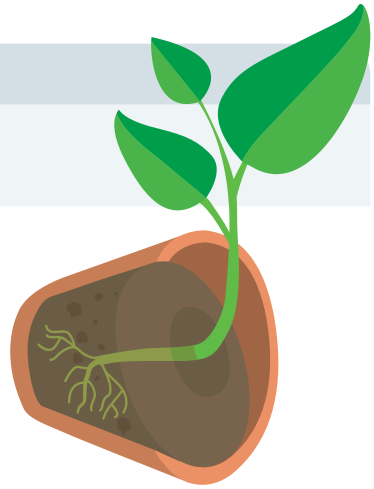


Figure 1 A plant seed demonstrating geotropism. The roots grow downwards, in the direction of gravity, and the stems grow upwards, against gravity.

Plants respond to changes in the environment

geotropism the growth or movement of a plant in the direction of gravity (positive geotropism) or against gravity (negative geotropism)

amyloplast a specialised plant organelle packed with starch granules and used in geotropism

auxin a plant hormone that plays a crucial role in regulating growth and development

Have you ever wondered how a plant seed knows to grow roots downwards and send their leaves upwards? They do it through **geotropism**, a process that allows them to detect and respond to gravity (Figure 1, Figure 3A).

A plant has specialised organelles called **amyloplasts** which are packed with starch granules that act like tiny weights. In early development, amyloplasts sink to the bottom of all cells, allowing the plant to determine which way is up and which is down. The plant then uses a growth hormone called **auxin** to control the amount and distribution of amyloplasts in different cell types. This causes the roots to move in the direction of gravity (positive geotropism) while the cells in the plant's stem move against gravity (negative geotropism) (Figure 1).

Figure 2 Sunflowers use phototropism to move their flowers to face the Sun.

Plants need light for photosynthesis. The amount of available light changes throughout the day depending on factors like cloud coverage, the time of day and the seasons. To maximise light exposure, plants use **phototropism** to move towards sunlight. This is seen in a field of sunflowers, moving through the day to always have the flower head facing the Sun (Figure 2). To do this, the cells of a plant that are in the dark (e.g. a shadow) elongate (lengthen). The lengthening of the cells causes the plant to bend towards the light (Figure 3B and C).

Plants also need water to survive. **Hydrotropism** is a process that results in a plant's roots growing towards or away from water. The roots have specialised receptors that cause the roots to grow downwards (Figure 3C). These receptors also detect changes in pressure in the soil. More pressure means more water, and so the roots of plants grow towards areas of increased pressure.

phototropism the growth or movement of a plant towards or away from light

hydrotropism the growth or movement of plant roots towards or away from moisture

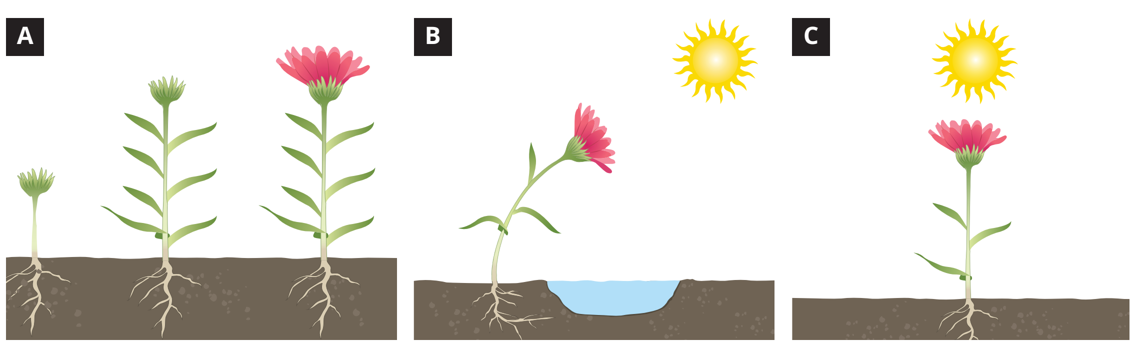


Figure 3 (A) Geotropism is the ability of plants to detect and respond to gravity. Roots grow down and stems grow up. (B) Phototropism is the movement of a plant towards a light source, caused by cells in the dark elongating (lengthening). (C) Hydrotropism is the process by which a plant's roots grow towards or away from water.

Deciduous plants lose their leaves

Plants that lose their leaves during the changing seasons are called **deciduous**. These plants typically lose their leaves in autumn before the coldest months of winter (Figure 4).

The shorter days during winter have fewer daylight hours, which means less light for photosynthesis. Plants detect the change in temperature and the reduced daylight length. This triggers a reduction in the amount of growth hormone being sent to the leaves.

deciduous a type of plant that loses its leaves during the cooler months to conserve energy when there is less sunlight; annual shedding of leaves

Figure 4 The life cycle of a deciduous tree: (A) spring, where new leaves grow; (B) summer, when the tree is full of leaves; (C) autumn, when a tree's leaves stop growing and begin to fall off and (D) winter, when a tree has no leaves left.

Epicormic buds: a response to fire

Epicormic buds are growth points that lay dormant under the trunk of a tree until they are stimulated. Many Australian plants, including eucalypts, have epicormic buds. These epicormic buds are kept dormant by higher plant shoots that inhibit the release of growth hormones to the lower buds. When a bushfire burns the higher plant shoots, the inhibition of the growth hormones ceases, which stimulates rapid growth from the epicormic buds (Figure 5). The new leaves that come from the epicormic buds allow the tree to photosynthesise and produce energy, which keeps the plants alive after a bushfire.

Figure 5 The new growth on this tree exists because of epicormic buds. These buds grow after a bushfire.

Check your learning 3.4

Check your learning 3.4

Retrieve

1 Identify the process that allows plants to respond to gravity.
2 Name the specialised organelles in plant cells that help them detect gravity.
3 Identify the growth points in many Australian plants that respond to fire.

Comprehend

4 Describe what happens to deciduous plants during the different seasons.
5 Explain the importance of a plant being able to perform geotropism.

Analyse

6 Distinguish between phototropism and hydrotropism.

Apply

7 Design an experiment that would allow you to observe a plant's response to a specific stimulus. Ensure your method addresses all variables, repetition, validity and accuracy.
8 Research five different plants and describe how each one responds to a specific stimuli.

Skills builder: Questioning and predicting

9 Imagine you are a scientist investigating the types of plants that grow around Australia. You make the following prediction:
"If palm trees from Queensland are moved to Tasmania, they will see less annual growth than those that stay in Queensland."
  a Identify the controlled and measured variables. (THINK: What is being manipulated?)
  b Predict what will happen to the trees as they grow in Tasmania. (THINK: What would colder weather do to the trees?)

Lesson 3.5
Nerve cells are called neurons

Learning intentions and success criteria

Key ideas

→ Neurons are cells in our body that enable messages to be passed on quickly.
→ Electrical messages are passed along the neuron to the synaptic terminal when receptors in the body detect changes.
→ Chemical neurotransmitters pass the message to the next neuron across a gap called a synapse.
→ The myelin sheath protects parts of the neuron and increases the speed of messages being sent.

Nerves

The basic unit of the nervous system is the nerve cell, or **neuron**. Scientists believe that we may have up to 100 billion neurons in our bodies, connected in paths called nerves.

Neurons have many highly specialised features. Each neuron has a large **cell body** that connects to a long thin **axon** (Figure 1). An axon carries nerve impulses (electrical signals) away from the cell body. The axons connecting your spinal cord to your foot can be up to 1 m long.

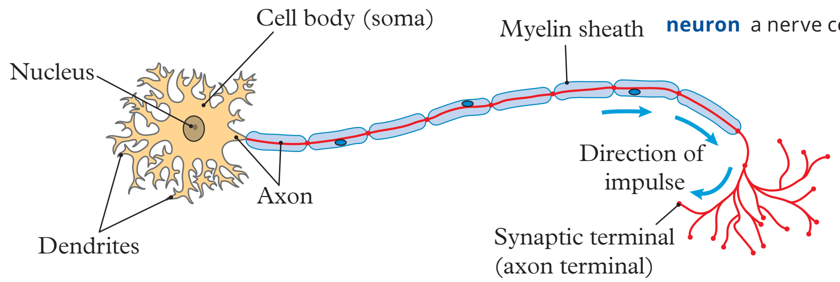


Figure 1 A typical neuron

Nerves work just like electrical wires and require insulation in the same way. The axons are covered by a fatty layer called the **myelin sheath**. The myelin sheath helps to speed up a nerve impulse along an axon by controlling its path. People with multiple sclerosis have damaged myelin sheaths. This means that the nerve impulse is disrupted, blocked or unable to move along the length of the axon. A person with multiple sclerosis can therefore have difficulties with movement.

Dendrites are nerve endings that branch out of the cell body (Figure 1). These highly sensitive, thin branches receive information from other neurons. Dendrites bring information to the cell body and axons take information away from the cell body. The nerve impulse travels from the dendrite to the cell body and along the axon.

At the end of the axon are small bulbs called **synaptic terminals** or axon terminals (Figure 1). When a message reaches the end of the axon, chemicals called **neurotransmitters** are released from the synaptic terminal and travel across the synapse to the dendrite of the next neuron (Figure 2). The **synapse** is a small gap between neurons where nerve impulses are transmitted from one neuron to another neuron. In this way, electrical messages are passed around the body.

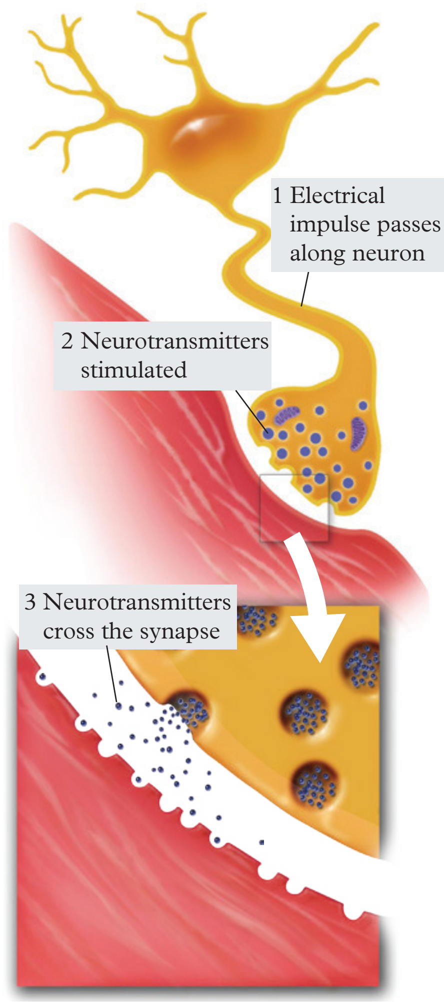


Figure 2 Electrical messages are converted to chemical messages (neurotransmitters), which cross the gap in the synapse.

Types of neurons

There are three specialised types of neuron, all with different jobs.

- **Sensory neurons** (or afferent neurons) are sensitive to various stimuli, collecting information from either the body's internal environment or the outside world. Sensory neurons send the information they have collected to the central nervous system for processing.
- **Motor neurons** (or efferent neurons) carry messages from the central nervous system to muscle cells throughout the body, which then carry out the response.

neuron a nerve cell

cell body the central part of a neuron that contains the nucleus and organelles

axon a long projection of a neuron that carries electrical impulses away from the cell body to other neurons, muscles or glands

myelin sheath a fatty layer that covers the axon of a nerve cell

dendrite the part of a neuron (nerve cell) that receives a message and sends it to the cell body

synaptic terminal the bulb-like structure at the end of an axon that transmits information (neurotransmitters) to the synapse; also called an axon terminal

neurotransmitter a chemical messenger that crosses the synapse between the axon of one neuron and the dendrite of another neuron

synapse a small gap between two neurons, across which nerve impulses are transmitted

sensory neuron a nerve cell that carries a message from a receptor to the central nervous system; also known as an afferent neuron

motor neuron a nerve cell that carries a message from the central nervous system to a muscle cell; also known as an efferent neuron

interneuron a nerve cell that links sensory and motor neurons; also known as a connector neuron

- **Interneurons** (or connector neurons) link sensory and motor neurons, as well as other interneurons. Interneurons are the most common neuron in your central nervous system (brain and spinal cord). They only make connections with other neurons.

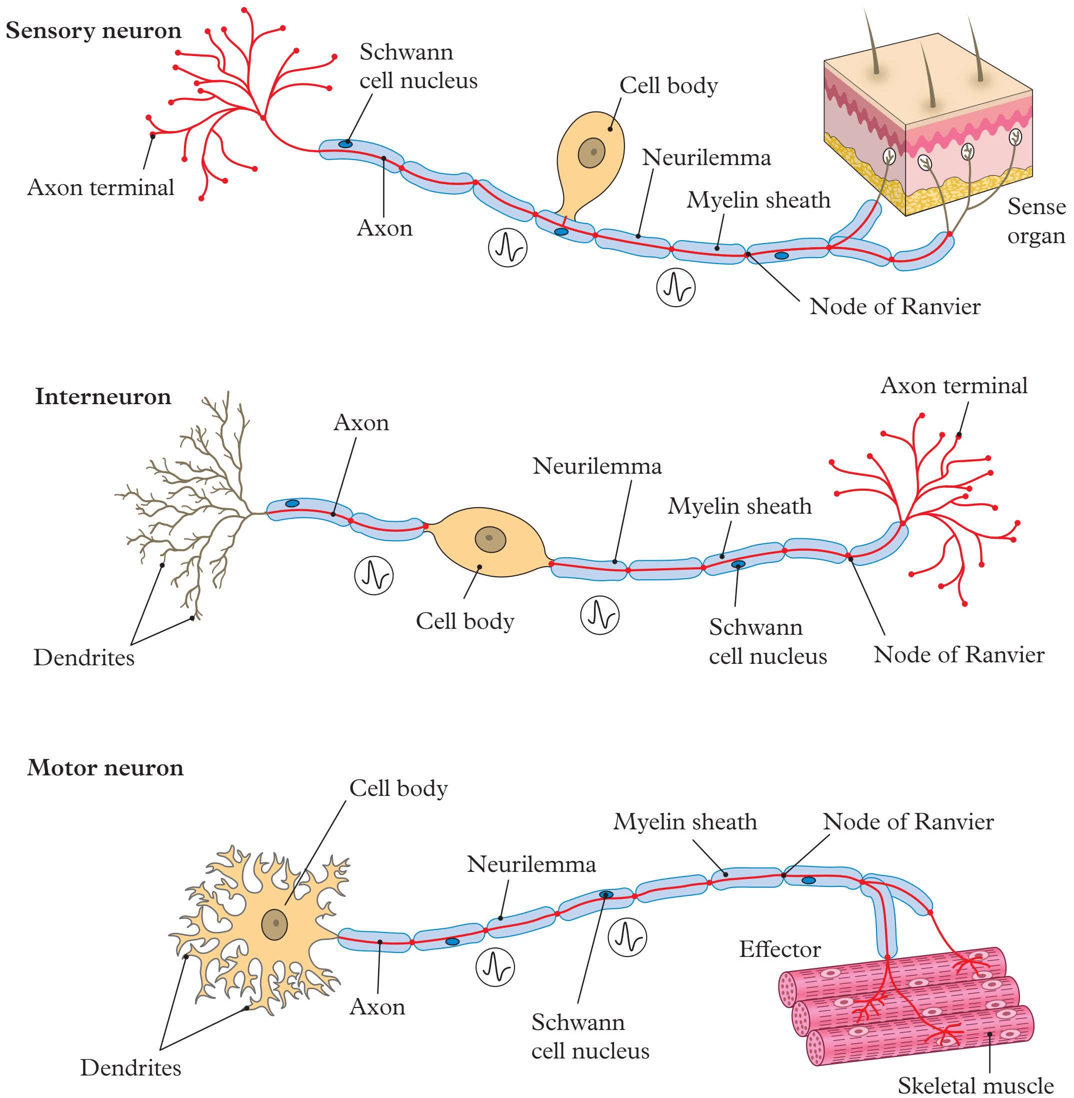


Figure 3 Sensory neurons, interneurons and motor neurons are structured differently to send and receive different messages.

Check your learning 3.5

Check your learning 3.5

Comprehend

1 Describe the features of a neuron that enable it to pass messages on to other neurons.

2 Identify where you will find sensory neurons that detect:

a smell
b taste
c sound
d touch
e light.

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3 Describe the role of the myelin sheath.

Analyse

4 Compare sensory neurons and motor neurons.
5 Contrast sensory neurons and interneurons.

Apply

6 With a partner, create a way to remember the difference between sensory neurons, interneurons and motor neurons. Be creative! Share your memory trick with the class.

7 Create a diagram to explain the problem that may result from damage to the myelin sheath.

Skills builder: Problem solving

8 A patient's myelin sheath is deteriorating. Identify two problems associated with this. (THINK: What does the myelin sheath do? How will this impact the patient's life?)

Lesson 3.6

The nervous system controls our body

Key ideas

→ The nervous system uses electrical impulses that are fast-acting and relatively short-lived.

→ Humans are constantly receiving stimuli from their environment through the peripheral nervous system.

→ Neurons use electrical messages that are passed along to neurons in the brain and spinal cord, which make up our central nervous system.

→ Receptors in the nervous system detect a stimulus and pass it on to control centres.

→ The control centres initiate a message to the effectors, which causes a response.

→ Reflexes are special pathways that allow a response to occur before the brain has time to think.

Learning intentions and success criteria

Stimulus–response model

Stimuli can come in many different forms. A stimulus may be pressure or heat on the skin, a puff of air or strong light in your eye. The stimulus is detected by receptors and the message is sent to the spinal cord and the brain via sensory neurons. The spinal cord and brain are the **control centre** of the nervous system. Interneurons in this control centre pass the message on to other interneurons while your brain thinks about how you should respond to the stimulus. Eventually, you make a decision and the motor neurons pass the message on to the muscles. In this case, the muscles are called the effectors, because they are the tissues that cause the body to respond. This simple pathway is called the **stimulus–response model** (Figure 1).

control centre the part of an organism, typically the brain or spinal cord in animals, that processes and responds to information received from receptors

stimulus–response model a model that describes how an organism responds to a stimulus (change in their environment)

Central nervous system

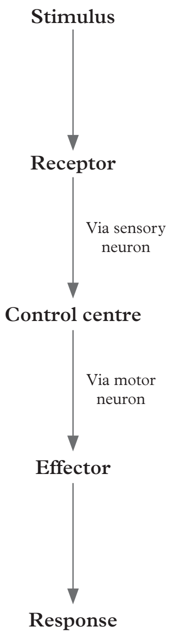


Figure 1 The stimulus–response model

central nervous system the brain and spinal cord

cerebrum the largest part of the brain; divided into four lobes called the frontal lobe, the parietal lobe, the temporal lobe and the occipital lobe

The **central nervous system** is the control centre of the body. All incoming messages from your environment and your responses to them are processed through your central nervous system. The two main parts of the central nervous system are the brain and the spinal cord (Figure 2).

Brain

The brain is the processing centre of the body and is mainly concerned with your survival. It is a soft, heavy organ surrounded by a tough skull. The interneurons in the brain gather information about what is going on inside and outside the body. The brain then compares the information to events that have occurred previously, before making decisions about things such as internal changes and movements. The brain is also home to your memories, personality and thought processes.

Lobes of the brain

The **cerebrum**, or outer section of the brain, is divided into four lobes or sections. These lobes have specific functions (Figure 3).

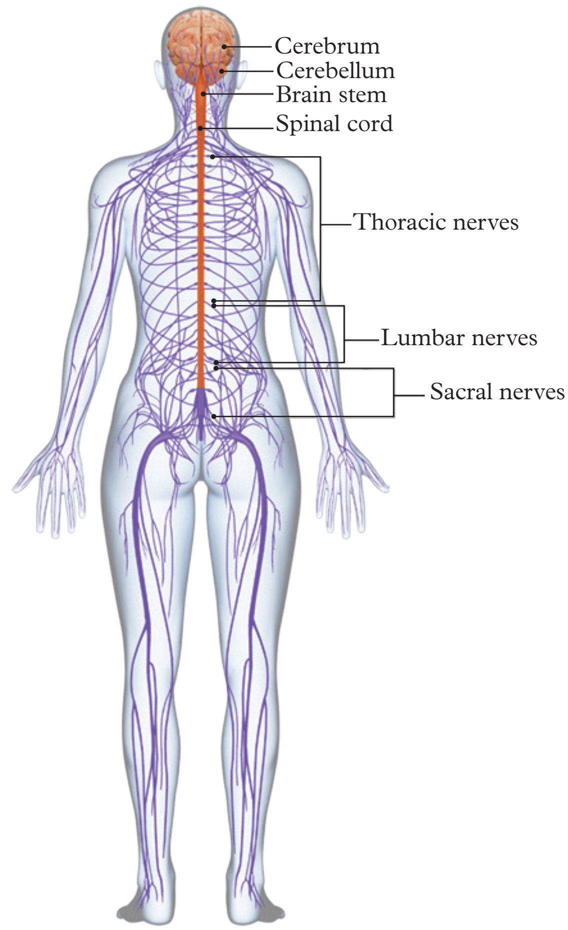


Figure 2 The nervous system of the body is made up of the central nervous system (red) and the peripheral nervous system (purple).

- The frontal lobe is at the front of the brain. Its functions include emotions, reasoning, movement and problem solving.
- The parietal lobe manages the perception of senses, including taste, pain, pressure, temperature and touch.
- The temporal lobe is in the region near your ears. It deals with the recognition of sounds and smells.
- The occipital lobe is at the back of the brain. It receives all the information from your eyes. It is responsible for the various aspects of vision.

spinal cord the cylindrical bundle of nerve fibres and associated tissue which is enclosed in the vertebrae

Spinal cord

The **spinal cord** has three major roles. It relays messages from the brain to different parts of the body, causing them to respond. It sends messages from sensory neurons to the brain, and it is also responsible for reflex actions.

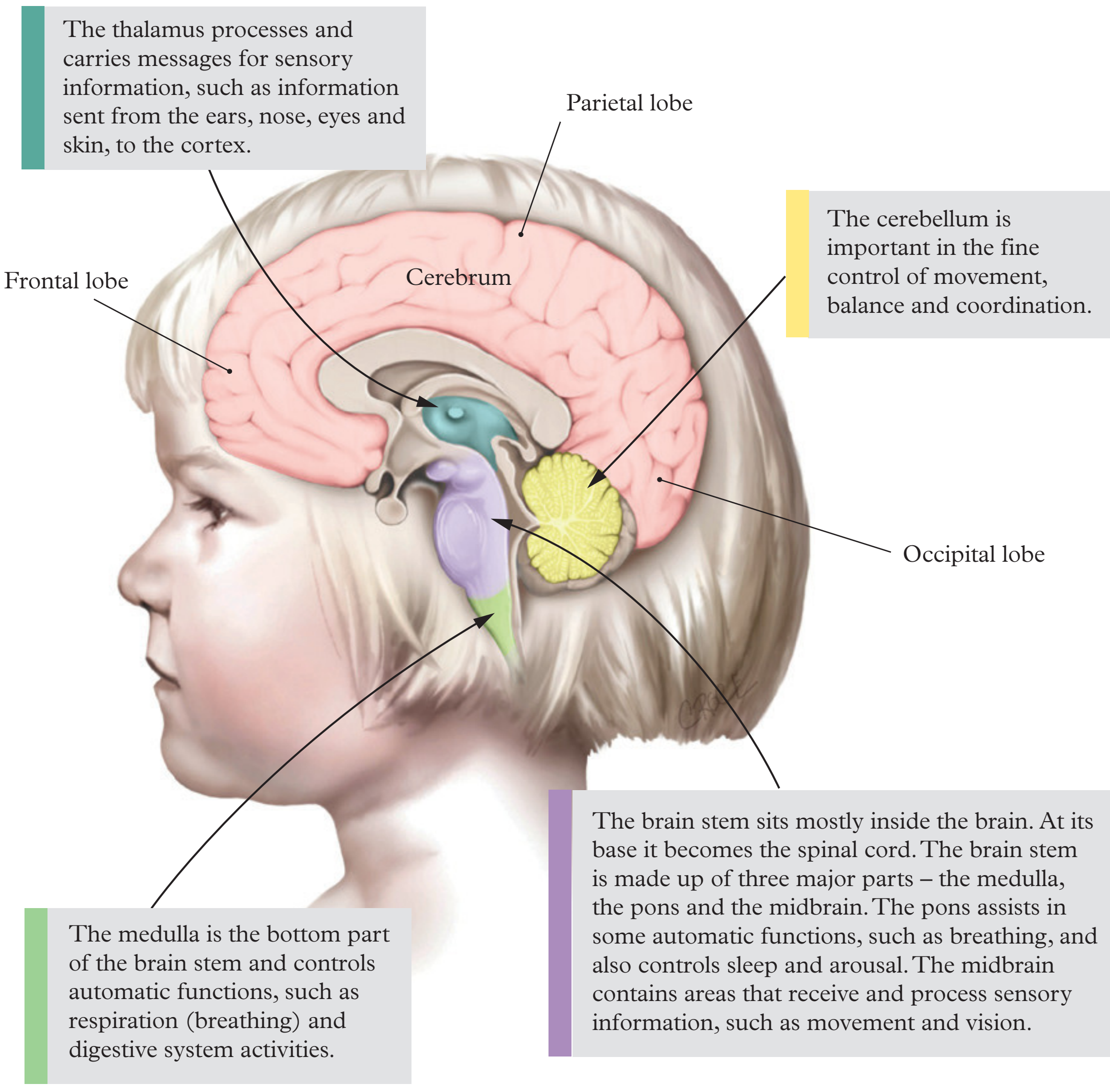


Figure 3 Structure of the human brain. The temporal lobe of the cerebrum (not shown here) is near the ears.

Peripheral nervous system

The **peripheral nervous system** is a large system made up of all the nerves outside the central nervous system. The peripheral nervous system carries information to and from the central nervous system to the rest of the body, such as the limbs and organs (Figure 2).

The peripheral nervous system is divided into two parts.

- The **somatic nervous system** controls voluntary skeletal muscle movements, such as waving or reaching out to take an object.
- The **autonomic nervous system** controls involuntary actions, which happen without our conscious control. This includes heartbeat, digestion, respiration, salivation and perspiration. The autonomic nervous system maintains your body’s internal environment (homeostasis).

The autonomic nervous system also has two parts: the sympathetic division and the parasympathetic division. These two divisions often have opposite effects. For example, the parasympathetic division slows down the heart rate, whereas the sympathetic division speeds up the heart rate. The systems work together to maintain a balance in the body.

peripheral nervous system all the neurons (nerve cells) that function outside the brain and spinal cord

somatic nervous system the part of the nervous system that controls the muscles attached to the skeletal system

autonomic nervous system the part of the nervous system that controls involuntary actions such as heartbeat, breathing and digestion

Reflexes

If you have ever accidentally touched something very hot, like a flame, you will remember how quickly you snatched your hand away. In fact, it would have been so quick that you didn't even have time to think about it – it was automatic.

reflex an involuntary movement in response to a stimulus

A **reflex**, or reflex action, is an involuntary and nearly instantaneous movement in response to a stimulus.

During a reflex action, a sensory neuron carries the message from a receptor to the spinal cord. An interneuron then sends two messages at the same time: one to the brain and the other to the muscles via a motor neuron (Figure 4). This means the muscle is moving at the same time as the brain gets the message (e.g. that the object is hot). This makes reflexes even faster than usual responses. Most reflexes help us in survival situations. Can you think of situations where a reflex response would be an advantage?

Your body has many different reflexes. Figure 5–9 show some common ones, illustrating how various reflex actions protect us and improve our ability to respond swiftly to potential dangers.

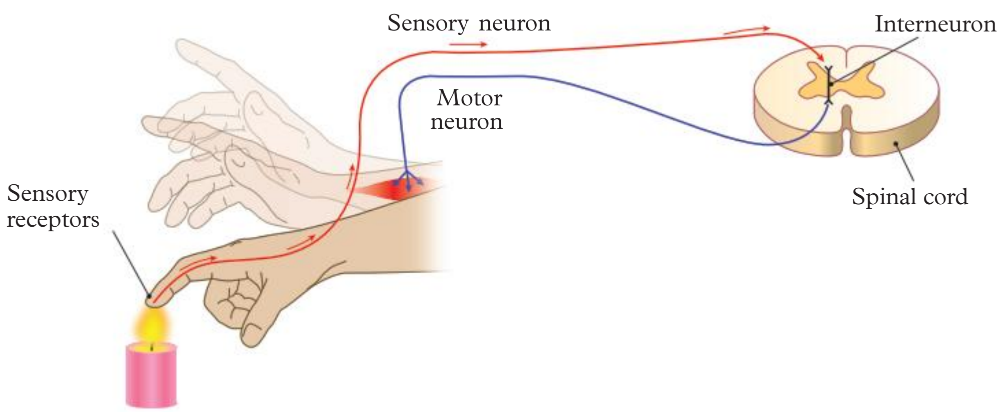


Figure 4 A reflex action ensures that your hand pulls away from the flame very quickly, even before you feel the pain.

Figure 5 Grasp reflex When an object is placed on a baby's palm, their fingers curl over and grasp it.

Figure 6 Sneezing reflex When small particles land on receptors in the back of your nose, the muscles in your diaphragm force air out rapidly.

Figure 7 Startle reflex When a newborn baby is startled, they will fling their arms out wide and grab anything they touch.

Figure 8 Plantar reflex When a blunt object (such as the blunt end of a pencil) is moved along the underside of the foot, the toes usually curl downwards.

Figure 9 Patellar (knee-jerk) reflex When a small section below the kneecap (the tendon that connects the muscle to the bone) is stimulated with a quick, firm tap, the foot will kick out.

Check your learning 3.6

Check your learning 3.6

Retrieve

1 Define the following terms:
- **a** receptor
- **b** effector
- **c** response.

2 Identify the two parts of the body that make up the central nervous system.

Comprehend

3 Describe the role or function of the peripheral nervous system.

4 Describe how the peripheral nervous system and the central nervous system work together. Use an example to illustrate your answer.

5 Explain why, if you slipped and hit the back of your head, everything might go black.

6 Describe the possible effect on behaviour that would occur if a person had damage to the frontal lobe of their brain.

7 Describe the stimulus–response model.

8 Explain why the brain is not involved in a reflex action.

9 Explain the advantage of a baby having the startle reflex.

Analyse

10 Contrast the somatic nervous system and the autonomic nervous system.

11 If a person has a damaged upper spinal cord, they may not be able to feel their toes. Analyse whether this will affect their knee-jerk reflex (How does a person "feel" their toes? How would you describe the role of the spinal cord in this reflex? How can you determine if damage to the upper spinal cord affects messaging in the knee-jerk reflex?)

Apply

12 Create a scientific diagram of the brain that shows the four lobes. In each of the lobes:
- **a** write the functions that are carried out in that lobe
- **b** draw something to remind you of the functions carried out in that lobe.

Skills builder: Communicating

13 Create an information booklet explaining the difference between the central nervous system and the peripheral nervous system. This booklet should help students in your year level understand the roles of each system and their similarities and differences.
- **a** Identify the key information. (THINK: Can you explain the components of each system simply? Why is this important?)

b Synthesise the information you found in part **a** and present this information for your target audience. (THINK: Who is your audience? Is the information age-appropriate?)

c Construct the information booklet. (THINK: What is the best way to present this information? Is the language I am using scientific [i.e. clear and concise]? Would including diagrams help?)

Lesson 3.7

Skills lab: Sheep brain dissection

Caution

- Wear your lab coat, safety glasses and plastic gloves.
- Be careful with the scalpel because it is very sharp. Cut away from your hands and other people.

Aim

To explore the structure of a sheep's brain

Materials

- Sheep's brain
- Dissecting board
- Scalpel
- Dissecting scissors
- Coloured pins
- Microscope (optional)
- Slide (optional)
- Coverslip (optional)
- Forceps

Method

1 Examine the outside of the brain. Set the brain down so that the flatter side, with the white spinal cord at one end, rests on the board (Figure 1). Using the coloured pins, identify the two hemispheres, the four lobes of the brain, the spinal cord, the cerebellum and the cerebrum. Draw a diagram (in pencil) or take a photo that displays the different sections of the brain. Check this with your teacher before continuing.

Figure 1 Step 1: Examine the top and sides of the brain.

2 Remove the pins and turn the brain over (Figure 2). Identify the medulla. Draw a diagram or take a photo that displays this part of the brain.

Figure 2 Step 2: Examine the underside of the brain.

3 Turn the brain over again, with the curved top side of the cerebrum facing up. Use a scalpel to slice through the brain along the centre line, starting at the cerebrum and going down through the cerebellum, spinal cord, medulla and pons (Figure 3). Separate the two hemispheres of the brain (Figure 4). Draw a diagram or take a photo that displays these parts of the brain.

4 Cut one of the hemispheres in half lengthwise. Record what you see.

5 If a microscope is available, slice a very thin section of the cerebrum and put it on a slide, covering it with a drop of water and a cover slip. Draw a diagram of what you observe at low and high magnifications. Follow the same procedure with a section of the cerebellum, and then compare the two sections of the brain.

Questions

1 Describe the texture of the brain (smooth, rough, slippery, waxy, tacky, flimsy, chalky, hard, soft, granular, rubbery).

2 Compare the structure of the sheep's brain and what you know about a human brain.

3 Contrast the cognitive functions (ability to think and reason) of a sheep and a human. Describe how these differences could be reflected in the structure of the brain.

Figure 3 Step 3: Slice along the brain.

Figure 4 Step 3: Separate the two hemispheres of the brain.

Lesson 3.8
The endocrine system causes long-lasting effects

Key ideas

→ The endocrine system uses chemical messengers called hormones to maintain control and to regulate growth.

→ Hormones travel through the bloodstream to receptors or target cells.

→ The effects of hormones often last longer than the effects of the nervous system.

Learning intentions and success criteria

The endocrine system

endocrine system a collection of glands that make and release hormones

target cell a cell that has a receptor that matches a specific hormone

peptide hormone a protein-based hormone that is fast acting and relatively short-lived

steroid hormone a cholesterol-based hormone that is slower acting and relatively long-lived

The **endocrine system** is a collection of glands that secrete (release) hormones. The hormones are secreted directly into the bloodstream and then travel around the body through the blood. Some cells in the body have receptors that match the hormone, like a lock to a key. These are called **target cells**. It only takes one hormone "key" to cause a change in the target cell "lock".

Hormones are classified into two groups based on their chemical structure: **peptide hormones** and **steroid hormones**. Peptide hormones are made from proteins. They are fast-acting and have relatively short-lived effects. They bind to the receptors on the surface of the target cell, causing a change in cell function without entering the cell. Examples include insulin, glucagon and adrenaline. In contrast, steroid hormones are derived from cholesterol (a lipid). They pass through the cell membrane of the target cell, bind to intracellular receptors and regulate gene expression from within the cell. Examples include testosterone and oestrogen.

The glands and organs of the endocrine system are spread throughout the body (Table 1 and Figure 1).

Table 1 Some organs and hormones of the endocrine system

Organ	Hormone	Target tissue	Main effects
Hypothalamus	Wide range of neurohormones	Pituitary gland	Sends messages from the nervous system to the pituitary gland to control functions such as body temperature, hunger, thirst and sleep patterns
Ovaries	Progesterone	Uterus	Thickens wall of uterus to prepare for pregnancy
	Oestrogen	Body cells	Involved in development of female sexual characteristics; aspects of pregnancy and foetal development
Testes	Testosterone	Male reproductive system, body cells	Involved in development of male sexual characteristics; production of sperm
Pancreas	Insulin	Liver, most cells	Lowers blood glucose level
	Glucagon	Liver	Raises blood glucose level
Pituitary gland	Thyroid-stimulating hormone (TSH)	Thyroid	Changes the rate of thyroxine release from the thyroid
	Antidiuretic hormone (ADH)	Kidneys	Increases the amount of water reabsorbed from the kidneys
	Pituitary growth hormone	Bones, muscles	Stimulates muscle growth; controls the size of bones
Thyroid gland	Thyroxine	Body cells	Affects rate of metabolism, and physical and mental development
Parathyroid glands	Parathyroid hormone	Blood	Regulates the amount of calcium in the blood
Adrenal glands	Adrenalin	Body cells	Increases body metabolism in fight-flight-freeze response
Pineal gland	Melatonin	Skin cells	Involved in daily biological rhythms

Fight, flight or freeze?

If you are ever in a dangerous or frightening situation, you may experience a "fight-flight-freeze" response. You break out in a cold sweat, your heart beats faster, everything around you seems to slow down and your senses bombard you with information.

Most of these symptoms are triggered by the release of the hormone adrenalin (also called epinephrine). Adrenalin is constantly produced by the adrenal glands in small doses. The adrenal glands are located above the kidneys.

The usual function of adrenaline is to stimulate the heart rate and enlarge blood vessels. When you are in danger, however, the hormone takes on another role. It floods your system, causing an increase in the strength and rate of the heartbeat, raising your blood pressure and speeding up the conversion of glycogen into glucose, which provides energy to the muscles. In this way, adrenalin prepares your body for the extra effort required should you need to defend yourself (fight), run away (flight) or hide (freeze) (Figure 2).

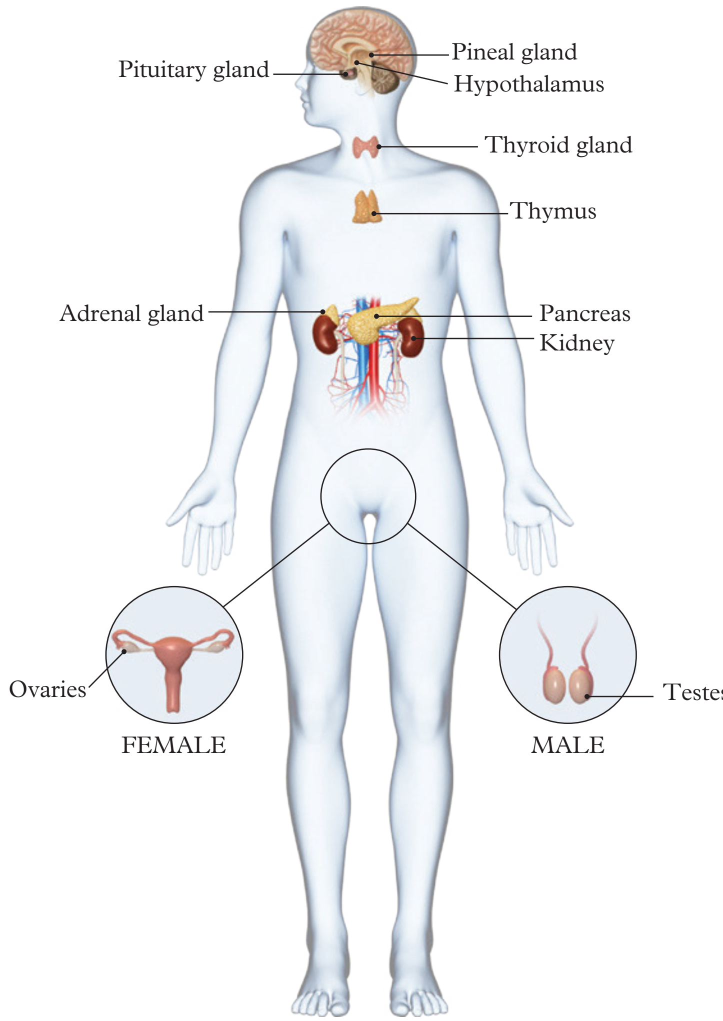


Figure 1 The human endocrine system

Figure 2 Adrenalin is responsible for the fight-flight-freeze response in mammals and can help them to survive.

Panic attacks

Sometimes the fight-flight-freeze response can be triggered without any obvious reason. This means adrenalin can flood the body, causing the heart to pound, breathing to become fast and shallow and a flood of sensory information to stimulate the brain. When this occurs, lights appear brighter, sounds are louder and smells are stronger. These sensory messages can become jumbled as the brain struggles to make sense of all the information. This combination of endocrine and nervous system responses is called a panic attack. These symptoms are not life-threatening and will eventually disappear. Support from friends, family or healthcare professionals can help.

Comparison of the nervous and endocrine systems

Both the nervous system and endocrine system are regulatory systems that react to stimuli and maintain homeostasis through negative feedback loops (see Lesson 3.1 Homeostasis regulates through negative feedback loops, page 106). Some key differences between these two systems are seen in Table 2.

Table 2 Differences between the nervous and endocrine systems

Characteristic	Nervous system	Endocrine system
Message	Electrical impulse	Hormones
Organs	Brain and spinal cord	Glands
Transmission	Neurons	Blood
Effects	Short-lived	Short-lived (peptide hormones) Long-lived (steroid hormones)
Control	Involuntary (autonomic nervous system) Voluntary (somatic nervous system)	Involuntary

Check your learning 3.8

Check your learning 3.8

Retrieve

1 Name the system in your body that is responsible for the production of hormones.

Comprehend

2 Describe what is meant by the term “fight-flight-freeze” and how it relates to hormones.

3 Explain why the endocrine system is referred to as a communications system.

4 Explain why telling someone to “calm down” during a panic attack will not stop their symptoms. (Hint: Are they able to control their hormones?)

5 Explain why the endocrine system tends to be slower than the nervous system.

Analyse

6 Compare and contrast the responses of the nervous and endocrine systems.

Apply

7 Research a disease associated with a hormone. Write a brief report that introduces the disease, explains its cause and symptoms, and summarises research into the disease.

Skills builder: Questioning and predicting

8 A scientist claimed that, because humans are highly evolved, we don’t experience stress that may put our lives at risk and we therefore no longer use the fight-flight-freeze response.

- **a** Identify the “if” in this claim. (THINK: What are we responding to?)
- **b** Identify the “then” in this situation. (THINK: What do you expect to happen?)
- **c** Construct a scientific question that you can test for this claim. (THINK: Is this question testable?)

Lesson 3.9
Review: Homeostasis

Summary

Lesson 3.1 Homeostasis regulates through negative feedback loops

- The body needs to detect and correct changes in its levels of nutrients, water and temperature to stay healthy.
- Homeostasis is the process whereby the body regulates and maintains a stable, balanced condition inside the body
- Negative feedback loops occur when the body responds in a way that removes the initial change (stimulus).

Lesson 3.3 Human and animal responses to stimuli

- Humans and animals have receptors that detect changes (stimuli) in the environment.
- The five main external receptors detect light, sound, touch, and chemicals in the mouth (taste) and the air (smell).

Lesson 3.4 Plant responses to stimuli

- Like humans and animals, plants also detect and respond to changes in their environment.

Lesson 3.5 Nerve cells are called neurons

- Neurons are cells in our body that enable messages to be passed on quickly.
- Electrical messages are passed along the neuron to the synaptic terminal when receptors in the body detect changes.
- Chemical neurotransmitters pass the message to the next neuron across a gap called a synapse.
- The myelin sheath protects parts of the neuron and increases the speed of messages being sent.

Lesson 3.6 The nervous system controls our body

- The nervous system uses electrical impulses that are fast-acting and relatively short-lived.
- Humans are constantly receiving stimuli from their environment through the peripheral nervous system.
- Neurons use electrical messages that are passed along to neurons in the brain and spinal cord, which make up our central nervous system.
- Receptors in the nervous system detect a stimulus and pass it on to control centres.
- The control centres initiate a message to the effectors, which causes a response.
- Reflexes are special pathways that allow a response to occur before the brain has time to think.

Lesson 3.8 The endocrine system causes long-lasting effects

- The endocrine system uses chemical messengers called hormones to maintain control and to regulate growth.
- Hormones travel through the bloodstream to receptors or target cells.
- The effects of hormones often last longer than the effects of the nervous system.

Review questions 3.9

Review questions Module 3

Retrieve

1 Identify which of the following is the stimulus.
   A A target cell that has a receptor
   B A hormone released into the bloodstream
   C A change in the environment that disrupts homeostasis
   D A response by the body that restores the homeostatic balance

2 Identify which of the following is not a hormone.
   A Testosterone
   B Adrenaline
   C Cestrogen
   D Neuron

3 Identify which of the following is not a response to increased body temperature.
   A Sweating
   B Shivering
   C Blood vessel dilation
   D Reduced urine output

4 Define the following terms:
   a stimulus
   b homeostasis
   c hibernation.

5 Identify the missing labels for the parts of a neuron in Figure 1.

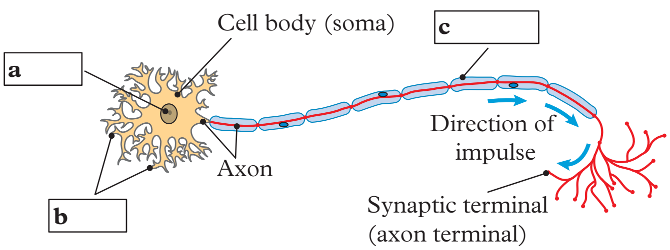


Figure 1 A typical neuron

6 Identify the four lobes of the brain and state their functions.

7 Identify two situations where a person might experience the fight, flight or freeze response.

8 Name two glands in humans that produce hormones.

9 Identify the missing words in the following sentence. A person with diabetes has a problem with the hormone ______________, which is secreted by the ______________.

Comprehend

10 Describe three ways the human body can receive a stimulus from the environment.

11 Explain why the nervous system and the endocrine system are both described as communication systems.

12 Describe how hormones are transported in the body.

13 Describe a sensory system not found in humans but used by other organisms.

14 Describe the passage of information through a neuron.

15 Explain why maintaining stable internal conditions is crucial for overall health.

16 Explain the process by which hormones control blood glucose levels in response to eating.

17 Use an example to explain how a negative feedback loop works.

18 When a person drinks a litre of water, their body produces extra urine. Use the concept of homeostasis to explain why.

19 Explain how the endocrine system assists your body to "respond to the world". Explain why your body also needs a nervous system.

20 Explain why holding your nose might help you to swallow something that tastes bad.

21 In 2006, a woman in Canada fought off a polar bear with her bare hands when it attacked her son. She literally wrestled the bear and won! Explain why this reaction could be attributed to the hormone adrenalin.

22 Given that the body has mechanisms to maintain stable internal conditions, explain why we still experience fluctuations in body temperature.

23 Describe in your owns words how the nervous system responds to a sudden change in the external environment, such as touching a hot surface.

Analyse

24 Compare the roles of the endocrine system and the nervous system in maintaining homeostasis within the body.

25 Contrast the roles of the somatic and autonomic nervous systems.

26 Contrast hyperglycaemia and hypoglycaemia.

Apply

27 Discuss how maintaining a balanced diet and regular exercise can assist your body in regulating hormone levels and overall homeostasis.

28 Investigate how stress affects the body's hormonal responses and outline the role of the hypothalamus and adrenal glands in this process.

29 Explain how factors such as air quality and temperature can impact the nervous system and the body's ability to maintain homeostasis. Describe strategies to minimise these effects.

Social and ethical thinking

30 Identify the various hormones that are essential for growth and development during childhood. Discuss the role of parents or guardians in ensuring children receive appropriate hormonal treatments if necessary. Describe at least four credible sources that support the importance of hormonal balance in children's health. Justify why these sources are reliable.

31 Consider how individuals with conditions affecting hormone regulation, such as diabetes or thyroid disorders, may experience challenges in their daily lives. Discuss the ethical implications of treatment options, including the use of medications or lifestyle changes, and justify your choice based on factors you considered.

Critical and creative thinking

32 Create a cartoon strip with at least five squares, illustrating a person receiving a stimulus and then responding.

33 Create a visual presentation illustrating the pathway of nerve impulses, including the role of neurotransmitters and the synapse in communication between neurons.

34 Consider the effects of stress on hormone levels, particularly cortisol. Use critical thinking to predict how prolonged stress may impact overall health and homeostasis.

35 Analyse the impact of lifestyle choices on insulin sensitivity. Use critical thinking to predict how different dietary patterns may influence the development of insulin resistance.

36 Construct a flowchart to distinguish the processes involved in the hormonal regulation of blood glucose levels, including the roles of insulin and glucagon.

Research

37 Investigate one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

The effects of exercise on hormonal regulation

Investigate how different types of exercise (aerobic versus resistance training) affect hormone levels and homeostasis.

- What hormonal changes occur in response to aerobic exercise, and how do they contribute to cardiovascular health?
- How does resistance training influence hormones like growth hormones and testosterone, and what are the implications for muscle health?
- What is the relationship between exercise, insulin sensitivity and blood glucose regulation?
- Discuss the importance of exercise as a non-pharmacological intervention for maintaining hormonal balance and preventing metabolic disorders.Summary

Multiple sclerosis and nerve transmission

Explore the impact of multiple sclerosis (MS) on nerve impulse transmission and homeostasis.

- How does the loss of the myelin sheath affect the speed and efficiency of nerve impulses?
- What are the symptoms of MS related to disrupted nerve communication?
- How do current treatments (e.g. immunotherapy) aim to slow the progression of MS and support nerve function?
- Discuss the importance of early diagnosis and intervention in managing the symptoms of MS.

Type 2 diabetes and hormonal regulation

Investigate the hormonal mechanisms involved in the regulation of blood glucose levels in individuals with type 2 diabetes.

- How does insulin resistance develop, and what role does it play in type 2 diabetes?
- What are the effects of lifestyle changes (diet and exercise) on hormone levels and blood glucose control in diabetes management?
- How do medications for type 2 diabetes target hormonal pathways to improve glucose regulation?
- Explain the long-term complications of poorly managed blood glucose levels and their impact on homeostasis.

Hormonal changes during stress

Research the physiological effects of stress on the endocrine system, particularly focusing on cortisol and adrenaline.

- How do stressors trigger the release of cortisol and adrenaline, and what are their effects on the body?
- What role does the hypothalamic-pituitary-adrenal (HPA) axis play in the stress response?
- How can chronic stress impact health by disrupting hormonal balance and homeostasis?
- Explain the potential interventions (e.g. mindfulness, exercise) that can help regulate stress hormones.

Module 4

Disease

Overview

Infectious diseases are caused by bacteria, viruses, fungi and parasites. To control these diseases, we use hygiene, quarantine, medical treatments and public education. Protections such as handwashing, masks and isolation help to stop the spread of the infection. Non-infectious diseases, such as cancer and diabetes, can be caused by various factors, including genetics, age and lifestyle.

Vaccination can help to reduce the spread of a disease or eradicate specific diseases. Smallpox, a disease responsible for over 300 million deaths, was declared eradicated from the world in 1980 after a successful global immunisation program.

Lessons in this module

Lesson 4.1
Non-infectious diseases

Learning intentions and success criteria

Key ideas

→ Non-infectious diseases can result from genetic, environmental or nutritional factors.

→ Non-infectious diseases are not contagious.

Introduction

Unlike infectious diseases, **non-infectious diseases** are not caused by a **pathogen**. Instead, they are the result of genetic, environmental or nutritional factors. They can also be caused by a combination of these factors. They are not contagious: you cannot "catch" a non-infectious disease from someone. Some non-infectious diseases, however, may be passed down from parent to child in the case of **genetic disorders** like Huntington's disease or cystic fibrosis.

non-infectious disease a condition or disorder caused by environmental or genetic factors rather than pathogens

pathogen a disease-causing agent such as bacteria, virus or fungi

genetic disorder a condition caused by abnormalities (mutations) in the DNA (genes); genetic disorders are inherited (passed from parent to child)

Nutritional deficiency can cause disease

The **nutrients** you supply to your body can affect how well your cells do their job. The right balance of nutrients is very important. A **nutritional deficiency** can cause diseases like rickets, scurvy and kwashiorkor.

Although other conditions such as type 2 diabetes, heart disease and obesity have nutritional links, patients can also have an underlying **genetic predisposition** to the disease.

To further complicate the situation, the environment in which someone lives can influence the development of nutritional diseases. If there is little fresh fruit and vegetables available, you are more likely to develop some of these diseases.

nutrient a compound that is required for the growth, repair and basic functions of a body; includes proteins, fats, carbohydrates, water, vitamins and minerals

nutritional deficiency a condition caused by inadequate intake or absorption of nutrients, such as proteins, fats, vitamins and minerals

genetic predisposition an increased chance of developing a disease due to genetic (inherited) characteristics

Kwashiorkor

Protein is an important component of any diet because it is essential for cell growth and repair. If not enough protein is consumed, the body responds by slowing cell growth and repair. Lack of protein can cause a disease called kwashiorkor, which leads to stunted growth, loss of muscle mass and fluid retention (Figure 1). If not treated, it is life-threatening.

Figure 1 A child with kwashiorkor, a disease caused by a diet that is very low in protein

Scurvy

Vitamin C plays an important role in the growth and repair of all body tissues. When people do not consume enough vitamin C (e.g. by eating citrus fruits, such as oranges, and green vegetables), the body's ability to repair damaged tissue is inhibited. This can lead to scurvy, with symptoms such as weakness, spontaneous bleeding, ulceration of the gums and loss of teeth.

Genetic diseases and disorders

All genetic disorders are a result of a mutation in the **DNA (deoxyribonucleic acid)** or **chromosomes**. If these mutations occur in the DNA of sperm and eggs, they can be passed on to future children. Examples of genetic diseases and disorders include haemophilia, cystic fibrosis, sickle-cell anaemia, muscular dystrophy, Down syndrome and fragile X syndrome.

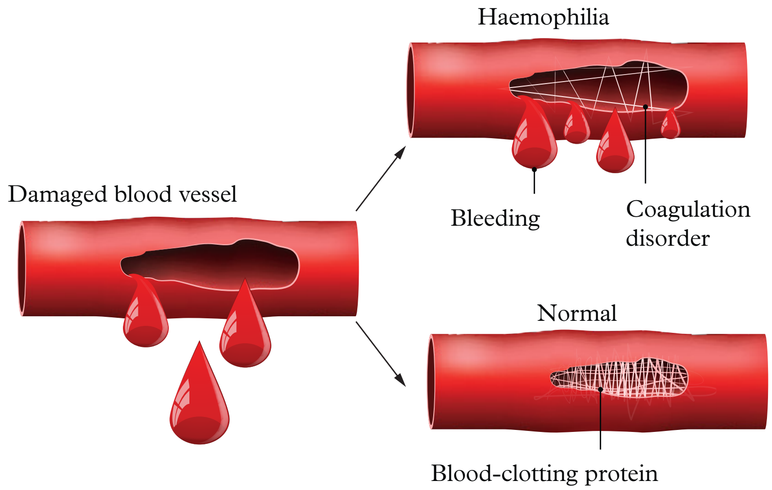


Figure 2 Haemophilia prevents a person's blood clotting.

Haemophilia

Haemophilia is an inherited disorder that prevents the affected person's blood from clotting. Typically, when we injure ourselves, our blood has proteins that assist in plugging the gap to stop the bleeding. If these proteins are not present, the body cannot prevent continuous bleeding. If someone with haemophilia injures themselves, they are at serious risk of losing a lot of blood. Modern science has isolated these clotting proteins in blood cells, and patients with haemophilia can be given the proteins when needed (Figure 2).

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

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

Cystic fibrosis

Cystic fibrosis (CF) is an inherited disorder that causes severe damage to the lungs, digestive system and other organs in the body. It is the most common genetic disorder in Australia, with nearly 4,000 people living with the condition and 1 in 25 carrying one copy of the **recessive gene**.

Cystic fibrosis occurs when a person inherits two copies of a mutated *CFTR* (cystic fibrosis transmembrane conductance regulator) gene: one from each parent. The normal *CFTR* protein helps to clear excess mucus from the lungs. When a person has cystic fibrosis, their mucus is very thick and sticky, and they are unable to clear it from their lungs. It clogs the tiny air passages and traps bacteria. This causes recurring infections and blockages, which can cause irreversible lung damage over time (Figure 3).

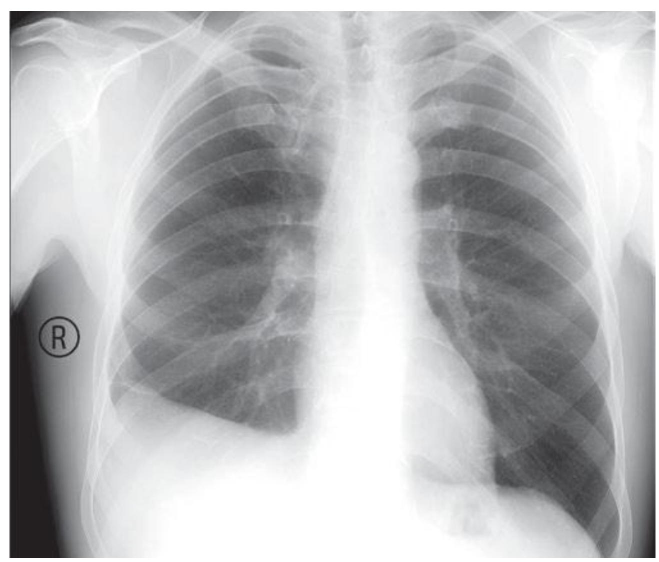


Figure 3 X-ray of a cystic fibrosis patient showing inflammation and scarring of the lungs caused by chronic infections

Environmental and lifestyle diseases

As humans we are exposed to toxins, **carcinogens** and radiation on a daily basis. Some of these are harmless in small amounts, but with prolonged or extreme exposure they can cause a non-infectious disease.

For example, excessive exposure to ultraviolet (UV) radiation can break chemical bonds within the DNA of your cells. DNA contains the instructions for every task and substance required for healthy functioning. Any change to these instructions can result in damage, which may be minor or major depending on where in the body the change occurs.

recessive gene a gene that must be present on both chromosomes to be expressed

carcinogen a substance that can cause cancer

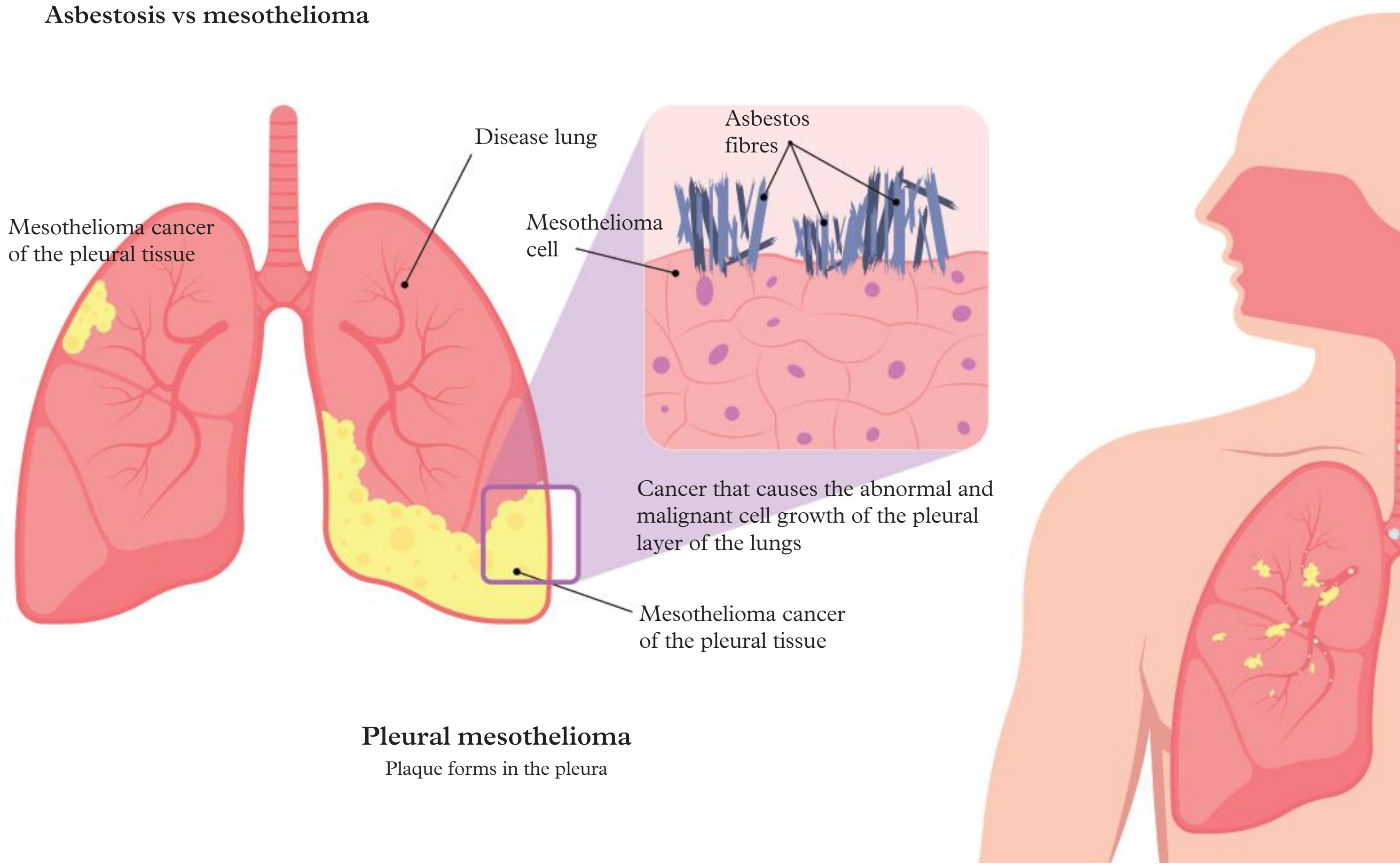


Figure 4 Asbestosis and mesothelioma are non-infectious diseases caused by exposure to asbestos.

Asbestosis and mesothelioma

In *Oxford Science Stage 4 NSW Curriculum*, you will have studied how certain factors affect the function of our body systems, including the respiratory system. Asbestos is a mineral that has been linked to several life-threatening diseases, including asbestosis, mesothelioma and lung cancer (Figure 4).

Asbestosis is a lung disease caused by the inhalation of asbestos fibres. The fibres lodge in the lung tissue, and the body responds with inflammation and the creation of scar tissue to enclose the fibres. This destroys the affected alveoli, making breathing difficult.

Mesothelioma is an aggressive type of cancer that results from asbestos fibres sticking to the protective layer (mesothelium) of the lungs. The asbestos fibres disrupt the normal functioning of the mesothelium cells, leading to uncontrolled cell division (cancer) that can quickly spread to other organs.

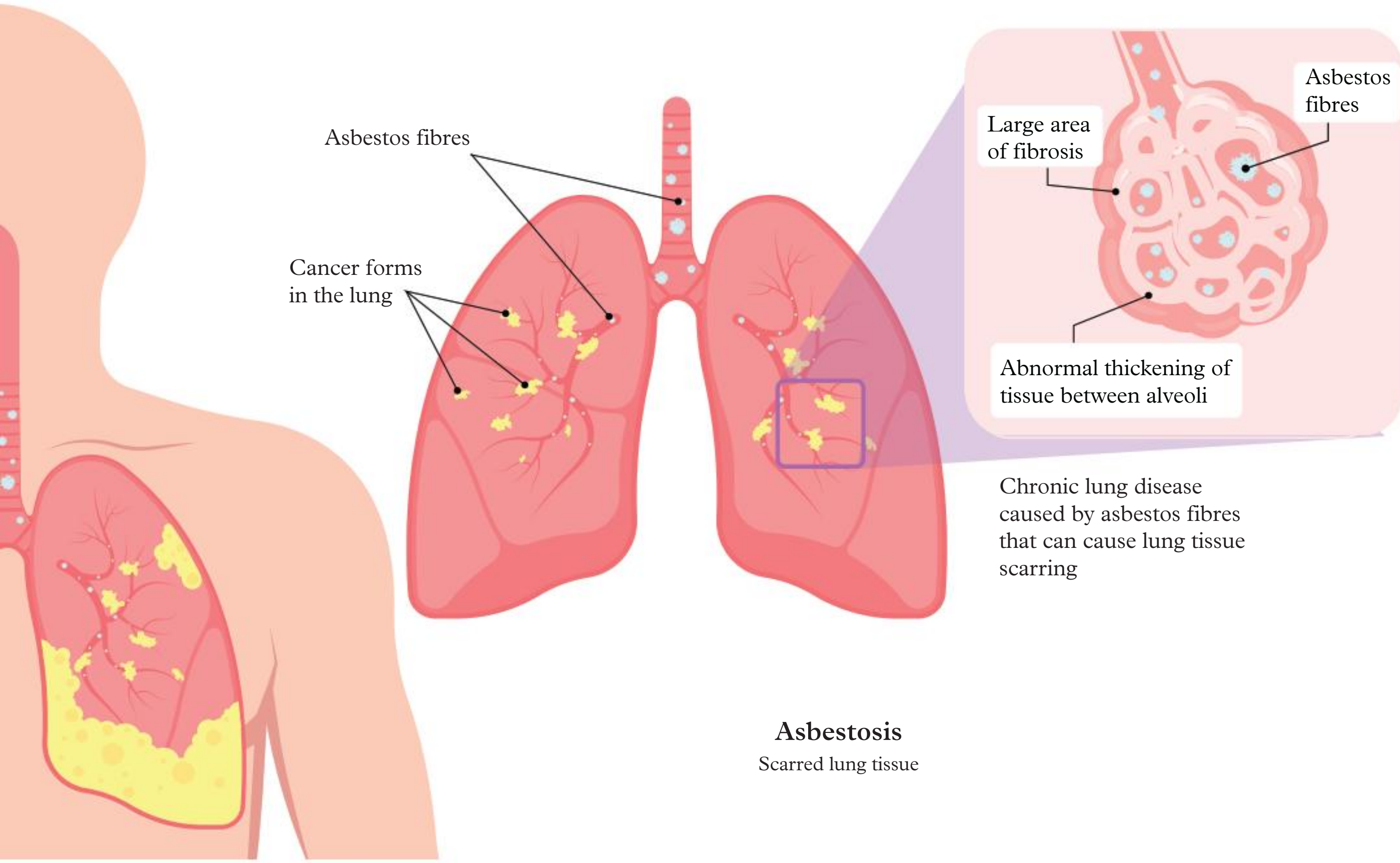
asbestosis a lung disease caused by the inhalation of asbestos fibres

mesothelioma an aggressive type of cancer that results from asbestos fibres sticking to the protective layer of the lungs

Emphysema

Emphysema is a progressive disease of the lungs. It is caused by long-term exposure to irritants such as air pollution and cigarette smoke. Cigarette smoke contains more than 70 known carcinogens, which are capable of causing emphysema, lung cancer and other health issues. Current research indicates that the rise of vape use among teenagers will see a significant increase in emphysema cases in the near future.

Emphysema causes irreversible damage to the alveoli and the protective cilia that line your respiratory tract. There is a reduction in surface area over which gas exchange can occur, eventually leading to extreme shortness of breath and an increased risk of infections (Figure 5).



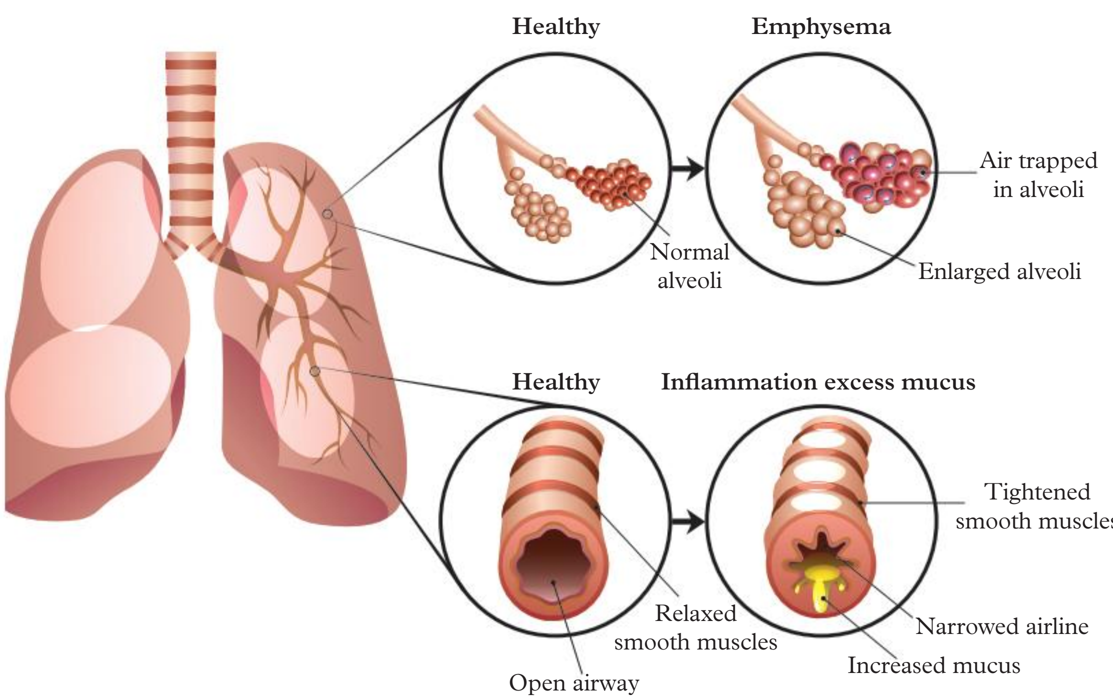


Figure 5 Emphysema destroys lung tissue, leading to shortness of breath and increased risk of infection.

Check your learning 4.1

Check your learning 4.1

Retrieve

1 Identify the three categories of non-infectious disease and provide an example of each.
2 Explain why our body needs a healthy diet.

Comprehend

3 Explain how asbestos exposure can lead to asbestosis or mesothelioma.

Apply

4 Techniques for detecting genetic disorders are becoming more accurate and accessible.
Write a brief essay discussing the benefits and disadvantages of screening parents for common genetic disorders before having children.
5 Investigate a nutritional, genetic or environmental disease not covered in this lesson. Construct a presentation that provides details about the cause, symptoms and treatment. Your presentation should be no longer than 2 minutes and can involve a digital presentation, poster or any other elements you may need.

Skills builder: Communicating

6 Evaluating existing research contributes to developing new theories to test.
   a Rate each source out of 10 for reliability. (THINK: Which is more credible? Is the source likely to have been reviewed?)
   b For each source, identify one reason why it is credible and one reason why it may not be credible. (THINK: Where was the information published? Did the source use the scientific method? Was the information reviewed? Is the author an expert in their field?)
   The following three sources may provide information about scurvy symptoms:
   » your friend
   » this course
   » a medical journal, such as *The Lancet*.

Lesson 4.2

Pathogens cause infectious diseases

Learning intentions and success criteria

Key ideas

→ Infectious diseases are caused by pathogens.

→ Infectious diseases can be spread between individuals.

History of infectious disease

Our understanding of how infectious pathogens disrupt the normal functioning of our body and cause disease has developed over many centuries.

Girolamo Fracastoro (1478–1553) was an Italian astronomer and doctor who was one of the first to suggest that disease could be transmitted from person to person via small invisible particles. He theorised that these particles could travel through the air, via contaminated clothing or by direct contact with the sick person. It took over 200 years and the discovery of the microscope to confirm his theories and to develop the “germ theory” used today.

Germ theory

Germ theory states that each **infectious disease** is caused by the presence and actions of a specific pathogen. Germ theory was confirmed by Louis Pasteur and Robert Koch in the late 1800s.

infectious disease a condition or disorder caused by pathogens such as bacteria, viruses and fungi

Louis Pasteur

Louis Pasteur disproved the long-held view that life and disease spontaneously generated. He did this through his famous swan neck flask experiment (Figure 1). Two swan neck flasks with nutrient broth were boiled to kill any microbes. One flask had the swan neck remain in place while the other was snapped off, exposing it to air. Only the second flask grew microbes, proving they had come from the air and that they could therefore be passed from one individual to another.

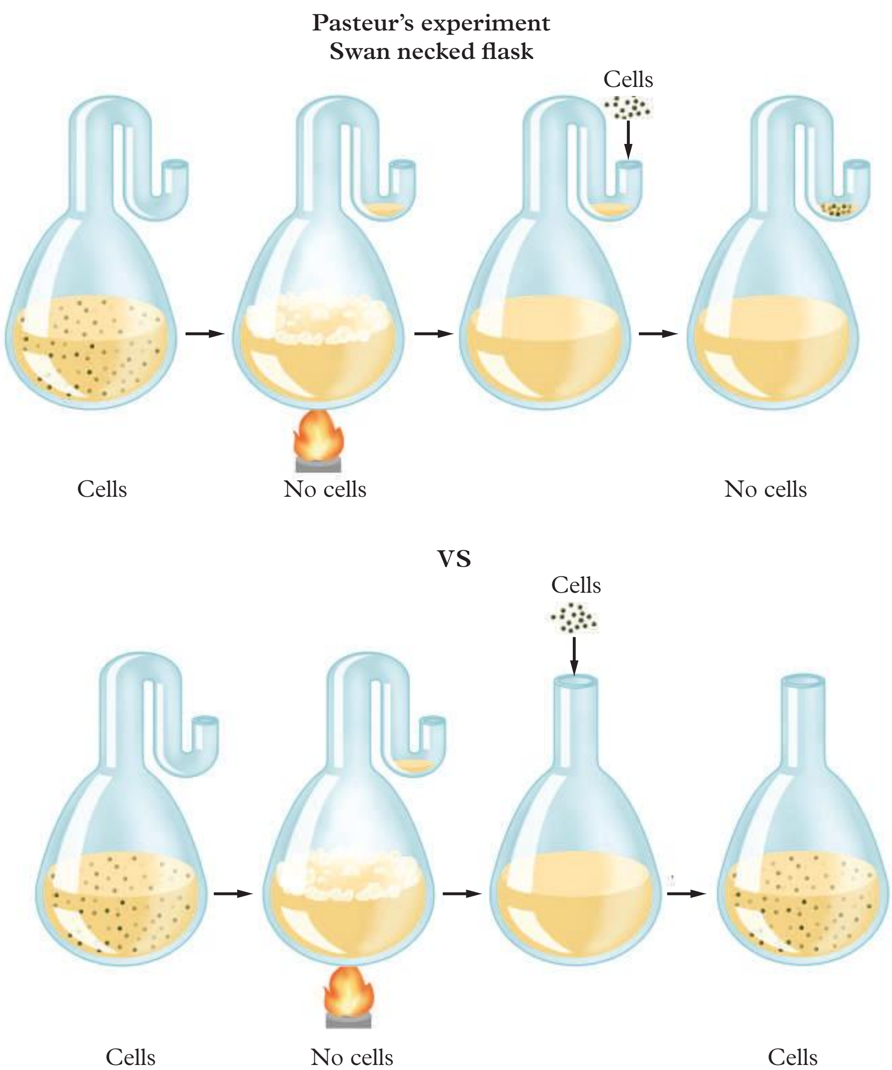


Figure 1 Louis Pasteur's swan neck flask experiment

Robert Koch

Robert Koch developed a set of rules known as Koch's postulates (Figure 2). These rules were developed in the late 1800s and were used to determine if a disease was caused by a specific pathogen.

Koch's postulates state the following.

1 The pathogen must be present in all cases of the disease.
2 The pathogen can be isolated from the diseased host and grown in the laboratory.
3 The pathogen from a pure culture must cause the disease when inoculated (introduced) into a healthy susceptible host.
4 The pathogen must be re-isolated from the new host and shown to be the same as the originally inoculated pathogen.

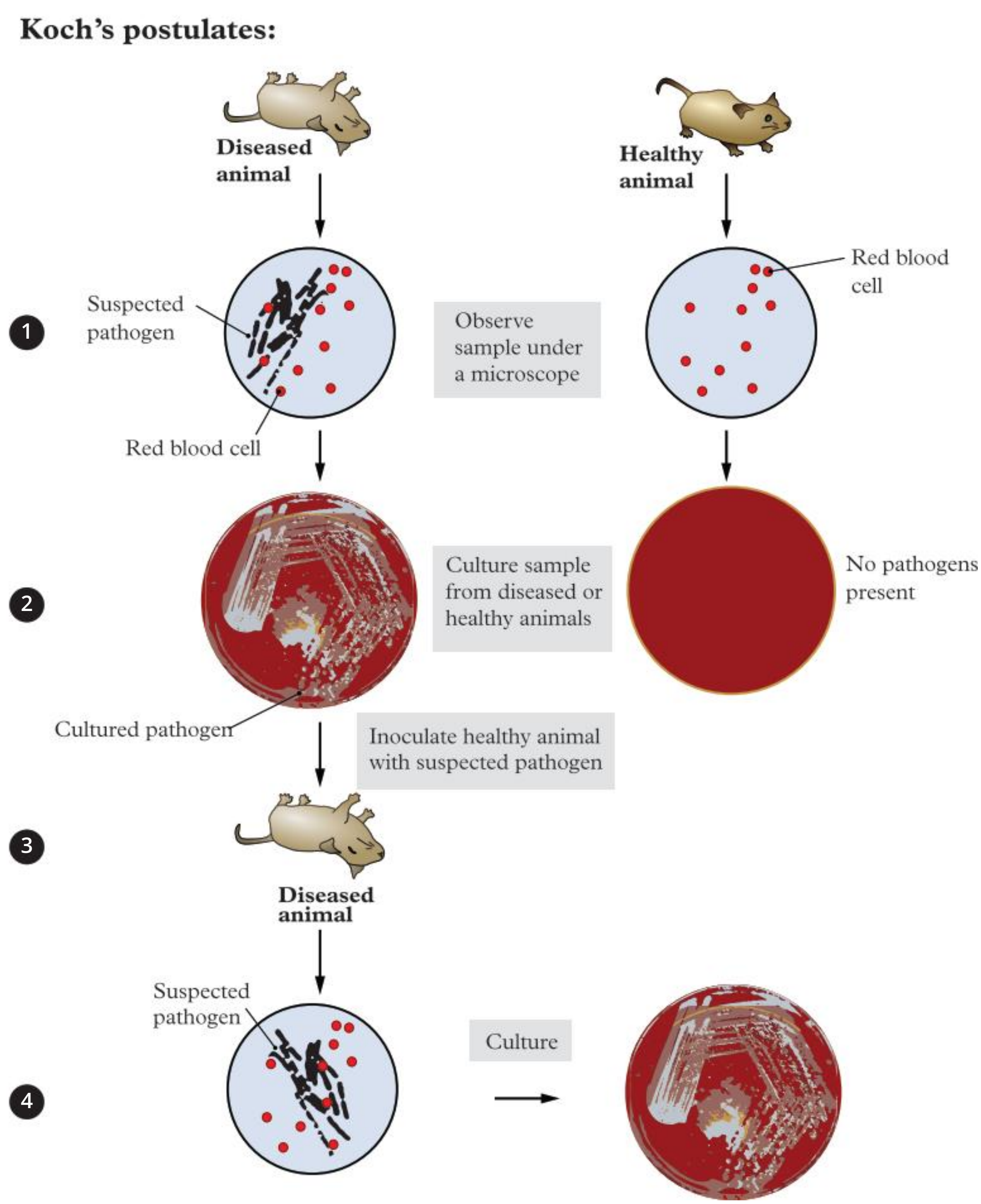


Figure 2 Koch's postulates are used to determine if a pathogen is the cause of a disease.

RNA (ribonucleic acid) a single-stranded molecule essential for protein synthesis; contains the sugar ribose, unlike DNA which has deoxyribose

Types of pathogens

There are six groups of pathogens: prions, viruses, bacteria, fungi, protozoa and macroparasites. They are classified based on factors such as size, cellular nature (living or not), presence or absence of genetic material, and different cellular structures. Table 1 shows the different types of pathogens and their distinguishing features.

unicellular prokaryotic organism a single-celled life form without a defined nucleus or membrane-bound organelles, including bacteria and archaea

Table 1 Different types of pathogens and their distinguishing features

Pathogen	Distinguishing features	Example of disease	Causative pathogen
Non-living			
Prion	A faulty protein molecule, which makes other proteins faulty through contact	• Mad cow disease • Creutzfeldt-Jakob disease	• Mad cow disease prion • Creutzfeldt-Jakob disease prion
Virus	Contains genetic material (DNA or **RNA**) surrounded by a protein shell	• AIDS • COVID-19 • Measles	• Human immunodeficiency virus (HIV) • SARS-CoV-2 virus • Measles virus
Living			
Bacterium	**Unicellular prokaryotic organism**	• Tuberculosis • Cholera • Golden staph infection	• *Mycobacterium tuberculosis* • *Vibrio cholerae* • *Staphylococcus aureus*
Fungus	Unicellular or multicellular **heterotrophic eukaryotic organism**	• Tinea • Candidiasis (oral thrush)	• *Trichophyton rubrum* • *Candida albicans*
Protozoan	Unicellular heterotrophic eukaryotic organism	• Malaria • Giardiasis	• *Plasmodium falciparum* • *Giardia lamblia*
Macroparasite	Multicellular eukaryotic organism; can be endoparasitic (inside) or ectoparasitic (outside)	• Cysticercosis • Taeniasis	• *Taenia solium* (Pork tapeworm) • *Taenia saginata* (beef tapeworm) Infection is caused when contaminated uncooked meat is eaten.

Prion

Prions do not contain any genetic material (DNA or RNA). Normal prion proteins are found in nerve tissue and play a role in maintaining neuron structure and memory formation. Infectious prions are misfolded forms of the "normal" protein. When the misfolded prion protein comes into contact with healthy cells, the "normal" prion protein is converted into the harmful form. Over time, this destroys the nervous system, and neurological function is lost.

Virus

Although all viruses have genetic material, they are classified as non-living pathogens because they are unable to reproduce without a host cell. Viruses reproduce only after entering a host cell or attaching to a host cell's surface and injecting their viral genetic material. The host cell's structures are hijacked to make copies of the viral DNA (or RNA). When enough copies have been made, the host cell ruptures, releasing large numbers of the virus that then go on the hunt for new host cells to infect.

Bacteria

Bacteria are **prokaryotic** organisms and are the smallest of the cellular pathogens. Some species of bacteria are harmful because they release chemicals that can damage cells and the surrounding tissue. These toxins can destroy cell structures or disrupt cellular processes.

heterotrophic an organism that consumes other organisms to obtain energy

eukaryotic an organism with cells that contain a nucleus and membrane-bound organelles; protists, fungi, plants and animals have eukaryotic cells

organism an individual living thing

prokaryotic a single-celled organism with no nucleus or membrane-bound organelles; bacteria and archaea are made up of a single prokaryotic cell

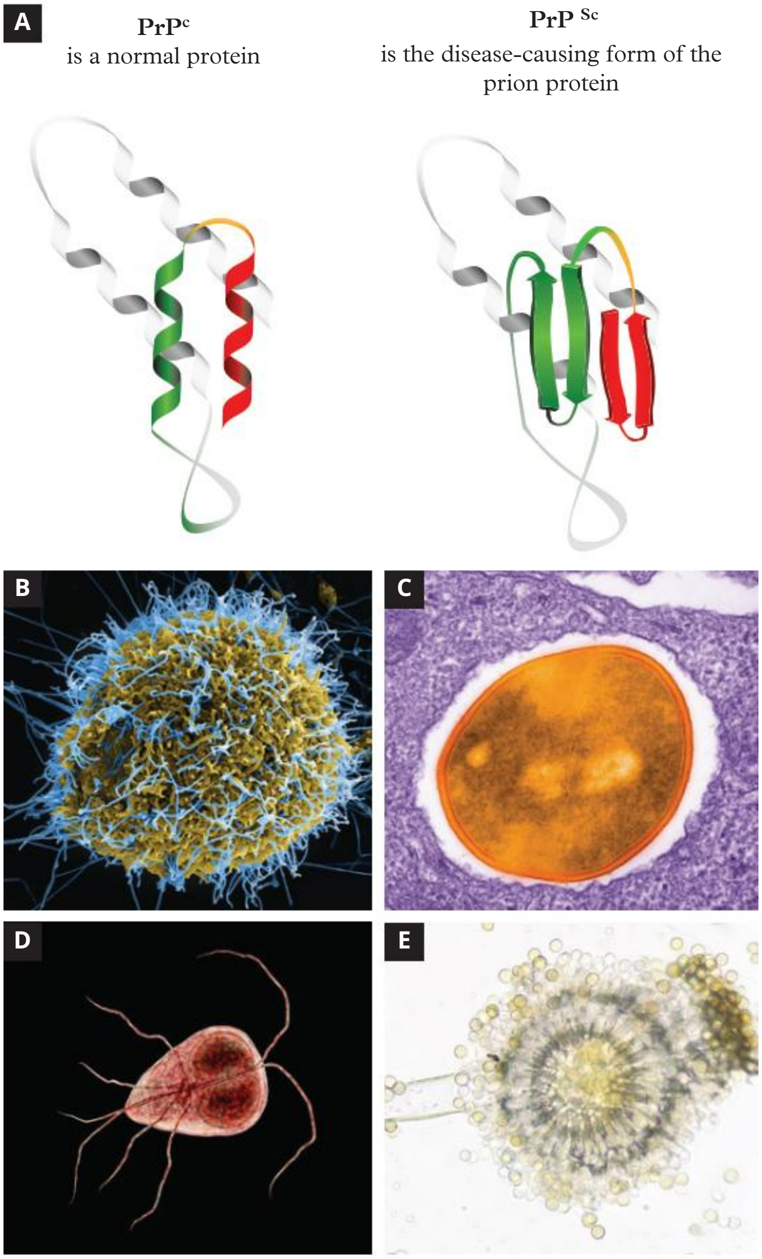


Figure 3 Most infections are caused by microscopic pathogens. (A) Prions are modified proteins that change the structure of the "normal" protein upon contact. (B) Viruses (blue) are unable to reproduce by themselves. Instead, they invade cells (yellow) and use the host cell's organelles to make new copies of themselves. This stops the host's cells from functioning properly. (C) Bacteria are very small prokaryotic cells that are able to reproduce by themselves. They can release toxins that affect the normal functioning of our body. (D) A protozoan is a single-celled organism that can live in other organisms and is responsible for parasitic infections. (E) The usually harmless mould species (*Aspergillus sp.*) can cause mild to severe symptoms in people with weakened immune systems. (F) Pork tapeworm (*Taenia solium*) causes cysticercosis. Larvae can migrate via the bloodstream to the brain, where they lodge and develop into cysts.

While not all bacteria cause disease, those that do can be highly infectious and harmful. For example, tuberculosis (TB) kills over 1 million people each year and is responsible for the most deaths in human history, estimated to be over 1 billion.

Protozoa

Protozoa are the "animal-like" group from the kingdom Protista. They usually have complex life cycles that include multiple hosts. For example, while many think malaria is caused by mosquitoes, it is in fact caused by one of five species of protozoan from the *Plasmodium* genus. The female *Anopheles* mosquito is an unwitting **vector** that transfers the protozoan parasite to humans when it takes a blood meal. There are over 2 million new cases of malaria each year and an estimated 400,000 deaths.

Fungi

Fungi are eukaryotic organisms that have a cell wall. There are only a small number of pathogenic fungi that affect humans, with most being opportunistic pathogens that impact immune-compromised individuals. A small number, however, can cause disease in healthy individuals. These include approximately 20 species that cause various forms of tinea. The name of each type of tinea is based on its location on the body; for example, *Tinea capitis* (scalp ringworm), *Tinea corporis* (body ringworm) and *Tinea pedis* (athlete's foot). Another common example is oral and vaginal thrush caused by *Candida albicans*. The symptoms observed with fungal infections are the result of digestive enzymes released by the fungi.

Macroparasites

Macroorganisms are all multicellular eukaryotic organisms, visible to the naked eye. They live either inside a host (endoparasites) or on a host (ectoparasites). They can cause disease directly or act as vectors that transmit other pathogens.

Endoparasites include *Taenia saginata* (beef tapeworm) and *Taenia solium* (pork tapeworm) which cause taeniasis and cysticercosis respectively. Both diseases are the result of eating contaminated undercooked meat and lead to significant digestive complaints. Unique to the pork tapeworm is that their larvae can migrate via the bloodstream to the brain, where they lodge and develop into cysts.

Ectoparasites typically do not cause disease themselves but act as vectors, passing on the pathogen when they come into contact with the host. For example, the Australian paralysis tick *Ixodes holocyclus* is a known vector of a different bacterial species that causes Lyme disease. The bubonic plague, caused by the bacteria *Yersinia pestis*, is transferred to humans from a flea bite, when the flea has had a blood meal from an infected rodent. It can then be passed from human to human through the air (aerosol inhalation).

vector an organism that transmits a pathogen to a different species

endoparasite a parasite that lives inside the host (e.g. a tapeworm)

ectoparasite a parasite that lives on the host (e.g. a tick)

Check your learning 4.2

Check your learning 4.2

Retrieve

1 Identify characteristics that can be used to distinguish between a virus, bacteria and protozoan pathogen.

2 Define the term “vector”.

Comprehend

3 Identify the steps in Koch’s postulates and explain their significance in determining that a specific pathogen causes a specific disease.

4 Explain how the development of microscopes contributed to germ theory and how this revolutionised our understanding of infectious diseases.

5 Explain why viruses are considered non-living, despite containing genetic material.

Apply

6 The contributions of Louis Pasteur and Robert Koch revolutionised our understanding of infectious diseases through the establishment of germ theory.

- a Assess the long-term impact of Louis Pasteur and Robert Koch’s work on our understanding of the cause and transmission of infectious diseases.
- b Describe some of the measures taken today that prevent the spread of infectious diseases, and explain how they can be attributed directly to the work of Pasteur and Koch.

7 Scientists believe an outbreak of an infectious disease in chickens is the result of a newly discovered species of bacteria. Explain the steps that would need to be taken to identify the causative pathogen.

Skills builder: Conducting investigations

8 Scientists who work with pathogens in the laboratory are at risk of being exposed to extremely dangerous diseases. You may have seen people in a laboratory wearing full personal protective equipment (PPE). Those who work with pathogens typically have all their skin covered and sealed. This is one of the ways scientists manage risk.

- a Explain why wearing PPE in the laboratory is important when working with pathogens. (THINK: What are the risks of contracting a virus? What could happen if the results were contaminated?)
- b Identify one other measure that can help keep scientists safe in the laboratory. (THINK: Should scientists work alone? What can go wrong if you are alone in the lab?)

Lesson 4.3
Endemic diseases, epidemics and pandemics

Learning intentions and success criteria

Key ideas

- → An endemic disease is always present in a particular area.
- → An epidemic is a localised outbreak of a disease in a limited geographical area.
- → A pandemic is an outbreak of a disease over a large geographical area.

Introduction

Recognising the distinction between endemic, epidemic and pandemic is essential for effective monitoring, prevention and response strategies to infectious diseases. This understanding enables health authorities to minimise the effect of diseases on populations and safeguard public health.

Endemic

endemic always found in a specific location

Many diseases are always present at stable levels in a particular area. They are said to be **endemic** (Figure 1A). For example, malaria is endemic in the tropical regions of Africa, South America and South-East Asia (Figure 2).

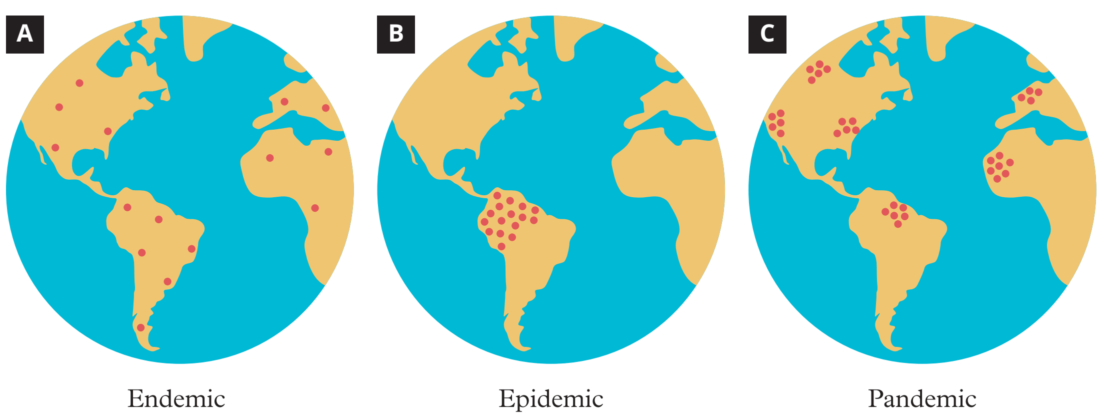


Figure 1 (A) Endemic diseases are present among a population at all times at a stable level. (B) Epidemics are an increased number of people with a disease in a specific geographic area. (C) Pandemics are the spread of a disease across geographic regions.

Epidemic

epidemic a widespread outbreak of an infectious disease that is typically isolated to a specific region

An **epidemic** occurs when there is an outbreak of an infectious disease, above endemic levels, in a limited geographical area over a relatively short period of time (Figure 1B). For example, cholera outbreaks often occur after tropical cyclones and heavy rainfalls in developing countries. Faecal matter contaminated with the pathogen *Vibrio cholera* is carried via ground surface water where it can enter water bodies used for drinking and cooking

(Figure 3). Once identified, it is relatively easy to treat and new cases can be prevented by ensuring all water that is consumed has been treated and is free from the pathogen.

Figure 2 Female *Anopheles* mosquito. The mosquito is the vector for malaria, a disease endemic to tropical regions of Africa, South America and South-East Asia.

Pandemic

A **pandemic** is typically the spread of a new disease, or a new variant of a disease, across a wider geographical area, sometimes worldwide (Figure 1C). The most recent example is COVID-19, which first emerged in China in late 2019. Despite a range of local, regional and global initiatives to slow the spread of the disease, it was too late, and in March 2020 the WHO declared a pandemic. It is estimated that COVID-19 has killed over 7 million people. Other pandemics that caused widespread illness and death are the Spanish flu (a dangerous strain of the influenza virus), which killed an estimated 50 million people between 1918 and 1920, and the Black Death (caused by the bacteria *Yersinia pestis*), which killed 200 million people between 1347 and 1353.

pandemic a widespread outbreak of an infectious disease that is spread across multiple global regions

Zoonotic pathogens

Many common viral pathogens are **zoonotic**, which means they can be transferred between animals and humans. For example, the SARS-CoV-2 virus that causes COVID-19 may have originated in different mammal species before it "jumped" to humans.

zoonotic a disease that can be transferred between non-human animals and humans

Different strains of influenza continue to cause health authorities concern every year. Since 2009, swine flu has caused up to 500,000 deaths around the world. This disease was transmitted between pigs and then from a pig to humans. Human immunodeficiency virus (HIV) crossed from chimpanzees to humans in the early 1900s, and to date, the HIV pandemic has killed over 40 million people globally.

Figure 3 Flooding in Afghanistan in 2024 led to a cholera outbreak, when groundwater contaminated with the pathogen *Vibrio cholera* entered drinking water.

Experts believe it is a matter of when, not if, another global pandemic occurs. With an ever-expanding world population and ease of world travel, humans are increasingly living in closer contact with animals that could transmit zoonotic diseases. The death toll from future pandemics will depend on how infectious the disease is, its **mortality** rate and how quickly we respond to limit the spread.

mortality number of deaths

In order to prevent endemic diseases or new strains of a disease becoming an epidemic or pandemic, the WHO (World Health Authority) liaises with local health authorities to monitor the incidence of many diseases. **Incidence** is the number of new cases of a disease, measured over a specific time. If the incidence of a disease of concern increases, measures are taken to contain its spread. This could include public awareness campaigns, quarantines, lockdowns and vaccination campaigns.

incidence the number of new cases of a disease measured over a specific time

Check your learning 4.3

Check your learning 4.3

Retrieve

1 Identify one key feature that distinguishes an endemic from an epidemic.
2 Define “zoonotic transmission”.

Comprehend

3 Explain why cholera outbreaks often occur in developing countries following tropical cyclones.
4 Explain why global pandemics are expected to occur more frequently in the future.

Apply

5 Investigate one of the following diseases, and explain how its mode of transmission, geographical distribution and host species impact global response strategies in controlling outbreaks.
- Ebola virus disease (EVD)
- Lassa fever
- Zika fever
- Bubonic plague
- Cholera
- Zoonotic influenza (bird flu or swine flu)
- Coronaviruses (SARS, MERS or COVID-19)

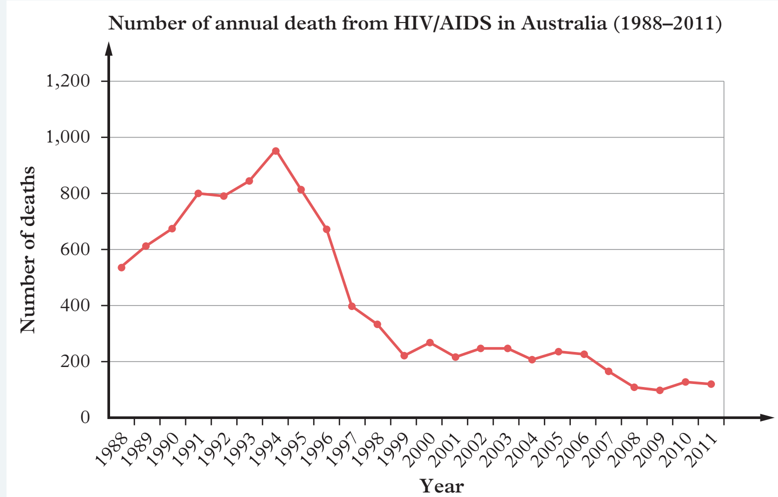


Figure 4 Number of people diagnosed with HIV/AIDS every year from 1988 to 2011 in Australia

Skills builder: Processing and analysing data and information

6 Figure 4 shows the number of deaths from AIDS per year (the incidence) from 1988 to 2011 in Australia.
   a Identify the information shown on the *x*-axis and the *y*-axis. (THINK: What are the labels? What is happening in the graph?)
   b Identify which year had the most deaths. (THINK: What is the highest point on the graph?)
   c Identify how many deaths were in the year for part **b**. (THINK: What is the corresponding point on the graph?)
   d Identify the death rate in 2001.

Lesson 4.4
Non-infectious diseases in Australia

Learning intentions and success criteria

Key ideas

→ Australians are much more likely to die from a non-infectious disease.

Causes of death in low-income and high-income countries

While the idea of being infected by a deadly pathogen strikes fear into many, the reality is that, in Australia, we are much more likely to die from a non-infectious disease.

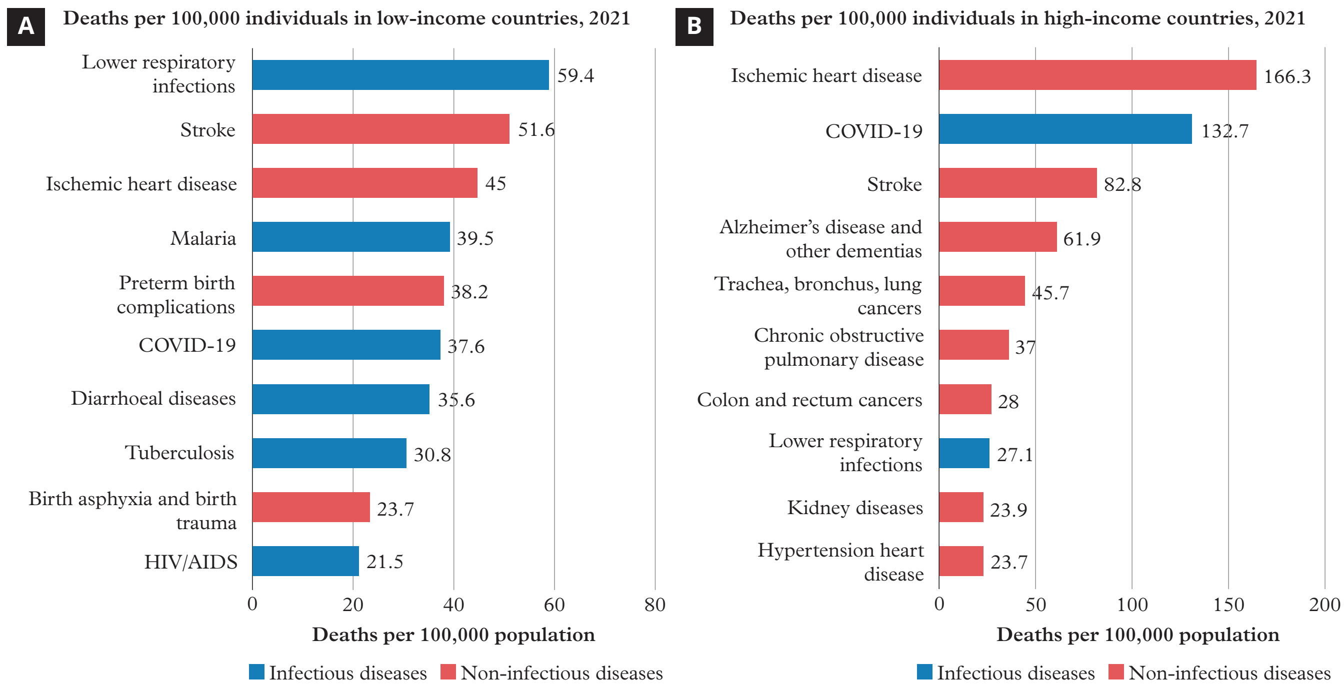


Figure 1 The top ten causes of death in (A) low-income and (B) high-income countries, 2021

A person's cause of death is heavily influenced by the socio-economic status of the country in which they were born. In 2021, six of the top ten causes of death in low-income countries were infectious diseases (Figure 1A). In contrast, in high-income countries, only two of the top ten causes were infectious diseases (Figure 1B). One of these was an anomaly caused by the COVID-19 pandemic while the other, lower respiratory tract infections, is directly linked to age. As we live longer, our organ systems (including the immune system, which protects us against disease) do not work as well as they used to. This, combined with other underlying health conditions, makes older people more prone to lung infections.

Leading causes of death in Australia

As healthcare has continued to improve, so has our life expectancy. The average Australian female and male will live to 85 and 80 years respectively. Of nearly 191,000 total deaths in 2022, 68 per cent were aged 75 or over (63 per cent for males and 74 per cent for females) (Figure 2).

Today, we are living longer, and the accumulation of life's bad choices, such as unhealthy diet, lack of exercise and habits such as smoking or vaping, combined with our genetics, means the most likely causes of death are some form of cardiovascular disease or dementia. Figure 3 compares the five leading causes of death in Australian males and females. Three of the five

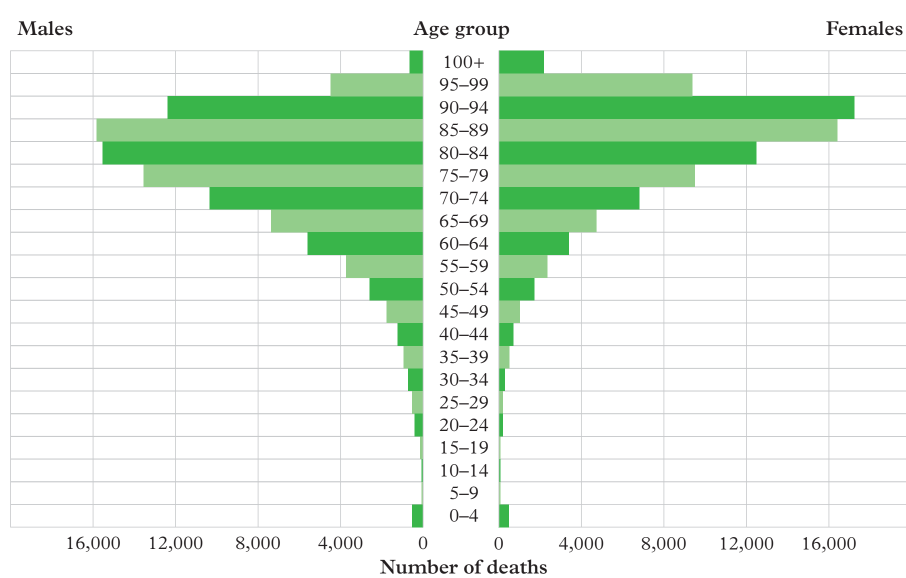


Figure 2 Deaths in Australia by sex and age group, 2022

causes of death in both groups are cardiovascular diseases or dementia. The high number of lung cancer deaths is due to the delayed impact of cigarette smoking. Up to 90 per cent of lung cancer cases are due to the effects of smoking.

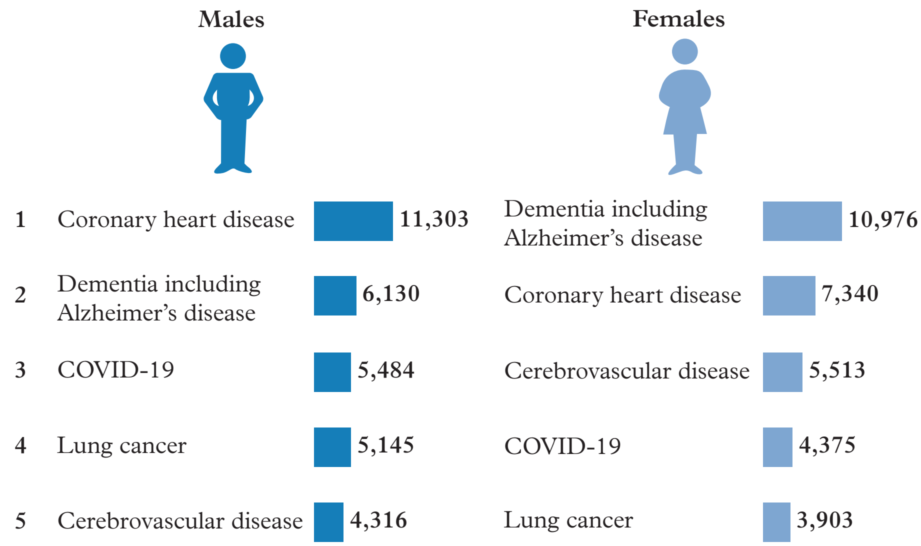


Figure 3 The top five causes of death in Australian males and females, 2022

As well as slight differences between biological sex, the leading causes of death vary by age (Figure 4). For example, among infants, perinatal (pregnancy to 1 year after birth) and congenital (structural or functional birth defects) conditions cause nearly 80 per cent of deaths. Between the ages of 15 and 24, death from infectious or non-infectious disease is highly unlikely but the risk increases after the age of 25. Between the ages of 25 and 44, coronary heart disease is the fifth leading cause of death, but it is the leading cause of death in the next three age brackets (45 to 84). Over the age of 85, forms of dementia are the most common cause of death in Australia.

The link between cardiovascular disease, obesity and type 2 diabetes

In Australia, the risk of cardiovascular disease is high after 45 years of age, however, choices made earlier in life can prevent or delay the disease.

There is a direct link between obesity, type 2 diabetes and the onset of cardiovascular disease. Obesity leads to insulin resistance, which prevents the body from effectively using glucose for energy production. This causes elevated blood sugar levels that damage blood vessels and organs over time. Combined with inflammatory processes caused by obesity, this increases the risk of developing a range of cardiovascular diseases including atherosclerosis, stroke and coronary heart disease (heart attack).

Obesity

The WHO defines obesity as “an excessive fat accumulation that presents a risk to health”. While a person’s genetics and environment can influence obesity, the root cause is a nutritional intake of calories greater than the amount being burnt off through your metabolism.

The body mass index (BMI) is based on the relationship between a person’s height and weight, and most health authorities use it to define obesity. A BMI of 25 to 29.9 is considered

Age group \ Rank	1st	2nd	3rd	4th	5th
Under 1	Perinatal and congenital conditions	Other ill-defined causes	Sudden infant death syndrome	Selected metabolic disorders	Accidental threats to breathing
1–14	Land transport accidents	Other ill-defined causes	Perinatal and congenital conditions	Brain cancer	Selected metabolic disorders
15–24	Suicide	Land transport accidents	Accidental poisoning	Other ill-defined causes	Accidental drowning and submersion
25–44	Suicide	Accidental poisoning	Land transport accidents	Other ill-defined causes	Coronary heart disease
45–64	Coronary heart disease	Lung cancer	Liver disease	Suicide	Colorectal cancer
65–74	Coronary heart disease	Lung cancer	Chronic obstructive pulmonary disease	Coronavirus disease 2019 (COVID-19)	Cerebrovascular disease
75–84	Coronary heart disease	Dementia including Alzheimer's disease	Lung cancer	Chronic obstructive pulmonary disease	Coronavirus disease 2019 (COVID-19)
85–94	Dementia including Alzheimer's disease	Coronary heart disease	Coronavirus disease 2019 (COVID-19)	Cerebrovascular disease	Chronic obstructive pulmonary disease
95+	Dementia including Alzheimer's disease	Coronary heart disease	Cerebrovascular disease	Coronavirus disease 2019 (COVID-19)	Heart failure and ill-defined heart disease

Disease groups

- Blood/Metabolic
- Cancer
- External causes
- Infant and congenital conditions
- Infectious
- Neurological
- Other ill-defined causes
- Respiratory
- Cardiovascular

Figure 4 Leading causes of death in Australia by age group, 2022

overweight, while a BMI of 30 or higher is classified as obese. Note that BMI is a basic measurement, with many other factors (such as bone density, race and sex) influencing the number.

Approximately 67 per cent of Australian adults are overweight or obese (Table 1). This places them at greater risk of cardiovascular disease, type 2 diabetes and a range of other diseases including cancer and musculoskeletal disorders.

Table 1 The percentage of male and female adults that are overweight or obese in Australia, 2017–18

Weight	Males	Females	Total
Overweight/obese	75%	60%	67%
Overweight	42%	30%	36%
Obese	33%	30%	31%

Over the last two decades, the proportion of both children and adults living with obesity has increased. In 2022, 26 per cent of children and adolescents (aged 2–17) and 67 per cent of adults (18 and over) were overweight or obese. In 1996, these numbers were 20 per cent and 56 per cent respectively (Figure 5).

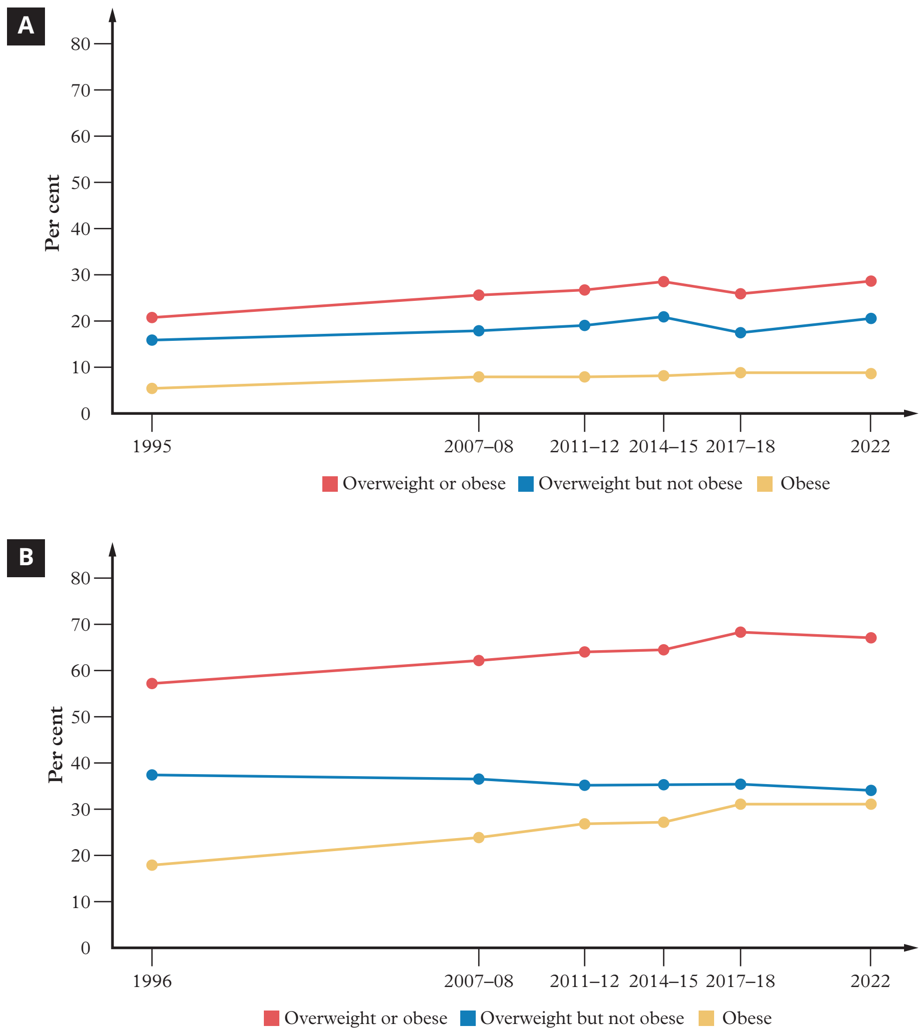


Figure 5 Percentage of overweight or obese (A) children and adolescents (aged 2–17) and (B) adults (18 and over) in Australia, 1996 to 2022

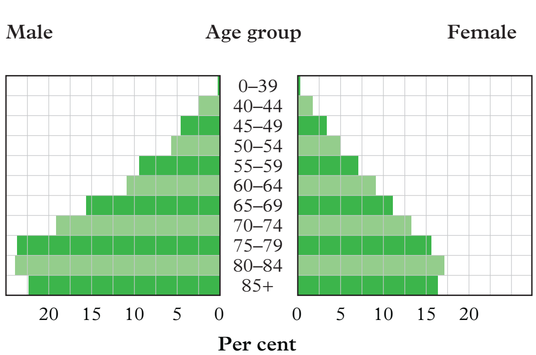


Figure 6 Percentage of individuals with type 2 diabetes by age and sex in Australia, 2021

Type 2 diabetes

Type 2 diabetes is a condition in which the body becomes resistant to the normal effects of insulin and gradually loses the ability to produce enough insulin in the pancreas. While there is a strong genetic link, the progression of the disease can usually be slowed or even stopped through lifestyle changes, including increased exercise and a healthy diet.

In Australia, an estimated 1.2 million people live with type 2 diabetes (Figure 6). In every age bracket, there are more males than females with the condition and the cumulative effect means each age bracket has more cases than the one before it.

Check your learning 4.4

Check your learning 4.4

Retrieve

1 Identify one reason why non-infectious diseases are more common in high-income countries.

2 Name one key factor that contributes to the higher rate of infectious diseases in low-income countries.

3 Identify one trend and one relationship from the data in this lesson.

Comprehend

4 Describe how cardiovascular disease is linked to obesity and type 2 diabetes.

5 Explain why non-infectious diseases (e.g. cardiovascular diseases and dementia) are more common in high-income countries.

6 Explain how two environmental factors have led to an increase in obesity levels in Australia.

Apply

7 Evaluate the effectiveness of using BMI as a tool to measure obesity.

8 Assess how socio-economic disparities between low-income and high-income countries contribute to differences in leading causes of death.

9 Figure 5 shows the change in percentage of overweight or obese children and adolescents or adults between 1996 and 2022.

   a Describe what the data suggest about the trend of obesity in Australia.

   b Explain why obesity rates are increasing, despite public health campaigns and awareness.

   c Your local council is launching a "Healthy living" campaign, aimed at getting people to be more active. Suggest one practical strategy that could be used to help reduce obesity in your community

10 Research the obesity rates in the USA, the United Kingdom, Japan and Spain.

   a Describe what the data suggest about the trend of obesity in those countries.

   b Provide reasons as to why some of these countries have higher obesity rates than others.

Lesson 4.5
The immune system protects us from infectious diseases

Key ideas

→ Our immune system has three lines of defence against pathogens.

→ The first line of defence acts to physically prevent pathogens entering our body.

→ The second line of defence is non-specific and identifies and destroys pathogens that have entered the body.

→ The third line of defence is specific and involves B and T cells that identify and destroy either pathogens or the "self" cells in which the pathogens are hiding.

Learning intentions and success criteria

Introduction

immune system a system of organs and structures that protect an organism against disease

The role of your **immune system** is to protect you against foreign invaders by physically stopping them from entering your body, and to identify and attack them if they do manage to enter. Your immune system has three lines of defence against pathogens, each with a different role.

First line of defence

cilia tiny hair-like structures on the surface of cells

sebum an oily secretion produced in the sebaceous glands of the skin

The first line of defence stops pathogens from entering your body. It consists of different physical and chemical barriers (Figure 1). Physical barriers include the skin and the mucous membranes and associated **cilia** that line the respiratory, digestive and urinary tracts (Figure 2). Chemical barriers include stomach acid and **sebum** secreted by glands in the skin.

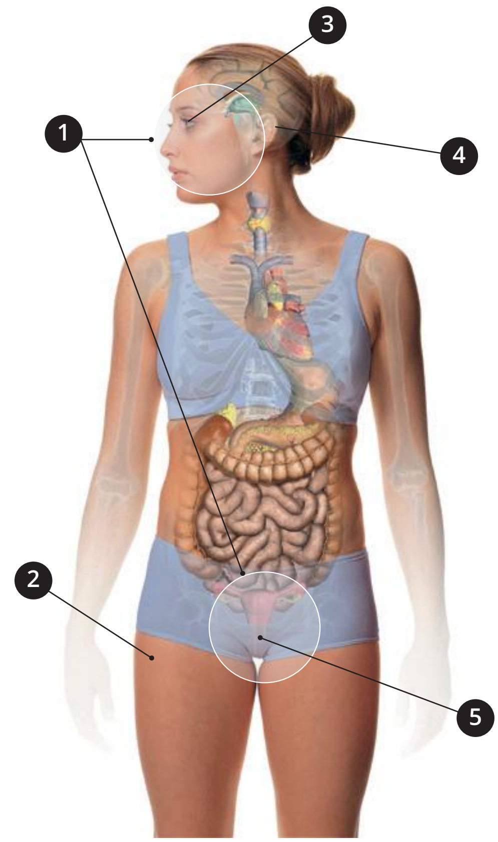


Figure 1 The skin and mucous membranes are the first line of defence against pathogens. The following parts are labelled:

1. Eyes, ears, nose, mouth and genitals are usually exposed to the air and environment, so pathogens can enter. Mucous membranes are thin, skin-like linings of these entry points. Chemical barriers here assist in defence. Slimy mucus can capture and kill some bacteria.
2. Skin is thick, waterproof and difficult to damage. Oils (sebum) and sweat help protect the skin. In dry conditions, bacteria are damaged and destroyed by the salt and antimicrobial chemicals in these secretions.
3. Tears wash pathogens out of the eyes.
4. Ear wax captures pathogens trying to enter through the ears.
5. Urine is slightly acidic, which makes it harder for bacteria to grow.

Second line of defence

non-specific immune response the generalised response of the immune system to protect the body against all pathogens, rather than targeting a specific pathogen; also called the "innate immune response"

white blood cell an immune cell that destroys pathogens

Viruses, unlike bacteria, contain a protective coating that allows them to slip through the first line of defence more easily. If a pathogen enters your body, the body tries to remove it in one of two ways.

First, a general "seek and destroy" approach occurs regardless of the type of pathogen. This is called a general or **non-specific immune response**. The key parts of the non-specific immune response are:

- blood clotting – to stop additional infection through skin damage
- inflammation – to increase the number of blood cells reaching an infected area
- fever – to heat up the body and destroy some pathogens that cannot survive at high temperatures.

Second, **white blood cells** are produced by the body to destroy pathogens. Inflammation increases the amount of blood reaching the infected area, so more white blood cells are able to attack the pathogen. The white blood cells may also release chemical messengers that increase the amount of fluid in the infected area, causing swelling.

There are different types of white blood cells. Each type has its own role, but they all work together to fight infection. For example, if the skin is broken and bacteria enter the wound site, **mast cells** release **histamine**, which allows **phagocytes** (Greek for "cells that eat") to pass through the capillaries at the site of infection (Figure 3). Some phagocytes release chemicals that cause **inflammation** and a temperature increase, while others engulf and destroy the pathogens, destroying them in a process called **phagocytosis** (Figure 4).

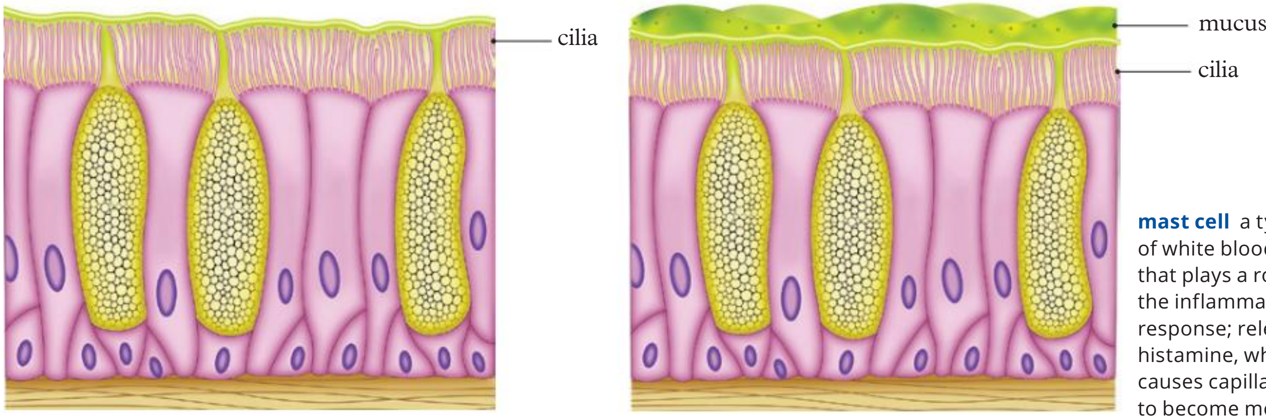


Figure 2 Mucus and ciliated epithelial cells lining the respiratory tract. The mucus traps microbes, and the cilia act in a wave motion to move the trapped microbes out of the body.

mast cell a type of white blood cell that plays a role in the inflammatory response; releases histamine, which causes capillary walls to become more permeable

histamine a chemical released by mast cells during allergic reactions and immune responses; causes blood vessels to dilate and become more permeable, leading to swelling, redness and itching

phagocyte an immune cell that surrounds, absorbs and destroys pathogens

inflammation the body's protective response to injury, infection or harmful stimuli

phagocytosis the process by which certain white blood cells engulf and destroy bacteria

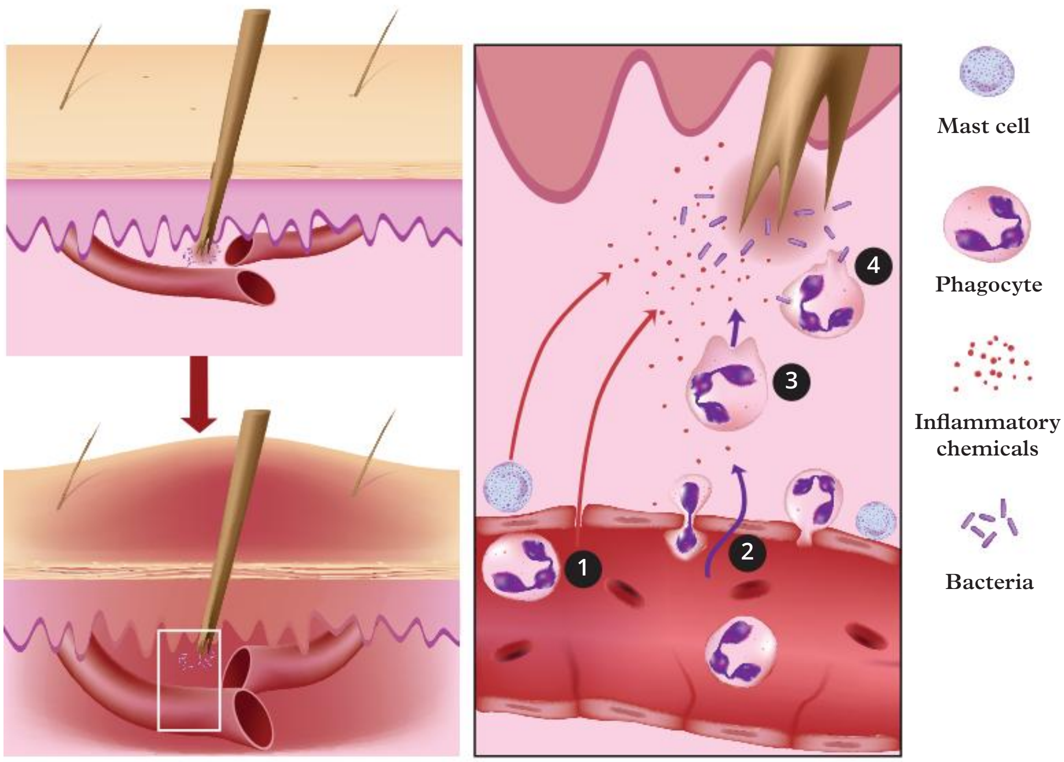


Figure 3 The inflammation response. 1. Mast cells release histamine at the site of infection, making the capillaries more **permeable**. 2. Phagocytes move from the blood into the infected tissue. 3. Inflammatory chemicals are released, causing swelling and temperature increase. 4. Phagocytes engulf and destroy pathogens by phagocytosis.

permeable a barrier that allows fluids, gases or other substances to pass through it

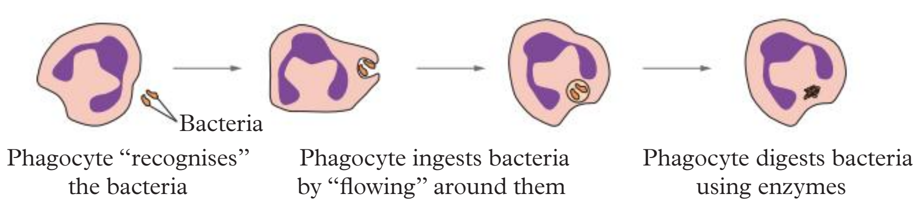


Figure 4 The process of phagocytosis

Third line of defence

specific immune response the response of the immune system that targets specific pathogens using B cells and T cells; also called the "adaptive immune response"

B cell an immune cell that produces antibodies in response to pathogens

Any pathogens that survive the non-specific immune response (second line of defence) are then targeted according to their type. This is called a **specific immune response**.

The specific immune response has two lines of attack (Figure 5). **B cells** produce special molecules called **antibodies**. These antibodies fit exactly onto a specific part of the pathogen called the **antigen** (Figure 6). Each antibody is specific to only one type of pathogen. When antibodies bind to the pathogens, it causes them to clump together and prevents further infection. **T cells** are able to recognise "self" cells that have been infected with the same specific pathogen. They bind to the "self" cell and release chemicals that kill the cell and any pathogens inside it. B and T cells may take up to a week to recognise and destroy a pathogen. This is why recovering from an illness takes time.

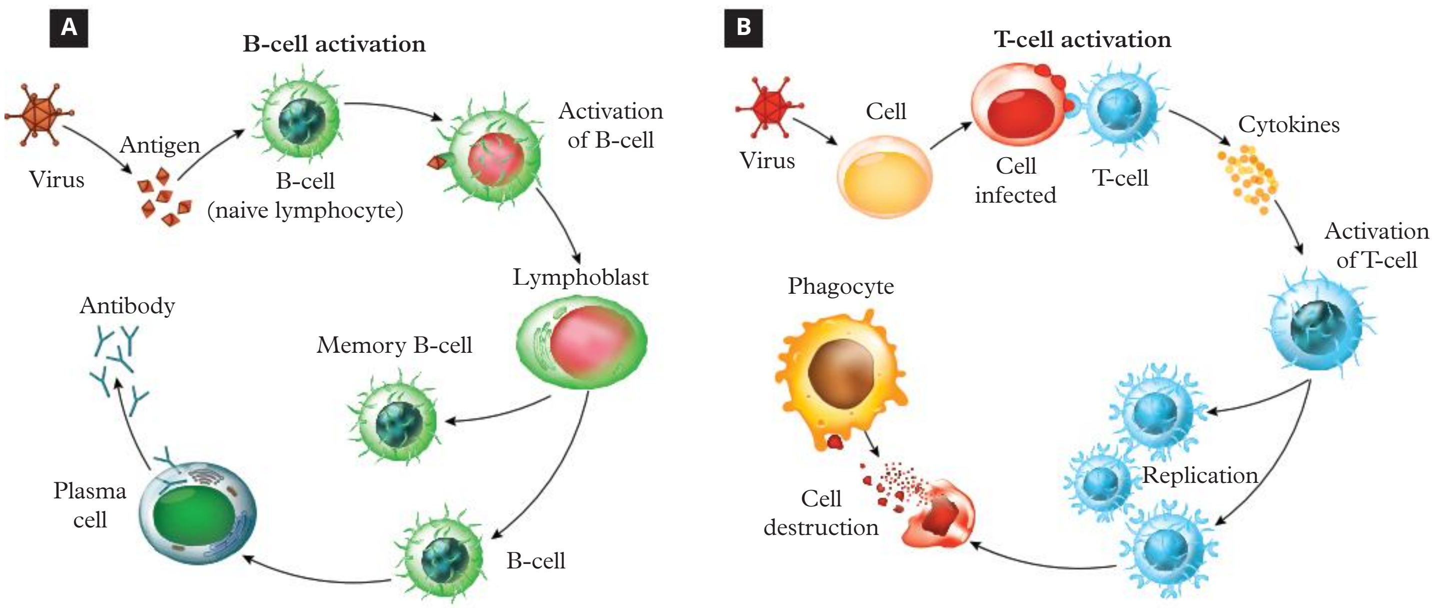


Figure 5 (A) Activation of B cells, which are responsible for producing antibodies specific to a pathogen. (B) Activation of T cells, which kill "self" cells that have been infected by the specific pathogen. Both B and T cell activation will result in memory cells.

antibody a molecule produced by B cells that binds to a specific pathogen

antigen a substance that triggers an immune response, such as a molecule on the surface of a pathogen or an allergen

T cell an immune cell that recognises and kills pathogens

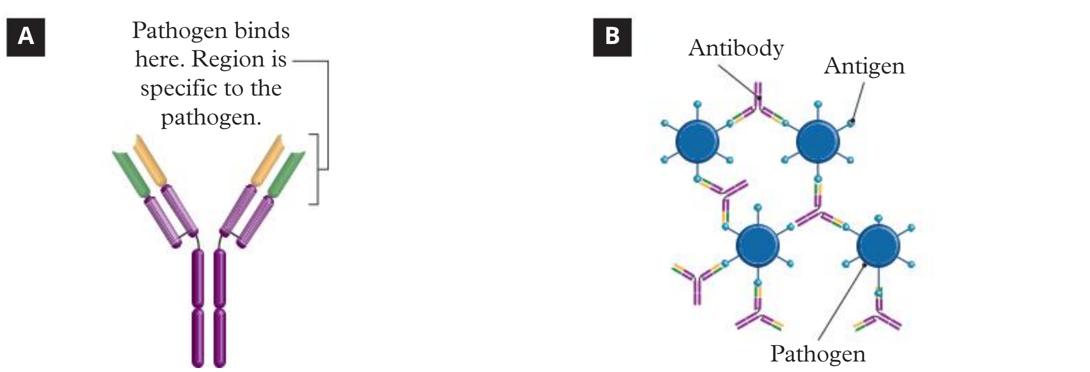


Figure 6 (A) Each antibody has a region that is specific to a particular antigen on a pathogen. (B) Antibodies cause pathogens to clump together.

Natural active immunity

Both B and T cells produce **memory cells** in case the same type of pathogen invades again. If there are future infections with the same pathogen, the memory cells will recognise the pathogen, resulting in a faster immune response and a milder illness or no illness at all. You are now **immune**. This is called **natural active immunity**.

Natural passive immunity

Unborn babies obtain some natural immunity by receiving antibodies through the placenta from the mother. Antibodies are also passed to babies through breastmilk. These are examples of **natural passive immunity**. Memory cells are not created because only antibodies are given. With time, the antibody levels will fall, placing the baby at risk of infection if they do not receive a vaccination.

Vaccination

Another way to acquire immunity is by ingestion or injection with specific parts of the pathogen (Figure 7). This is called **vaccination** (or inoculation) and results in **artificial active immunity**.

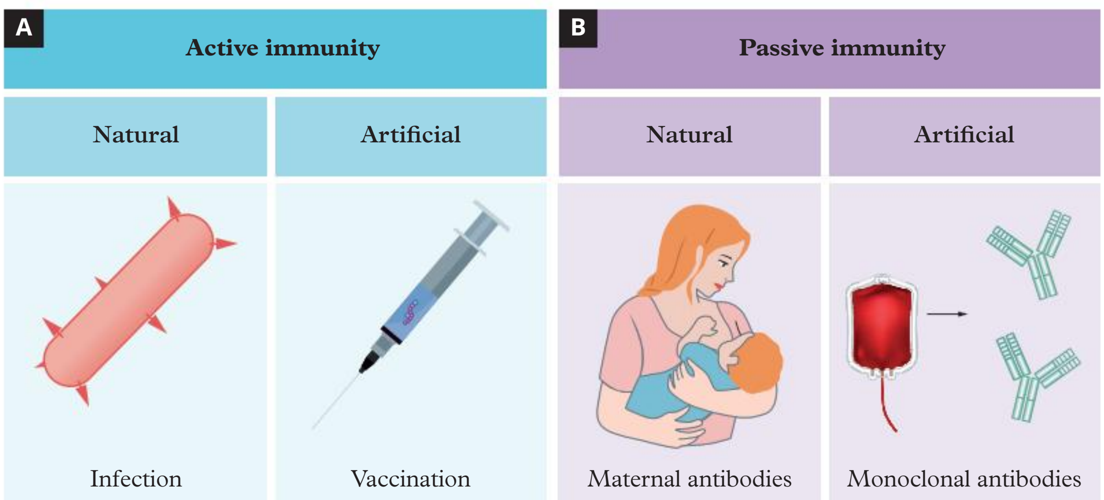


Figure 7 (A) Active immunity. A person can become actively protected or immune through exposure to a pathogen or vaccine containing a weakened form of the pathogen. Exposure to the pathogen causes memory B and T cells to be produced, resulting in long-term immunity. (B) Passive immunity. A person can also become protected for a short period of time after receiving antibodies from their mother (through the placenta or breastmilk) or a vaccine containing antibodies specific to the disease.

Artificial active vaccination

An active vaccine can be made up of:

- the dead pathogen
- a living but non-virulent (weakened) form of the pathogen
- parts of the broken-up pathogen
- genetic material from a viral pathogen.

After active vaccination, a person makes antibodies and memory cells that will recognise the pathogen in the future, which usually leads to immunity. Vaccinations are often given as a preventive measure. For instance, the influenza vaccine is recommended for people over 65 years of age because complications from influenza can be life-threatening in older people.

memory cell an immune cell produced in response to an infection; retains the memory of how to fight the pathogen

immune able to fight infection as a result of prior exposure

natural active immunity the long-lasting immunity that develops when the immune system is naturally exposed to a pathogen, leading to the production of specific antibodies and memory cells

natural passive immunity the temporary immunity that occurs when a baby receives antibodies in breast milk or through the placenta from the mother

vaccination an injection of an inactive or artificial pathogen that results in the individual becoming immune to a particular disease

artificial active immunity the long-lasting immunity that develops after a vaccination when the immune system is exposed to a weakened version of a pathogen

Vaccinations can also be administered when there is an urgent need to provide widespread community immunity, such as minimising the spread of COVID-19. Modified genetic material from the SARS-CoV-2 coronavirus can be used in vaccines, allowing a person to produce antibodies and activate T cells in advance. In most cases, this minimises symptoms if infected with the virus and reduces the risk of passing the virus on.

Artificial passive vaccination

In some cases, vaccines contain antibodies specific to a particular pathogen. These antibodies are given to create **artificial passive immunity**. Like natural passive immunity, memory cells are not produced and so the protection is only short term. For example, a tetanus vaccine will be given after a tetanus-prone injury, such as an open wound caused by a rusty or dirty object, to provide the person with artificial passive immunity. Tetanus can be fatal, and antibody levels decline over time, so a booster shot will be recommended if another injury occurs after 5 to 10 years.

artificial passive immunity the temporary immunity that occurs when a person receives ready-made antibodies from an outside source

Check your learning 4.5

Check your learning 4.5

Comprehend

1 Describe the body's major first line of defence.

2 Identify one other way the body can prevent pathogens from entering.

3 Describe in your own words how the non-specific immune response works.

4 Describe how a vaccine prevents a person from "catching" a disease.

5 Explain how the body responds if a pathogen gets past the first line of defence.

Analyse

6 Compare active and passive immunity.

Apply

7 Newborn babies cannot be vaccinated against whooping cough until they are 2 months old. The antibodies in breastmilk are not enough to protect them from this deadly disease. Discuss why it is important for everyone who comes into contact with a newborn baby to be vaccinated against whooping cough.

Skills builder: Communicating

8 You have been asked by a teacher at your school to explain to Year 7 science students the differences between the three lines of defence. The teacher has encouraged you to use a diagram to explain this to the students, as they think the class will respond better to this.

   a Identify what you need to include in a diagram for the three lines of defence. (THINK: What is the most important information?)

   b Construct one or more scientific diagrams to explain the three lines of defence to Year 7 students. (THINK: What do scientific diagrams include? Where should you place labels?)

Lesson 4.6

Investigation: Modelling the spread of infectious disease

Introduction

Models are important in science as they help to visualise concepts that are too large or too small to be seen and to demonstrate concepts that are abstract or difficult to understand.

Purpose

To model how an infectious disease can spread through a population

Materials

- Water
- Plastic cup
- Felt-tipped pen
- 1 M sodium hydroxide
- Pipette
- Phenolphthalein indicator
- 0.1 M hydrochloric acid

Procedure

1 Half-fill a plastic cup with water and label it with your name.
2 Place your cup on a table with the other students' cups.
3 Turn your back while the teacher adds 2 mL of sodium hydroxide to one cup. This represents a student having an infection.
4 Collect your cup and use the pipette to exchange 3 mL of water with three other students. This is equivalent to shaking hands. Record who you "shook hands" with in a table like Table 1.

Table 1 Record the names of the three people with whom you "shook hands".

Person 1	Person 2	Person 3

5 Add a few drops of phenolphthalein indicator to each cup, to determine who caught the disease. A red/pink colour indicates infection.
6 Use the information recorded in your table and a class discussion to determine who the original source of the infection was.
7 Repeat Steps 1 to 5, this time choosing whether or not to become "vaccinated". Vaccination is done by adding 2 mL of hydrochloric acid to your cup of water. Redraw the table to record who you shook hands with after some people were vaccinated.
8 Repeat this activity, increasing the number of people vaccinated.

Discussion

1 Identify the number of people who became infected when no one had been vaccinated.
2 Identify the number of people who became infected when a few people had been vaccinated.
3 Identify the number of people who became infected when more people had been vaccinated.
4 Explain why vaccination affected the number of people who became infected.
5 Describe a real-life example of how vaccination can protect vulnerable members of the community.

Lesson 4.7
Minimising the impact of infectious and non-infectious diseases

Learning intentions and success criteria

Key ideas

→ Non-infectious diseases can be categorised as genetic, environmental or nutritional.

→ A healthy lifestyle, including a balanced diet and exercise, helps reduce risk.

→ Genetic testing can determine individual risks for diseases.

→ Educational campaigns to raise awareness about non-infectious diseases and promote healthy behaviours are often run by governments.

Reducing the incidence of non-infectious diseases

Non-infectious diseases can have a genetic, environmental or nutritional cause, and in many cases a combination of them.

A range of strategies can be used to reduce the incidence of non-infectious diseases. At the individual level, our focus should be on a healthy lifestyle that includes a balanced diet, exercise and avoiding habits like smoking and excessive alcohol consumption, which are known to cause disease. If we know we are predisposed to certain diseases like breast cancer or bowel cancer, we can do a genetic test to determine and monitor our likely risk.

Governments and health agencies also take measures to reduce the incidence of many non-infectious diseases. This can include public health and education campaigns highlighting the risks of certain diseases and the steps that should be taken to minimise the risk.

Genetic screening

There is a strong genetic link to diseases like breast cancer, dementia and cardiovascular disease. You have two copies of every gene: one inherited from your mother and the other from your father. Different versions of the gene are called **alleles**. For example, if a female receives two copies of a faulty *BRCA1* gene (**BR**east **CA**ncer gene **1**) the chance of developing breast cancer or ovarian cancer is over 60 per cent, compared to 13 per cent for those that have the "normal" genes.

allele a version of a gene; a person inherits two alleles for each gene, one coming from each parent

Another example is the *apoE* gene, which produces a protein (**apo**lipoprotein **E**) that is used to transport fats around your body. There are three *apoE* alleles called *E2*, *E3* and *E4*. The *E4* allele is associated with a significantly increased risk of developing cardiovascular disease and Alzheimer's disease (dementia). Having one copy of the *E4* allele triples your risk for these diseases. Two copies of the *E4* allele dramatically increases the risk to over 60 per cent chance of developing these diseases.

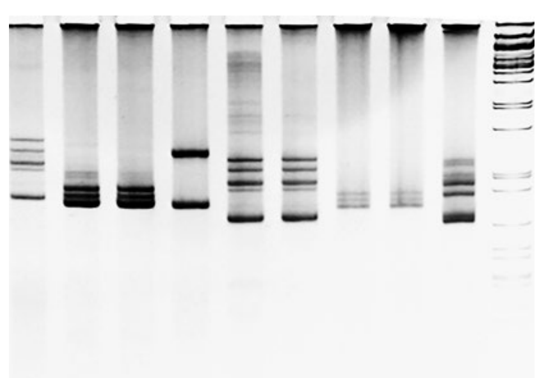


Figure 1 Genetic screening results can inform someone of their likelihood of certain genetic diseases.

Knowledge is power. Armed with the results of a genetic screening test, individuals have options (Figure 1). They can change their diet and lifestyle to reduce the risk of disease onset, increase screening to minimise the risk of disease progression, and in some cases consider pre-emptive surgery as an option.

Lifestyle choices

Many non-infectious diseases are linked to poor diet, lack of exercise and lifestyle choices like smoking and alcohol consumption. Consuming high levels of processed foods, sugars and unhealthy fats contributes to diseases like obesity, type 2 diabetes, cardiovascular disease and many cancers. Replacing these foods with a diet rich in vegetables, fruit, whole grains and lean proteins significantly reduces the risk of these diseases.

Regular exercise improves cardiovascular health and helps to maintain a healthy weight, therefore reducing the risk of these same diseases. Exercise also causes the release of endorphins and serotonin, which provides the added benefit of improving mental health.

Public health and education programs

Governments and health agencies play an important role in reducing the incidence of many non-infectious diseases. For example, they are responsible for media advertisements (ads) that highlight the risks associated with smoking and alcohol consumption.

Cigarettes contain over 60 known carcinogens, linked to at least 16 types of cancer and over 20,000 preventable deaths in Australia each year. State and federal governments introduced laws to reduce the number of Australians smoking, which in turn reduced the incidence of diseases associated with smoking (Figure 2). This has included banning smoking ads, providing health warnings on plain packaged boxes and banning cigarette companies from sponsoring sporting teams or events.

Bowel cancer, responsible for 5,000 deaths per year, is the second-biggest cancer killer in Australia after lung cancer. Recognising the importance of early detection, the Australian Federal Government introduced the National Bowel Cancer Screening Program in 2020. From the age of 45, you are eligible to do a test every two years. From the age of 50 to 74, you will receive a bowel cancer screening kit (often called the "poo test") in the mail (Figure 3). A sample is taken at home and sent for screening. If caught early, there is nearly a 100 per cent chance of successful treatment.

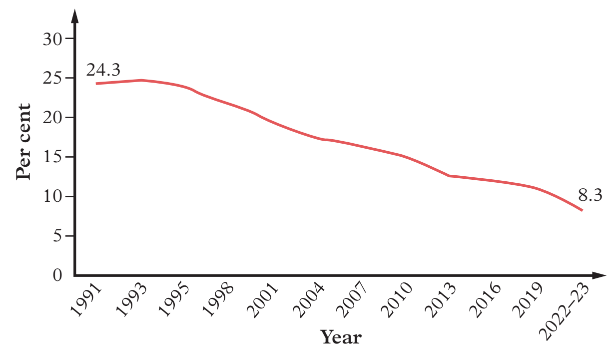


Figure 2 The fall in the number of daily smokers in Australia between 1991 and 2023

Figure 3 Free bowel cancer screening kits are available to every Australian from the age of 45.

Reducing the incidence and spread of infectious diseases

In most cases, individual measures in isolation are not as effective in reducing the incidence and spread of infectious disease as employing multiple strategies. These could include a combination of improved hygiene practices, quarantine, vaccination and public health campaigns.

Hygiene practices

Individual hygiene practices are some of the most effective ways to reduce the risk of becoming infected or from infecting others when sick. These include washing your hands with soap and water after going to the toilet and before eating or handling food, and covering your mouth correctly when coughing or sneezing.

Community hygiene is also essential to protect a population from infectious diseases. Water treatment and purification and the correct removal and treatment of sewerage minimise the risk of infectious disease outbreaks.

Quarantine

Quarantine requires strict isolation for a set period of time to prevent infected people from coming into contact with uninfected people. Quarantine measures are highly effective if followed. Australia is free from many highly contagious agricultural diseases such as foot-and-mouth disease (FMD) because of strict border control measures.

The lockdowns during the COVID-19 pandemic had some success in reducing the incidence of new cases; however, it did not eliminate the disease. A degree of good will was needed by the population to follow the rules and depended on authorities catching those who didn't. Essential service workers also continued to work, which meant the pathogen was able to continue to spread.

Vaccination

Like other measures, the success of vaccination programs varies. In many cases, they are highly effective at reducing the spread of specific diseases. For example, in 1980 the World Health Organisation (WHO) declared that smallpox, a disease responsible for over 300 million deaths, had been eradicated from the world. This was the result of a global immunisation program (Figure 4).

Vaccination against COVID-19 has played an important role in reducing the number of deaths and severe symptoms caused by the disease, as well as reducing the overall burden on the healthcare system. Given the virus's high mutation rate, however, health authorities must remain vigilant. Ongoing booster doses will likely be required to keep the disease at manageable endemic levels.

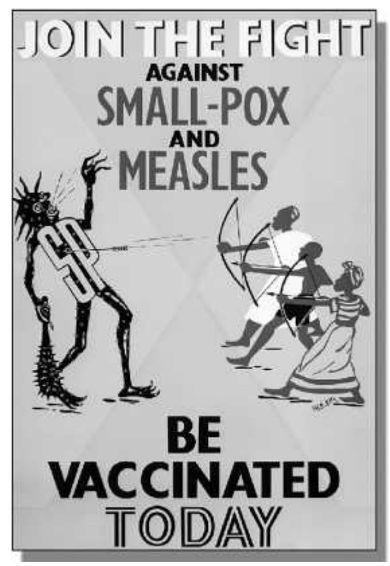


Figure 4 Early advertisment campaign encouraging people to be vaccinated against smallpox

Public health campaigns

Figure 5 The 1980s grim reaper commercial aimed to shock viewers into behavioural changes.

Public health campaigns educate the population about behaviours that can reduce disease transmission. During the COVID-19 pandemic, campaigns on multiple media platforms promoted mask-wearing and social distancing. Combined with other measures, this successfully reduced the spread and incidence of the disease.

In the early 1980s, the first case of HIV/AIDS was detected in Australia. At the time, there was no treatment, and the average life expectancy after contracting the virus was 8 years. The Australian Federal Government responded quickly with a series of public health campaigns, aimed at educating the public on how to prevent the spread of the disease. The most significant of these was the "grim reaper" commercial that was intentionally confronting, designed to shock viewers and promote behavioural changes (Figure 5).

Aboriginal and Torres Strait Islander Peoples' use of bush medicines

Aboriginal and Torres Strait Islander Peoples have over 65,000 years of accumulated knowledge surrounding the use of plant materials to treat the symptoms of a range of health complaints. Collectively, these products are referred to as "bush medicine".

Examples include the Kakadu plum (*Terminalia ferdinandiana*), which is now known to be the world's richest food source of vitamin C (one hundred times more Vitamin C than oranges) (Figure 6A). Vitamin C is essential for the growth and repair of damaged tissue and also for a strong immune system. The fruit is only found in the Northern Territory and Western Australian and forms an important part of the diet of local Aboriginal and Torres Strait Islander Peoples.

The leaves from various species of tea tree (*Melaleuca sp.*) are used for their antiseptic and antibacterial properties (Figure 6B). The leaves are crushed to create a paste (poultice) that can be applied to cuts and wounds to prevent infections and promote healing. The oils present in the leaves have multiple active ingredients, shown by modern science to kill microbes. Tea tree oil is now widely used in modern medicine and healthcare products.

A

B

Figure 6 Examples of bush medicine are (A) the Kakadu plum and (B) tea tree (*Melaleuca alternifolia*).

Check your learning 4.7

Check your learning 4.7

Retrieve

1 Name the three main causes of non-infectious diseases.

2 Identify a strategy that individuals can use to reduce the risk of non-infectious diseases.

Comprehend

3 Describe the role of genetic screening in managing hereditary diseases.

4 Explain why public health campaigns are essential in reducing smoking rates and preventing related diseases.

5 Explain why multiple strategies (e.g. hygiene, quarantine, vaccination) are more effective than individual measures in reducing the incidence of infectious diseases.

Analyse

6 Discuss the challenges health authorities face in maintaining an effective vaccination program for rapidly mutating viruses, such as COVID-19.

Apply

7 Assess the effectiveness of quarantine and lockdown measures during the COVID-19 pandemic. Discuss the limitations of these strategies in completely eliminating the virus.

8 Evaluate the ethical concerns that arise when pharmaceutical companies seek to use traditional Indigenous bush medicines for commercial purposes.

Lesson 4.8
Immunisation programs and the occurrence of infectious diseases

Learning intentions and success criteria

Key ideas

→ Immunisation programs significantly lower the incidence of infectious diseases by increasing vaccination coverage and promoting herd immunity.

→ Patterns of vaccine-preventable diseases indicate that lower vaccination rates are linked to an increase in cases and the emergence of new variants.

→ There is a clear relationship between high vaccination rates and reduced illness and death from infectious diseases.

Cervical cancer and HPV vaccination

Human papilloma virus (HPV) is primarily transmitted through sexual contact. In the late 1980s, scientists discovered a link between HPV and many cancers, most significantly cervical cancer, with between 90 and 100 per cent of cases now known to be caused by the virus.

In response, the Australian Federal Government began a National Immunisation Program (NIP) against HPV in 2007. Initially, the vaccine was offered to females in Year 7; in 2013 the program was extended to include males.

Analysis of the data in Figure 1, however, raises some interesting questions. Despite the NIP being introduced in 2007, the number of cervical cancer cases had already fallen to 7 cases per 100,000 females per year, 5 years earlier in 2002, and there was no further improvement after the vaccine was introduced.

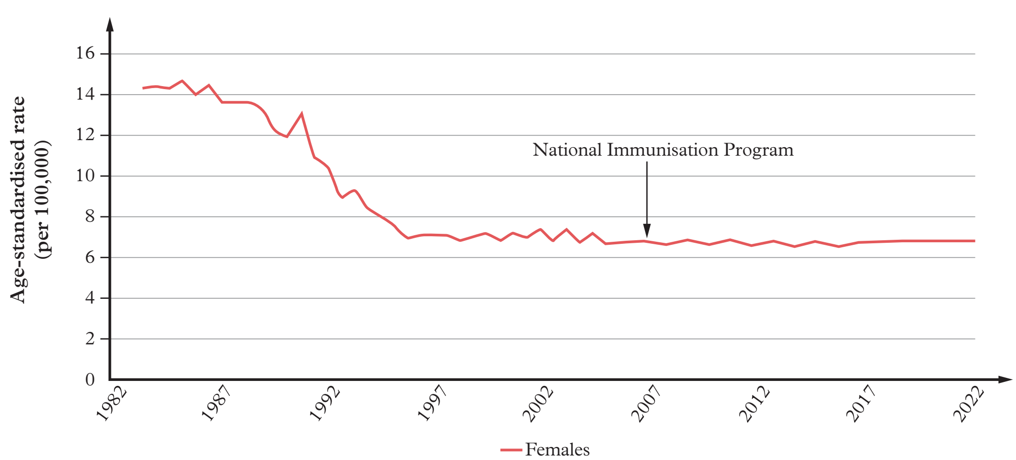


Figure 1 Incidence of cervical cancer in Australia between 1982 and 2022

This raises the obvious question: what is the point of the vaccination if numbers are already low and the vaccine has not reduced numbers further? What do you think is going on and what does the data really tell us?

When the link between HPV and cervical cancer was discovered in the 1980s, there was no vaccine available. The Federal Government introduced a National Cervical Screening Program (NCSP) in 1991. This initiative focused on early detection and treatment of pre-cancerous lesions. The strong uptake of screening resulted in the trend seen between 1991 and 2002, where the rate fell from 15 to 7 cases per 100,000 females per year. This demonstrates a strong relationship between the uptake of screening and a decline in the cases of cervical cancer.

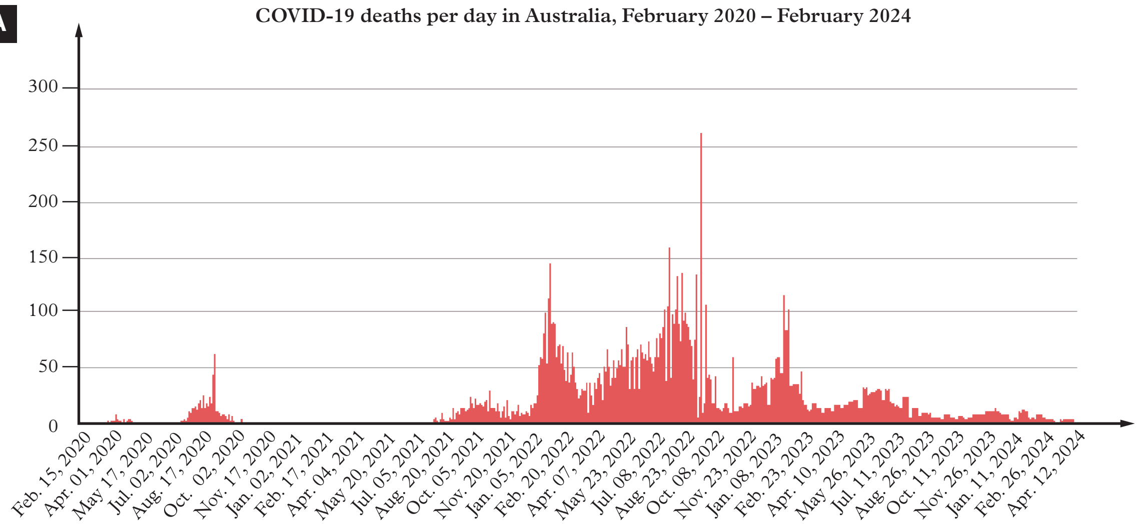
With the introduction of the immunisation program in 2007, the focus turned from treatment to prevention. The vaccine prevents the development of pre-cancerous lesions that turn cancerous if left untreated.

Despite the effectiveness of the HPV vaccine, cases of cervical cancer continue to occur. Between 2002 and 2023, the number of cases has remained relatively stable; however, there is a clear pattern observed, with repeating peaks and troughs every 2 years.

This is due to incomplete vaccination coverage, the rise of HPV variants that the vaccine is not effective against, and some females who contracted the virus prior to being vaccinated. If health authorities detect a rise in cases, they respond with a public health program to promote vaccination and screening. As time passes, the importance of vaccination and screening can subside, and cases can rise.

As of 2023, 85 per cent of 15-year-old females have been fully vaccinated against HPV. What do you predict will happen to the number of annual cases in the decades to come as the percentage of the population vaccinated increases?

A



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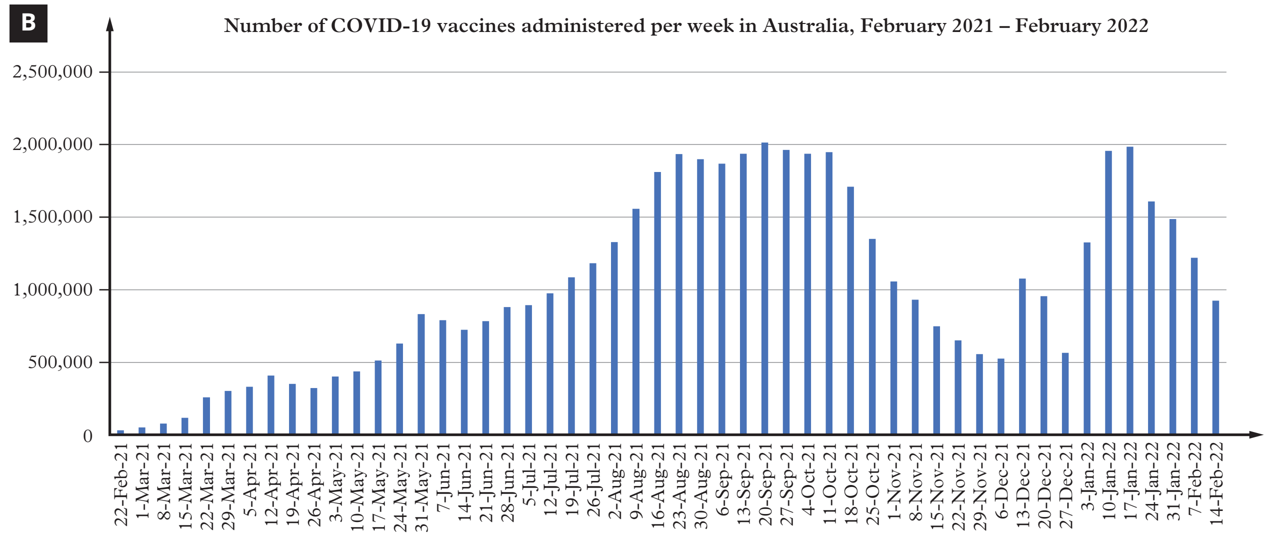


Figure 2 (A) Number of daily deaths in Australia from COVID-19 between February 2020 and February 2024. (B) Number of weekly vaccines administered at the height of the COVID-19 pandemic between February 2021 and February 2022.

COVID-19 and vaccination

In Australia as of 2025, there have been approximately 12 million cases and 25,000 registered deaths due to the COVID-19 pandemic. These numbers reflect the significant impact of the pandemic on the country's public health, even with widespread vaccination efforts and public health measures in place to reduce the spread of the virus.

Analysing the graphs in Figure 2 shows an exponential increase in COVID-19 vaccinations from their introduction in February 2021 to August 2021, where it then plateaus. Despite 95 per cent of Australian adults being vaccinated by late-2021, the most significant number of deaths occurred after this in mid-2022. The number of deaths likely increased following the reduction and elimination of measures such as mandatory mask-wearing, social distancing and lockdowns in late 2021. These changes increased the movement and contact between infected and uninfected people. While vaccination against COVID-19 reduces the likelihood of contracting the disease, it does not prevent it. It does, however, significantly lower the risk of severe illness and death.

So was the immunisation program worth it? In short, yes. There is a clear relationship between the introduction of the immunisation program and the reduction of severe illness and death. Most deaths and hospitalisations were for unvaccinated people. While the size of peak deaths varies, a repeating pattern can be seen from mid-2021 onwards. One reason for this pattern is the emergence of mutant strains of the virus, which were more transmissible and sometimes resistant to existing immunity. Another is the influence of seasonal changes on the spread of COVID-19 and other respiratory diseases. The relaxation and reintroduction of preventative measures have also had an impact on the observed pattern.

The number of deaths would likely have been much higher were it not for the immunisation program. As of late 2024, a total of 72.3 million COVID-19 vaccination doses have been administered in Australia.

Check your learning 4.8

Check your learning 4.8

Retrieve

1 Identify the primary mode of HPV transmission.

2 Identify the percentage of 15-year-old females who have been fully vaccinated against HPV as of 2023.

Comprehend

3 Describe the observed pattern of cervical cancer incidence from 2002 to 2023.

4 Explain why cervical cancer rates fell prior to the introduction of the HPV vaccination program.

Analyse

5 Analyse the long-term trends in cervical cancer incidence in Figure 1 in relation to vaccination and screening programs.

6 Discuss the reasons behind the peaks and troughs in cervical cancer cases from 2002 to 2023 in Figure 1.

7 Analyse the relationship between public health initiatives and changes in cervical cancer case trends depicted in Figure 1.

Apply

8 Explain the impact of HPV variants on the effectiveness of the vaccination program.

9 Research the immunisation program for an infectious disease not covered in this lesson.

a Identify the occurrence of the disease before and after the immunisation program.

b Analyse trends, patterns and relationships in the data associated with the introduction of the vaccine.

c Document your research and conclusions in a written report. Examples to consider include:

» measles, mumps, rubella (MMR)

» chickenpox

» shingles

» influenza

» 6-in-1: diphtheria, tetanus, pertussis (whooping cough), hepatitis B, polio, *Haemophilus influenzae* type b (Hib).

Lesson 4.9

Using stem cells to restore damage to the retina

Key ideas

→ Stem cells can be classified into two main groups: embryonic stem cells, which are pluripotent and can become nearly any cell type, and adult stem cells, which have a limited differentiation potential.

→ Induced pluripotent stem (iPS) cells are adult cells reprogrammed to an embryonic-like pluripotent state, which reduces ethical concerns and allows for a personalised medical approach.

Learning intentions and success criteria

Stem cells

Stem cells are "unprogrammed" cells that have the potential to develop into different cell types in the body. There are two main types of stem cells used in medical research: embryonic stem cells and adult stem cells. Embryonic stem cells are **pluripotent**, which means they can differentiate into almost any cell type. This makes them very useful in medical research. Their use is controversial, however, because they come from embryos. In

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

pluripotent a stem cell that can develop into nearly all cell types in an organism

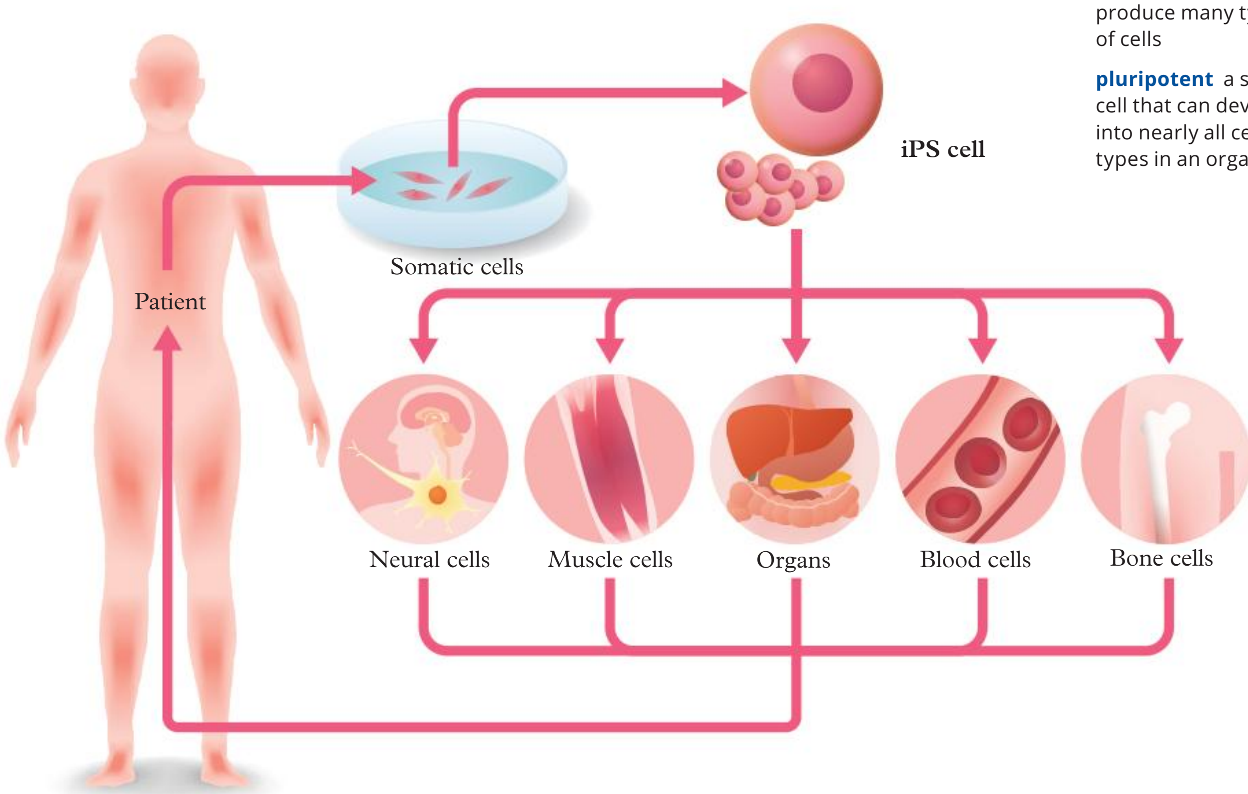


Figure 1 Induced pluripotent stem (iPS) cells are adult cells reprogrammed into an embryonic-like pluripotent state.

contrast, adult stem cells are more restricted in their potential because they can only develop into a limited number of cell types, determined by what tissue they are harvested from. They do not use human embryos, however, so ethical concerns are reduced.

A major breakthrough in stem cell research occurred in 2006 when a Japanese scientist, Shinya Yamanaka, and his colleagues first engineered induced pluripotent stem (iPS) cells. The iPS cells are adult skin or blood cells that have been reprogrammed into an embryonic-like pluripotent state, removing much of the controversy surrounding the use of embryonic stem cells (Figure 1).

Stem cell breakthrough in Australia

An Australian team of scientists led by Associate Professor Anai Gonzalez-Cordero from the Children's Medical Research Institute (CMRI) in Sydney is leading world research in the use of iPS cell technologies to treat vision loss and blindness.

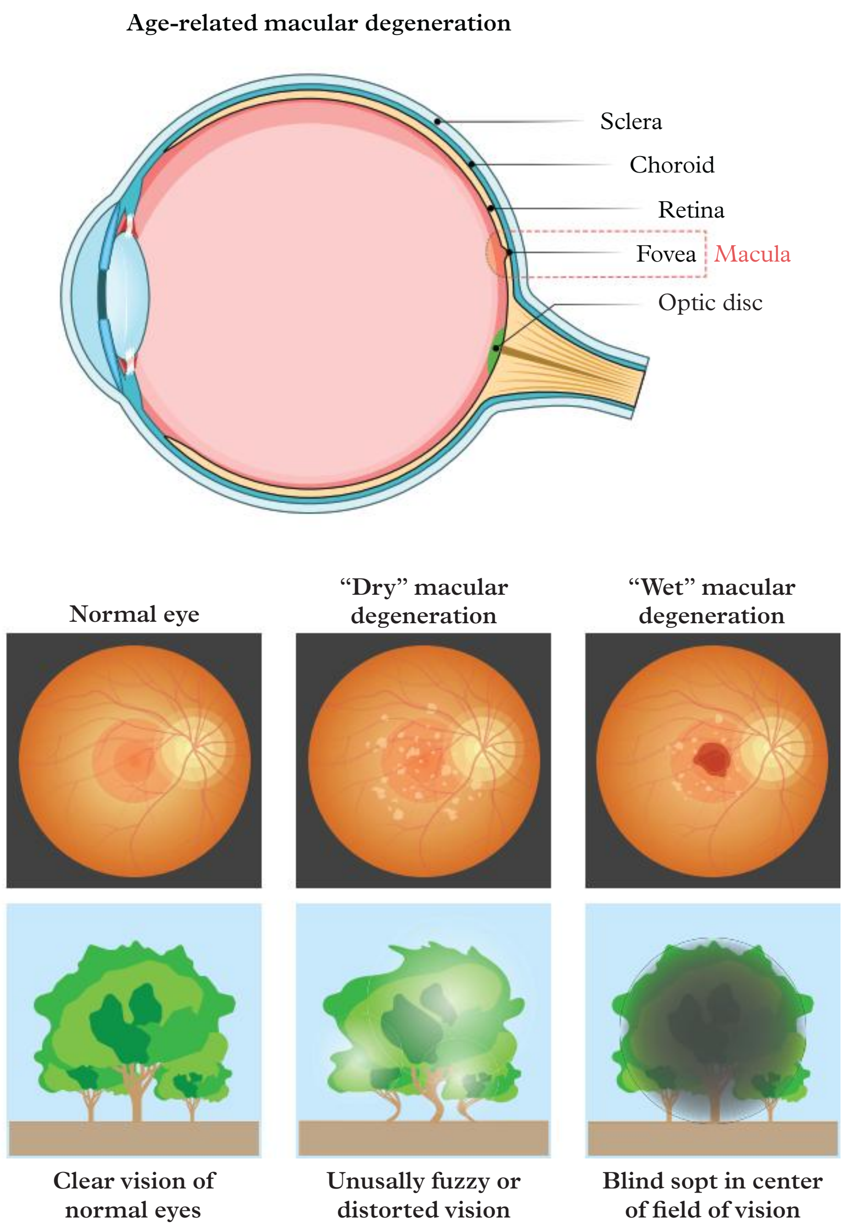


Figure 2 Macular degeneration is a degenerative disease of the eye that affects the retina.

After being reprogrammed, the iPS cells are differentiated into **retinal cells** and grown in culture to form organoids: small, self-organised, three-dimensional tissue clusters that mimic the structure and function of the desired target tissue. By using organoids derived from a patient's own cells, Associate Professor Gonzalez-Cordero and her team are able to investigate the specifics of an individual's disease. This personalised approach aims to develop targeted genetic therapies, tailored to the genetic makeup of the patient.

retinal cell a photoreceptor cell of the eye's retina

In the near future, the goal is to generate healthy retinal cells, grown in the lab, that can be transplanted into a patient's eye. These would then be kickstarted with an electrical impulse to repair damaged retinal tissue and make new connections with the brain to restore vision. This approach holds significant promise for treating degenerative eye conditions such as macular degeneration, a disease that causes blurring of central vision and continues to progress with age (Figure 2). In Australia, 8.5 million people over the age of 50 are at risk of macular disease, and over 1.7 million have some evidence of macular disease.

Check your learning 4.9

Check your learning 4.9

Retrieve

1 Identify the two main types of stem cells used in medical research.
2 Outline what is meant by "pluripotent".
3 Name the scientist using iPS cells to study degenerative eye disease.
4 Identify a degenerative eye disease that stem cell therapy could help treat.

Comprehend

5 Explain how iPS cells reduce the controversy associated with using embryonic stem cells.
6 Explain how stem cell therapies might help treat macular degeneration.

Apply

7 Assess the potential of personalised stem cell treatments for individuals with genetic eye disorders.
8 Evaluate the long-term benefits and risks of using iPS cells in medical therapies.

Lesson 4.10
Review: Disease

Summary

Lesson 4.1 Non-infectious diseases

- Non-infectious diseases can result from genetic, environmental or nutritional factors.
- Non-infectious diseases are not contagious.

Lesson 4.2 Pathogens cause infectious diseases

- Infectious diseases are caused by pathogens.
- Infectious diseases can be spread between individuals.

Lesson 4.3 Endemic diseases, epidemics and pandemics

- An endemic disease is always present in a particular area.
- An epidemic is a localised outbreak of a disease in a limited geographical area.
- A pandemic is an outbreak of a disease over a large geographical area.

Lesson 4.4 Non-infectious diseases in Australia

- Australians are much more likely to die from a non-infectious disease.

Lesson 4.5 The immune system protects us from infectious diseases

- Our immune system has three lines of defence against pathogens.
- The first line of defence acts to physically prevent pathogens entering our body.
- The second line of defence is non-specific and identifies and destroys pathogens that have entered the body.
- The third line of defence is specific and involves B and T cells that identify and destroy either pathogens or the "self" cells in which the pathogens are hiding.

Lesson 4.7 Minimising the impact of infectious and non-infectious diseases

- Non-infectious diseases can be categorised as genetic, environmental or nutritional.
- A healthy lifestyle, including a balanced diet and exercise, helps reduce risk.
- Genetic testing can determine individual risks for diseases.
- Educational campaigns to raise awareness about non-infectious diseases and promote healthy behaviours are often run by governments.

Lesson 4.8 Immunisation programs and the occurrence of infectious diseases

- Immunisation programs significantly lower the incidence of infectious diseases by increasing vaccination coverage and promoting herd immunity.
- Patterns of vaccine-preventable diseases indicate that lower vaccination rates are linked to an increase in cases and the emergence of new variants.
- There is a clear relationship between high vaccination rates and reduced illness and death from infectious diseases.

Lesson 4.9 Using stem cells to restore damage to the retina

- Stem cells can be classified into two main groups: embryonic stem cells, which are pluripotent and can become nearly any cell type, and adult stem cells, which have a limited differentiation potential.
- Induced pluripotent stem (iPS) cells are adult cells reprogrammed to an embryonic-like pluripotent state, which reduces ethical concerns and allows for a personalised medical approach.

Review questions 4.10

Review questions Module 4

Retrieve

1 Identify which of the following is not a pathogen.
   A Fungi
   B Bacteria
   C Adrenalin
   D Yeast

2 Identify which of the following cells produce antibodies.
   A B cells
   B Phagocytes
   C T cells
   D Viruses

3 Identify which of the following is not part of the immune system's first line of defence.
- **A** Skin
- **B** Saliva
- **C** Macrophages
- **D** Mucous membrane

4 Define the following terms:
- **a** antibody
- **b** phagocyte
- **c** pathogen.

5 Complete Table 1.

Table 1 Pathogen types and characteristics

Type of pathogen	Distinguishing features	Example of disease
Virus		
Bacteria		
Fungi		

6 Identify three categories of non-infectious disease and provide an example of each.

7 Identify a disease that is transmitted by a vector and name the vector.

8 Distinguish between endemic, epidemic and pandemic.

9 Name two organs in humans that are commonly affected by chronic non-infectious diseases.

Comprehend

10 Describe how lifestyle choices, such as diet and exercise, can influence the body's ability to combat both infectious and non-infectious diseases.

11 Describe the role of vaccines in helping the body recognise and fight infections. (THINK: How do they prepare the immune system?)

12 Explain how the body uses inflammation as a response to infection. (THINK: What are the signs of inflammation, and why is it important?)

13 Explain how the body's immune response differs when dealing with a virus compared to a non-infectious disease like diabetes.

14 Explain how the immune system's third line of defence remembers pathogens for when you are exposed to the pathogen a second time.

15 Describe the experiment performed by Louis Pasteur and explain how the results disproved spontaneous generation.

16 Explain how the body maintains homeostasis when faced with an infectious disease. (THINK: What systems work together to achieve this?)

17 Given that people have usually caught a cold before, explain why we continue to catch colds.

18 Describe in your own words how the non-specific immune response works.

19 Explain in your own words Koch's postulates.

20 Explain why it is incorrect to define all pathogens as living.

Analyse

21 Contrast the mechanisms by which the body responds to infectious diseases versus non-infectious diseases.

22 Contrast the effects of high blood glucose levels (hyperglycaemia) and low blood glucose levels (hypoglycaemia) on the body, especially regarding their impact on overall health.

23 Examine Figure 1.
- **a** Compare the number of deaths from ischaemic heart disease in low-income and high-income countries.
- **b** Compare the number of deaths from COVID-19 in low-income and high-income countries.
- **c** Of the top 10 causes of death, identify how many are caused by infectious diseases in low-income versus high-income countries.
- **d** Suggest reasons for any of the above differences observed.

Apply

24 Describe the symptoms of an autoimmune disease and explain how the immune system mistakenly attacks the body itself.

25 The hygiene hypothesis suggests that childhood exposure to microbes and certain infections helps the immune system develop. As a result of potentially being too hygienic, developed countries continue to see a rise in autoimmune conditions such as type 1 diabetes and rheumatoid arthritis. Investigate these conditions and outline the role of the body's own immune response in causing the symptoms.

26 Transmission of pathogens can cause mass outbreaks of an infectious disease and affect large numbers of people. Examples are COVID-19, HIV, the SARS virus, swine flu and the outbreak of cholera in Zimbabwe. Investigate one infectious disease and explain how it can spread so quickly. Describe what can be done to prevent the spread of such diseases.

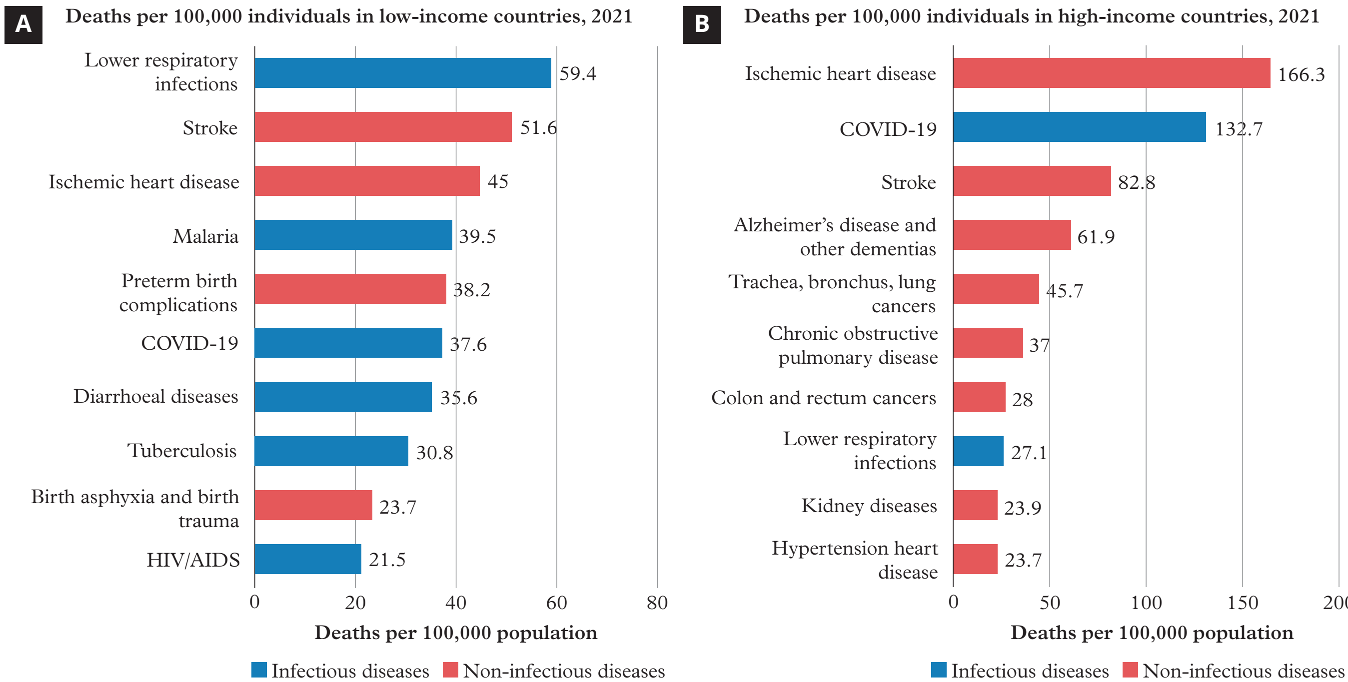


Figure 1 The top ten causes of death in (A) low-income and (B) high-income economies in 2021

27 Your body is constantly monitoring and controlling the number of pathogens in and on it. Discuss what you can do to assist your body in controlling pathogens.

Social and ethical thinking

28 Babies can be vaccinated against a wide range of diseases in the first months and years of their lives. They are not old enough to choose to be vaccinated, so the decision is made by their parents or guardians.

- **a** Investigate and identify which vaccinations are available in Australia.
- **b** Describe at least four secondary sources that have consistent information about the effectiveness of vaccination for babies.
- **c** Justify why your sources of information are valid.

29 A person with Alzheimer's disease can often forget what has happened in the past 30 minutes. An example of this is forgetting they have already eaten their lunch. This means the person can become very frustrated and upset if they think they are being refused food. Their carers may explain (many times) that the person has already eaten, but this can upset the person more, because they think they are being lied to. Other carers may lie to the person and say that lunch will be ready in five minutes. This settles the person, who will often forget about eating in that time.

- **a** Determine which approach you would use.
- **b** Justify your decision by describing the factors you considered when making your decision.

Critical and creative thinking

30 Create a visual presentation on the role of the different types of white blood cells in attacking pathogens.

31 Alcohol blocks the production of antidiuretic hormone (ADH). Use critical thinking to predict the effect this will have on urine volume.

32 Construct a table that distinguishes between the different lines of defence in the immune system.

33 Louis Pasteur found that heat could kill microorganisms in milk. This discovery is still applied today.

- **a** Investigate two reliable secondary sources that discuss the use of heat in killing pathogens.
- **b** Summarise two practical applications of heat treatment in food safety or public health.

Research

34 Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

Artificial skin

Skin is one of the main ways a body protects itself from infections. It provides a barrier against almost all pathogens and helps to control the amount of water lost by the body. When a person is burned, they may lose several layers of their skin. This can increase the risk of infection and make it difficult to control body temperature and water levels.

- Investigate the work of Australian scientists Dr Fiona Wood and Dr Marie Stoner on skin regeneration, including spray-on skin.
- Explain why their area of research is so important.
- Explain how the rising frequency and intensity of bushfires due to climate change and global warming highlight the importance of the research conducted by Dr. Fiona Wood and Dr. Marie Stoner on skin regeneration and spray-on skin technology for treating burn injuries.

Figure 2 Spray-on skin being applied to an arm

Bionic ears and eyes

Professor Graeme Clark was instrumental in the development of the cochlear ear implant. This device is able to detect the soundwaves through a receiver on the outside of the skin. The information is transmitted to inside the cochlea where it is able to pass the message directly to the sensory nerves going to the brain.

- Compare the human-made cochlear implant to the way information is normally detected and transmitted by nerves.
- Research the bionic eye project.
- Identify and describe the way light is detected and the information transmitted to the part of the brain responsible for decoding the information.

Figure 3 Cochlear implant. Sound signals are passed from the processor behind the ear to the round transmitter, then to electrodes that have been implanted in the cochlea.

Preventing childhood diseases

Dr Helen Mayo was one of the first female medical doctors in Australia and made a significant contribution to the reduction of childhood mortality (death).

- Identify at least four accomplishments of Dr Mayo.
- Create a timeline of her studies, travel and accomplishments.
- Explain why Dr Mayo was considered "unusual" for suggesting that mothers needed assistance to raise healthy children. (HINT: Consider the assumption that all women know how to be a mother and the level of education of women in 1913.)

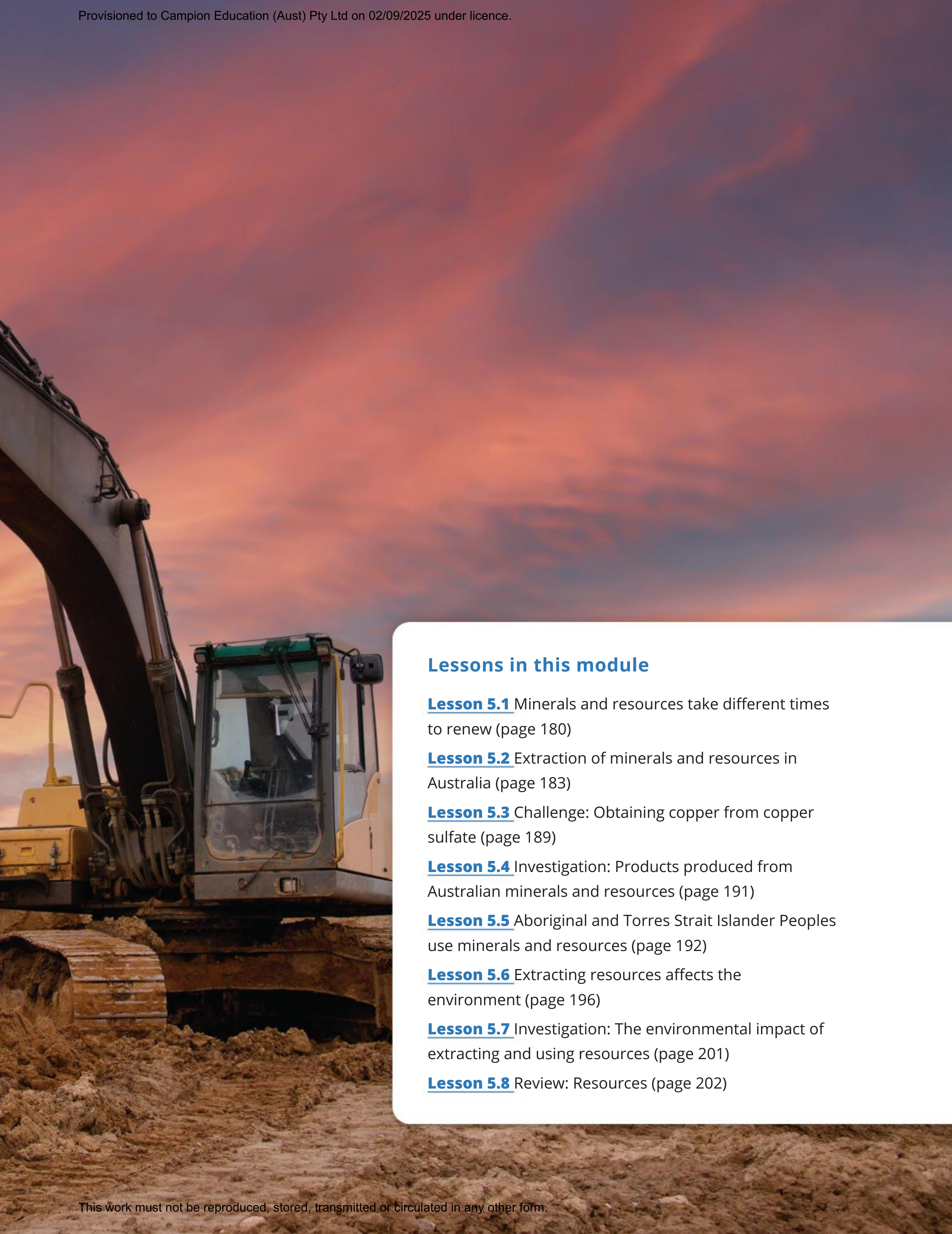
Module 5

Resources

Overview

Humans have always relied on the Earth's natural resources to survive. How we use the Earth's resources depends on whether they are renewable or non-renewable. Renewable resources can naturally regenerate over time, while non-renewable resources take much longer. As the world's population continues to grow, we are putting more pressure on our minerals and resources than ever before.

The extraction and use of non-renewable resources has an environmental impact. By considering the relative enviornmental impacts of extracting and using each type of natural resource, we can make informed decisions regarding the management of these resources.



Lessons in this module

Lesson 5.1
Minerals and resources take different times to renew

Learning intentions and success criteria

Key ideas

→ The Earth's resources fall into two categories: renewable resources, which can regenerate naturally or are available continuously, and non-renewable resources, which take a long time to replenish and are limited in supply.

→ Humans rely on natural resources like air, water, soil and minerals for survival and economic activities.

→ As the world's populations grows, the demand for minerals and resources also grows, risking the depletion of non-renewable resources.

Introduction

Humans have always relied on the Earth's natural resources found in the air, water and ground. Essential substances like oxygen and water sustain life, while soil is crucial for growing food for both humans and livestock. Minerals and resources extracted from the Earth, such as coal, iron ore, copper and gold, support the mining industry, manufacturing industry and Australia's economy. Forests provide habitats for wildlife and timber for construction. As our population continues to grow, we are putting more pressure on our minerals and resources than ever before.

Australia is particularly rich in minerals, but they are finite in nature. Minerals such as iron ore, bauxite (aluminium ore) and gold are non-renewable and take millions of years to form. Ongoing mining activities risk depleting these valuable resources, raising concerns about sustainability and long-term availability. This situation requires careful management and conservation strategies. We must ensure that future generations can access these essential materials while balancing economic growth with environmental responsibility.

Minerals and resources

mineral a naturally occurring inorganic substance with a definite chemical composition and crystalline structure

resource any natural material that can be extracted and used

A **mineral** is a naturally occurring, inorganic substance with a definite chemical composition and crystalline structure, such as quartz (silicon dioxide) or gibbsite (aluminium hydroxide). In contrast, a **resource** is any natural material that can be used for economic benefit, for nutrition or for environmental purposes.

While all minerals can be resources if they hold economic value, not all resources are minerals, as resources encompass a wider range of materials used for various purposes. For example, iron ore contains hematite (iron oxide), a mineral that is a valuable resource, while coal is not a mineral (based on its organic origins) but it is a resource.

Resources can be classified into two major groups:

- renewable resources
- non-renewable resources.

Renewable resources are either available in a continuous and unlimited supply (like sunlight and wind) or can naturally replenish in most conditions (like the trees in a forest). Even though they can regenerate naturally, renewable resources still need to be managed carefully and used sustainably.

Non-renewable resources are resources that take an extremely long time to replenish and are therefore only available in limited supply. If we use non-renewable resources at a faster rate than they can replenish naturally, they will run out. Minerals such as gold and hematite, and resources such as coal and oil, are non-renewable resources.

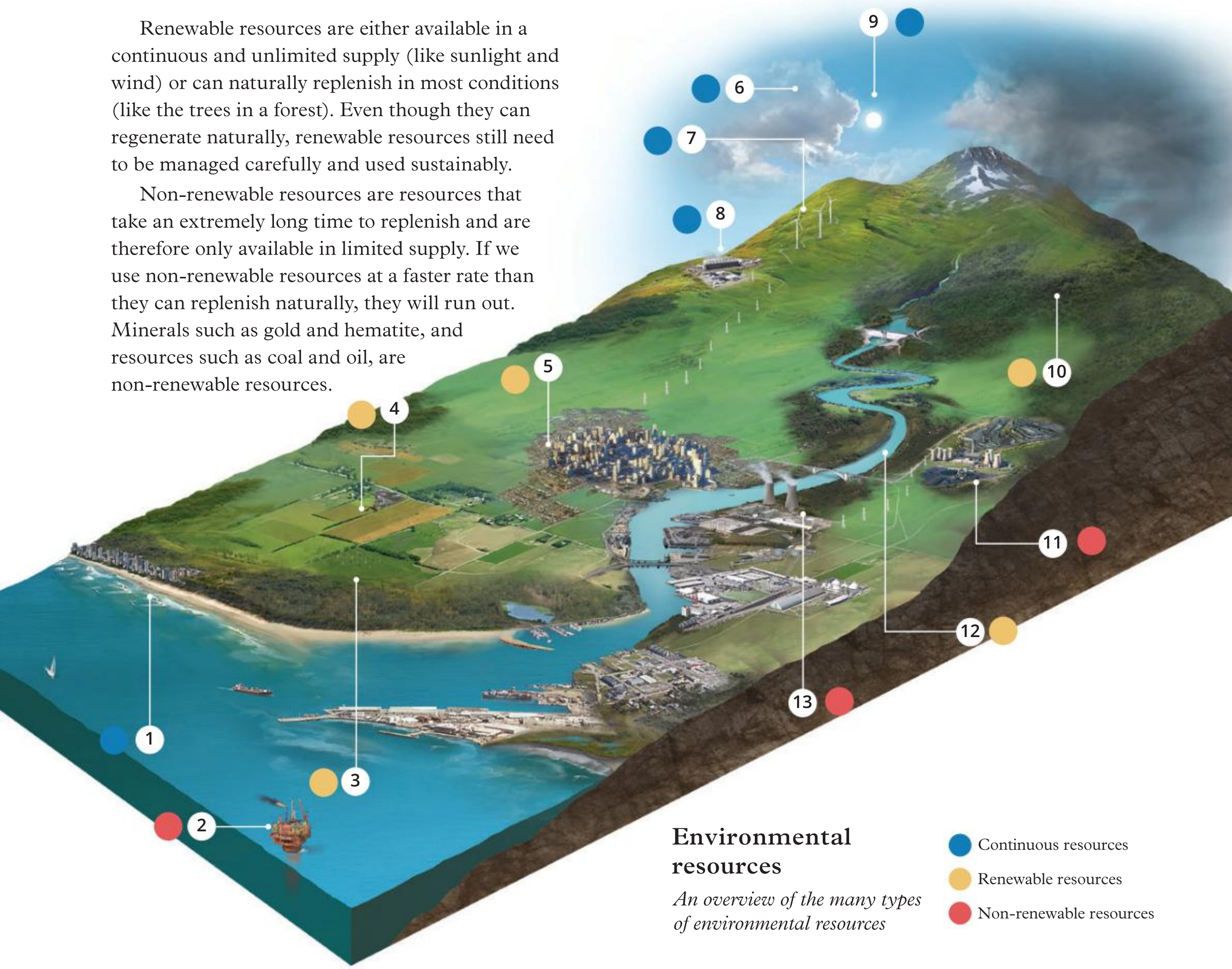


Figure 1 Our environment provides us with many minerals and resources. The following parts are labelled.

1. Ocean waves are resources for surfers and holiday-makers. They can also be used to generate electricity.
2. Oil, a non-renewable resource, is the world's most commonly used source of energy. It is also used to make many important goods, such as plastics, petrol and fertiliser for farms.
3. Soil is formed when rocks break down. We use soil to grow the crops we eat and to feed the animals we farm for food.
4. Plants are renewable resources because they produce seeds in order to reproduce themselves.
5. Our use of the Earth's resources is disrupting the Earth's natural systems.
6. The amount of oxygen in our atmosphere stays about the same because it is constantly recycled through plants, animals and oceans.
7. Wind is used to turn turbines and produce electricity.
8. In some parts of the world, electricity is generated from heat deep within the Earth. This is known as geothermal energy.
9. The Sun provides the energy for plants and animals and forms the basis of everything we eat. It can also provide electricity.
10. Forests are a renewable resource that are under threat. Much of the world's natural forest cover has been cleared or logged.
11. Most of Australia's electricity comes from the burning of coal. Coal is an important energy resource in many countries.
12. Fresh water is vital for life on the Earth, including plants, animals and people.
13. Minerals are used as a resource in many ways. Uranium is just one of the many minerals mined around the world. It is used at nuclear power stations to produce electricity.

Aboriginal and Torres Strait Islander Peoples' management of resources

Aboriginal and Torres Strait Islander Peoples have managed renewable and non-renewable resources sustainably through traditional knowledge for over 65,000 years. Practices such as firestick farming, along with clear roles and responsibilities, helped build respect for the land and its resources. This supported the sustainable use of both renewable and non-renewable resources and helped maintain cultural traditions. These resources are managed under cultural protocols.

Renewable resources

Fire management (firestick farming)

Aboriginal people strategically use fire to manage the land, burning vegetation to reduce the risk of large, destructive bushfires, encourage the growth of different plants and improve food availability.

Sustainable harvesting

Aboriginal and Torres Strait Islander Peoples use techniques that support sustainable harvesting of plants and animals, ensuring that resources are available for future generations.

Water management

Aboriginal and Torres Strait Islander Peoples developed sophisticated water management techniques, including protecting water sources from contamination and evaporation and storing water in rock wells and other natural features.

Figure 2 Gnamma holes on top of Pildappa Rock, Eyre Peninsula, South Australia.

Food preservation

Aboriginal and Torres Strait Islander Peoples developed methods for preserving food, such as storing seeds underground or drying them out, as well as drying and smoking meat and fish.

Non-renewable resources

Scientific knowledge

Aboriginal and Torres Strait Islander Peoples have sustained a deep knowledge of local resources, their properties and their uses. These resources are used to make tools, weapons and shelters. Refer to Lesson 5.5 Aboriginal and Torres Strait Islander Peoples use minerals and resources (page 192) for more details.

Resource conservation

Aboriginal and Torres Strait Islander Peoples identify and carefully conserve resources, ensuring essential resources remain available over time.

Check your learning 5.1

Check your learning 5.1

Retrieve

1 Identify the two main types of resources.

2 Recall one renewable resource that is continuous and one that can be replenished.

3 Distinguish between a mineral and a resource, with examples.

4 Identify all the non-renewable resources you have used in the past hour.

5 List three examples of renewable, natural resources used by Aboriginal and Torres Strait Islander Peoples and explain what they are used for.

Analyse

6 Examine the resources shown in Figure 1. Based on your understanding, explain which you think are well managed in Australia today and which are not well managed. Justify your answer.

7 Evaluate Figure 1. Which resources do you think are the most important? Justify your response.

8 Research and analyse the role of technological advancements in the efficient extraction and processing of mineral resources. How have these advancements influenced the sustainability of these resources?

Apply

9 Imagine that you had to investigate one of the resources displayed in Figure 1. Which would be the easiest to design a testable investigation for? Justify your response. (How would you access these resources? What kind of equipment would you need?)

Lesson 5.2
Extraction of minerals and resources in Australia

Key ideas

→ Minerals like gold and hematite (iron oxide) along with resources like natural gas and coal are finite and take millions of years to form, making them non-renewable.

→ Fossil fuels are formed from ancient organic matter, and a significant portion of Australia's electricity is generated from coal, particularly brown coal.

→ The extraction and use of minerals and fossil fuels has substantial environmental impacts.

Learning intentions and success criteria

Renewable and non-renewable resources

Renewable resources are made naturally and are available in an almost unlimited amount. For example, solar energy is a renewable resource with an unlimited amount available while the Sun shines in the sky. Of course, during the night and when the weather is cloudy, solar energy is not available, so it can have some disadvantages too. Other examples of renewable resources include clean air, timber and fish (Figure 1). Given the right conditions, they will be available if we don't use them too fast. We need to consider the consequences of taking too much.

Figure 1 Some of the Earth's natural renewable resources: (A) timber, (B) fish and (C) solar energy

Non-renewable resources (including certain minerals like gold, metallic ores of copper, aluminium and iron, as well as fossil fuels) are continually being formed, but on a geological timescale of hundreds of thousands or even millions of years. It is for this reason they are more accurately called "long-term renewable resources" because they do eventually replace themselves. But practically, they are non-renewable in our lifetime. If we continue to use non-renewable resources and they are not recycled, they will run out.

The Australian economy is highly dependent on non-renewable resources, particularly fossil fuels and mineral exports (Table 1). Approximately 30 per cent of Australia's export earnings, equating to over $200 billion annually, comes from minerals. Additionally, fossil fuels, in the form of coal and natural gas, account for another 26 per cent of export earnings, contributing an additional $180 billion.

Table 1 Australia's export earnings

Resource	Type	Approximate value (billion $AUD)	Percentage of total exports (%)
Iron ore	Mineral	136	20.3
Coal	Fossil fuel	103	15.3
Natural gas (LNG)	Fossil fuel	74	11.1
Gold	Mineral	28	4.2
Alumina	Mineral	15	2.3
Copper	Mineral	12	1.6
Other ores (e.g. nickel, zinc, uranium)	Mineral	4	1
Other (e.g. education, agriculture, tourism)	Not applicable	100	44

Source: Australian Government, Department of Foreign Affairs and Trade, 2023

Domestically, less than 10 per cent of Australia's electricity is generated by renewable sources, such as solar, wind and geothermal (Table 2), despite having significant reserves (Figure 2). Our economic and domestic dependence on non-renewable resources highlights the importance of sustainable practices and the need to explore alternative energy sources while reducing reliance on minerals.

Table 2 Australian energy consumption by fuel type

Resource	Type	Use	Percentage of total energy consumption (%)
Oil	Non-renewable	Transport fuel	38.9 (imported)
Coal	Non-renewable	Electricity generation	25.9
Natural gas	Non-renewable	Electricity generation	25.8
Renewables (solar, wind, geothermal, tidal)	Renewable	Solar heating and electricity generation	9.4

Source: Australian Government

Figure 2 The location of Australia's energy resources

Non-mineral-based resources

Coal

Coal deposits were formed from the remains of trees and other plants that grew in tropical swamps millions of years ago. When the trees and plants died, they fell into the swamps. The dead plants could not decompose completely because they were underwater where there was not much oxygen. The partly rotted plant material gradually built up, forming a layer of peat.

Over time, the layers of peat built up, and then rocks formed on top of them. The pressure from the rocks on top and the heat from the Earth's crust underneath caused chemical reactions that gradually changed the peat into coal (Figure 3). When coal is burnt, the chemical energy originally stored in the plants is released.

Australia is one of the world's largest producers and exporters of coal and natural gas, both of which are vital to the country's economy. In the 2023 financial year, Australia exported approximately 156 million tonnes of coal, generating around $100 billion in export earnings. Australia is particularly known for its high-quality thermal coal, used for electricity generation, and metallurgical coal, which is essential for steel production. The export demand for this finite resource remains high, despite a global shift towards cleaner energy sources.

Based on current export rates, if new reserves are not discovered or alternative energy sources are not developed, Australia's coal reserves are projected to run out within 150 years. While exports remain high, domestically, all coal-fired power electricity generators are expected to be retired by the mid-2030s.

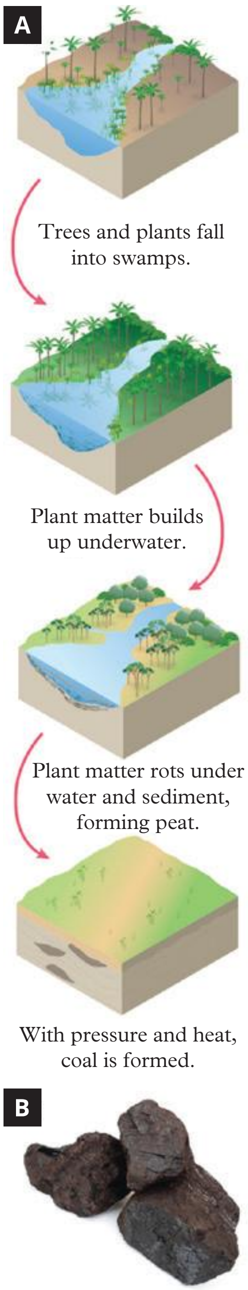


Figure 3 (A) Formation of fossil fuels; (B) a piece of brown coal

Natural gas

Natural gas, like other fossil fuels, formed millions of years ago from the decomposition of dead plants, animals and microorganisms. As layers of organic material were buried by soil and sediment, they were subjected to high pressure and temperatures. This compression and heat converted the organic matter into solid and liquid fossil fuels. Over time, the intense pressure and high temperatures caused the carbon bonds in the organic matter to break down and release methane (CH_4), which is the primary component of natural gas.

Natural gas is extracted and used domestically in its gaseous state for heating, cooking and electricity generation, or it can be liquified and transported for the export market.

Australia holds substantial reserves of natural gas. Approximately 30 per cent of extracted natural gas is kept for the domestic market, while the other 70 per cent is exported as liquefied natural gas (LNG) (Figure 4). In the 2023 financial year, Australia produced around 80 million tonnes of natural gas, with export earnings reaching approximately $74 billion, primarily from LNG. Australia has become one of the largest LNG exporters globally, with the industry playing a crucial role in meeting domestic energy needs and supporting the transition to a lower-carbon economy, serving as a bridging fuel while renewable energy sources continue to grow.

While estimates vary, at current usage and export rates, Australia's natural gas reserves are projected to run out within 20 years.

Figure 4 Australia is a major world exporter of liquefied natural gas (LNG).

Mineral resources

An **ore** is a solid material that contains a high concentration of valuable minerals or metals, mixed with other substances, making it economically viable for mining and extraction. Most metals occur in compound minerals that must be mined and purified to isolate the desired metal before it can be used. For example, aluminium is not found as solid sheets in the ground. It is part of the ore called bauxite, which is made of up of different aluminium-bearing minerals, most notably gibbsite (aluminium hydroxide) (Figure 5). Bauxite is mined and processed to extract aluminium metal.

ore a naturally occurring solid material from which metals or minerals can be extracted

Figure 5 Bauxite ore contains aluminium.

Figure 6 Australia's single largest deposit of bauxite is at Weipa in northern Queensland. It is mined in an open-cut mine.

Iron ore

Iron ore forms through geological processes over millions of years, with the most common iron-containing minerals being hematite (Fe_2O_3) and magnetite (Fe_3O_4). Australia is the world's largest exporter of iron ore, accounting for 56 per cent of the global market, followed by Brazil at a distant second with 19 per cent. In the 2023 financial year, this equated to approximately 900 million tonnes of iron ore, valued at $136 billion.

The majority of Australia's iron ore is extracted from large **open-cut mining** operations located in the Pilbara region of Western Australia (Figure 7 and Figure 9). The iron extracted from iron ore is primarily used in steel production, which is essential for construction and manufacturing around the world.

At current extraction rates, Australia's iron ore reserves are projected to last for only another 50 to 60 years if new deposits are not discovered.

Figure 7 An open-cut iron ore mine in the Pilbara region of Western Australia

open-cut mining a surface mining method that digs a large hole to extract minerals near the surface

Figure 8 An open-cut gold mine in a remote region of Western Australia

Gold

Gold is one of the few metals found in its pure elemental form in nature, making it a mineral in its native state. Deposits are formed over millions of years through hydrothermal activity, where heated, mineral-rich water circulates through the Earth's crust. As these solutions rise and cool, dissolved gold precipitates out, creating gold veins in fractures and cavities of rocks. Over time, weathering and erosion can break down these rocks, releasing the gold particles, which are transported by water to accumulate in riverbeds and floodplains.

Australia is typically one of the top three largest gold producers each year, along with China and Russia. Approximately 60 to 70 per cent of Australia's gold deposits are found throughout Western Australia and mined in both open-cut and **underground mining** operations (Figure 8 and Figure 9). In the 2023 financial year, Australia exported approximately 300 tonnes of gold, generating around $28 billion in export revenue. Gold is highly valued for its use in jewellery and electronics, and as an investment in the form of gold bullion and coins.

underground mining a method that creates tunnels to reach and extract deeper minerals

At current extraction rates, Australia's gold reserves are projected to last for another 20–30 years, depending on market conditions and the discovery of new deposits.

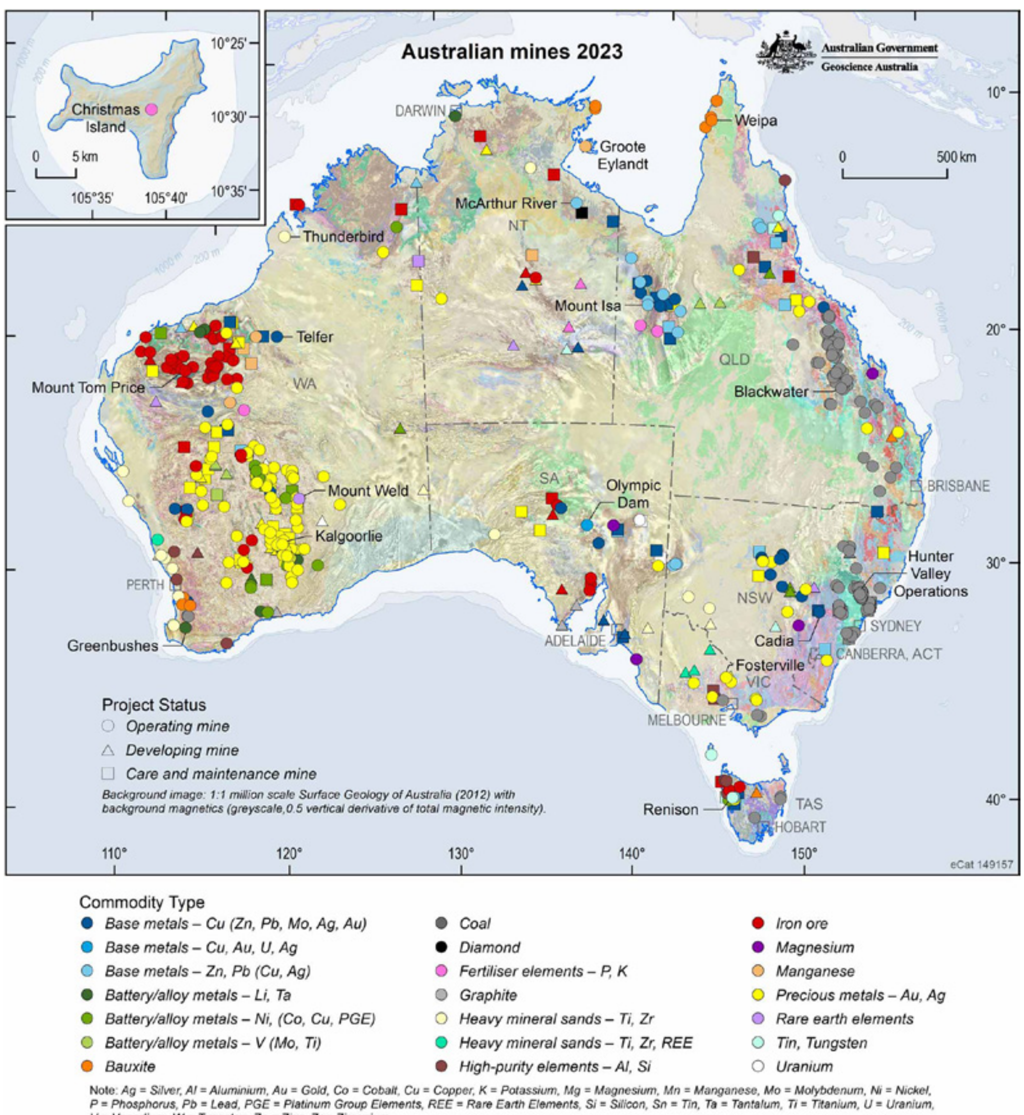


Figure 9 Major mining and mineral deposits in Australia

Check your learning 5.2

Check your learning 5.2

Retrieve

1 Distinguish between a renewable and non-renewable resource, with examples.

2 Identify the time scale for the formation of non-renewable resources.

3 Identify the primary source of electricity generation in Australia.

4 Distinguish between a mineral and an ore.

Comprehend

5 Explain why fossil fuels are considered non-renewable resources.

6 Explain why the time scale of a resource is an important issue.

Analyse

7 Assess the environmental impact of using non-renewable resources for energy production.

8 Identify the advantages and disadvantages of relying on coal as a primary energy source in Australia.

9 Suggest what strategies can be implemented to minimise the environmental impact of mining operations in Australia.

Apply

10 Examine Figure 2.

a Identify the energy resources that are found in Western Australia or off the coast of Western Australian.

b Explain why the coal mines in Australia are located where they are.

11 Australia is one of the largest producers of lithium, and the mining of this mineral is expanding quickly because of the growing global need for it. Lithium is mainly used in batteries, which are essential for electric vehicles (EVs) and renewable energy storage systems.

Assess whether lithium mining in Australia is beneficial or detrimental to the environment.

In your response, discuss the implications of lithium extraction in the context of Australia's current reliance on non-renewable energy sources for electricity generation and the potential for transitioning to a sustainable energy future.

12 Suggest how communities can reduce their reliance on non-renewable resources in their daily energy consumption.

Lesson 5.3

Challenge: Obtaining copper from copper sulfate

Aim

To obtain pure copper from the mineral copper sulfate

What you need:

- Power supply
- Two electrical leads with alligator clips on one end
- Two carbon rods
- 250 mL beaker
- 0.5 M copper sulfate solution
- Safety glasses

What to do:

1. Plug the electrical leads into the DC terminals of the power supply.
2. Connect the top end of the carbon rods to the alligator clips on the end of the electrical leads.
3. Fill the beaker with approximately 100 mL of the copper sulfate solution.
4. Place the carbon rods into the copper sulfate solution, being careful not to let them touch each other or the beaker.
5. Set the power supply knob to 6 V and turn the power on.
6. Observe the rods over the next 10 minutes.
7. After 10 minutes, turn the power supply off. Remove the carbon rods and place them on paper towel.

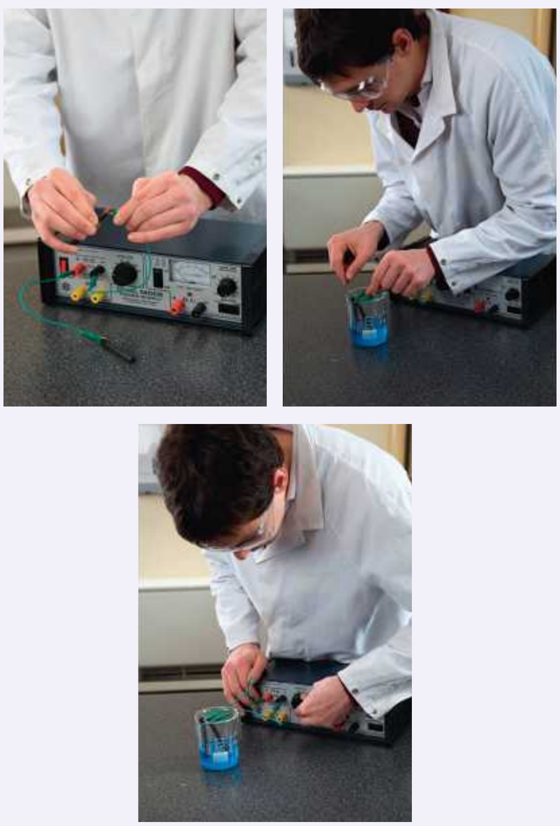


Figure 1 Experimental set-up

Inquiry: Improving metal production

1. Choose one of the inquiry questions below.
   - What if the voltage was increased?
   - What if more copper sulfate was used?
2. Answer the following questions with regard to your inquiry question.
   - Write a hypothesis for your inquiry.
   - Which (independent) variable will you change from the first method?
   - Which (dependent) variable will you measure and/or observe?
   - Name three variables you will keep the same or control.
   - Which variables will you need to control to ensure a fair test? How will you control them?

Results

Record your observations about the appearance of the rods and the copper sulfate solution.

Questions

1. Examine something else made of copper, such as an old copper water pipe or copper wire. State whether the coating on the copper looks like pure copper.
2. Identify where the copper coating came from.
3. Explain what you think the electricity did in this experiment.

Conclusion

How successful were you in obtaining pure copper from copper sulfate?

Lesson 5.4

Investigation: Products produced from Australian minerals and resources

Introduction

Australia is one of the most resource-rich countries in the world. Mining and energy exports account for 60 to 70 per cent of Australia's exports, valued at over $400 billion per annum. The country is a leading exporter of a wide range of minerals, with iron ore being the most valuable, contributing over $120 billion annually. As the world's largest producer and exporter of iron ore, Australia accounts for nearly 50 per cent of global iron ore exports.

Coal is another major export – worth around $60 billion annually – making Australia the second-largest exporter globally, after Indonesia. Gold also plays a significant role, generating around $30 billion in export revenue, with Australia ranking as the second-largest global gold producer after China.

Other important exports include copper and nickel, both of which contribute billions in revenue. Australia ranks among the top five global producers of both metals, with copper exports valued at around $13 billion annually and nickel exports valued at approximately $5 billion.

Lithium, a critical mineral for EV batteries, has seen a rapid increase in demand, and Australia is the world's largest exporter, accounting for nearly 50 per cent of global production. Australian lithium exports are valued at approximately $10 billion.

Bauxite, the primary ore for aluminium production, is another key export, with Australia being the top global supplier. The country's bauxite exports are valued at $5 billion annually. Additionally, zinc and rare earth elements, which are essential for electronics, renewable energy and defence technologies, are becoming increasingly important. Australia's zinc exports are valued at approximately $2.5 billion, while rare earth element exports are worth around $2 billion.

Australia's mining sector is not only vital to its own economy, but also to global industries, supporting everything from construction and manufacturing to energy production and technology around the world. As global demand for minerals rises, particularly with the transition to renewable energy and the growth of EVs, Australia's role in global mining is expected to remain crucial.

Purpose

To investigate products produced from Australian minerals and resources

Materials

- Computer
- Internet access

Procedure

1 Research the following minerals and resources.
   - Aluminium
   - Bauxite
   - Coal
   - Copper
   - Gold
   - Iron ore
   - Liquefied natural gas (LNG)
   - Lithium
   - Nickel
   - Rare earth elements (REEs)
   - Wheat and other agricultural exports (sometimes grouped with minerals)
   - Zinc

2 Construct a table that contains the following headings and information.
   – Name of mineral or resource
   – Description and key facts
   – Percentage of Australia's export market and value earned
   – Main export destinations
   – Australia's global production and export rank

Discussion

1 Which resource is the most valuable to Australia's export economy and why?
2 Why do you think China is the leading destination for many of Australia's mineral exports?
3 How might Australia's economy be affected if demand from countries like China or Japan decreases?
4 Should Australia reduce its coal exports due to climate change concerns? Why or why not?
5 Why are rare earth elements considered strategically important for countries around the world?
6 Which of Australia's exported resources do you think will become more important in the future? Why?
7 If you were advising the Australian Government, would you recommend investing more in agriculture or mining? Explain your reasoning.
8 What role do you think Aboriginal and Torres Strait Islander Peoples should play in decisions about mining on their land?

Figure 1 Ships loading iron ore for export in Port Hedland, Western Australia

Figure 2 The Port of Hay Point terminal, exporting coal from Central Queensland's Bowen Basin mines to ports around the world

Lesson 5.5
Aboriginal and Torres Strait Islander Peoples use minerals and resources

Learning intentions and success criteria

Key ideas

→ Aboriginal and Torres Strait Islander Peoples have a deep understanding of the land and its resources, using them sustainably for various purposes including food, tools, medicine and art.

Introduction

Aboriginal and Torres Strait Islander Peoples have a deep understanding of and relationship with the land and its resources, which they have used sustainably for thousands of years for a wide variety of purposes.

This connection to minerals and natural resources is not only practical but also spiritual and cultural. Aboriginal and Torres Strait Islander Peoples continue to use the land's resources to meet their needs, engage in trade, and create tools, art and ceremonial objects. Their knowledge and sustainable use of resources are key elements of their life and cultural practices.

Tools and weapons

Aboriginal and Torres Strait Islander Peoples craft a wide array of tools and weapons from minerals, stones and other natural resources. These items are central to hunting, food production and daily life.

Stone and wooden tools

Resources such as flint, obsidian and quartzite were chipped, flaked or ground to create sharp-edged tools for cutting, scraping and piercing. These resources are commonly used to create axes, knives, spearheads and scrapers for hunting, skinning animals and processing food. Hard rocks like sandstone or coarse-grained basalt are commonly crafted into grinding tools for processing seeds, nuts and plant material for food (Figure 1).

Figure 1 Grinding stones used to process seeds and nuts

Spears

Aboriginal and Torres Strait Islander Peoples craft stone-tipped spears from flint and basalt, shaping the stones into sharp points that are then attached to wooden shafts. This creates an effective tool for hunting large game and fishing. The choice of stone is important; flint can be shaped to have razor-sharp edges, while the tougher basalt provides greater durability. Spears are also used in ceremonial conflict displays and other cultural practices.

Clubs and boomerangs

In addition to spears, Aboriginal and Torres Strait Islander Peoples create clubs and boomerangs from dense hardwoods that provide both strength and durability. Clubs, often decorated with **ochre**, were used in ritualised combat and for striking large animals, and are still used as ceremonial objects in rituals and cultural performances. The iconic boomerang was primarily designed for hunting birds and small game. Its unique shape and aerodynamic design allow it to be thrown in a specific way, enabling it to glide and spin, which increases the chances of hitting a target. Various types of boomerangs are

ochre a natural clay earth pigment rich in iron oxide, commonly found in yellow, red and brown hues crafted from different woods and shaped according to their intended purposes; some are specifically designed for hunting, others for ceremonial or symbolic use and some for recreational purposes (Figure 2).

Figure 2 A collection of Aboriginal and Torres Strait Islander Peoples' tools and weapons

Figure 3 Different-coloured ochres

Adornment and ceremonial use

Many minerals and natural resources were and continue to be used for personal adornment and in ceremonial contexts, linking the physical and spiritual worlds.

Ochre

Ochre has always been used by Aboriginal and Torres Strait Islander Peoples and evidence dates back approximately 40,000 years. Ochre is a naturally occurring pigment, found in red, yellow and brown hues, and is used for body painting, ceremonial artwork and the decoration of tools and shelters (Figure 3). Additionally, ochre plays a significant role in rituals, as it is believed to possess spiritual and healing powers. It is utilised not only for artistic purposes but also in ceremonial contexts and potentially for medicinal applications.

Shells and stones for jewellery

Polished shells, seeds and stones like turquoise, jade and pearls are crafted into necklaces, earrings and adornments by Aboriginal and Torres Strait Islander Peoples. These items hold social and cultural significance, symbolising identity and status, and they are often used in ceremonies. Historically, they facilitated trade and social interactions between groups.

Clothing and personal objects

Feathers, bones and animal skins have been and continue to be used in ceremonial dress and body decoration, often featuring intricate patterns that convey cultural stories relating to language groups or kinship responsibilities. Feathers can be woven into garments and headpieces, while animal skins provide warmth and protection. Bones can be fashioned into tools or decorative items. These clothing and personal objects are both functional and symbolically significant, representing connections to the environment, ancestors and cultural identity.

Medicinal uses

Aboriginal and Torres Strait Islander Peoples have a deep understanding of the medicinal properties of plants, minerals and other natural resources in their environment, which has developed over many tens of thousands of years.

Plant materials are combined with different minerals to create **poultices**, balms or medicines. For example, rock salt or sandy soil mixed with the crushed leaves of the tea tree (*Melaleuca alternifolia*) are used to create a poultice for treating infections and promoting wound healing. The antiseptic properties of tea tree oil, combined with the soothing qualities of the mineral mix, work together to cleanse the wound and reduce inflammation.

Figure 4 The Kakadu plum has the highest vitamin C content of any fruit.

Eucalyptus leaves can be crushed and infused in hot water to create steam inhalation remedies for respiratory ailments like colds, flu and congestion. The vapours help clear nasal passages and provide relief. Eucalyptus leaves continue to be valued for their antiseptic, anti-inflammatory and pain-relieving properties. Eucalyptus-based poultices would be applied to wounds to prevent infection and promote healing. The oil from eucalyptus leaves is commonly used on sore muscles and joints, as well as for pain relief from headaches. Today, the medicinal benefits of eucalyptus remain integral to modern bush medicine and are widely used in commercial creams and ointments.

poultice a soft, moist mass of material, often made from herbs, plants or clay, that can be applied to the skin, typically to relieve pain, reduce inflammation or treat infections

In Northern Australia, the Kakadu plum (*Terminalia ferdinandiana*) has long been used by Aboriginal groups for its medicinal properties. The fruit, now known to have the highest vitamin C content of any fruit, is also rich in antioxidants and antimicrobial compounds. The pulp of the fruit can be consumed to boost immunity, relieve cold and flu symptoms and improve overall health. It can also be used as an antiseptic to treat wounds and skin infections.

Use of fire for cooking and environmental management

Fire remains central to the daily lives of Aboriginal and Torres Strait Islander Peoples, both as a tool for cooking, keeping warm and for managing the environment. Techniques used to start fires included the use of friction, where a wooden "drill" is rotated at speed against a softer wooden base to create an ember, or by striking stones like flint or pyrite together to produce sparks.

Firestick farming is a method used for controlled burning to manage the land, promote the growth of specific plants and encourage the movement of animals. This technique has an important role in maintaining healthy ecosystems and enhancing biodiversity.

For cooking, hot stones are placed in cooking pits. The process involves first heating stones in a fire until hot, then transferring them to a prepared pit along with food such as fish, roots or meats wrapped in leaves or bark. The stones provide even heat, while wrapping the food preserved moisture and flavour. The pit is then covered with earth or vegetation to trap heat and steam, creating an ideal cooking environment.

Waterholes in natural features were cleared out and hot stones were placed in the small waterholes to cleanse and purify the water for drinking.

Check your learning 5.5

Check your learning 5.5

Retrieve

1 Identify the types of minerals and stones used by Aboriginal and Torres Strait Islander Peoples for toolmaking.

2 Outline the medicinal properties of the Kakadu plum.

3 Describe the various techniques used by Aboriginal and Torres Strait Islander Peoples for starting a fire.

Comprehend

4 Explain the importance of tools and weapons in hunting and daily life for Aboriginal and Torres Strait Islander Peoples.

5 Explain how firestick farming enhances biodiversity and maintains healthy ecosystems.

6 Explain the role of traditional bush medicine in the health practices of Aboriginal and Torres Strait Islander Peoples.

7 Explain the importance of sustainable resource management for Aboriginal and Torres Strait Islander Peoples.

Analyse

8 Compare and contrast the effectiveness of traditional bush medicine and modern medical practices.

9 The vitamin C content of different fruits is listed below. The amount is measured in milligrams (mg) per 100 grams (g) of fruit.

  a Construct a graph of the data.

  b Determine how much more vitamin C the Kakadu plum has compared to an orange.

  » Orange: 50 mg per 100 g
  » Pineapple: 50 mg per 100 g
  » Papaya: 60 mg per 100 g
  » Strawberry: 60 mg per 100 g
  » Kiwifruit: 100 mg per 100 g
  » Guava: 228 mg per 100 g
  » Kakadu plum: 5,000 mg per 100 g

Apply

10 In consultation with the local Aboriginal or Torres Strait Islander community, develop a community awareness program that educates others about the importance of sustainable resource management based on Aboriginal and Torres Strait Islander practices.

Lesson 5.6

Extracting resources affects the environment

Learning intentions and success criteria

Key ideas

→ Open-cut and underground mining methods have different environmental and human health impacts.

→ Coal is one of Australia's most significant natural resources, and its mining and usage have substantial environmental, economic and social impacts.

→ Balancing the economic benefits of using resources like coal against the environmental impacts is a source of debate amongst key stakeholders.

Introduction

To evaluate the environmental impact of extracting and using a resource involves assessing its entire life cycle, from extraction to disposal. This includes examining the ecological consequences of resource extraction, the sustainability of the practices used, and the potential harm to habitats and biodiversity caused by its use.

The potential environmental effects must be identified at each stage, such as habitat destruction, pollution, energy use and emissions. Extraction methods like mining or drilling can cause land degradation and biodiversity loss, while processing and transportation require significant energy and water, often releasing pollutants. The long-term environmental effects of resource use, including waste generation and carbon footprints, must also be considered.

By considering the relative environmental impacts, a well-informed decision can be made regarding the management of the resource.

Types of mining operations

There are two main types of mining operations used to extract minerals: open-cut mining and underground mining. The method used depends on the depth and concentration of the mineral.

Open-cut mining (also called open-pit mining) is a surface mining technique that involves digging a large hole or pit in the ground. It is used when mineral deposits are located near the surface and spread over a large area. Resources like coal, iron ore and copper are commonly extracted using this method. While open-cut mining is more cost-effective and safer than underground mining, it can have significant environmental impacts, including habitat destruction, soil erosion and water pollution.

In contrast, underground mining is a method that involves creating tunnels or shafts to extract minerals that are deep beneath Earth's surface and cannot be accessed by open-cut mining. It is often used for resources such as gold, silver and certain types of coal. While underground mining disturbs less of the surface, which can be better for the environment, it is more expensive and poses greater risks for workers, such as cave-ins and breathing issues caused by harmful gases.

Case study Coal

Coal has been a critical resource for energy production, industrial processes and economic development for over a century. In Australia, coal is one of the country's most significant natural resources, contributing to the national economy as both a primary energy source and a major export commodity. As of recent years, Australia ranks as one of the world's largest coal exporters, supplying coal to countries like China, India and Japan for electricity generation and steel manufacturing. The extraction and use of coal, however, are associated with a variety of environmental and health concerns that have gained significant attention in recent decades.

Coal is primarily extracted through two methods: open-cut mining and underground mining. Open-cut mining has significant consequences for the land and ecosystems, causing habitat destruction, soil erosion and water contamination. Underground mining causes **subsidence** and groundwater pollution.

subsidence the gradual caving in or sinking of an area of land

The use of coal as a fuel source, primarily in coal-fired power plants, also contributes heavily to environmental degradation. When burned, coal releases large amounts of carbon dioxide (CO_2) – a greenhouse gas responsible for climate change – as well as pollutants like sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which contribute to air pollution and smog formation. These emissions not only exacerbate global warming but also impact human health and biodiversity.

As Australia moves toward addressing climate change and reducing its carbon footprint, understanding the environmental impacts of coal extraction and use becomes increasingly important.

In recent times, the use of coal in Australia has been hotly debated. Students around the world participated in climate strikes to protest the use of fossil fuels and raise awareness for climate change.

There are a number of factors that should be considered when deciding how we use resources. Australia's economy receives a significant income from mining companies and the export of coal and minerals to other countries. Some argue that getting rid of mining in Australia would leave many people out of work. Meanwhile, others argue that these jobs could move into the renewable energy sector.

The Australian Government must weigh up the values and interests of different stakeholders. Table 1 provides some questions that might be considered when making decisions about coal mining in Australia.

Table 1 Considerations for coal mining in Australia

Environmental impact	How does mining coal in Australia impact on the local landscape, habitats or wildlife? Can mining companies rehabilitate the land they have mined? How does mining coal contribute to climate change?
Financial impact	How many people rely on coal for jobs? How much do coal companies pay in taxes to the Australian Government? Would Australians need to pay more or less for energy if a different source was used?
Alternative resources	Is there another resource that could support Australian energy requirements? Is there another resource that would reduce our impact on the environment?

Figure 1 Peakhill open cut gold mine, which closed in 2022

Figure 2 Entrance to an old underground mine in Katoomba Jamison Valley in the Blue Mountains

Why do people have different viewpoints?

When deciding what resources to use, individuals or groups may have different interests or values that inform their decision-making. These views come from a complex combination of factors, including education, where people live, quality of life, political beliefs and whether people have any financial interest in the use of these resources.

For example, someone who is wealthy might be happy to pay more for renewable energy because they can afford it. Someone who works at a coal mine might prefer that Australia continues to use coal-powered energy because it will help them keep their job. Or someone who is environmentally conscious might value the use of renewable resources because they are concerned about the environmental damage caused by burning fossil fuels. Ultimately, our opinions are often influenced by our own interests.

What is your view?

The New Ecological Paradigm (NEP) scale was developed by researchers in the United States. It is a set of 15 statements designed to assess people's views on environmental issues, such as the use of renewable resources.

The NEP is based on the concept that people can have a human-centred world view (focused on personal or human issues) or an Earth-centred world view (focused on sustainability and environmental impact).

To complete the test, you need to answer whether you agree or disagree with each statement on a scale of 1 to 5 (1 for strongly disagree and 5 for strongly agree). The total score will, therefore, range from 15 to 75.

Lower scores indicate a more anthropocentric (human-centred) perspective, where individuals may hold less concern for environmental issues or may believe that humans have control over nature.

Higher scores suggest a more ecocentric (nature-centred) perspective, where individuals tend to view humans as part of a larger ecological system and believe in the need for environmental preservation and sustainability.

The statements on the test are as follows:

1. We are approaching the limit of the number of people the Earth can support.
2. Humans have the right to modify the natural environment to suit their needs.
3. When humans interfere with nature it often produces disastrous consequences.
4. Human ingenuity will ensure that we do not make the Earth unlivable.
5. Humans are seriously abusing the environment.
6. The Earth has plenty of natural resources if we just learn how to develop them.
7. Plants and animals have as much right as humans to exist.
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations.
9. Despite our special abilities, humans are still subject to the laws of nature.
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated.
11. The Earth is like a spaceship with very limited room and resources.
12. Humans were meant to rule over the rest of nature.
13. The balance of nature is very delicate and easily upset.
14. Humans will eventually learn enough about how nature works to be able to control it.
15. If things continue on their present course, we will soon experience a major ecological catastrophe.

Source: Riley Dunlap et al. (2000).
Measuring endorsement of the new ecological paradigm: A revised NEP scale. Journal of Social Issues, 56 (3), 425–442.

"Entire eco systems are collapsing. We are at the beginning of a mass extinction and all you can talk about is money and fairytales of eternal economic growth. How dare you."

– Greta Thunberg, environmental activist

"We will be energy independent. Drill, baby, drill. That's what we're going to do."

– Donald Trump, politician

"Clean nuclear energy is reliable. It will underpin renewables. It will get the cost of electricity down. It will keep the lights on."

– Peter Dutton, politician

Figure 3 Three people whose views would influence their stance on resources

Check your learning 5.6

Check your learning 5.6

Retrieve

1 Identify two factors that may influence a person's opinion on using non-renewable or renewable resources.

2 Identify one reason to support the continued use of coal in Australia and one reason against it.

3 Outline the considerations that the government might take into account when weighing up the decision to continue coal mining in Australia.

Analyse

4 Consider the quotes from different people in Figure 3. Based on their views, predict how they would react to the following scenarios. Justify your response by discussing how their opinions may affect their attitudes or actions regarding these issues.

  a Banning the use of coal

  b Reducing the cost of biofuels to power cars

Apply

5 Complete the NEP test. If you agree with the even-numbered statements, researchers would describe you as having a human-centred world view. If you agree with the odd-numbered statements, researchers would describe you as having an Earth-centred world view.

6 Reflect on your world view based on the NEP scale. How do you think it compares with the rest of Australia?

7 Evaluate the following statement from the Australian Minerals Council: "Mining companies contribute to local schools, medical services, sporting clubs and charities in communities around Australia". (What influences their opinion?)

Lesson 5.7

Investigation: The environmental impact of extracting and using resources

Purpose

To evaluate the environmental impact of extracting and using coal or another named resource, and to document findings in a written scientific report

Procedure

Use the information on coal from Case study Coal in Lesson 5.6 Extracting resources affects the environment (page 196) or research another non-renewable resource. Document your findings in a written scientific report using the following structure.

Title

Write a clear and concise title for your investigation.

Introduction

- State the purpose of the report. What are you investigating and why?
- Provide background information about the methods used to extract the resource and its uses.
- What is the significance of the resource to the Australian economy?

Environmental impact of resource extraction

- Explain the main methods used to extract the resource.
- Discuss how extraction of the resource affects the environment, including the removal of vegetation, destruction of habitats and potential for water contamination.

Environmental impact of resource use

Discuss examples of environmental impacts caused by using the resource. Consider harmful pollutants and greenhouse gas emissions and the effect they have on air quality and public health.

Mitigation strategies

- Discuss strategies used to mitigate (minimise) the impact of extracting and using the resource. For example:
  – site rehabilitation (revegetation or habitat restoration)
  – carbon capture and storage (CCS).
- Discuss the effectiveness of these strategies in restoring ecosystems.

Alternatives

- Discuss the potential for Australia and other countries to transition from the non-renewable resource to other alternatives.
- Discuss technological innovations that could improve extraction of the resource and reduce environmental impact.

Conclusion

- Summarise the key environmental impacts of extracting and using the resource.
- Reflect on the challenges and potential solutions to mitigate these effects.
- Offer an opinion and judgement on the future extraction and use of the resource.

Lesson 5.8

Review: Resources

Summary

Lesson 5.1 Minerals and resources take different times to renew

- The Earth's resources fall into two categories: renewable resources, which can regenerate naturally or are available continuously, and non-renewable resources, which take a long time to replenish and are limited in supply.
- Humans rely on natural resources like air, water, soil and minerals for survival and economic activities.
- As the world's populations grows, the demand for minerals and resources also grows, risking the depletion of non-renewable resources.

Lesson 5.2 Extraction of minerals and resources in Australia

- Minerals like gold and hematite (iron oxide) along with resources like natural gas and coal are finite and take millions of years to form, making them non-renewable.
- Fossil fuels are formed from ancient organic matter, and a significant portion of Australia's electricity is generated from coal, particularly brown coal.
- The extraction and use of minerals and fossil fuels has substantial environmental impacts.

Lesson 5.5 Aboriginal and Torres Strait Islander Peoples use minerals and resources

- Aboriginal and Torres Strait Islander Peoples have a deep understanding of the land and its resources, using them sustainably for various purposes including food, tools, medicine and art.

Lesson 5.6 Extracting resources affects the environment

- Open-cut and underground mining methods have different environmental and human health impacts.
- Coal is one of Australia's most significant natural resources, and its mining and usage have substantial environmental, economic and social impacts.
- Balancing the economic benefits of using resources like coal against the environmental impacts is a source of debate amongst key stakeholders.

Review questions 5.8

Review questions Module 5

Retrieve

1 What is a key characteristic of non-renewable resources?

A They can be easily replaced
B They are only found in specific regions
C They are available in unlimited amounts
D They take a long time to replenish and are limited in supply

2 Which of the following is considered a non-renewable resource?

A Wind power
B Solar power
C Nuclear power
D Wave power

3 Which of the following is considered a renewable resource?
   A Metal ore
   B Fossil fuel
   C Wind energy
   D Nuclear power

4 Define the following terms:
   a ore
   b ochre
   c resource.

5 Describe the differences between renewable and non-renewable resources. Provide two examples of each.

6 Classify the following resources as renewable or non-renewable:
   a wind
   b biofuel
   c coal
   d wave power
   e natural gas.

7 Coal is a fossil fuel. Outline how it was formed.

8 Distinguish between an open-cut and underground mine, and identify a mineral that is extracted by each method.

Comprehend

9 Distinguish between a mineral and an ore.

10 Explain why oil and gas are described as fossil fuels.

11 If coal is so widely used for generating electricity, outline why some people are concerned about building new coal-fired power stations.

12 What advantages and disadvantages do electric vehicles have over petrol-driven cars?

13 What is wind farming? Are there any disadvantages to this method of energy production?

14 Compare open-cut and underground mining operations in terms of their respective advantages and disadvantages.

15 Describe how Aboriginal and Torres Strait Islander Peoples traditionally managed the Earth's natural resources. What lessons can be learned from their practices?

Analyse

16 Table 1 shows the percentage of Australian energy consumption by fuel type.
   a Construct an appropriate graph to display this data.
   b Interpret this graph to describe how much oil, coal, gas and renewable energy we use in Australia.

Table 1 Australian energy consumption by fuel type

Resource	Type	Percentage of total energy consumption (%)
Oil	Non-renewable	38.9
Coal	Non-renewable	25.9
Natural gas	Non-renewable	25.8
Renewables (solar, wind, geothermal, tidal)	Renewable	9.4

Source: Australian Government

17 Analyse Figure 1, which shows how much of a state's total energy consumption comes from coal, oil, gas or renewables.
   a Identify which state uses the highest percentage of renewables.
   b Identify which state uses the lowest percentage of renewables.
   c Describe the energy mix used by NSW.

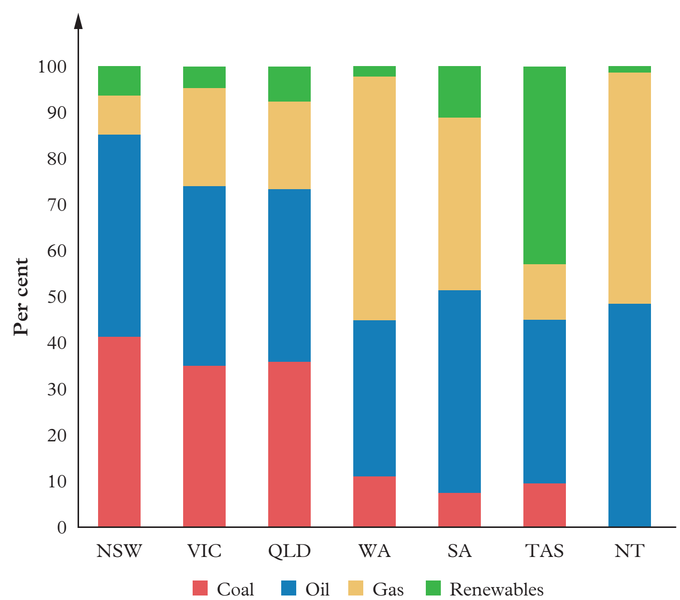


Figure 1 Total energy consumption by state

Apply

18 Explain how the extraction of a specific non-renewable resource (e.g. coal or gold) impacts local communities and ecosystems. Provide examples of both positive and negative effects to illustrate your points.

19 Explain how public awareness and education about the importance of renewable resources can drive changes in consumer behaviour. Discuss strategies that could be employed to raise awareness and encourage sustainable choices among the population.

Social and ethical thinking

20 As Australia's population continues to grow, the demand for non-renewable resources, including minerals and natural resources, increases. At the same time, the country relies heavily on mineral and fossil fuel exports for economic growth.

- **a** Explain the challenges that increasing resource demand poses for sustainable resource management in Australia.
- **b** Discuss the trade-offs that policymakers and industry leaders must consider when balancing economic growth, environmental sustainability and social impacts.

21 Passenger cars, like those most people drive, are responsible for a significant amount of the population's energy consumption. Should people consider walking, cycling or taking public transport to reduce their energy consumption (Figure 2)? What issues might they consider?

Figure 2 Should people consider walking to work?

Critical and creative thinking

22 A mining company would like to drill near a reef to extract crude oil. Identify possible advantages and disadvantages of this idea from the perspective of:

- **a** an environmental activist
- **b** a mining engineer.

23 Write a letter to the Federal Minister for Resources, Energy and Tourism, suggesting changes you would like to see happen in Australia. In your letter, demonstrate that you have an understanding of the advantages and disadvantages of all options, include evidence and list the current sources you have used. You might like to prepare a renewable energy plan for Australia and explain how your plan will be more sustainable than the current use of energy in our country.

24 What factors do you think are important when considering the use of a resource? Would others agree with you? Suggest a list of four key criteria that people could use to help them decide whether or not to use a resource.

25 Consider a future where non-renewable resources become even more scarce due to over-extraction. Create a detailed scenario describing how Australian society might adapt to this reality. What alternative materials or renewable resources would emerge as vital to the economy? How would lifestyle changes occur to accommodate this shift?

26 New Zealand produces a large amount of its energy from geothermal power (Figure 3). Discuss why this does not happen on a large scale in Australia.

Figure 3 Wairakei Geothermal Power Plant in New Zealand

Research

27 Choose one of the following topics to research. Present your findings in a written report or as a multimedia presentation. Some questions have been included to get you started. An important part of your submission is to include references to the "big picture" and to discuss how your topic relates to the entire planet.

Clean coal

Find out about clean-coal technology and how it applies to Australia.

- What are the environmental impacts associated with traditional coal mining and usage?
- Is there such a thing as "clean" coal?
- Why does coal need to be cleaned?
- Does clean coal exist or is it still only available in the future? Is it costly?
- How does clean-coal technology compare to other renewable energy sources in terms of efficiency and environmental benefits?

Trapping carbon

The use of fossil fuels causes the release of carbon dioxide into the atmosphere. This has been linked to the gradual increase in global temperatures. Many countries are now finding ways to trap carbon dioxide and store it less destructively.

- How are Australia and other countries encouraging industry to use fewer fossil fuels?
- Describe one way that carbon can be trapped and stored.
- Which countries are using this method of trapping carbon?

Exploration of renewable alternatives

Identify existing projects and initiatives aimed at increasing the use of renewable resources.

- What is the current state of renewable energy sources in Australia, such as solar, wind and geothermal energy?
- What challenges will be faced in transitioning from non-renewable to renewable energy?
- What are the consequences if we do not transition?

A simple pencil

Examine a wooden pencil and determine all of its component, including the lettering on the side. You may even want to dismantle the pencil and isolate each part. Next, think of all the steps needed to make the pencil.

- What are the components made of?
- Where would all the components have come from?
- What resources are needed to make the components?
- What resources are needed to assemble and finish the pencil in the factory?
- Present your research in a creative way.

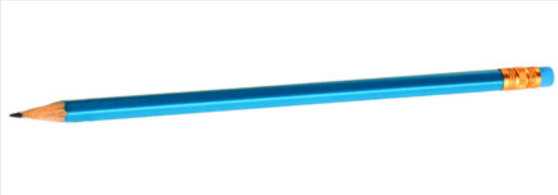


Figure 4 How is a wooden pencil made?

Module 6

Bonding, compounds and polymers

Overview

When we understand the structure of an atom and how ions and other atoms bond, we can better understand the structure and properties of different materials, including metals, non-metals and compounds and polymers.

Plastics are polymers that are produced by joining many smaller molecules together. Synthetic polymers are produced by chemists or chemical engineers. Polymers have specific properties, for example, thermoplastic polymers soften when gently heated and can be formed into new shapes.

Lessons in this module

Lesson 6.1
The structure of an atom determines its properties

Learning intentions and success criteria

Key ideas

→ The atomic number and name of an atom is determined by the number of protons it contains in its nucleus.

→ 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.

Atoms and their electrons

neutron a neutral (no charge) subatomic particle in the nucleus of an atom

nucleus (chemistry) the small region at the centre of an atom that consists of the protons and neutrons; plural "nuclei"

atomic number the number of an element in the periodic table, which equals the number of protons in that element

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 so have a strong influence on the properties of the atom. The number of protons is called the **atomic number** and is used to order the elements in the periodic table.

In contrast, electrons have a "negligible" mass, meaning the mass is so small it is ignored; it is almost too small to measure. Electrons orbit the nucleus, so they affect the way the atom bonds with other atoms.

Electron configurations

You learnt about Ernest Rutherford's model of the atom in *Oxford Science Stage 4 NSW Curriculum*. After Rutherford had refined his model, where he proposed that the negatively charged electrons surround the nucleus of an atom, another scientist, Niels Bohr (Figure 1), concluded that the electrons in the atom do not behave exactly like the planets around the Sun.

electron shells the placement of electrons around an atom's nucleus; an atom may have one or more electron shells

Bohr model the model of the atom developed by Niels Bohr in the 1910s, with electrons placed in shells centred on the nucleus

Bohr used a spectroscope (a device that shows 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**.

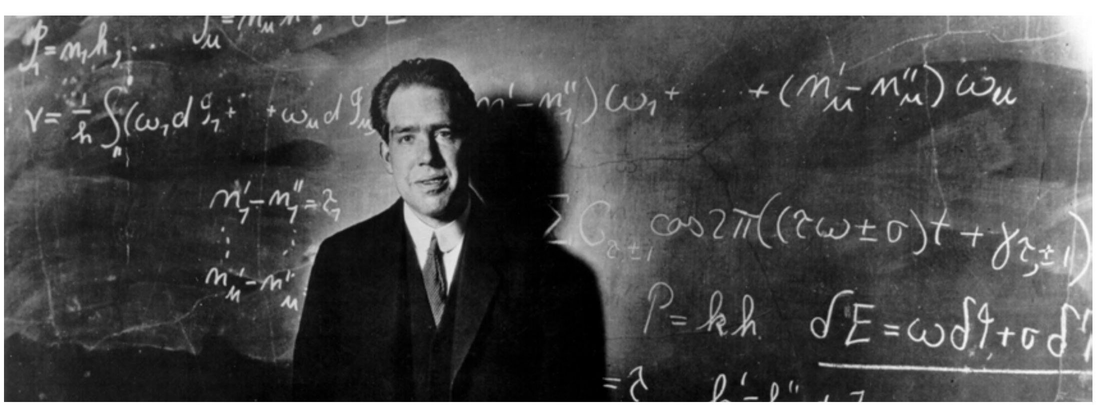


Figure 1 Niels Bohr proposed the idea of electron shells.

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 third shell can hold is $2 \times 3^2 = 18$.

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

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 further from the nucleus need more energy to stay in the high-energy shell. This arrangement applies to the elements of the periodic table up to the element calcium (Ca). This is because, up to calcium, electrons fill the shells in a simple order; however, after calcium, the pattern changes because the electrons fill the shells in more complex ways.

The arrangement of electrons in an atom is called its **electron configuration**. The electronic configurations of oxygen and calcium are compared in Figure 2.

Electron configurations are often represented by simple **shell diagrams** that show the electron shells as circles. The electrons are presented in pairs. The outermost occupied shell of uncharged atoms is known as the **valence shell**. The number of electrons in the valence shell of an atom determines the chemical properties of the element and affects how the atom will bond with other atoms.

electron configuration the arrangement of electrons of an atom, placed in electron shells centred on the 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 of an atom

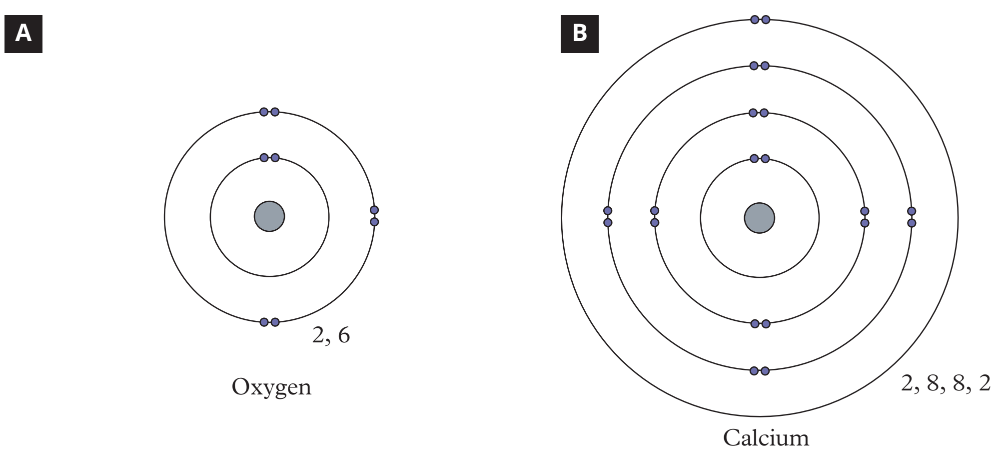


Figure 2 The electron configurations for oxygen (A) and calcium (B) are shown as simple shell diagrams.

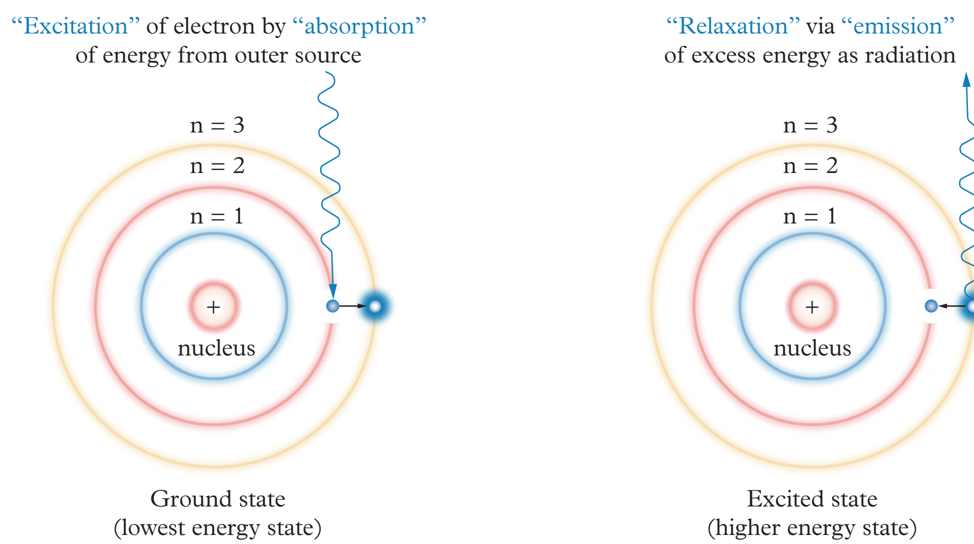
Evidence for electron shells

Many substances give off coloured light when a small sample is introduced into a flame. This pattern of coloured lines of light can be seen through a spectroscope. The pattern is known as an **emission spectrum** and is unique for each element.

emission spectrum the pattern of coloured lines of light that are seen through a spectroscope when an element is heated

Bohr explained the emission spectrum 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". This higher energy state is unstable, so the electrons almost instantly jump back to their normal levels (Figure 3). 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 (Figure 4).

An electron is accompanied by an emitted or absorbed amount of electromagetic energy through its jumps between energy levels (a.k.a "orbits").



When the electron gets moved from its original energy level to a higher one, it then jumps back each level until it comes to the original position, which results in energy being emitted.

Figure 3 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.

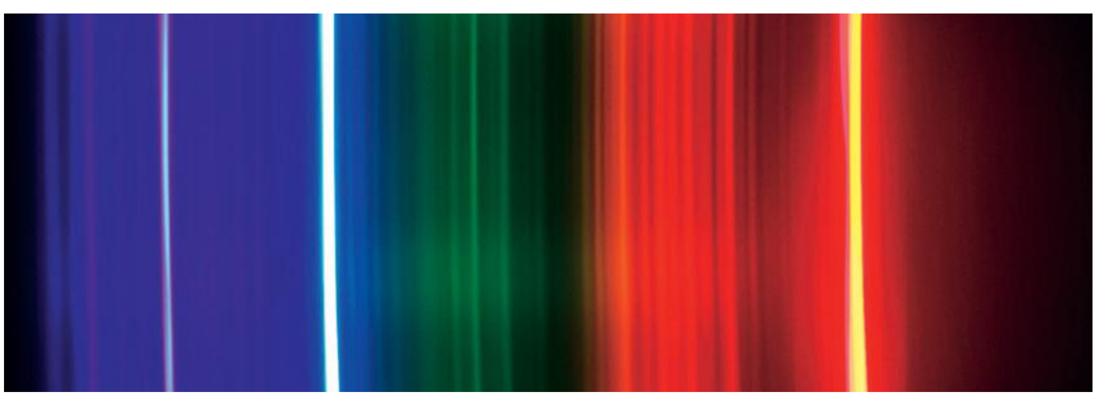


Figure 4 The emission spectrum of hydrogen

The development of the spectroscope allowed scientists like Bohr to identify the number and energy levels of electron shells that exist around different atoms.

Worked example 6.1A Determining electron configuration

Determine the electron configuration of:

a oxygen **b** chlorine.

Solution

Steps	What to do	Working out
a.	For part **a**, determine the atomic number of oxygen.	Oxygen has eight electrons
b.	Determine the period of oxygen on the periodic table.	Oxygen is found in period 2, so it has two electron shells
c.	Determine the number of electrons in each shell, knowing the first shell can hold two electrons and the second shell can hold eight electrons.	The electron configuration of oxygen is 2,6
d.	For part **b**, determine the atomic number of chlorine.	Chlorine has 17 electrons
e.	Determine the period of chlorine on the periodic table.	Chlorine is in period 3, so it has three electron shells
f.	Determine the number of electrons in each shell, knowing the first shell can hold two electrons, the second shell can hold a maximum of 18 electrons.	The electron configuration of chlorine is 2,8,7

Stable electron configuration

Atoms are most stable when they have a full valence shell. In order to achieve this, an atom will gain, lose or share electrons. When an atom does this, it becomes an ion. You will learn more about ions in Lesson 6.2 Ions have more or less electrons (page 215).

We can use an atom's **valency** to predict how many electrons it needs to either gain, lose or share to achieve a stable electron configuration.

valency the number of electrons an atom needs to lose, gain or share to have a full outer shell

valence electrons the electrons in the valency shell of an atom

Valence electrons

Valence electrons are the electrons in the valence shell, which is the outermost energy level (shell) of an atom. These are the electrons involved in chemical bonding because they are the easiest to lose, gain or share.

Example 1: The Oxygen (O) atom has six valence electrons because it has six electrons in its outer shell.

Example 2: The Sodium (Na) atom has one valence electron because it has one electron in its outer shell (Figure 5).

The valency of an element and its valence electrons are closely related, but they describe slightly different things about atoms.

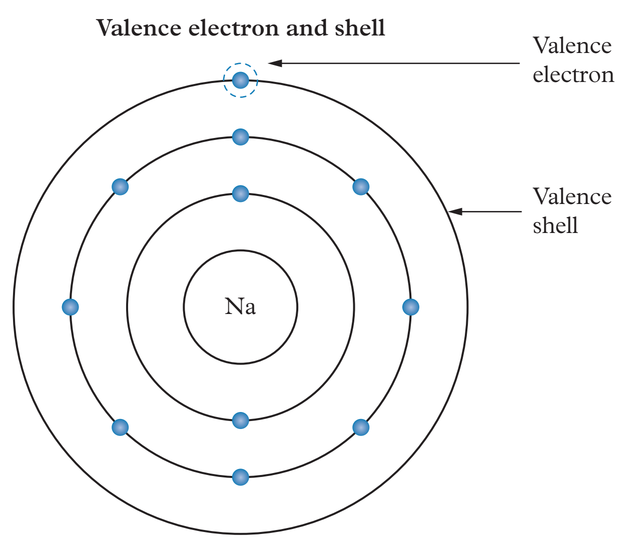


Figure 5 Sodium (Na) has one electron in its valence shell; therefore, it has a valency of one.

Valency

Valency is the number of electrons an atom needs to lose, gain or share to have a full outer shell. Valency tells us how an atom will bond with other atoms.

Example 1: Oxygen needs two more electrons to complete its outer shell of eight, so its valency is two.

Example 2: Sodium needs to lose one electron to have a full outer shell (the one before the valence shell) so it has a valency of one (Figure 5).

The periodic table

element a pure substance made of only one type of atom

atom the smallest particle of matter; cannot be created, destroyed or broken down (indivisible)

periods the horizontal rows of the periodic table; elements in each period have the same number of electron shells

octet a group or set of eight

The periodic table organises **elements** (or types of **atoms**) in rows and columns (Figure 6). 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.

Electron arrangement

The periodic table and the way it is organised is based on the number of protons an atom has, and therefore how many electrons it has and what shells they occupy.

Noble gases (Group 18; He, Ne, Ar, etc.) all have full outer shells, making them the most stable. The group next to it, Group 17 (F, Cl etc.), has seven electrons, meaning these elements need to gain just one electron to complete their **octet** and have a full outer shell.

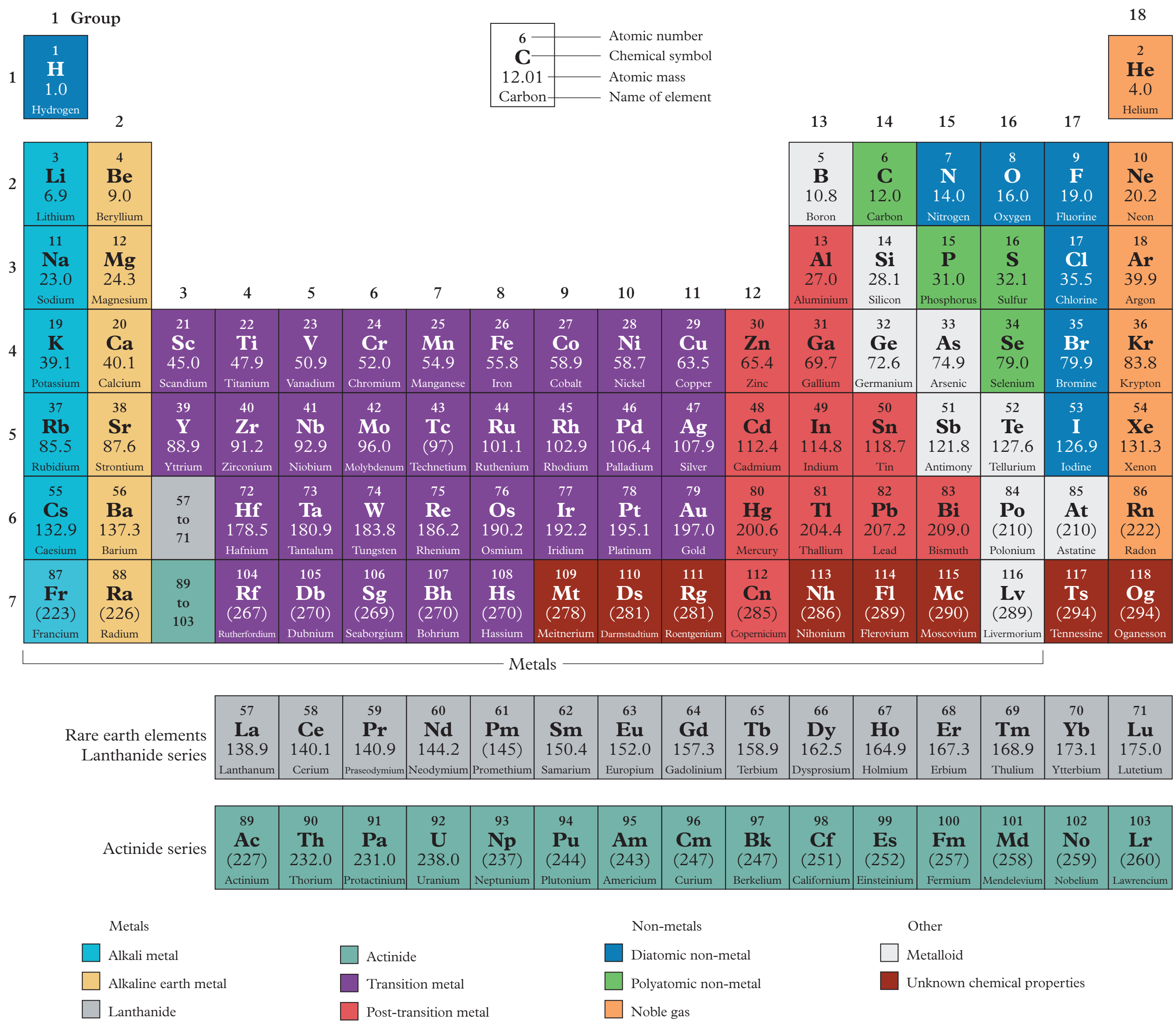


Figure 6 The periodic table of elements

These all have a valency of one. The Group 1 elements (H, Li, Na, etc.) on the far left of the periodic table all have only one electron in their outermost shell. This means they can achieve stability by losing only one electron; they will then have a full outer shell. It's easier (i.e. takes less energy) to lose one electron than to gain seven! Group 1 elements also have a valency of one.

Although Groups 1 and 17 both have valencies of one, the way they achieve it is different. Group 1 needs to lose an electron, while Group 17 needs to gain an electron.

groups the vertical columns of the periodic table; elements in each group have the same number of electrons in their valence shell

Electrons and properties of elements

Electron configurations can explain the properties of 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.

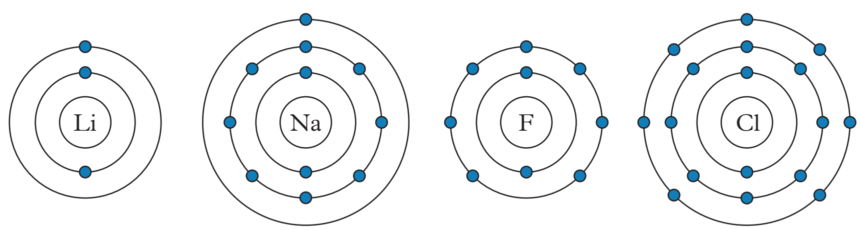


Figure 7 In Group 1, the electron configuration of lithium (Li) is 2,1 whereas that of sodium (Na) is 2,8,1. The atoms of all other Group 1 elements also have one electron in their outer valence shell of electrons. Elements in Group 17, such as fluorine (F) and chlorine (Cl), have seven valence electrons.

Group 18: The noble gases

The **noble gases**, such as neon and argon, are found in Group 18 on the far right of the periodic table. The uncharged atoms of the noble gases have eight electrons in their outer shell, except for helium, which has two. The noble gases are called this 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 6).

noble gases gases with a full electron shell; noble gases are extremely stable and do not easily react with other elements

inert a substance that does not react with other substances

Check your learning 6.1

Check your learning 6.1

Retrieve

1 Identify the maximum number of electrons in the:
   a first shell
   b second shell
   c third shell.
2 Identify where the different subatomic particles can be found, and their charges.
3 Explain how the periodic table can be used to determine the number of valence electrons in an element.

Comprehend

4 Describe how the structure of a Group 18 element makes it inert.
5 Determine the electron configuration of:
   a magnesium
   b phosphorus.
6 Fireworks are bright, colourful displays when used at events. Explain how firework technicians are able to produce different colours.

Figure 8 Fireworks use science to produce colourful displays in the night sky

Lesson 6.2
Ions have more or less electrons

Key ideas

→ Electrons have a negative charge.

→ Ions are atoms that have gained or lost electrons.

→ 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). If electrons are lost or gained from the outside of the atom, however, 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 two, eight and eight electrons respectively.

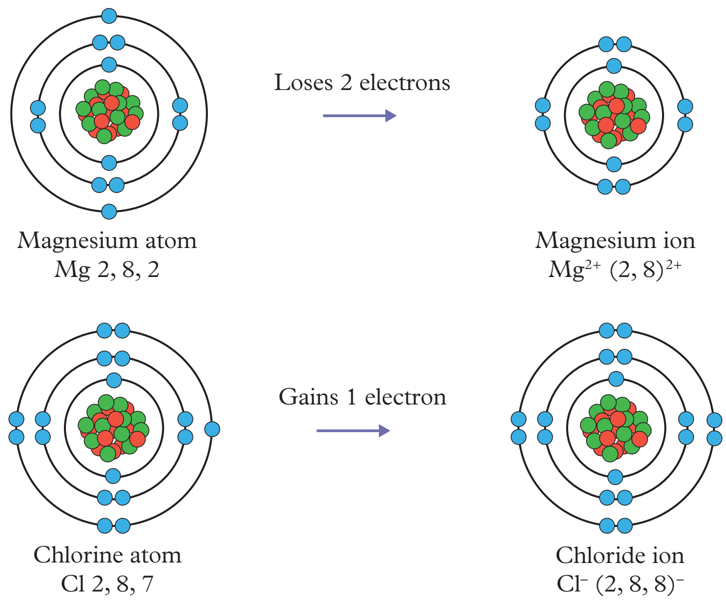


Figure 1 How magnesium and chloride ions are formed

ion an atom that has either a net positive or negative electrical charge

ionisation the process by which atoms become ions by losing or gaining electrons

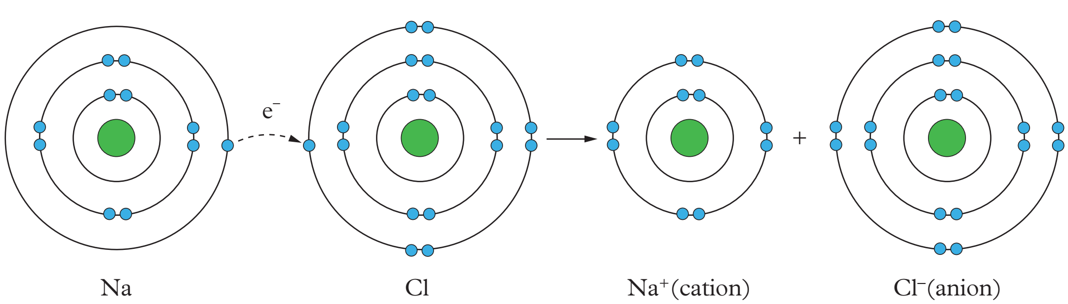


Figure 2 A sodium (Na) atom loses an electron to become a positively charged cation. Chlorine (Cl) gains an electron to become a negatively charged anion. This process forms sodium chloride, NaCl (also called salt).

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. This is because 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 and Figure 2 shows how sodium chloride (NaCl) is formed from the ions of sodium and chloride.

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 in the outer shell 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**.

anion a negatively charged ion; an anion has more electrons than protons

If an electron is lost from an atom, the resulting ion will have an overall positive charge because there are more protons than electrons. Losing one electron means there is effectively one extra proton. A positively charged ion is called a **cation**.

cation a positively charged ion; a cation has more protons than electrons

Table 1 contains some examples of anions and cations.

Figure 3 To remember the difference between cations and anions, think of a “paw”sitive CATion.

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 6.2A Calculating the charge of atoms

Determine the likely charge of the following atoms:

a sodium ion

b oxide ion

c neon atom.

Solution

Steps	What to do	Working out
a.	For part **a**, determine the group sodium is found in.	Sodium is found in Group 1
b.	In Group 1, these atoms only have one valence electron, which is easier to lose (rather than gaining seven electrons). This means the sodium ion will have one less negatively charged electron and have one more positive proton than electrons.	A sodium ion will have a charge of 1+ (or just +)
c.	For part **b**, determine the group oxygen is found in.	Oxygen is found in Group 16
d.	In Group 16, these atoms have six valence electrons. It is easier to gain two electrons than to lose six electrons. This means the oxygen ion will have two more negatively charged electrons.	An oxygen ion will have a charge of 2−
e.	For part **c**, determine the group neon is found in.	Neon is found in Group 18 (noble gas)
f.	In Group 18, these atoms have eight valence electrons and will not gain or lose electrons (stable outer shell).	Neon will have no charge

Check your learning 6.2

Check your learning 6.2

Retrieve

1 Define what an ion is.

Comprehend

2 Determine the charge on the following ions:

a fluorine

b aluminium

c beryllium.

3 Explain how the structure of the periodic table can help you determine the ionic charge of different elements.

Analyse

4 Contrast a cation and anion.

Apply

5 Construct a diagram to explain how the following ions are formed:

a sodium

b sulfur

c argon.

Lesson 6.3
Investigation: Modelling the formation of cations and anions

Purpose

To model the formation of cations and anions

Materials

- Periodic table
- Small coloured counters or beads (two colours: one for electrons, one for lost electrons)
- Large paper or mini whiteboards
- Markers

Procedure

1 Select an element from the following list.
  a Sodium (Na)
  b Magnesium (Mg)
  c Chlorine (Cl)
  d Oxygen (O)
  e Aluminium (Al)
  f Fluorine (F)
2 Determine the number of valence electrons by using the periodic table to find the number of electrons in the outermost shell.
3 Build the neutral atom.
  – Draw the nucleus on a large paper or whiteboard and write the number of protons and neutrons inside.
  – Place the correct number of counters around the nucleus to represent electrons in energy levels.
4 Form the ion.
  – If the element is a **metal**, remove the correct number of electrons to show cation formation and set them aside.
  – If the element is a **non-metal**, add the correct number of electrons to complete the outer shell, representing an anion.
5 Write the final ion formula by putting the correct ion symbol with its charge (e.g. Na^+, Cl^-).
6 Compare models by discussing in pairs or groups what happens to each type of element.
7 Record your findings (Table 1). Fill in the table with the element name, number of valence electrons, ion formed and its charge.

Results

Copy and complete Table 1.

Discussion

1 What happens to the number of electrons when an atom forms a cation? What about when it forms an anion?
2 How did the counters help you visualise how

Table 1 The electron loss or gain required to form cations and anions

Element name	Number of valence electrons	Ion formed	Charge of ion	Electron loss or gain

ions are formed?

3 What pattern did you notice in how metals and non-metals form ions?

4 Why do some atoms lose electrons while others gain them?

5 How does this activity help explain why ionic compounds form?

Lesson 6.4
Metal cations and non-metal anions combine to form ionic compounds

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.

Learning intentions and success criteria

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.

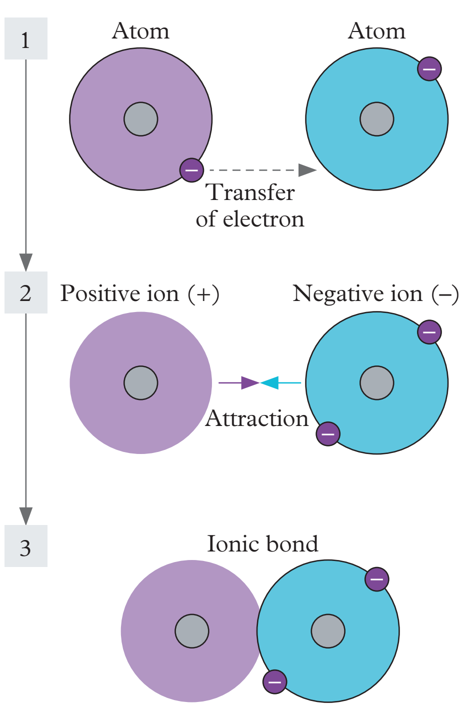


Figure 1 Ionic bonds form when a positive cation is attracted to a negative anion.

In contrast, the valence shells of most non-metal atoms are almost full. 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).

ionic bond a chemical bond formed from the electrostatic attraction between oppositely charged ions

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,

ionic compound a compound that is formed by ionic bonding; ionic compounds consist of both positively and negatively charged ions 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. These forces bind the ions together, so 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.

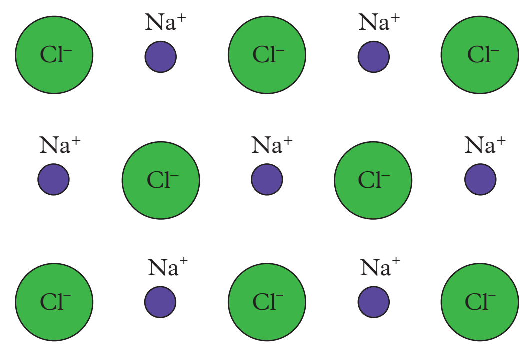


Figure 2 In an ionic compound, such as sodium chloride (NaCl), the ions are arranged in alternating positions.

Polyatomic ions

polyatomic ion an ion consisting of two or more atoms that have been bonded together

A number of ions are made up of two or more atoms. These are termed **polyatomic ions**. Figure 3 shows some examples of polyatomic ions.

These clusters of atoms have a charge because the total number of protons does not equal the total number of electrons present. For example, in the hydroxide ion, which is made up of two 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–.

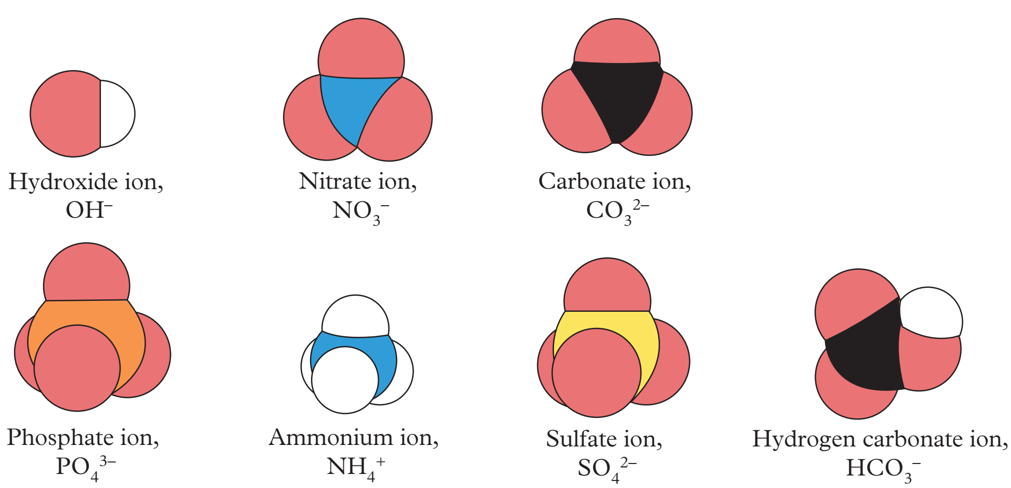


Figure 3 Some common polyatomic ions. A positive charge number indicates how many electrons have been lost. A negative charge number indicates how many electrons have been gained.

Names of common polyatomic ions

Table 1 Names and formulas of common polyatomic ions

Polyatomic ions	Formula
Ammonium ion	NH_4^+
Carbonate ion	CO_3^{2-}
Hydroxide ion	OH^-
Nitrate ion	NO_3^-
Nitrite ion	NO_2^-
Phosphate ion	PO_4^{3-}
Sulfate ion	SO_4^{2-}
Sulfite ion	SO_3^{2-}
Hydrogen carbonate ion	HCO_3^-

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 charge equals the total negative charge. This means the final compound, calcium carbonate ($CaCO_3$), will be neutral, which demonstrates 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.

IUPAC naming conventions – ionic compounds

The International Union of Pure and Applied Chemistry (IUPAC) is the international authority responsible for ensuring there is a consistency in how we name chemical compounds. This ensures that, regardless of where you are in the world, chemists speak the same language when referring to compounds.

When naming ionic compounds, we adhere to the simple principle of "cation first, anion second", meaning we always start with the name of the cation first, followed by the name of anion.

The following rules should be applied when naming ionic compounds.

1 When both ions are **monatomic**, use the element name for the metal cation (e.g. sodium for Na^+ or magnesium for Mg^{2+}). For the non-metal anion, the element name is modified to end in -ide (e.g. chloride for Cl^- or oxide for O^{2-}).

2 When the cation or anion is polyatomic, use the name of the ion, without the word "ion" (e.g. lithium hydroxide or ammonium nitrate).

3 If you have a metal cation that can have more than one charge (i.e. transition metals), use roman numerals to indicate which one you are using (e.g. iron can become either Fe^{2+} or Fe^{3+}). So, if either of these formed a compound with carbonate, they would be called iron (II) carbonate and iron (III) carbonate respectively.

monatomic an ion consisting of single, isolated atoms that are not bonded together

Worked example 6.4A Determining names of ionic compounds

Determine the names of the following ionic compounds.

a $MgCl_2$ **b** $Na_3(PO_4)$ **c** $Cu(NO_3)_2$

Solution

Steps	What to do	Working out
a.	The elements in the compound $MgCl_2$ are magnesium and chlorine. Both ions (Mg^{2+} and Cl^-) are monatomic. • Magnesium is the cation (positively charged), so its name goes first. • The element name is used for the cation (magnesium). • Chlorine is the anion (negatively charged), so its name goes second. • The anion's element name is modified to end in "-ide", so chlorine becomes chloride.	The name for $MgCl_2$ is "magnesium chloride"
b.	The elements in the compound $Na_3(PO_4)$ are sodium and phosphate. Phosphate is made of multiple elements (phosphorus and oxygen) and is therefore polyatomic. • Sodium is the cation (positively charged), so its name goes first. • The element name is used for the cation (sodium). • Phosphate is the anion (negatively charged), so its name goes second. • The polyatomic ion name is used for the anion (phosphate).	The name for $Na_3(PO_4)$ is "sodium phosphate"
c.	The elements in the compound $Cu(NO_3)_2$ are copper and nitrate. Nitrate is made of multiple elements (nitrogen and oxygen) and is therefore polyatomic. • Copper is the cation (positively charged), so its name goes first. • The element name is used for the cation (copper). • Nitrate is the anion (negatively charged), so its name goes second. • The polyatomic ion name is used for the anion (nitrate). • Copper is a transition metal, so it can have multiple charges. Work backwards from the number of each of cation and anion to determine the charge of the transition metal. – There are two nitrates and they each have a charge of –1. – The charge of copper must therefore be +2. • Roman numerals are used to indicate the charge of the transition metal (copper).	The name for $Cu(NO_3)_2$ is "copper (II) nitrate"

Check your learning 6.4

Check your learning 6.4

Retrieve

1 Explain how ionic compounds are formed.

2 Identify the force that binds ions together.

3 Identify a characteristic of ionic compounds.

Comprehend

4 Determine the names of the following ionic compounds:

a NaOH

b $Ca(CO_3)$

c Al_2O_3.

5 Determine the ionic formulas for:

a potassium bromide

b barium sulfate

c iron (III) oxide.

6 Explain how the charge of the ion determines the ratio in which they combine to form neutral compounds.

Apply

7 Use the information from Figure 3 to determine the formula of the following ionic compounds:
  a a calcium cation and a hydrogen carbonate anion
  b a sodium cation and a carbonate anion
  c a magnesium cation and a hydroxide anion.

8 Answer the following questions.
  a Explain what it means when an atom gains or loses electrons. Identify what kind of particle is formed.
  b Look at aluminium (Al) from Group 13.
    i Identify how many electrons it will lose when it forms an ion.
    ii Determine the charge on the aluminium ion.
  c Now look at phosphorus (P) from Group 15.
    i Identify how many electrons it will gain when it forms an ion.
    ii Determine the charge on the phosphorus ion.
  d Think about carbon (C) in Group 14.
    i Explain why it is harder to predict how many electrons carbon will gain or lose.
    ii Explain if it always forms the same type of ion.
  e Based on your answers to parts b to d:
    i determine the maximum number of electrons any atom might gain or lose when forming an ion.
    ii explain how you worked this out, using examples.

9 Draw or describe a model to show how the following atoms form cations or anions. Include electron transfer where applicable.
  a Sodium forming a cation
  b Chlorine forming an anion
  c Magnesium forming a cation
  d Oxygen forming an anion

Lesson 6.5

Non-metals combine to form covalent compounds

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 is used to explain the compound's properties.

Learning intentions and success criteria

Introduction

When electrons are transferred from one atom to another, positive and negative ions are produced and ionic compounds are formed. 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).

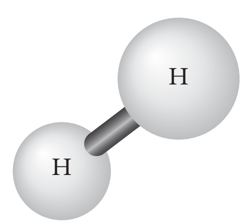


Figure 1 The ball-and-stick model is often used to show atoms (balls) and the bonds (sticks) between them. This image shows a ball-and-stick model of a hydrogen (H_2) molecule.

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 hydrogen atom.

As two uncharged hydrogen atoms come close together, the electrons are drawn into the region between each atom's nucleus. 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.

covalent bond a chemical bond involving the sharing of electrons between atoms; the sharing of electrons creates a stable electron configuration within the atoms

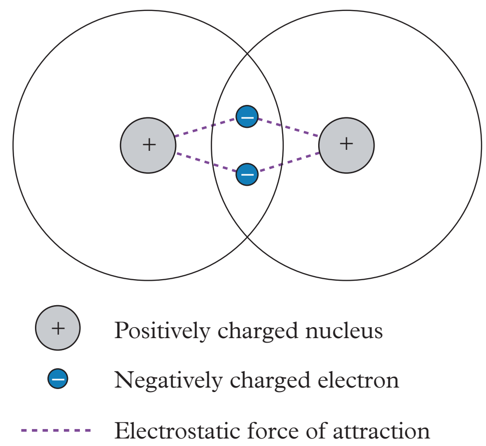


Figure 2 Some diagrams of molecules show the electrons being shared between the atoms.

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.

molecule a group of two or more atoms connected by chemical bonds; a molecule is the smallest unit of a substance that retains its properties

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:

diatomic molecule a molecule that is composed of two atoms of the same or different chemical elements

- fluorine (F_2) and chlorine (Cl_2), where one pair of electrons are shared. This is known as a single covalent bond.
- oxygen (O_2), where two pairs of electrons are shared. This is known as a double covalent bond.
- nitrogen (N_2), where three pairs of electrons are shared. This is known as a triple covalent bond.

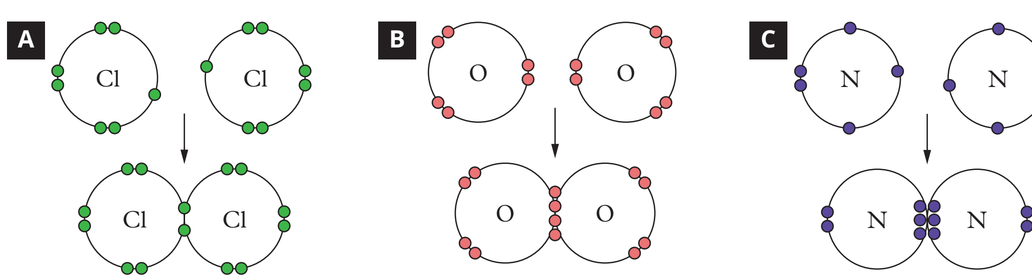


Figure 3 Chlorine (A) is an example of a diatomic molecule where one pair of electrons are shared, whereas in oxygen (B), two pairs of electrons are shared and in nitrogen (C), three pairs of electrons are shared.

In a molecule such as the hydrogen molecule, there is strong electrostatic attraction between the shared electrons and the positively charged nuclei.

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.

molecular compound a compound composed of two or more non-metal atoms held together by chemical bonds

Molecular compounds

Molecules can also form by combining different 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, needs one more electron
- an uncharged oxygen atom, which has six valence electrons, needs 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 4. Notice that each atom now has a full, stable outer shell of electrons.

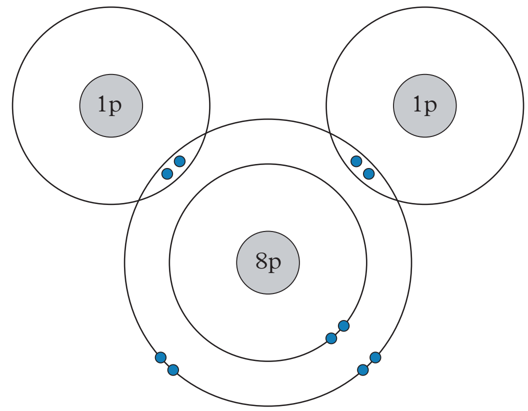


Figure 4 A shell diagram of a water molecule (H_2O)

There are other ways of representing the structure of molecules, including with three-dimensional (3D) models (Figure 1 and Figure 5, for example). Remember, however, 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.

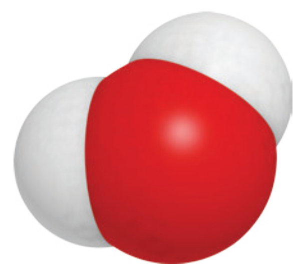


Figure 5 A 3D model is often used to show the arrangement of atoms in a molecule. This 3D model represents a water molecule (H_2O).

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.

IUPAC naming conventions – covalent molecules

When naming covalent molecules, we need to be familiar with some Greek prefixes to indicate the number of atoms.

Number of atoms	Greek prefix	Number of atoms	Greek prefix
1	mono (usually not included for the first element)	6	hexa
2	di	7	hepta
3	tri	8	octa
4	tetra	9	nona
5	penta	10	deca

The following basic principles are used to name covalent molecules:

- For the first element: Greek prefix + element name.
- For the second element: Greek prefix + element name stem + “-ide”.

There are some exceptions to this rule; for example, when a covalent compound has a common name, such as water (H_2O) and ammonia (NH_3).

Worked example 6.5A Determining the name of covalent molecules

Determine the names of the following covalent molecules.

a CO **b** CO_2 **c** N_2O_4

Solution

Steps	What to do	Working out
a.	For part **a**, determine the elements in CO.	• There is one carbon atom, but the Greek prefix “mono” is not included as it is the first element. • There is one oxygen atom, and the Greek prefix “mono” is used as it is the second element. The element name stem is changed to “-ide”. The name for CO is “carbon monoxide”.
b.	For part **b**, determine the elements in CO_2.	• There is one carbon atom, but the Greek prefix “mono” is not included as it is the first element. • There are two oxygen atoms, so the Greek prefix “di” is used. The element name stem is changed to “-ide”. The name for CO_2 is “carbon dioxide”.
c.	For part **c**, determine the elements in N_2O_4.	• There are two nitrogen atoms, so the Greek prefix “di” is used. • There are four oxygen atoms, so the Greek prefix “tetra” is used. The element name stem is changed to “-ide”. The name for N_2O_4 is “dinitrogen tetraoxide”.

Check your learning 6.5

Check your learning 6.5

Retrieve

1 Define the term “covalent compound”.

2 Define the term “diatomic molecule”.

3 Identify the types of atoms (metals, non-metals) that form covalent bonds.

Comprehend

4 Describe how a covalent compound is formed.

5 Explain why molecular substances cannot conduct electricity.

6 Explain why carbon dioxide has the formula CO_2. (HINT: It has covalent bonding.)

Analyse

7 Calculate the number of electrons needed to be shared between two chlorine atoms when they combine to form a molecule.

8 Compare the process of forming chlorine molecules to the process of forming an oxygen molecule.

9 Compare ionic bonding and covalent bonding.

10 Determine the IUPAC name of the following covalent compounds.

a SO_3

b N_2O

c CCl_4

Apply

11 Write the correct chemical formulas for the following common covalent molecules.
  a Carbon dioxide
  b Sulfur dioxide
  c Dinitrogen pentoxide
  d Phosphorus trichloride

Lesson 6.6
Investigation: Modelling covalent molecules

Figure 1 The structural arrangement of molecules can be modelled.

Purpose

To model the sharing of electrons in covalent molecules

Materials

Molecular modelling kits (or use different coloured marshmallows and toothpicks)

Procedure

1 Choose three different colours to represent carbon, hydrogen and oxygen.
2 For each of the molecules shown in Table 1:
  a provide the names of the atoms in the molecule
  b state the number of each atom
  c make and draw a model of the molecules
  d draw the number of electrons in the valence shell of each atom, including the shared electrons.

Results

Copy and complete Table 1.

Table 1 Investigation results

Molecule	Atoms present	Number of each atom	Model	Electron dot diagram
H_2				
H_2O				
CH_4				
CO_2				

Discussion

1 Identify and describe the type of bond that occurs between two non-metals.
2 Define the term “valence shell”.
3 Explain the meaning of the term “sharing electrons” in covalent bonds.

Conclusion

Describe a covalent bond and the elements that form this bond.

Lesson 6.7
Metals form unique bonds

Learning intentions and success criteria

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). These properties are due to 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).

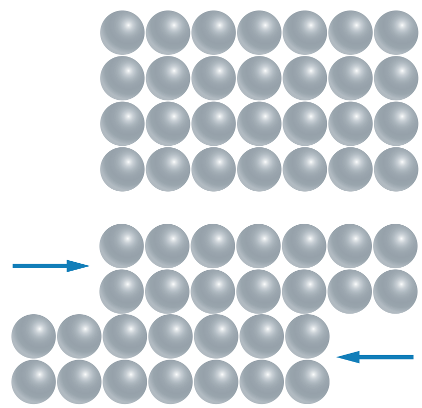


Figure 1 The arrangement of atoms in metals allows them to slide over each other when the metals are bent or hammered into shape.

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 why metals are so good at conducting electricity.

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), while most of the other electrons remain localised, moving 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 electrons electrons that are not restricted to a single atom or covalent bond

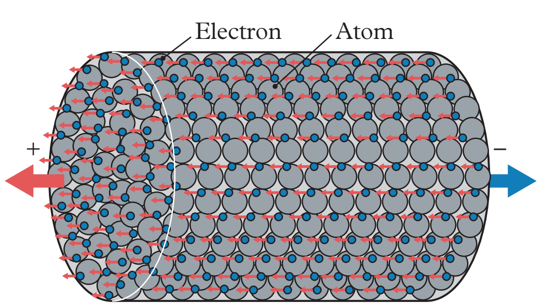


Figure 2 Delocalised electrons move about randomly in a metal, but they move towards the positive terminal of a power source when connected in a circuit.

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 shows the electrical conductivity (how well a material allows the flow of electric current) of some common elements at 25°C.

All metals conduct electricity in the solid state, some better than others. They continue to conduct electricity when they are molten liquid, but not as well as when they are in the solid state. The higher the temperature, the lower a metal's electrical conductivity.

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.

Table 1 Electrical conductivities of some common elements at 25°C

Element	Electrical conductivity (S/m)
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

Delocalised electrons are responsible for a pure metal being lustrous (shiny). The delocalised electrons in its surface reflect light extremely well (Figure 3).

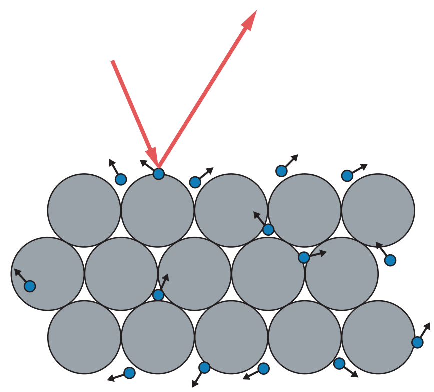


Figure 3 The delocalised electrons in the surface of a metal reflect light and cause it to be lustrous.

Metal alloys

A metal alloy occurs when a metal is mixed with another metal or compound. The atoms in an alloy are different sizes, so 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

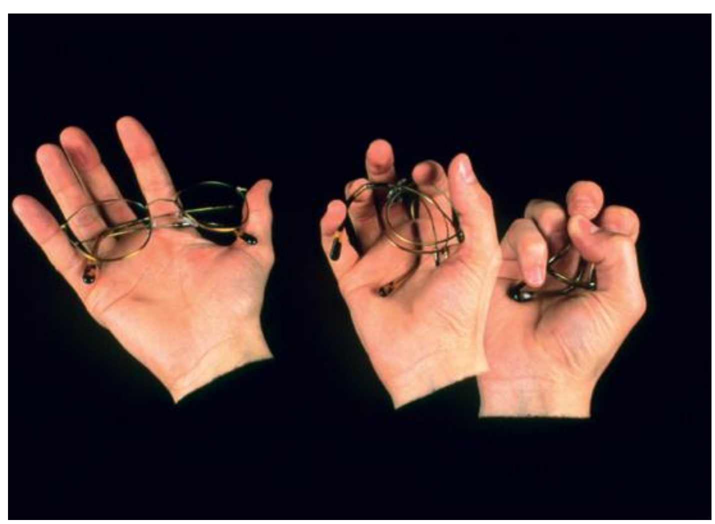


Figure 4 Memory wire is useful in eyeglass frames, allowing them to be bent out of shape without breaking.

or electrical current can cause it to return to its original shape. These metals are often called memory alloys (Figure 4). Gold bonding wire (Figure 5) is used in integrated circuits, taking advantage of gold's excellent conductivity and resistance to corrosion, making it essential in electronic applications.

An example of memory wires are those used in orthodontic braces. The wires will constantly return to their original shape, reducing the need to re-tighten or adjust the wire.

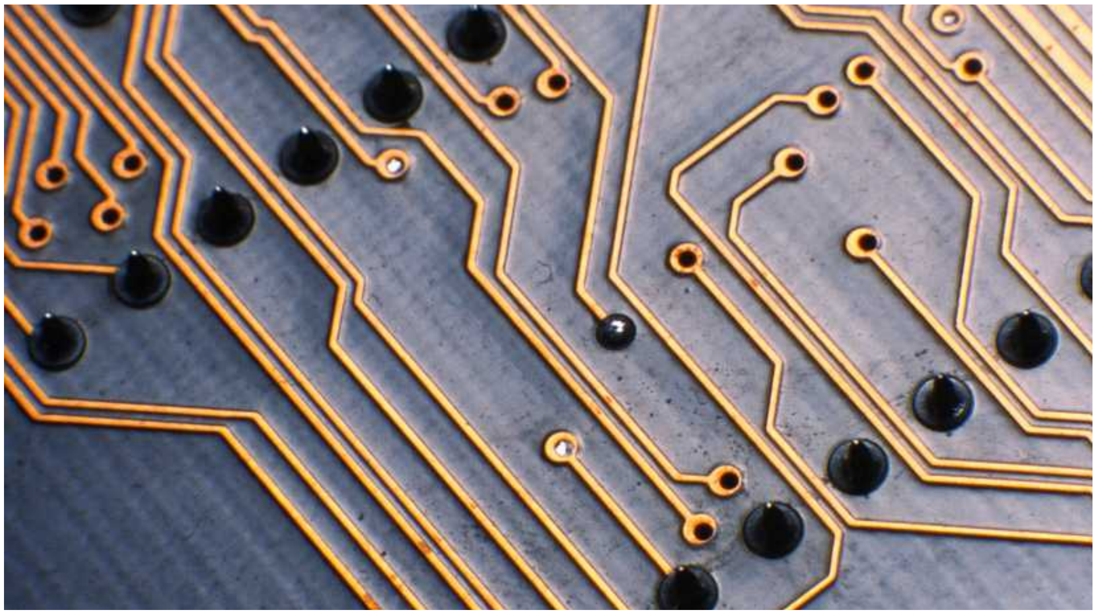


Figure 5 Gold bonding wire is used in integrated circuits.

Check your learning 6.7

Check your learning 6.7

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 needs brain surgery (by comparing the properties of NiTi to the properties of the skull and deciding whether NiTi will be effective).

Lesson 6.8

Investigation: Comparing properties of ionic, covalent and metallic substances

Purpose

To investigate and compare the physical and chemical properties of ionic, covalent and metallic substances and relate these properties to their real-world applications

Materials

- Samples of the following substances:
  - ionic: sodium chloride (table salt), copper(II) sulfate
  - covalent: sugar (sucrose), paraffin wax
  - metallic: copper wire, aluminium foil
- Tongs
- Test tubes
- Test-tube rack
- Distilled water
- Stirring rod
- Petri dish for each substance
- Conductivity probe*
- Crucible
- Heat source (e.g. Bunsen burner with a tripod and gauze or a hot plate)
- Thermometer
- 60 mL 0.1 M HCl

*If you don't have access to a conductivity probe, set up an electrical circuit (Figure 1) and follow the method "Alternative method for conductivity" below.

Procedure

Part A: Observation of physical properties

1 Add each substance to a Petri dish.
2 Examine the appearance of each substance (e.g. colour, texture, lustre).
3 Record whether the substance is hard, brittle or malleable.
4 Retain these samples for part C.

Part B: Testing solubility

1 Place a small amount of each substance into separate test tubes.
2 Add 10 mL of distilled water to each test tube and stir gently.
3 Record whether the substance dissolves completely, partially or not at all.
4 Retain these samples for part C.

Part C: Testing conductivity

1 Test the conductivity of each substance in its solid form using the conductivity probe* in the Petri dish. Retain this sample for part D.
2 If a substance dissolves in water (from part B), test the conductivity of the solution.
3 Record your observations.

Part D: Chemical reactivity

1 Take the solid sample from part C (that was in the Petri dish) and add it to a clean test tube.
2 Add 10 mL 0.1 M HCl to each substance and observe any reaction (e.g. gas production, temperature change).
3 Record your observations.

Part E: Testing melting point (heat resistance)

1 Place a small piece of each substance in a crucible and place it over a heat source.
2 Record whether the substance melts, burns or changes state, noting the temperature range at which this occurs (if measurable).

Alternative method for conductivity

Materials

- 4 V battery or other 4 V DC power supply
- Ammeter
- Large spatula
- Small Petri dish
- 2 graphite electrodes (for liquids)
- Sodium chloride (table salt)
- One 100 mL beaker
- Water
- Glass stirring rod
- Wires with alligator clips (for solids)
- 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.
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 results.
3 Place half a large spatula of sodium chloride crystals into a 100 mL beaker 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 results.
5 Turn off the power supply and rinse the electrodes with fresh tap water, then dry them with a paper towel.

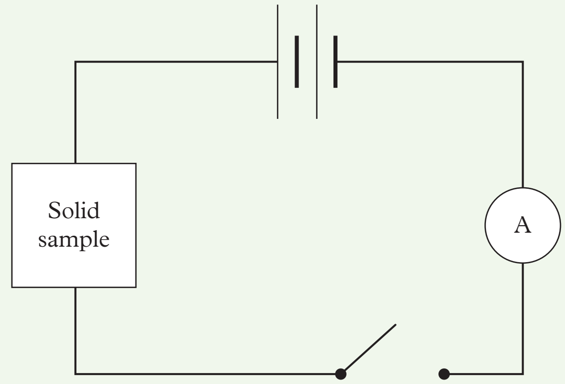


Figure 1 Series circuit set-up to test solid samples

Results

Create a table or spreadsheet to record your observations for each substance.

Discussion

1 Compare the solubility and conductivity results for ionic, covalent and metallic substances.
2 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.
3 Describe how dissolving an ionic compound in water changes its ability to conduct electricity.
4 Describe how the melting point or heat resistance relates to the bonding type in each substance.
5 What do the results tell you about the types of bonding present in these substances?
6 Explain how the observed properties of each substance relate to its typical uses in daily life or industry.
7 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).

Lesson 6.9
Compounds can be organic or inorganic

Key ideas

→ Inorganic compounds do not contain C–H bonds, while organic compounds are primarily made of carbon bonded to hydrogen, oxygen, nitrogen or other elements.

→ Alkanes are saturated hydrocarbons with only single bonds, following the formula $C_{\square}H_{2\square+2}$, making them stable and commonly used as fuels.

→ The IUPAC naming system for alkanes is based on the longest carbon chain, using prefixes (e.g. "meth-", "eth-", "prop-") and the suffix "-ane" (e.g. ethane, butane).

→ Alkanes can have straight or branched structures, affecting their physical properties but not their chemical formula.

→ Alcohols contain the hydroxyl (–OH) functional group, and their names include a number indicating its position in the chain, ending in "-ol" (e.g. butan-2-ol).

→ Carboxylic acids contain the carboxyl (–COOH) group, always on the first carbon, and are named with the suffix "-oic acid" (e.g. ethanoic acid, butanoic acid).

→ The naming of alcohols and carboxylic acids follows similar rules to alkanes, using carbon chain length and functional group placement.

→ Understanding the structure and naming of organic compounds helps predict their properties and reactions.

Learning intentions and success criteria

Inorganic compounds

Inorganic compounds encompass all chemical compounds that are not classified as organic. Inorganic compounds may contain carbon, but typically lack the C–H bonds characteristic of organic compounds. Inorganic chemistry studies these substances and their interactions.

inorganic compound a chemical compound that does not have any carbon–hydrogen bonds

Organic compounds

Organic compounds are chemical compounds that primarily consist of carbon atoms bonded to hydrogen, oxygen, nitrogen, sulfur or other elements. These compounds are the basis of life on Earth and are found in all living organisms. They are also found in synthetic substances like plastics. Organic chemistry focuses on the study of these compounds, their reactions and their structures.

Table 1 outlines the key differences between organic and inorganic compounds.

organic compound a chemical compound that has carbon–hydrogen bonds

Table 1 Key features of organic and inorganic compounds

Feature	Organic compounds	Inorganic compounds
Primary elements	Carbon and hydrogen	Diverse (e.g. metals, non-metals, ions)
Bonding type	Covalent	Ionic and covalent
Complexity	Often complex	Often simpler
Flammability	Mostly flammable	Mostly non-flammable
Occurrence	Found in living organisms and synthetic products	Found in minerals, salts and industrial products
Examples	Glucose, proteins, plastics	NaCl, CO_2, H_2SO_4

Alkanes

alkane an organic compound that only includes carbon and hydrogen atoms

octet rule where the valence shell of an electron has eight electrons

Alkanes are one of the simplest groups of organic compounds, forming the building blocks of many substances we encounter daily. These compounds consist only of carbon and hydrogen atoms, connected by single bonds in a chain-like structure. Each carbon atom in an alkane is surrounded by four bonds, ensuring that it follows the **octet rule**. Examples of alkanes include methane (CH_4), the main component of natural gas, and propane (C_3H_8), commonly used in gas cylinders for cooking and heating.

One of the defining features of alkanes is their general formula, C_nH_{2n+2}, where n represents the number of carbon atoms. This pattern allows chemists to predict the molecular formula of any alkane in the series. Alkanes are also known as "saturated hydrocarbons" because they have the maximum number of hydrogen atoms attached to each carbon atom, with no double or triple bonds. This saturation makes alkanes relatively unreactive compared to other organic compounds, which is why they are often used as fuels and solvents.

IUPAC naming conventions – alkanes

IUPAC provides a systematic naming convention for organic compounds. The following rules should be applied when naming alkanes.

1. Identify the longest continuous chain of carbon atoms. This determines the root name.
2. Use prefixes to indicate the number of carbon atoms in the chain (e.g. "meth-" for one carbon) as shown in Table 2.
3. Add the suffix "-ane" to indicate that the compound is an alkane.
4. Combine the root name and suffix to name the compound. For example:
   - two carbons = ethane
   - four carbons = butane.

Table 2 Names of simple alkanes with one to eight carbons

Number of carbons (n)	Prefix	IUPAC name of alkane (suffix-ane)	Formula C_nH_{2n+2}
1	meth-	methane	CH_4
2	eth-	ethane	C_2H_6
3	prop-	propane	C_3H_8
4	but-	butane	C_4H_{10}
5	pent-	pentane	C_5H_{12}
6	hex-	hexane	C_6H_{14}
7	hept-	heptane	C_7H_{16}
8	oct-	octane	C_8H_{18}

Structure of simple alkanes

Understanding the structures of simple alkanes helps us visualise their properties and reactions. Alkanes consist of carbon atoms bonded in a straight or branched chain, with hydrogen atoms filling all available bonding sites.

Steps to reproduce simple alkane structures

1 Draw the carbon backbone by arranging the carbon atoms in a straight line (Figure 1).

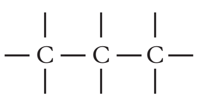


Figure 1 Carbon atoms arranged in a straight line

2 Add hydrogen atoms. Ensure that each carbon has four bonds in total (Figure 2).

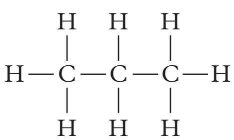


Figure 2 Hydrogen atoms added to the carbon backbone

Other simple organic compounds

Organic alcohols are a family of organic compounds that include the functional group –OH (hydroxyl-) bonded to a carbon. This group can be bonded to any carbon in a chain.

Carboxylic acids are organic compounds that are acidic in nature. These include the functional group –COOH (Figure 3).

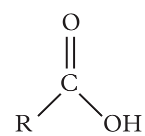


Figure 3 General chemical structure of the –COOH functional group. The “R” represents the rest of the chain, which is commonly made up of carbons and hydrogens.

IUPAC naming conventions – other simple organic compounds

IUPAC names organic alcohols and carboxylic acids using steps similar to those used for naming alkanes.

Rules for naming alcohols

1 Identify the longest continuous chain of carbon atoms. This determines the root name.

2 Use prefixes to indicate the number of carbon atoms in the chain (e.g. “meth-”, “eth-”, “but-”).

3 Number the carbon chain.

  a Start numbering the chain from the end closest to the functional group (–OH), so that the functional group is located on the carbon with the smallest number (Figure 4).

  b Assign the number to the carbon that has the –OH group. If there is only one option (e.g. methanol), then this step is ignored.

4 Insert the position of the –OH group in the name.
   a Place the number after the root name (e.g. "butan-2"). Use a hyphen to separate the parts. The "an" communicates that there are only single bonds in the main chain.
5 Add the suffix "-ol".
6 Combine the root name, –OH group position number and suffix to name the compound. For example:
   – propan-2-ol has the –OH on the second carbon of a three-carbon chain
   – butan-2-ol has the –OH on the second carbon of a four-carbon chain.

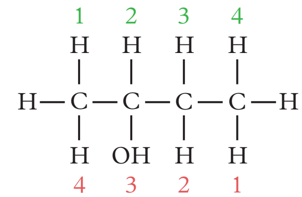


Figure 4 The green numbers at the top show the –OH group on the second carbon is a smaller number than the red numbers at the bottom, which show the –OH group on the third carbon. Therefore, this compound is butan-2-ol.

Rules for naming carboxylic acids

1 Count the carbons in the chain.
2 Use the same base names as for alkanes.
3 Add the suffix "-oic acid". The –COOH group is always on the first carbon, so numbering is not needed.
4 Combine the base name and suffix to name the compound. For example:
   – two carbons = ethanoic acid
   – four carbons = butanoic acid.

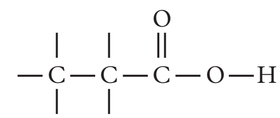


Figure 5 Propanoic acid has three carbons; one of these belongs to the –COOH group and the other two form the "R" group from Figure 3.

Check your learning 6.9

Check your learning 6.9

Retrieve

1 Identify the key elements found in organic compounds.
2 Identify the compound represented by C_5H_{12}.

Comprehend

3 Describe the primary differences in bonding types between organic and inorganic compounds.
4 Describe the general process for naming simple alkanes using the IUPAC naming system.
5 Explain why carbon dioxide (CO_2) is classified as an inorganic compound despite containing carbon.

Analyse

6 Examine Table 1 (comparing organic and inorganic compounds) and discuss how their differences influence their uses in various industries.

Apply

7 Recreate Table 2 and add two more columns: "Name of C-1 alcohol" (–OH is on the first carbon) and "Name of carboxylic acid".
8 Name the four compounds in Figure 6.

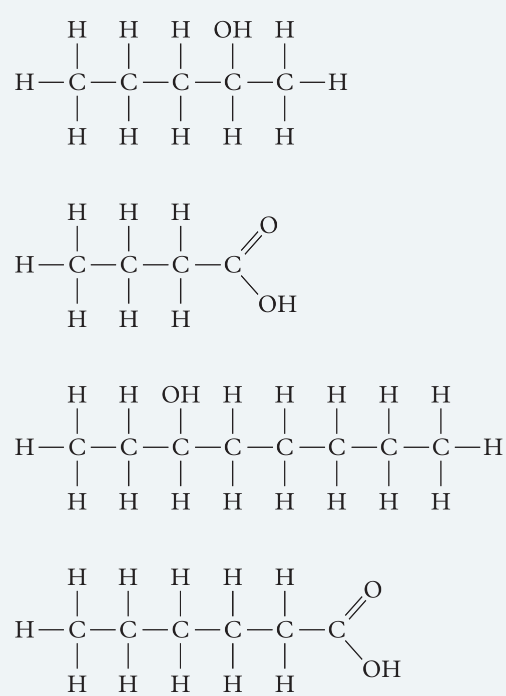


Figure 6 Structural diagrams of four compounds

Lesson 6.10

Hydrocarbons can be separated from crude oil

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.

Learning intentions and success criteria

Our carbon economy

The chemical fuels that our society relies on are based on carbon. Our ancestors burnt wood, which is mainly the carbon compound cellulose. Later generations burnt coal, which comes from buried plant remains that have been naturally dehydrated and compacted underground for millions 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, which is made of carbon and hydrogen, as a liquid fuel for transport.

All these fuels contain molecules made of carbon. Petrol is mostly octane, or $C_8H_{18}(l)$, 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, or $C_3H_8(l)$.

Fossil fuels such as petrol, diesel, natural gas and LPG are derived from **hydrocarbons** found in crude oil, a naturally occurring substance extracted from underground reservoirs. The energy in these hydrocarbons (Figure 1) was originally captured by photosynthesis millions of years ago, and the carbon they contain has remained locked away beneath the Earth's surface. When fossil fuels are burned, this carbon is released into the atmosphere as carbon dioxide. Crude oil is a valuable resource because it can be refined into various useful products, including fuels, lubricants and raw materials for the chemical industry.

hydrocarbon a molecule that contains only carbon and hydrogen atoms

In contrast, renewable fuels like biodiesel and ethanol also contain carbon atoms, but this carbon was recently captured through photosynthesis during the last growing season. Unlike fossil fuels, which release carbon that has been stored for millions of years, renewable fuels recycle carbon already present in the environment, making them a more sustainable energy source.

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.

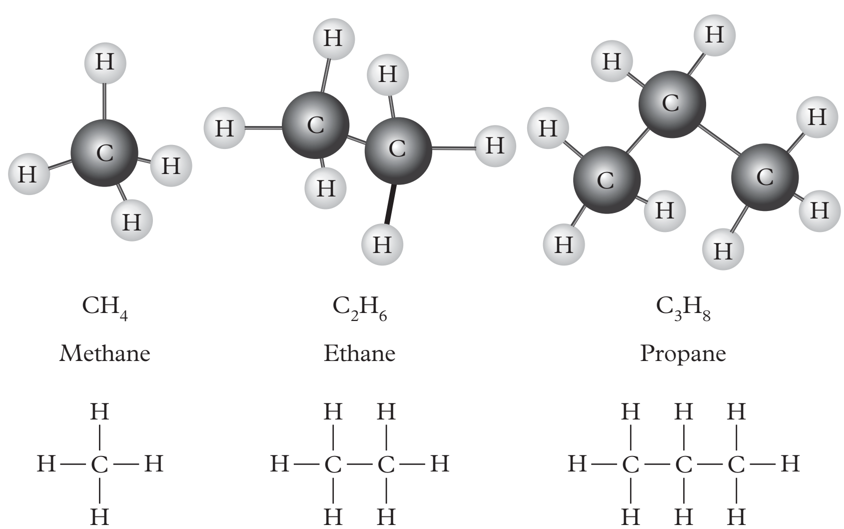


Figure 1 Hydrocarbons are compounds containing only carbon and hydrogen molecules.

Fractional distillation

Fractional distillation is a process used to separate the various components of crude oil into fractions based on their boiling points. Crude oil is first heated in a furnace, causing it to vaporise. The vapour then enters a distillation column, a tall tower that is cooler at the top and hotter at the bottom. As the vapour rises, the temperature decreases and the different hydrocarbons condense at different heights in the column, forming fractions (Figure 2).

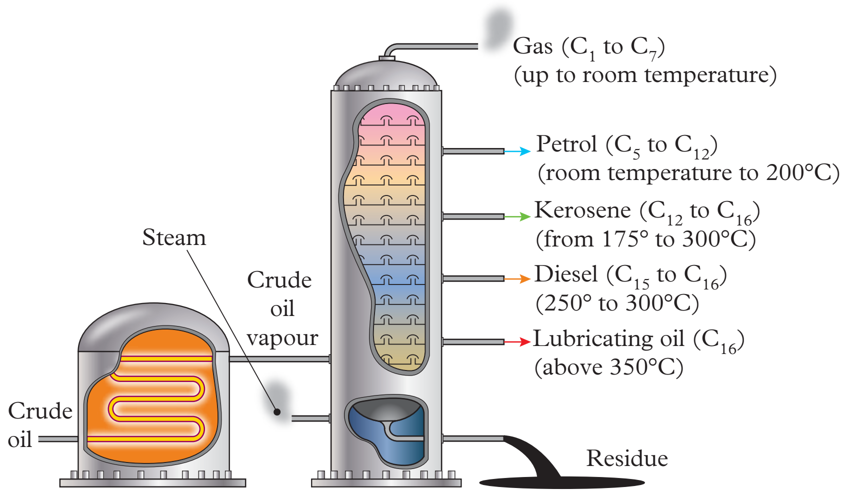


Figure 2 As crude oil is slowly heated, vapour (gas) forms. As the vapour rises, it cools. When the vapour reaches the height where the temperature is equal to the fraction's boiling point, it condenses into a liquid.

Figure 3 In oil refineries, distillation towers are used to isolate the different liquid fractions in crude oil as part of the process of making petroleum.

- Low boiling fractions: The lightest hydrocarbons, such as gases like methane, ethane and propane, have low boiling points and are collected at the top of the column.
- Medium boiling fractions: Liquids like gasoline and kerosene, which have medium boiling points, condense in the middle of the column.
- High boiling fractions: Heavier liquids, such as diesel and lubricating oils, condense lower down in the column.
- Residue: At the bottom of the column, substances with a very high boiling point, such as bitumen or asphalt, are collected.

Using hydrocarbon fractions

The separated hydrocarbon fractions have a range of uses.

- Gases (e.g. methane, ethane) are used as fuels for cooking, heating and electricity generation.
- Gasoline is a fuel for cars and other vehicles.
- Kerosene is used in jet fuel and for heating.
- Diesel is a fuel for trucks, buses and other large vehicles.
- Lubricating oils are used to reduce friction in engines and machinery.
- Bitumen and asphalt are used in road construction.

How each fraction is used is based on its specific properties, such as its boiling point, viscosity and flammability.

Combustion of hydrocarbons

Carbon is the principal constituent of coal. When burned with oxygen, both reactions produce a flame and so are classified as **combustion** reactions.

combustion a reaction that involves oxygen and releases light and heat energy

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 both heat and electricity, and to run engines and motors.

Complete combustion

Complete combustion occurs when a hydrocarbon reacts with unlimited oxygen. The products of complete combustion are carbon dioxide (CO_2) and water (H_2O), and it releases the maximum amount of energy possible from the fuel.

hydrocarbon + oxygen → carbon dioxide + water

Incomplete combustion

Incomplete combustion occurs when there is insufficient oxygen for the hydrocarbon to react completely. As a result, the products of incomplete combustion include carbon monoxide (CO), carbon (soot) and water (H_2O), and less energy is released compared to complete combustion:

hydrocarbon + limited oxygen → carbon monoxide + water

With even less oxygen, unburnt carbon (soot) is formed, along with water:

hydrocarbon + limited oxygen → carbon + water

Incomplete combustion is less efficient because harmful carbon monoxide is produced and the energy released is lower. Additionally, the formation of soot can lead to pollution and the clogging of engines.

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.

Comparing complete and incomplete combustion

The differences between complete and incomplete combustion are given in Table 1.

Table 1 The differences between complete and incomplete combustion

Aspect	Complete combustion	Incomplete combustion
Oxygen supply	Sufficient oxygen	Limited oxygen
Products	Carbon dioxide (CO_2) and water (H_2O)	Carbon monoxide (CO), soot (C) and water (H_2O)
Energy released	Maximum energy released	Less energy released
Efficiency	Highly efficient	Less efficient, more energy wasted
Examples	Burning of natural gas, gasoline in cars	Poorly ventilated stoves, car engines running with insufficient oxygen

Worked example 6.10A Equations for complete and incomplete combustion

Determine the word and chemical equation for each of the following reactions:

a Complete combustion of methane (CH_4)

b Incomplete combustion of methane (CH_4); show both incomplete combustion equations.

Solution

Steps	What to do	Working out
a.	For part **a**, identify the reactants.	Methane (CH_4) and oxygen (O_2)
b.	Identify the products, recognising that complete combustion occurs when there is sufficient oxygen.	Carbon dioxide (CO_2) and water (H_2O).
c.	Write the word equation.	methane + oxygen → carbon dioxide + water
d.	Write the unbalanced equation.	$CH_4 + O_2 \rightarrow CO_2 + H_2O$
e.	• Balance the carbon atoms (C) • Balance the hydrogen atoms (H) • Balance the oxygen atoms (O)	• 1 carbon on both sides – already balanced. • 4 hydrogen atoms in CH_4 → need 2 H_2O molecules. • Total of 4 oxygen atoms needed → 2 O_2 molecules.
f.	Write the final balanced equation.	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
g.	For part **b**, identify the reactants.	Methane (CH_4) and limited oxygen (O_2).
h.	Identify the products, recognising that in oxygen-deficient conditions, carbon monoxide (CO) or carbon (C) is formed instead of carbon dioxide (CO_2).	Carbon monoxide (CO) or carbon (C)
i.	Write the word equation for each reaction.	**1** methane + oxygen → carbon monoxide + water **2** methane + oxygen → carbon + water
j.	Write the unbalanced equation for each reaction.	**1** $CH_4 + O_2 \rightarrow CO + H_2O$ **2** $CH_4 + O_2 \rightarrow C + 2H_2O$
k.	Balance the carbon, hydrogen and oxygen atoms. If you end up with fractions, multiply to eliminate them.	**1** $2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$ **2** $CH_4 + O_2 \rightarrow C + 2H_2O$

Check your learning 6.10

Check your learning 6.10

Retrieve

1 Identify the primary element contained in the fuels our society relies on.

2 Identify the property of hydrocarbons that allows them to be separated during fractional distillation.

3 In a distillation column, where are hydrocarbons with the highest boiling points collected?

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.

9 How have the uses of hydrocarbons changed over time? Consider the following in your response.

a Give three examples of how hydrocarbons were used in the past.

b Explain one way their use has changed due to new technology or environmental concerns.

c Name one modern alternative to a hydrocarbon-based product and explain why it is used.

Lesson 6.11
Polymers are long chains of monomers

Key ideas

→ Polymerisation is the process of forming a long-chain polymer from smaller monomer molecules.

Learning intentions and success criteria

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 was able to 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.

polymerisation a chemical reaction where small molecules (monomers) combine 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 that is capable of reacting with other similar molecules to form a long-chain molecule (polymer)

Linear polymers and elastomers

Linear polymers form long chains (Figure 1). Generally, the chains consist of carbon atoms held together by covalent bonding, with other atoms or groups of atoms 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.

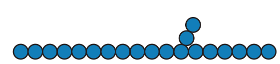


Figure 1 The basic structure of a linear polymer. The small circles represent small groups of atoms.

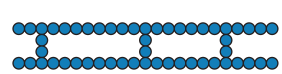


Figure 2 The basic structure of an elastomer

linear polymer a long single chain of polymers

elastomer a long chain of polymers occasionally linked together like a ladder

The structure of **elastomers** is like a ladder (Figure 2). Elastomers form 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.

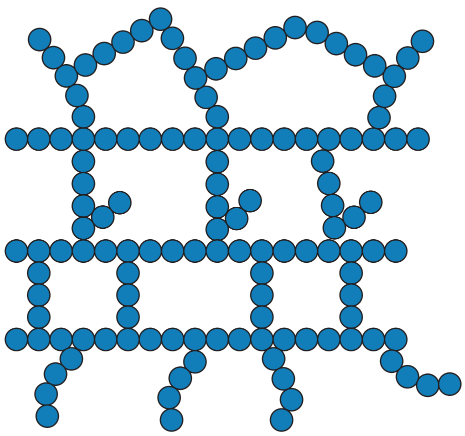


Figure 3 A cross-linked polymer

Cross-linked polymers

Cross-linked polymers are a type of giant structure where atoms are held together by strong covalent bonds (Figure 3). These structures are similar to covalent lattices, which are networks of atoms bonded in a continuous framework, rather than separate molecules. Covalent lattices, like diamond, have a very regular arrangement of atoms, whereas cross-linked polymers have a more irregular and flexible structure. Despite this difference, both rely on strong covalent bonds, which make them durable and resistant to heat and chemicals.

Polymer properties

cross-linked polymer a polymer consisting of multiple long polymer chains that have been linked together to form a three-dimensional structure

thermoplastic polymer a polymer that softens and forms new shapes when heated

thermosetting polymer a polymer that does not melt or change shape when heated

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 (Figure 4).

Apart from being classified according to their structure, polymers are classified according to how they respond to heat. This is a very important property.

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 5).

Figure 4 Thermoplastic paint is used to mark roads.

Formation of polymers

There are many types of polymerisation reactions, but they all follow the same process. Small molecules react under specific temperature and pressure conditions that allow them to join together in a chain reaction to form giant molecules that can contain thousands of atoms. Polyethene (or polyethylene) 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 6. This polymerisation reaction requires high temperature and pressure, as well as a chemical catalyst.

Figure 5 The plastics that make up the covers of gaming consoles such as the Nintendo Switch are made of thermosetting polymers.

Raw materials

Most synthetic polymers are made from raw materials that come from petrochemicals, which are chemicals produced from oil and natural gas. For example, ethene (also called ethylene) is a simple molecule made from natural gas or oil, using a process called cracking. Ethene is the main material used to make polyethene, which is one of the most common plastics found in things like packaging, containers and everyday products. Similarly, propene (or propylene) is used to make polypropylene, a plastic used in products like plastic containers, clothing and car parts.

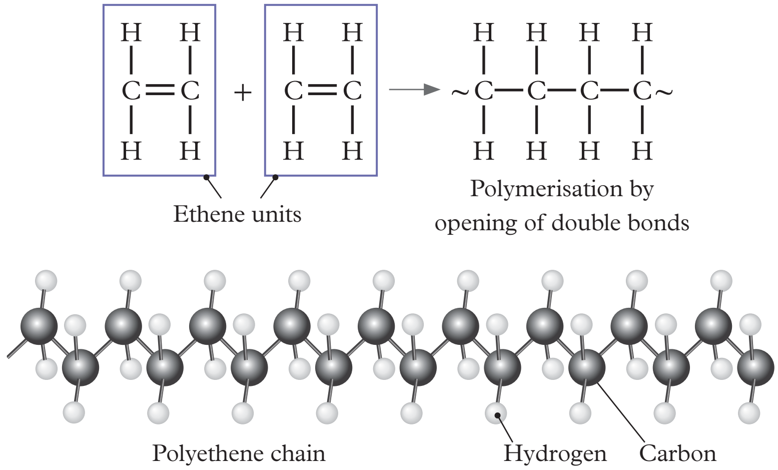


Figure 6 The formation of polyethene from ethene molecules

Another important material is styrene, which is also made from oil and used to make polystyrene, the plastic found in items like disposable cups and packaging. Terephthalic acid and ethylene glycol are used to make polyethylene terephthalate (PET), which is commonly found in plastic bottles and clothing fibres.

Bioplastics

Besides oil-based materials, there is growing interest in using bio-based monomers. Bioplastics are plastics that are made from renewable biological sources, such as vegetable based oils, wood chips and corn (Figure 7). Polylactic acid (PLA) is a common bioplastic made from corn. Its properties are similar to fossil fuel-derived plastics such as polyethylene (PE). You may have used disposable cutlery made from bioplastic derived from avocado seeds (Figure 8). This is an eco-friendly alternative to traditional plastic that helps reduce waste and reliance on fossil fuels.

Bioplastics are said to use less energy to manufacture compared to fossil fuel-derived plastics, and they produce significantly less greenhouse gases during production as well. It is, however, a major misconception that all bioplastics are biodegradable. A lot of research is currently being done in this area to minimise the environmental impact of bioplastics after their use.

Figure 7 Biodegradable plastic pellets can be made from plants like corn.

Figure 8 Disposable cutlery made from a bioplastic that uses avocado seeds.

How polymers are used

Many polymers are used today. More and more designer polymers are being developed and modified to suit particular applications. Camping tents are made from nylon, which produces a lightweight, tear-resistant fabric. Bigger tents are made of cotton polyester. Tent bases are made of polyurethane, another useful polymer which is waterproof.

A popular material for clothing is polar fleece because it is warm yet lightweight. Polar fleece is a synthetic wool made from PET (polyethylene terephthalate) which 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. PET is a thermoplastic polymer.

Check your learning 6.11

Check your learning 6.11

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.

7 Evaluate the importance of developing alternatives to common chemicals used in industry and commercially. Use examples to support your answer.

Lesson 6.12
Investigation: Exploring different polymers

Investigation 1: Making a polymer

Introduction

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 World War II, casein plastic was used to make buttons, beads and jewellery.

Purpose

To form polymers of casein monomers

Materials

- 100 mL full-cream milk
- 250 mL beaker
- Tripod
- Bunsen burner
- Heatproof mat
- Gauze mat
- Matches
- Thermometer
- Heatproof gloves
- 5 mL vinegar (CH_3COOH)
- Stirring rod
- Filter paper
- Funnel
- Conical flask
- Spatula

Procedure

1. Place the tripod and the Bunsen burner on the heatproof mat. Place the gauze mat on top of the tripod.
2. Safely light the Bunsen burner and move it under the tripod on the heatproof mat. Open the collar on the Bunsen burner to produce a blue flame.
3. 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.
4. Turn off the Bunsen burner. Wearing heatproof gloves, carefully move the beaker of milk to a heatproof mat on the bench.
5. Add 5 mL of vinegar to the milk, stirring gently for 5 seconds. The milk will separate into curds.
6. Place the filter paper in the funnel and put it into the conical flask. Filter the casein polymer curds from the whey. Use the spatula to help remove all of the curds.
7. Weigh the casein polymer you obtained to determine the effectiveness of the reaction.
8. 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.
- Develop a method for your experiment and write it in your logbook.
- Show your teacher your planning for approval before starting your experiment.

Results

Construct a table to record your results.

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.

Investigation 2: Investigating properties of different polymers

Purpose

To investigate and compare the properties of various polymers, including their flexibility, strength, solubility and transparency

Materials

- Polyethylene (plastic bag or plastic film)
- Polystyrene (styrofoam cup or packaging)
- Natural rubber (rubber band)
- Polyvinyl alcohol (PVA) solution
- Ruler
- Retort stand
- Clamp
- Rubber band
- Weights (in 1 g increments)
- Test tubes or small containers
- Water
- Timer
- 50 mL beaker
- Heat source (for testing thermal properties)
- Tongs (for handling heated materials)
- Thermometer

Procedure

Part A: Preparation of materials

Cut pieces of polyethylene, polystyrene, rubber and PVA polymer into squares approximately 5 cm by 5 cm for testing.

Part B: Testing flexibility

1. Qualitative test: Take each polymer and attempt to bend it by hand. Record the degree of flexibility for each polymer (e.g. flexible, semi-flexible, rigid).
2. Quantitative test: Measure the bending angle.

Part C: Testing strength

1. Set up the equipment as shown in Figure 1.
2. Hang the polymers vertically and slowly add weight to the bottom of the polymer.
3. Record the maximum weight each polymer can hold before breaking or deforming.
4. Use a ruler to measure and record the elongation (stretching) before breaking.

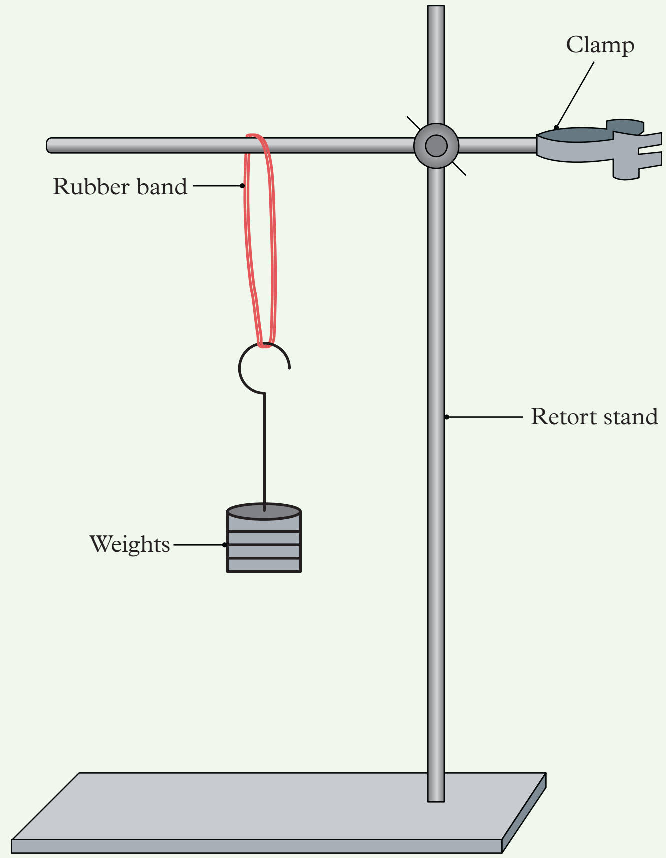


Figure 1 Set-up of strength-testing experiment

Part D: Testing solubility

1. Place small pieces of each polymer in test tubes or small containers.
2. Submerge the pieces in water and observe any changes in shape, size or texture after a set period (e.g. 5 min, 15 min, 30 min).
3. Record whether any polymer dissolves or swells in water.

Part E: Testing transparency

1. Hold each polymer up to a light source (e.g. a flashlight or desk lamp) and observe how much light passes through the material.
2. Rank the polymers from most transparent to least transparent based on the amount of light that passes through the material.

Part F: Thermal properties

1. Heat each polymer gently in a 50 mL beaker

with warm water over a hot plate (water bath). Use a thermometer to record the temperature.

2 Observe any changes in physical properties (e.g. softening, melting or discolouration) and the temperature at which the change occurs.

Results

Construct a table to record your results.

Discussion

1 Compare the properties of the different polymers. For example, how do natural rubber and synthetic polymers differ in flexibility or strength?

2 Discuss why each polymer has these properties based on its molecular structure and the types of bonds between monomers.

Conclusion

Describe what you have learnt about the properties of different polymers.

Lesson 6.13

Investigation: Biodegradability of packaging materials

Purpose

To explore the biodegradability of various packaging materials

Materials

- 250 cm × 250 cm × 50 cm tray (or various containers)
- Soil
- Spades
- 100 mm × 100 mm samples of each of the following materials:
  - plastic foam
  - "biodegradable" plastic shopping bag
  - plastic shopping bag
  - cardboard
  - thin woven cotton fabric
  - aluminium foil
- Coloured marker pegs
- Sheets of acetate with a fine grid (100 mm squares) copied onto it
- Whiteboard pens

Procedure

1 Fill the container with soil.

2 Dig holes in the soil (approximately 200 mm × 200 mm × 100 mm deep) and place a sample of each material in each hole.

3 Cover the material with soil.

4 Place a coloured marker peg over the hole, so the material can be identified later.

5 Leave the samples for at least 2 weeks.

6 Carefully dig up the samples.

7 Place the acetate sheet over the samples and trace the outline of the sample using whiteboard pens.

8 Identify if the sample has decreased in size and record this in Table 1 (decide how you will measure the change in the size of the sample).

Results

1 Copy and complete Table 1.
2 Group your samples into "most biodegradable", "somewhat biodegradable" and "least biodegradable".

Table 1 The biodegradability of various packaging materials

Name of material	Change in size (mm)

Discussion

1 Identify what each of these groups has in common and determine how they could be categorised.
2 Determine the most biodegradable category from the identified groups.
3 Determine the least biodegradable category from the identified groups.

Conclusion

1 Share your results with different groups and compare whether the results were the same for each group.
2 If the results differed, analyse potential reasons for these differences.
3 Summarise your conclusions from the experiment.
4 Identify variables that might affect biodegradability.
5 Suggest improvements you would make if conducting this experiment again.

Lesson 6.14
Investigation: Bioaccumulation of microplastics in the environment

Introduction

To explore the effects of microplastics in the environment, you will conduct independent research to find relevant case studies and articles. You will need to understand how microplastics "bioaccumulate" (become concentrated inside the bodies of living things) in food webs and what effects microplastics have on living organisms. By the end of this task, you will present your findings, summarising the key points from the case studies and providing a conclusion about the potential consequences of microplastic pollution.

Purpose

To research the effects of microplastic bioaccumulation in the environment by locating and analysing case studies. You will explore how microplastics accumulate in different organisms, their impact on ecosystems and potential risks to human health.

Important terms

Before starting your research, make sure you understand the following terms:

- Bioaccumulation: The buildup of substances, such as toxins or microplastics, in the tissues of organisms over time.
- Microplastics: Small plastic particles less than 5 mm in size that come from the breakdown of larger plastic items or are manufactured as small particles.
- Trophic levels: Different levels in a food chain or web, such as primary producers (plants), primary consumers (herbivores), secondary consumers (carnivores) and tertiary consumers (top predators).
- Ecosystem: A community of living organisms interacting with each other and their environment.

Search for relevant case studies

Your task is to locate at least two case studies or scientific articles that explain the bioaccumulation of microplastics in ecosystems. Follow these steps to get started.

1 Choose reliable sources. Use trusted sources like scientific journals, government or environmental websites and educational platforms. Avoid unreliable sources like social media or websites without proper references.

2 Search keywords. To find case studies, you can use these keywords when searching the internet or research databases.
   – "Bioaccumulation of microplastics case study"
   – "Impact of microplastics on food chain"
   – "Microplastics in marine ecosystems"
   – "Effects of microplastics on wildlife"
   – "Bioaccumulation in food webs and microplastics"
   – "Microplastics and human health"

3 Use Google Scholar or databases such as ScienceDirect, PubMed or National Geographic for reliable articles and case studies. Tip: Look for articles with the most citations or those published within the last few years for up-to-date information.

Organise your findings

1 Once you've found your case studies, read through them and take notes. Focus on the following questions.
   – What species or ecosystems are affected by microplastic bioaccumulation?
   – How do microplastics move up the food chain (trophic levels)?
   – What are the specific effects on organisms at each trophic level (e.g. fish, birds, humans)?
   – What are the possible long-term consequences for ecosystems and human health?

2 Take notes on:
   – the main findings of each case study
   – any graphs or data that are included to show the amount of microplastics found in organisms
   – the sources of microplastic pollution (e.g. oceans, rivers, landfills)
   – solutions or recommendations offered in the studies to reduce microplastic pollution.

Summarise your findings

After gathering the information, write a summary (about 150–200 words) for each case study, answering the following.

- What was the case study about (e.g. location, type of organisms studied)?
- What did the researchers find about microplastic bioaccumulation in the organisms?
- What are the main environmental or health concerns raised by the case study?
- What recommendations or solutions were proposed?

Reflection

After you've completed your research and summaries, answer the following questions in a final reflection (150–200 words).

1 What are the key effects of microplastic bioaccumulation on ecosystems?

2 How might microplastics affect humans?

3 What can be done to reduce microplastic pollution?

Lesson 6.15
Alternatives to crude oil products

Learning intentions and success criteria

Key ideas

→ Alternatives to crude oil-based materials are being created and developed due to environmental concerns and the limited amount of fossil fuels.

→ Bioplastics can be made using corn, sugarcane and algae.

→ Cotton, hemp and bamboo are textile alternatives to nylon and polyester.

→ The environmental impact of crude oil-based materials should be compared with that of alternative materials, as the production and end-of-life processes of these alternatives may not be sustainable.

Alternatives to crude-oil-based materials

Crude oil has long been a primary source for materials used in manufacturing products such as plastics, fuels and synthetic chemicals. As the world faces increasing concerns about sustainability, pollution and the depletion of fossil fuels, alternatives to materials derived from crude oil are gaining attention.

Figure 1 Bioplastic spoon and fork, and biodegradable lunch box made from sugarcane fibre

Figure 2 A common bioplastic is polylactic acid (PLA, polylactide).

Bioplastics

Bioplastics are a major alternative to petroleum-based plastics. They are derived from renewable resources such as corn, sugarcane (Figure 1) and algae. Common bioplastics include polylactic acid (PLA) (Figure 2), polyhydroxyalkanoates (PHA) and starch-based plastics.

Plant-based fibres and textiles

Textiles traditionally made from petroleum-based synthetic fibres such as nylon and polyester are increasingly being replaced by plant-based fibres like cotton (Figure 3), hemp and bamboo, as well as bio-based synthetic fibres like PLA.

Algae-based materials

Algae are another promising source of alternative materials. Algae can be used to create bioplastics, biofuels and even food packaging materials. Algae-based products are increasingly being researched for their potential as sustainable alternatives to petroleum-derived substances.

Comparing environmental impacts

When assessing alternative materials to conventional plastics, it is important to consider their overall environmental impact across different stages of their life cycle. Factors such as carbon footprint, energy consumption and biodegradability all play a role in determining whether a material is truly sustainable.

Figure 3 Various cotton harvests to be used for textiles

Carbon footprint

One of the primary environmental advantages of alternatives to crude-oil-based materials is their potential for a lower carbon footprint. Materials such as bioplastics and algae-based materials can contribute to a reduction in greenhouse gas emissions when compared to conventional plastics derived from petroleum. The overall environmental benefit, however, depends on factors such as energy inputs, transportation and end-of-life disposal.

Energy consumption

The energy required for producing alternative materials varies significantly. While some, like bio-based plastics and fibres, require less energy to produce than their petroleum-based counterparts, others, such as algae-based materials, can be energy intensive to process. The choice of energy sources used in production is a key determinant in assessing the sustainability of alternative materials.

Waste and end-of-life considerations

The end-of-life disposal of materials is a crucial factor in determining their environmental impact. Bioplastics such as PLA are biodegradable in some environments but may still require specific conditions to break down effectively. In contrast, many conventional plastics can take hundreds of years to degrade, leading to pollution and waste accumulation in landfills and oceans. The biodegradability of alternative materials can be a significant advantage, but challenges remain in terms of effective waste management and recycling infrastructure. The advantages and environmental impacts of using alternative materials to plastics are detailed in Table 1.

Table 1 Advantages and environmental impacts of alternative materials compared to materials produced from crude oil

Alternative material	Advantages	Environmental impacts
Bioplastics	• Made from renewable resources (e.g. corn, sugarcane) • Reduced carbon footprint • Some are biodegradable	• Large-scale agricultural production can cause deforestation and habitat loss • Requires significant water, pesticides and fertilisers • Energy-intensive production
Plant-based fibres	• Renewable and biodegradable • Lower energy consumption compared to synthetic fibres • Requires fewer pesticides and fertilisers in some cases (e.g. hemp, bamboo)	• High water usage in farming (e.g. cotton) • Pesticide and fertiliser run-off in non-organic farming • Chemical processing required for some fibres (e.g. bamboo)
Algae-based materials	• High growth rate • No land use required for cultivation • Carbon dioxide absorption during growth • Can grow in wastewater	• Energy-intensive processing • Potential impact on marine ecosystems if not managed properly

Challenges and limitations

While alternative materials present significant opportunities for reducing the environmental impacts associated with crude-oil-based products, there are several challenges.

- Scalability: Many alternative materials, particularly those derived from agricultural products or algae, are still in the early stages of commercialisation. Scaling up production to meet global demand without increasing land use and environmental impacts remains a challenge.
- Economic viability: The production of alternative materials can be more expensive than conventional materials, particularly in industries where cost is a major consideration. Economic incentives and technological advancements are needed to make alternative materials more competitive.
- Environmental trade-offs: Some alternatives, such as bio-based plastics, may reduce dependence on fossil fuels, but they can introduce other environmental trade-offs, such as increased land and water use or reliance on energy-intensive manufacturing processes.

Check your learning 6.15

Check your learning 6.15

Retrieve

1 List two advantages of bioplastics over petroleum-based plastics.

2 State one environmental impact of large-scale bioplastic production.

3 Name a raw material commonly used to produce algae-based materials.

Comprehend

4 Describe the environmental impact of cotton farming when it is not done organically.

5 Describe how algae-based materials help reduce carbon emissions.

6 Explain why plant-based fibres might be considered a more sustainable alternative to synthetic fibres made from petroleum.

7 Explain how biodegradable bioplastics could reduce waste in landfills compared to conventional plastics.

Analyse

8 Analyse the trade-offs between using bioplastics made from agricultural crops and the potential environmental impacts of large-scale crop cultivation.

9 Assess how the energy requirements for producing alternative materials like bioplastics compare to those of petroleum-based plastics.

Evaluate

10 Evaluate the potential for bioplastics to replace petroleum-based plastics in various industries, considering both environmental and economic factors.

Lesson 6.16

Review: Bonding, compounds and polymers

Summary

Lesson 6.1 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.
- 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 6.2 Ions have more or less electrons

- Electrons have a negative charge.
- Ions are atoms that have gained or lost electrons.
- When an atom loses electrons, it forms a cation (positive charge).
- When an atom gains electrons, it forms an anion (negative charge).

Lesson 6.4 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 6.5 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 is used to explain the compound's properties.

Lesson 6.7 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 6.9 Compounds can be organic or inorganic

- Inorganic compounds do not contain C–H bonds, while organic compounds are primarily made of carbon bonded to hydrogen, oxygen, nitrogen or other elements.
- Alkanes are saturated hydrocarbons with only single bonds, following the formula C_nH_{2n+2}, making them stable and commonly used as fuels.
- The IUPAC naming system for alkanes is based on the longest carbon chain, using prefixes (e.g. "meth-", "eth-", "prop-") and the suffix "-ane" (e.g. ethane, butane).
- Alkanes can have straight or branched structures, affecting their physical properties but not their chemical formula.
- Alcohols contain the hydroxyl (–OH) functional group, and their names include a number indicating its position in the chain, ending in "-ol" (e.g. butan-2-ol).
- Carboxylic acids contain the carboxyl (–COOH) group, always on the first carbon, and are named with the suffix "-oic acid" (e.g. ethanoic acid, butanoic acid).
- The naming of alcohols and carboxylic acids follows similar rules to alkanes, using carbon chain length and functional group placement.
- Understanding the structure and naming of organic compounds helps predict their properties and reactions.

Lesson 6.10 Hydrocarbons can be separated from crude oil

- 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 6.11 Polymers are long chains of monomers

- Polymerisation is the process of forming a long-chain polymer from smaller monomer molecules.

Lesson 6.15 Alternatives to crude oil products

- Alternatives to crude oil-based materials are being created and developed due to environmental concerns and the limited amount of fossil fuels.
- Bioplastics can be made using corn, sugarcane and algae.
- Cotton, hemp and bamboo are textile alternatives to nylon and polyester.
- The environmental impact of crude oil-based materials should be compared with that of alternative materials, as the production and end-of-life processes of these alternatives may not be sustainable.

Review questions 6.16

Review questions Module 6

Retrieve

1 State the difference between a cation and an anion.
2 Identify three elements that exist as diatomic molecules.
3 State the difference between organic and inorganic compounds.
4 Identify the atoms that hydrocarbons are made from.
5 Outline how hydrocarbons are separated from crude oil.
6 Name and draw the first five alkanes (C1–C5).
7 State the general formula for alkanes.
8 Identify the raw materials used to produce polymers.

Comprehend

9 Describe how valency helps predict the bonding behaviour of an element.
10 Explain why noble gases do not readily form chemical bonds.
11 Describe the differences between ionic, covalent and metallic bonding in terms of how electrons are shared or transferred.
12 Explain how the structure of a polymer affects its properties.
13 Describe why some hydrocarbons are more useful for fuel than others.
14 Explain the differences between complete and incomplete combustion of hydrocarbons in terms of products and energy released.
15 Describe why microplastics are a concern in the environment.

Analyse

16 Assess the patterns in the naming of simple organic compounds using IUPAC naming systems.
17 Evaluate how the use of hydrocarbon compounds has changed over time and what factors have influenced these changes.
18 Compare thermosetting and thermoplastic polymers.

Apply

19 In many industrial environments, the presence of 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 which gave a high yield of a product in summer gave a low yield of that same product in winter, despite the mixtures and concentrations being identical. Propose a possible explanation for the different yields.
21 Sodium metal reacted with purified bauxite (Al_2O_3) to produce aluminium (Al) 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.)

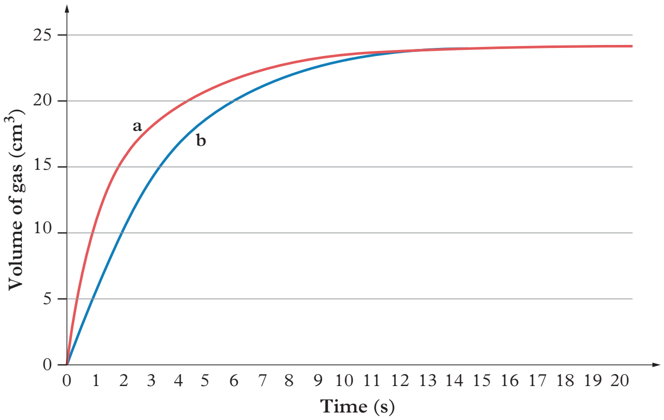


Figure 2 The results of each trial

Social and ethical thinking

23 Should governments enforce stricter regulations on single-use plastics, even if it leads to higher costs for consumers and businesses? Discuss the social and ethical implications.

Critical and creative thinking

24 Evaluate the trade-offs between using bioplastics and conventional plastics in terms of cost, durability and environmental impact. Are bioplastics always the better choice?

25 Design an innovative solution to reduce plastic pollution in your local community using alternative materials or recycling methods.

Research

26 Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

Material properties

Materials have a variety of physical and chemical properties, which are determined by their bonding structure. Within the medical or construction industries, these materials are used to create new medicines or diagnostic tools or even energy-efficient building materials.

- Investigate how the bonds between materials are altered and how it would improve the material.
- Explain if nanotechnology could be used to manipulate bonding at a microscopic level.
- Describe how altering bonds can be utilised in the medical or construction industry.

Plastic waste

Plastic waste has become a significant environmental challenge due to its prevalence in society. As such, its impact on wildlife and human health has been detrimental. In response, the development and adoption of biodegradable polymers has emerged as a potential solution to address this issue. These innovative materials are designed to break down more efficiently under natural conditions, reducing the accumulation of non-degradable plastics in landfills and habitats, particularly the ocean.

Investigate how advancements in biodegradable polymers have influenced plastic waste management and compare their effectiveness with traditional plastics.

Polymers

Polymers are versatile materials that have become crucial for our everyday life, from clothing and packaging to advanced applications in medicine and engineering. Understanding the properties of polymers, including their structure, is essential for innovation and sustainability.

- Explain what the key differences are between natural and synthetic polymers
- Describe how the molecular structure of a polymer influences its flexibility, strength or durability.
- Discuss uses of polymers in daily life and what makes them suitable for their applications.
- Investigate how sustainable these polymers are and what sustainability measures must be taken when they are produced or when they are collected as waste.Table 2 Elements, atomic numbers

Module 7
Environmental sustainability

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, ocean 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 our impact on them.

Lessons in this module

Lesson 7.1
Sustainability is a long-term goal to live within our means

Learning intentions and success criteria

Key ideas

- → Sustainability is our ability to meet our current needs without compromising the needs of future generations.
- → Three key principles of sustainability are environmental sustainability, social sustainability and economic sustainability.
- → Our supply of non-renewable resources is limited.
- → Strategies to conserve our resources include reducing consumption, reusing materials and recycling.

Sustainability

sustainability to maintain, manage and minimise damage to resources so they are available for future generations, while meeting the needs of the present

economy the supply of money and goods and services that are produced, distributed and consumed

In 1987, the United Nations defined **sustainability** as:

> "meeting the needs of the present without compromising the ability of future generations to meet their own needs".

Development is a common goal for all countries aiming for a better quality of life and a stronger **economy**. Sustainable development is pursued through three key principles: environmental sustainability, social sustainability and economic sustainability.

These three principles of sustainable development are interconnected. For example, a recycling company can reduce the amount of waste it sends to landfill, which decreases pollution and the consumption of resources. This supports environmental sustainability, and additionally, it creates jobs, which supports social and economic sustainability.

Environmental sustainability

environmental sustainability practices to maintain, manage and minimise damage to natural resources today so they are available for the future needs of generations

Our environment is the place we live and all its resources. The goal of **environmental sustainability** is to maintain the health of the environment and manage natural resources responsibly, such as water, forests, air and minerals. This is important to prevent or minimise damage to the environment and the living things that inhabit it, and to ensure that natural resources are available in the long-term for many generations to come.

Environmentally sustainable practices include using renewable energy sources such as solar and wind energy, conserving natural resources, designing and using energy-efficient appliances, vehicles and buildings, and minimising waste and pollution by reducing the consumption of products or by recycling and reusing products.

Social sustainability

social sustainability practices that focus on inclusion, equity and just societies to ensure the wellbeing of current and future generations

The focus of **social sustainability** is equality, ensuring that everyone can meet their basic needs, such as education, healthcare and access to housing, healthy food and clean water. Everyone, regardless of their background, race or religion, should have the opportunity to grow and thrive.

Economic sustainability

The goal of **economic sustainability** is to ensure long-term economic development and growth without having a negative impact on the environment or society. Economic activities and development should occur with the responsible use of resources, taking into account both environmental and social sustainability.

economic sustainability practices that manage environmental, economic and social factors to support long-term economic growth and development today, without compromising this ability for future generations

Issues with sustainability and how to resolve them

We often take our resources for granted, only thinking about them when they are in short supply. There are, however, scientists, engineers and other people who are very aware of the shortage of resources. Their work focuses on sustainably managing natural resources and developing energy-efficient technology. Two key questions we need to ask are: Do we have enough resources for the future? What is the impact on the planet of the resources we use?

Natural resource use

Non-renewable resources, such as fossil fuels and metal ores, must be managed carefully so that our supply does not run out. We are increasingly aware of the environmental impact of burning fossil fuels. Carbon emissions from burning fossil fuels trap heat in the atmosphere, contributing to climate change. To manage the supply of natural resources and the impact of their use on the planet, we need to reduce consumption as well as recycle and reuse materials. Recycling plays a crucial role in managing resources. For example, recycling just one plastic bottle can save enough energy to power a laptop for 25 minutes.

Deforestation

Throughout history, humans have cleared forests for various purposes, including agriculture, road construction, urban development and to use wood to build housing and furniture (Figure 1). Forests play a vital role in maintaining environmental health, including removing carbon dioxide (CO_2) from the atmosphere, preventing soil erosion, protecting against floods and providing habitats for many species.

Figure 1 Forests are cleared to grow more food, but this has a negative effect on ecosystems, soil health and the atmosphere.

To minimise the impacts of deforestation, we can plant more trees, reduce paper consumption, recycle paper products and purchase wood products certified by the Forest Stewardship Council (FSC).

Waste production

The rate of global waste production is increasing rapidly due to growing populations and industrialisation. When wastes such as plastics, electronic devices and food are discarded, they often end up in landfill or waterways, where they can take a very long time to break down (Figure 2).

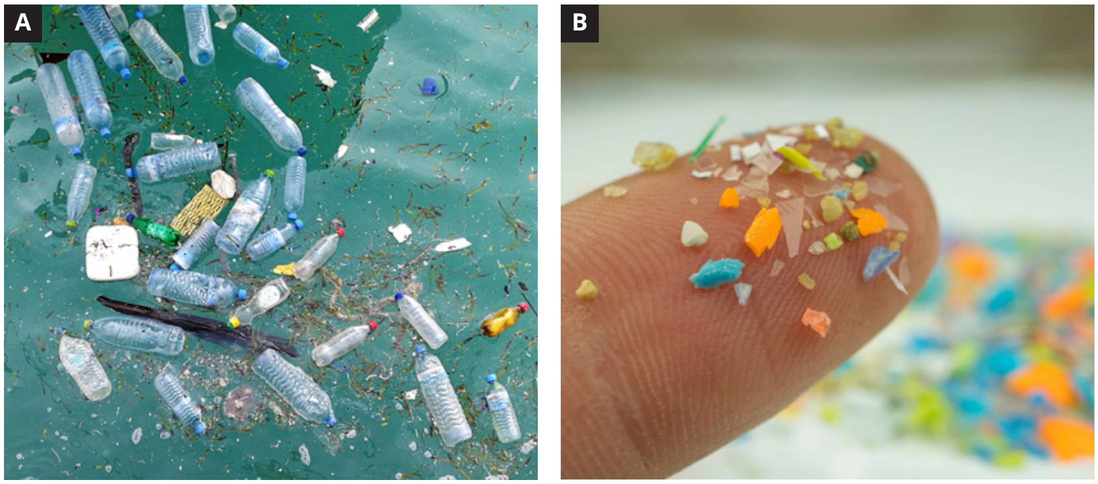


Figure 2 (A) Plastic can take between 20 and 500 years to break down. In ecosystems, plastics cause a lot of damage, especially if eaten by animals. (B) Scientific evidence shows that humans have microplastics in their blood and organs. Studies are being conducted to determine the effect on our health.

Plastic, for example, is often made from non-renewable sources like oil. Unlike food waste, plastic does not break down naturally. It accumulates in landfills or floats in oceans, causing significant harm to wildlife. Animals may mistake plastic waste for food or become entangled in it, resulting in injury or death. To manage this issue, we must focus on reducing, reusing and recycling plastic, which helps minimise landfill waste and conserve fossil fuels. The production of single-use plastic items should also be limited.

Separating food and garden waste to create compost as well as recycling electronic devices are practical strategies that contribute to a more sustainable future. Table 1 lists some ways we can reduce the amount of waste we produce.

Table 1 Strategies to reduce, reuse and recycle plastics

Strategy	Example
Reduce	Buy products that do not have plastic packaging and use alternatives to plastic (e.g. reusable bags or metal straws). You can also choose alternative products, such as packaging made from natural, biodegradable materials.
Reuse	Reuse plastics such as containers for storage or refill reusable drink bottles rather than buying one every time you are thirsty.
Recycle	Avoid putting plastic in the bin. Recycle your plastic so that it can be made into something else. Not all plastics can be recycled in the same way, so if in doubt, check your local council's website to see the types of plastic that can be recycled.

Check your learning 7.1

Check your learning 7.1

Retrieve

1 Identify two reasons why we need to reduce our plastic usage.

Comprehend

2 Explain why we need to manage non-renewable resources.

Analyse

3 Apply the "reduce, reuse, recycle" approach to come up with your own strategies to manage the use of a fossil fuel.

4 Your school is investigating how they could reduce the amount of plastic waste produced. Propose strategies that could be implemented across the school.

Apply

5 Conduct an investigation in your local area. This might be within 10 km of your home or further. If necessary, you or your teacher will choose the distance.

a List all the natural resources you can locate in this area.

b Identify what each is used for.

c Present your findings on a large map in the classroom where every student can contribute their research.

Skills builder: Communicating

6 Imagine that you need to convince a group of people to use your strategies from question 3 to reduce and reuse plastic. Choose a text type to communicate your ideas and persuade people to try them. (THINK: What format do you think people would find appealing or engaging? How will you make your key points clear?)

Lesson 7.2
Climate change is global

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 the atmosphere, ocean and land to affect the global climate system.

→ Low-pressure and high-pressure systems affect the weather.

→ Warm air rises from the Equator and cold air from the poles moves towards the Equator, causing the movement of air (wind).

→ The Earth's terrain can affect the speed and direction of the wind.

Learning intentions and success criteria

What is climate change?

Many systems in nature are balanced. When the balance is disrupted, it can cause a chain of reactions that have long-term impacts. For thousands of years, there has been a balance between the geosphere (the rocks and minerals on the surface of the Earth), the biosphere (all living things), the hydrosphere (all the water, ice and vapour on the Earth) and the atmosphere (the layer of gases surrounding the Earth). These spheres act together to make the global climate one in which humans and other parts of the biosphere are able to survive.

Climate change refers to the change in the global climate, since this change causes the spheres to become unbalanced, resulting in changes to our weather and climate.

climate change the change in global climate patterns, including temperature, over time

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

Weather and climate

Weather reports tell us about the temperature, humidity, rainfall and wind on particular days at a particular place. They provide a snapshot of day-to-day changes. **Climate** is concerned with longer periods of time and involves the collection and analysis of large amounts of data. We can use weather predictions to decide what to wear each day, whereas climate predictions can assist in making longer term decisions, such as what types of crops a farmer should grow each year, the technologies that governments should invest in or whether a household should install an air conditioner.

Solar radiation

solar radiation radiant electromagnetic energy from the Sun

Light and thermal energy produced by the Sun are things that we 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** heating the rocks and minerals that form the geosphere under our feet. The geosphere includes everything from the molten rocks of the mantle to the peaks of the mountains of Earth.

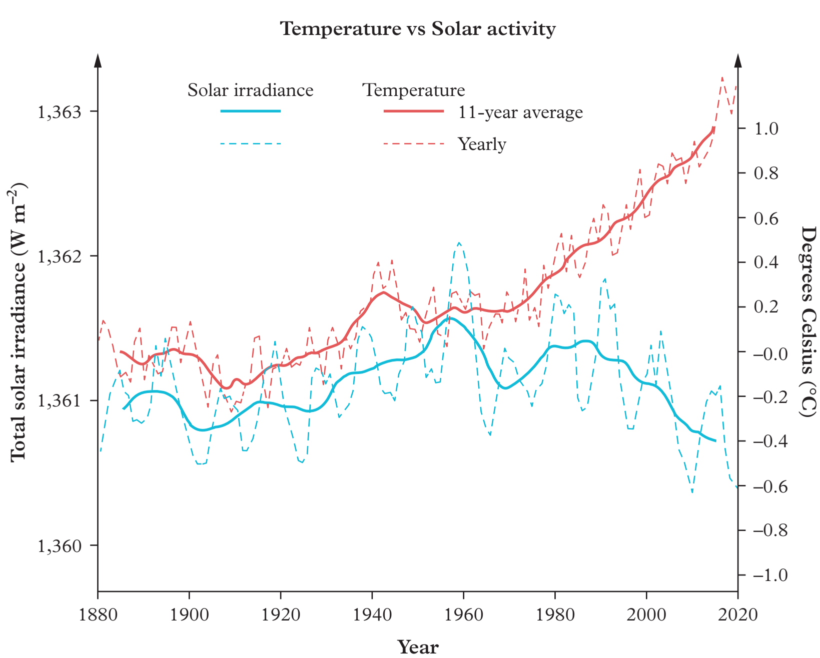


Figure 1 The blue line shows the amount of the Sun's energy reaching the top of Earth's atmosphere; and the red line shows the global average surface temperature over time

The amount of solar radiation released by the Sun varies by 0.1 per cent every 9–11 years (blue line in Figure 1). This small variation has no impact on the amount of solar radiation that reaches the top of the Earth's atmosphere. This means that the amount of solar radiation released by the Sun is not the cause of the increase in global average surface temperature (red line in 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 longer wavelength, lower-energy infrared radiation (known as heat) into the gases in the air. The more solar radiation that is absorbed by the Earth, the hotter the surface becomes. This in turn heats the air.

Some parts of the 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 and less energy is available to heat the Earth.

Regions near the Equator are warmer than regions near the Earth's poles. Near the Equator, the Earth is exposed to long periods of solar radiation because the Equator faces the Sun all year (Figure 2), so this area of the Earth's surface is heated 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.

Areas of the Earth that experience long periods of solar radiation from the Sun have higher temperatures.

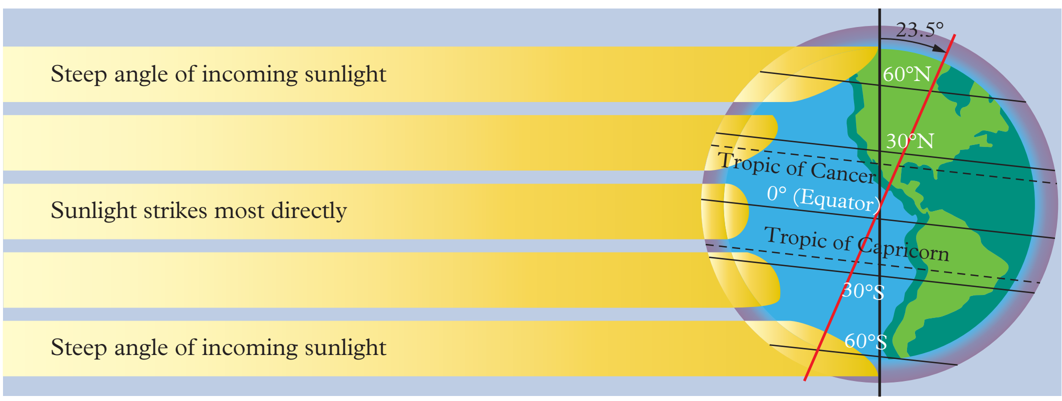


Figure 2 The angle of solar radiation (sunlight) can affect the amount of energy absorbed by the Earth's surface.

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 3B). Low-pressure systems are frequently associated with clouds and precipitation and are represented by an "L". High-pressure systems bring clear blue skies and are represented by an "H".

isobar a line drawn on a weather map that joins places of equal air pressure

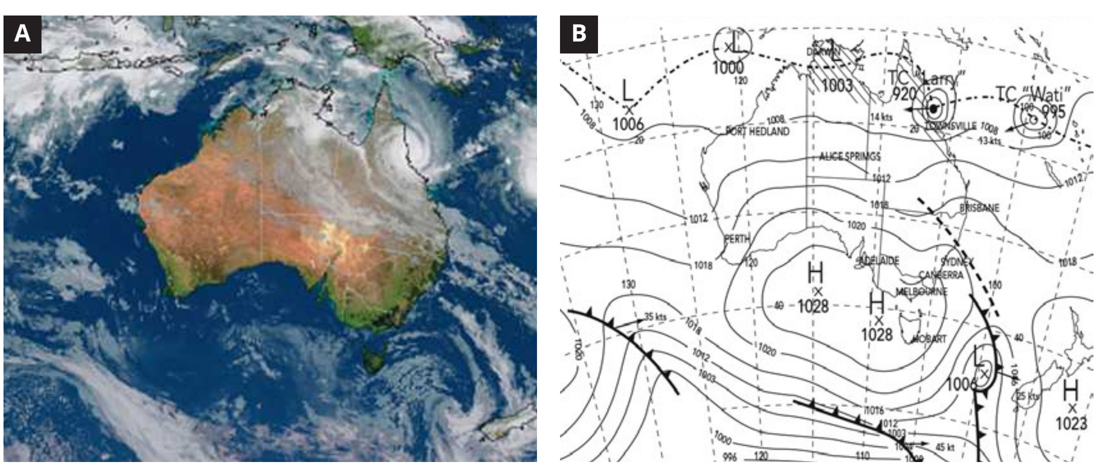


Figure 3 (A) A satellite image; (B) a weather map showing tropical cyclone Larry as it crosses the Australian coast at Innisfail, just south of Cairns, in 2006

high-pressure system regions where the air pressure is higher than surrounding areas

low-pressure system regions where the air pressure is lower than surrounding areas

Coriolis effect the influence of Earth's rotation on the direction of movement of air or water

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 air moves towards the centre and upwards, forming water vapour, clouds and rain. This means warm air near the Equator rises into the upper atmosphere and colder air near the poles moves towards the Equator to fill the space left by the warm air (Figure 4). The movement of air is better known as wind. Wind is the result of sideways or horizontal movements of air due to pressure differences.

The **Coriolis effect** is the influence of 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 the Earth (Figure 5). The surface of the Earth can also interfere with the speed and direction of wind. Rough and mountainous terrain will slow the wind and significantly change the wind's direction.

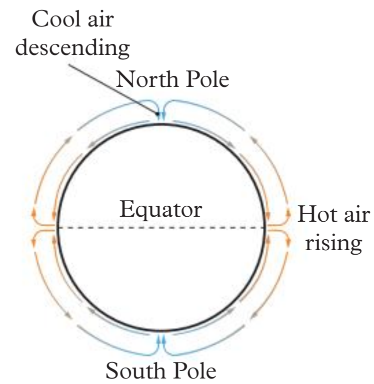


Figure 4 Movement of air at the Equator and at the poles can result in the circular movements of air called cyclones.

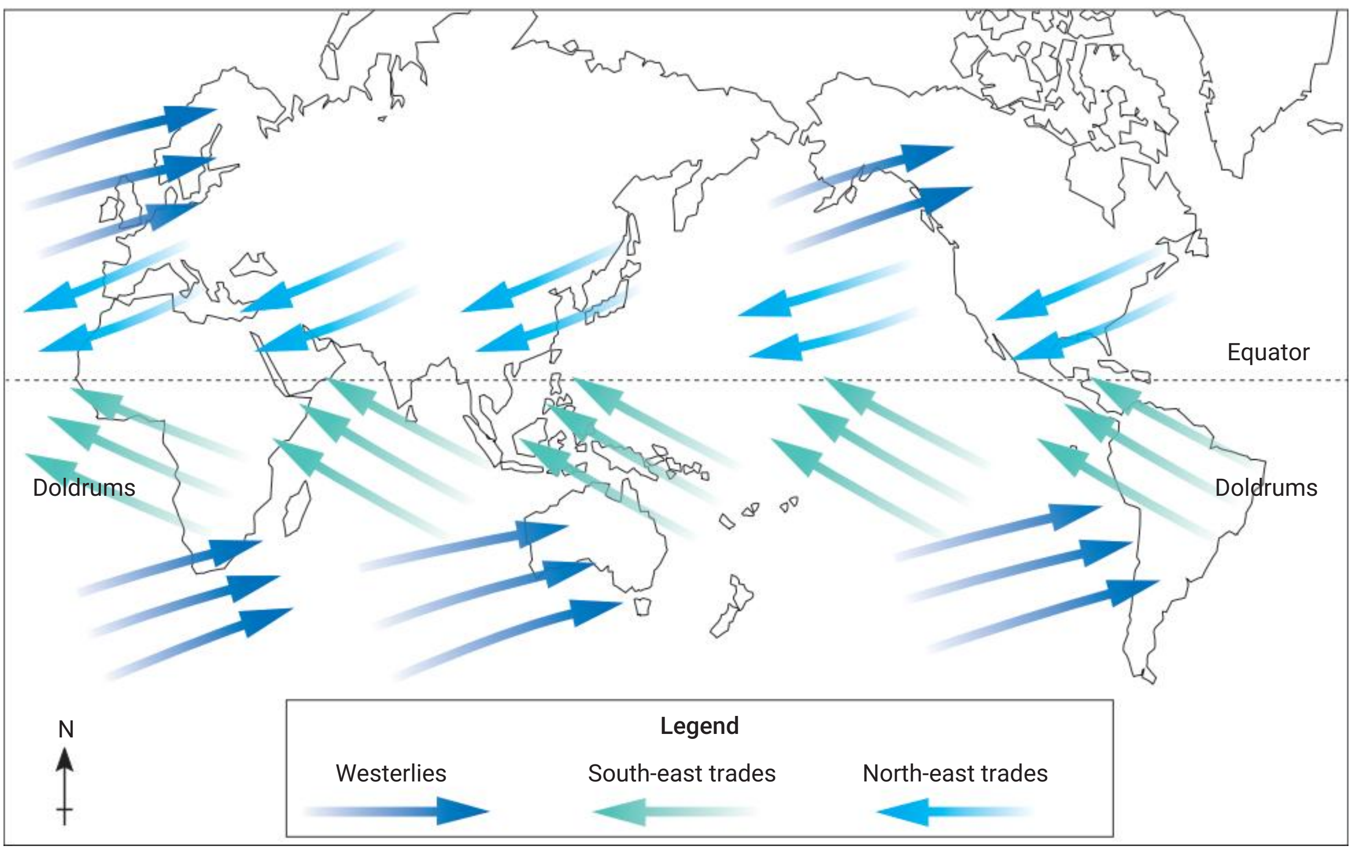


Figure 5 Wind patterns over the Earth; the doldrums are areas of low pressure where winds tend to be very calm.

Check your learning 7.2

Check your learning 7.2

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. Describe what is meant by the term "wet season" and investigate the climate conditions that contribute to the formation of a cyclone. Create a 2-minute video in which you are a meteorologist on the news who explains why the cyclone is forming.

8 In Australia, the frequency of extreme weather events is increasing, such as heat events, as seen in the following graph (Figure 6).

  a Identify the trends you observe from this graph.

  b Explain how the relationship in the graph relates to other characteristics of climate change.

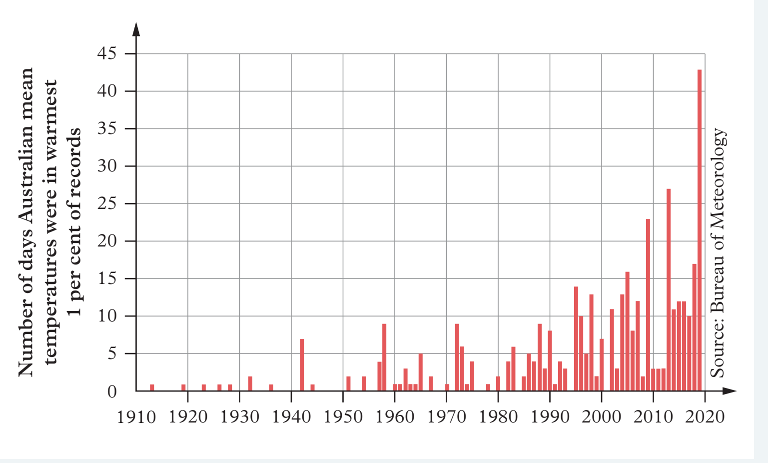


Figure 6 The frequency of extreme weather events is increasing in Australia.

Lesson 7.3
Challenge: Making a simple barometer

Caution

Consider if there are any allergies to latex.

Aim

To make a simple barometer that measures 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 that is 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.

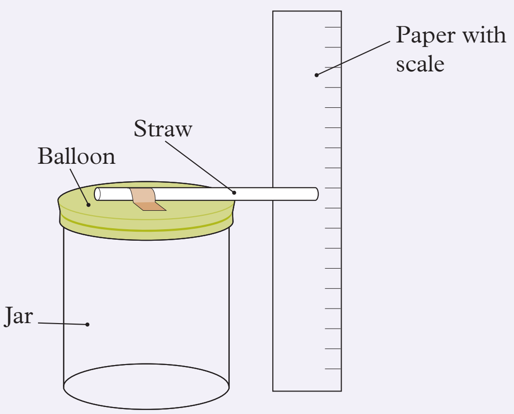


Figure 1 Experimental set-up

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 7.4

Evidence supports the enhanced greenhouse effect

Learning intentions and success criteria

Key ideas

→ The Earth is surrounded by an atmosphere of natural greenhouse gases that reflect radiation from the Sun and retain the warmth from the Earth.

→ Ice core samples are used to analyse the amount of greenhouse gases trapped in the ice over time.

→ The enhanced greenhouse effect is the increase in greenhouse gas levels and an increase in the temperature of the land and oceans.

→ Evidence for enhanced global warming can be found in higher sea levels and the melting of sea ice and permafrost.

Introduction

The Earth's climate has changed many times throughout history. These changes are very slow and can take many thousands of years to warm or cool the Earth and change the climate. A climate change event is occurring now: from dusty farms experiencing drought in the outback to serious flooding events. This climate change is due to the enhanced greenhouse effect and is different from previous changes. It started during the second Industrial Revolution (1870) and has increased the Earth's average temperature by 0.95°C since 1900. This short time period (100 years instead of 1,000 years) does not allow time for living organisms (including humans) to adapt and evolve.

The greenhouse effect

The **natural greenhouse effect** is critical for maintaining life on Earth. Most of the Sun's energy is reflected back into space by the upper surface of the atmosphere. The reflective surface of clouds also prevents the Sun's energy from reaching the Earth's surface. The solar energy that does pass through the atmosphere warms the Earth's surface. Heat gradually leaves the Earth's surface and is radiated back into space. Some heat is trapped by the gases in the atmosphere. These gases act like a giant greenhouse of warm air (Figure 1), keeping the Earth warm. If heat was not trapped, the temperature would drop to –100°C each night and rise to 80°C during the day. The gases that contribute to the greenhouse effect include carbon dioxide, water vapour (H_2O), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3).

natural greenhouse effect the natural warming of Earth due to water vapour and other gases being present in small amounts in the atmosphere and affecting Earth's radiation balance

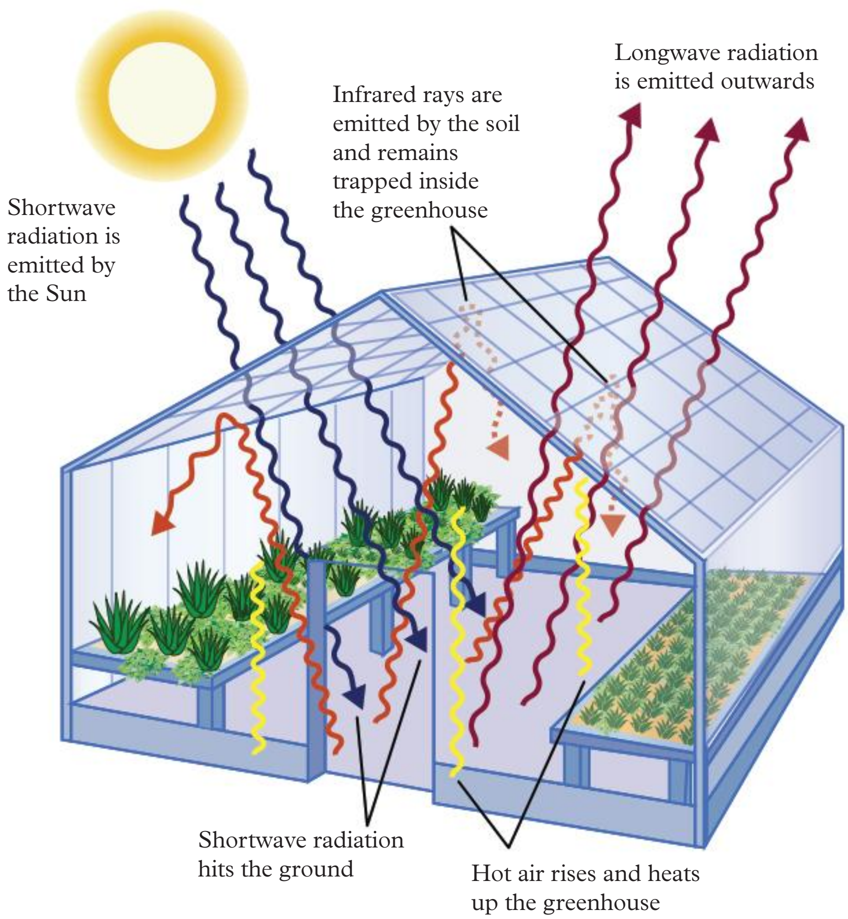


Figure 1 High-energy solar radiation enters the greenhouse. The ground absorbs some of the energy and emits lower-energy radiation. Infrared radiation cannot pass through the glass and is trapped inside the greenhouse, causing the temperature to rise. The glass acts like greenhouse gases, trapping heat inside.

Ice core samples

Scientists have collected 800,000 years' worth of data on atmospheric carbon dioxide and air temperature by drilling deep into ice sheets in Antarctica and collecting ice core samples (Figure 2A). Each layer of ice, typically deposited annually, traps air bubbles that contain the atmospheric composition at the time of formation. By analysing these air bubbles, scientists can accurately determine the amount of carbon dioxide present at various points in history (Figure 2B). Additionally, isotopic analysis of the ice (e.g. the ratio of oxygen-18 to oxygen-16) allows scientists to infer past air temperatures. Radiometric dating and other methods are used to determine the age of each layer, providing a detailed chronological record of past climate conditions due to the natural greenhouse effect.

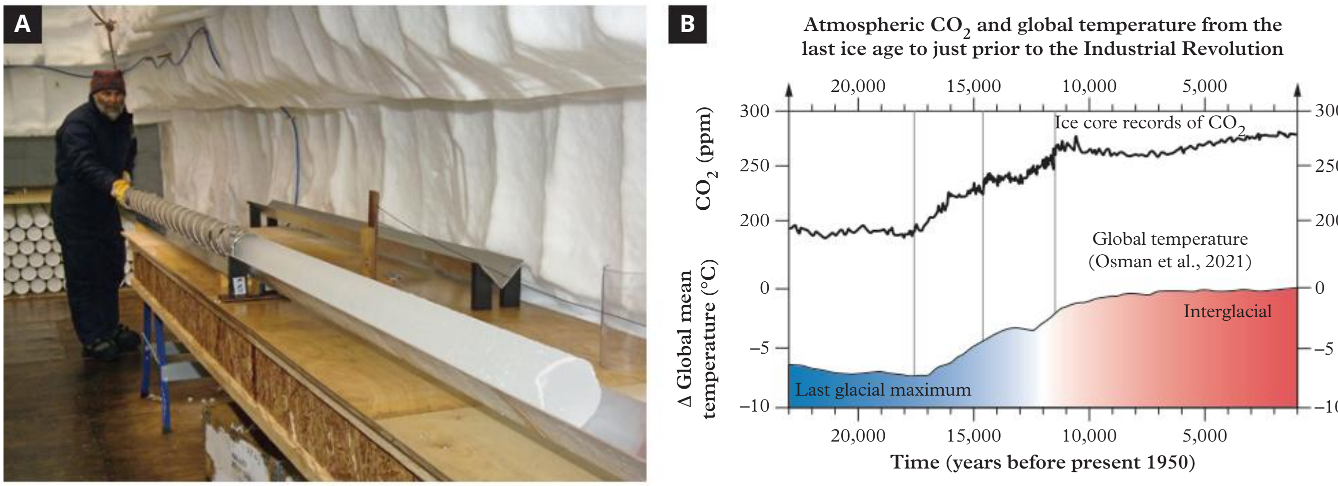


Figure 2 (A) Ice core samples collected in Antarctica; (B) analysis of ice core samples has provided a timeline of the changes in global temperature and carbon dioxide levels.

enhanced greenhouse effect the additional effect that humans are having on the natural greenhouse effect due to the burning and release of fossil fuels

Since the Industrial Revolutions of the eighteenth and nineteenth centuries, the level of greenhouse gases have been increasing, causing an **enhanced greenhouse effect** (Figure 3).

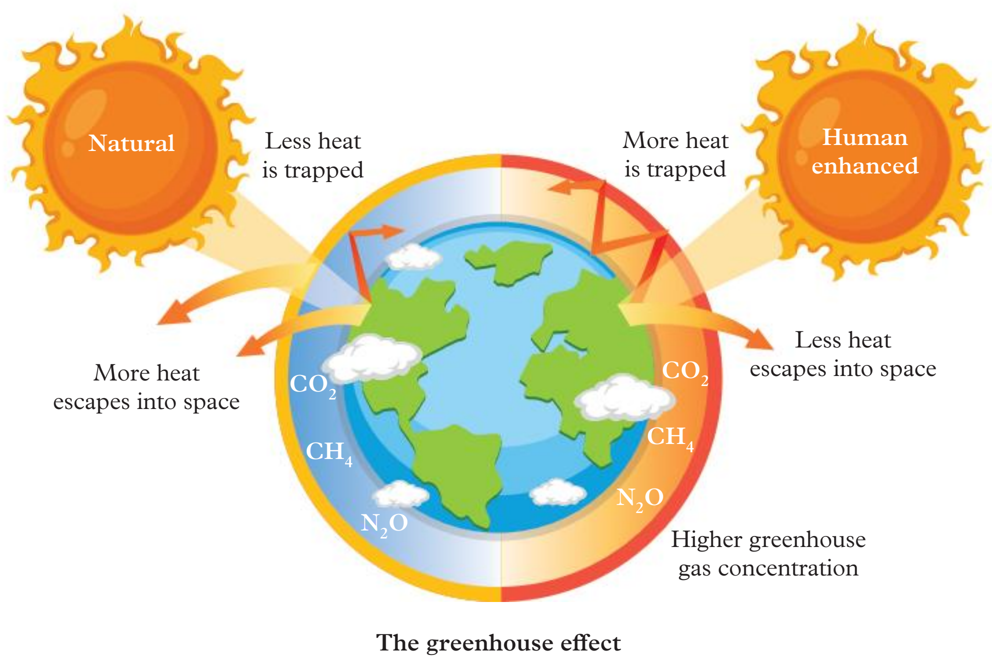


Figure 3 Human activities have increased the concentration of greenhouse gases in the atmosphere, causing more heat to be trapped and global temperatures to increase.

Increased levels of greenhouse gases

The concentration of carbon dioxide in the air has changed significantly. Since the first Industrial Revolution (1750), it has grown by approximately 34 per cent (Figure 4). The bulk of that increase has happened since 1959. The concentration of methane in the atmosphere has also risen dramatically over the past century, more than doubling.

The main greenhouse gas is carbon dioxide. It is formed by the burning of fossil fuels, such as coal, petrol, oil and gas. We all use energy for heating, lighting, transport, industry and communications. Burning carbon-based fossil fuels releases energy (usually as heat) and produces carbon in the form of carbon dioxide and sometimes carbon monoxide or solid particulate carbon.

Forests use carbon dioxide in the process of photosynthesis. Large-scale deforestation for farming and urban land has reduced the amount of carbon dioxide being removed from the atmosphere by forests. This contributes to the increase in carbon dioxide levels in the atmosphere.

The increase in carbon dioxide production and decrease in carbon dioxide absorption have resulted in an overall increase in the amount of carbon dioxide in the atmosphere (Figure 4). Figure 5 shows which parts of the world emit the highest amounts of carbon dioxide.

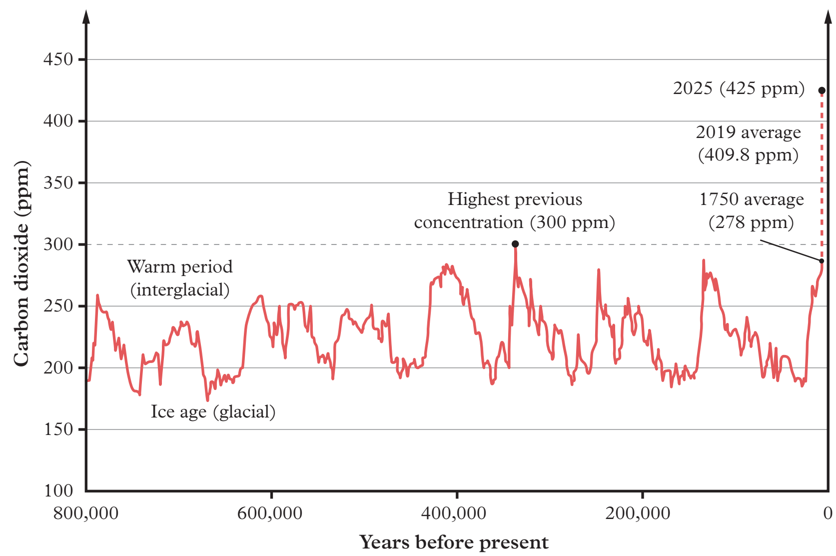


Figure 4 Carbon dioxide levels in the atmosphere have increased significantly since 1750.

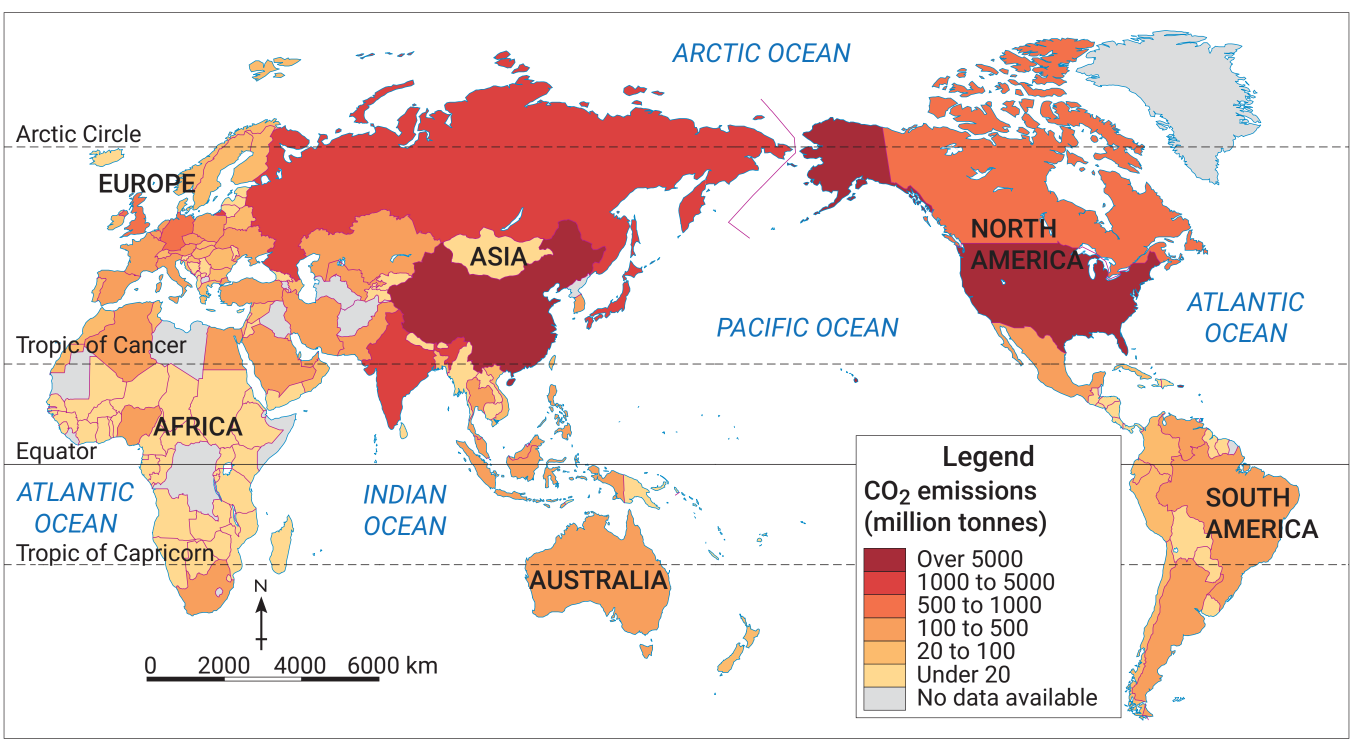


Figure 5 Global carbon dioxide emissions by area

Natural sources of methane gas in the Earth's atmosphere include the decay of organic materials in wetlands, emissions from the oceans and the melting of methane hydrates, which are frozen forms of methane found in the ocean floor. Human activity also produces methane through energy production, increased emissions from livestock (e.g. cattle), landfill, biomass burning and waste treatment (Figure 6). The increase in these greenhouse gases has resulted in more heat being trapped in the atmosphere. Figure 7 shows how average global temperatures have changed since 1900.

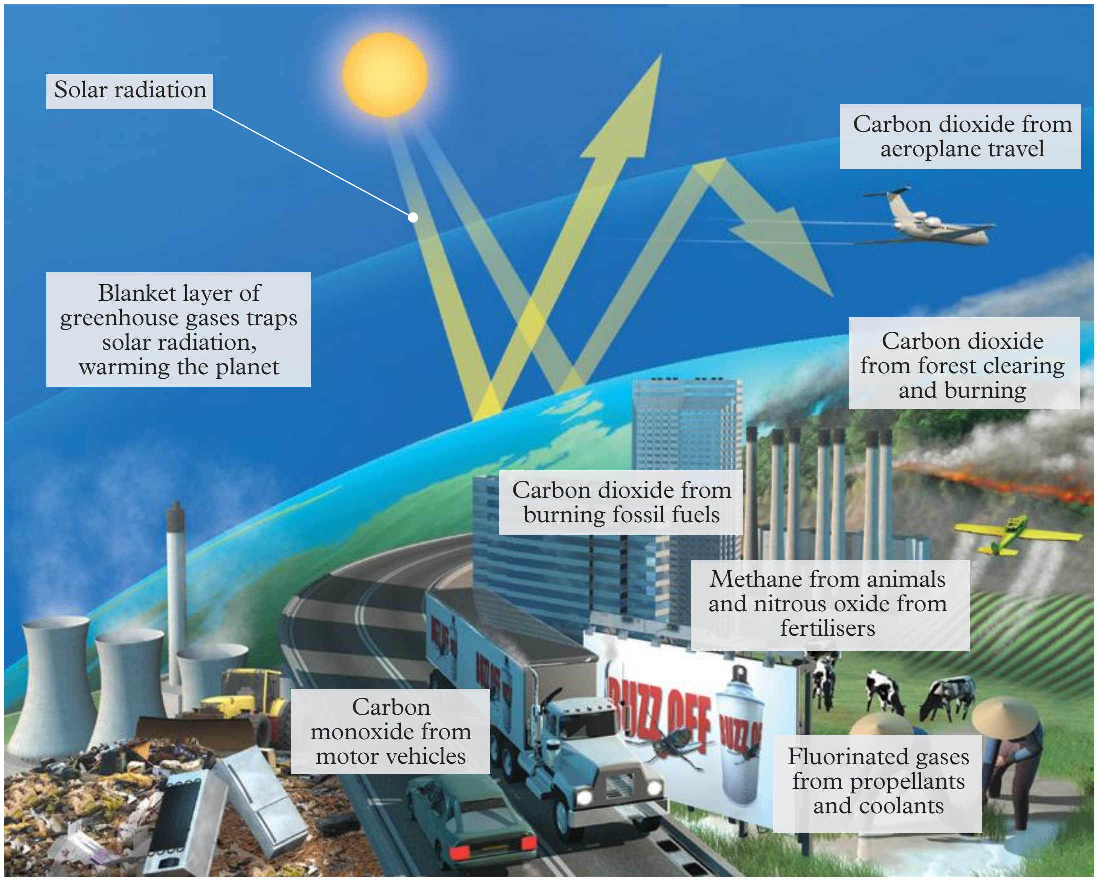


Figure 6 Factors contributing to human-induced climate change

While correlation does not always imply causation, the comprehensive body of scientific evidence from ice core data, paleoclimate studies, climate models and laboratory experiments strongly supports the idea that increased atmospheric carbon dioxide levels lead to higher global temperatures, driving climate change.

If we accept this, based on the overwhelming evidence, consider that in the 275 years since industrialisation, human activities have raised atmospheric carbon dioxide by over 50 per cent. This means current levels are 150 per cent of the amount present pre-industrial revolution (1750), with measures of atmospheric carbon dioxide over 400 ppm regularly recorded. For perspective, atmospheric carbon dioxide levels at the end of the last Ice Age (20,000 years ago) were approximately 275 ppm.

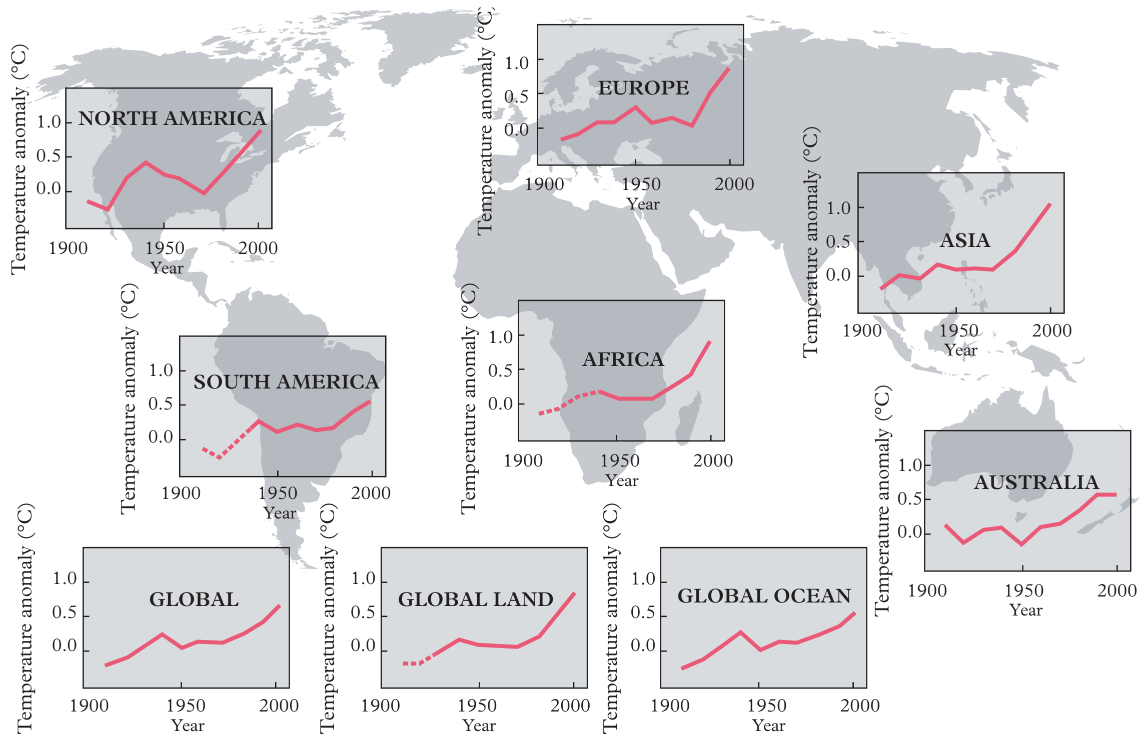


Figure 7 Global changes in long-term average temperature (temperature anomaly) since 1900

Ocean warming

The ocean is a vast and complex ecosystem with a huge variety of organisms that are dependent on each other for survival. The ocean itself is a heat sink. It absorbs excess heat that is trapped by greenhouse gases. Data shows that this has resulted in the ocean warming up (Figure 8), which has affected coral reefs and the populations of organisms, some of which we rely on as a food source. The ocean is not the only ecosystem affected by the enhanced greenhouse effect, however, with ecosystems on land also feeling its effects.

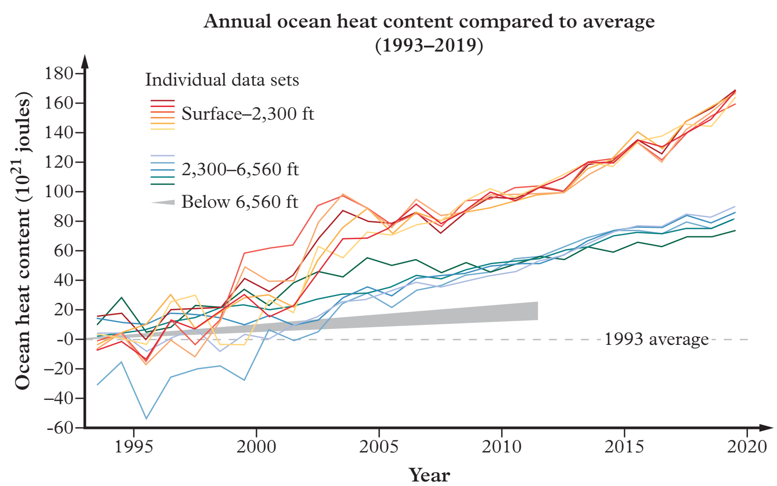


Figure 8 The heat content of the ocean has increased significantly over the last 20 years.

Check your learning 7.4

Check your learning 7.4

Retrieve

1 Identify the two most significant carbon-containing greenhouse gases.

2 Identify how much the temperature on the Earth has risen over the past century.

Comprehend

3 Explain why climate scientists compare trends over many decades rather than data for 1 or 2 years.

4 Explain why the natural greenhouse effect is actually good for life on Earth.

5 Explain why greenhouse gases are called that.

Analyse

6 Examine the data shown in this lesson. Use the data to support your opinion of the validity of global warming caused by the enhanced greenhouse effect.

7 Industrialisation saw a move away from an agricultural economy to one dominated by manufacturing. The reliance on machinery meant a demand for fossil fuels to power them. Figure 9 shows the change in global average temperature from 1850 to 2023. Use Figure 9 and Figure 10 to determine the relationship between industrialisation and the rise in global temperatures.

Skills builder: Communicating

8 Information about climate change is shared in the scientific community and through media platforms.

a Find two sets of data related to climate change. (THINK: Search for data sets by using popular terminology.)

b For each set of data, read the information surrounding it. Assess whether the language used increases or decreases the credibility of the data. (THINK: Is the data impacted by the information surrounding it?)

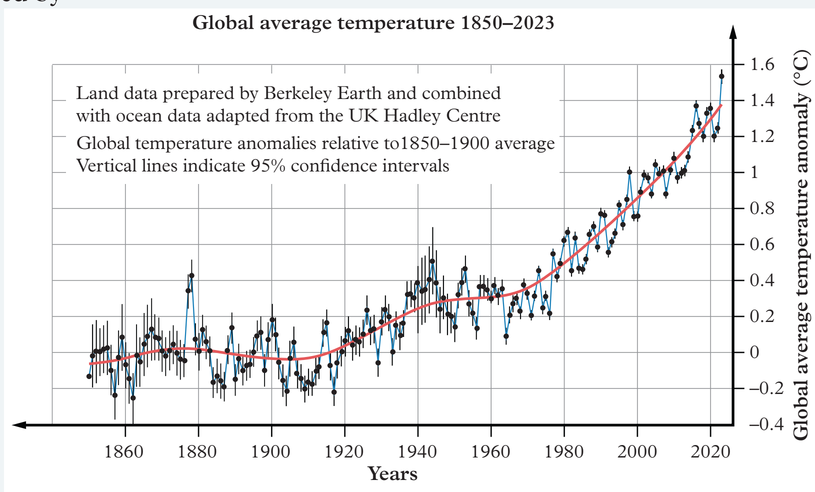


Figure 9 Global average temperature, 1850–2023

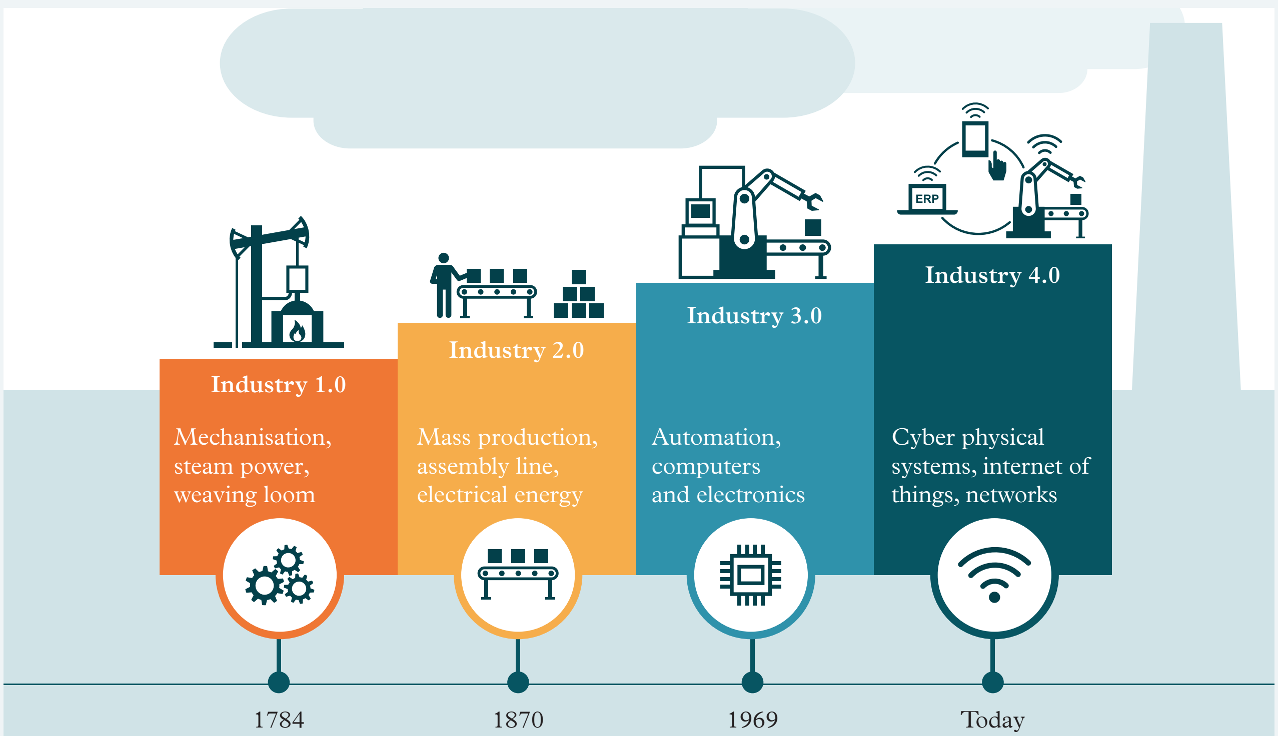


Figure 10 Industrial revolution timeline

Lesson 7.5

Investigation: How the greenhouse effect influences climate

Purpose

To determine which surfaces of the Earth absorb energy and radiate it as heat and so are likely to contribute most to the warming of the atmosphere

Materials

- Six identical clear, empty 600 mL soft-drink bottles with labels removed
- Marker pen
- White paint and brush
- Funnel
- Three cups of dark soil
- Three cups of white sand or perlite
- Water
- Six thermometers inserted into one-hole rubber stoppers that fit securely into the tops of the bottles (or data-logging equipment using long steel temperature probes with Blu Tack to secure the probe in place)
- Sunlight or portable reflector lamp with 150 W floodlight bulb
- Stand to support the lamp set-up (retort stand and clamps)
- Stopwatch

Procedure

1. Work as a group and label the bottles A, B, C, D, E and F. Paint the upper one-third of bottles B, D and F white to represent cloud cover.
2. Use a funnel to fill the base of bottles A and B with dark soil, bottles C and D with white sand or perlite, and bottles E and F with room-temperature water. Ensure that you fill each bottle to the same depth (5 to 7 cm).
3. Put the six thermometers inserted into the rubber stoppers into the top of each bottle. Ensure that the thermometer bulbs are just above the top of the dark soil, sand/perlite and water, so you measure the temperature of the air (atmospheric). If the thermometer bulbs are touching the substances in the bottles, they will record the heat absorbed directly by the soil, sand or water, which will affect your data. If using a data-logger temperature probe, secure and seal it into the top of the bottle with Blu Tack.
4. Record the initial baseline atmospheric temperature of each bottle in a table. Predict which bottle will reach the highest temperature and justify your prediction.
5. If it is a sunny day, take your bottles outside. Alternatively, set up the 150 W light source on a stand facing down. Place the bottles underneath the light source approximately 15 cm away from the lamp. It is important that all bottles receive equal light. Depending on your light source, you may only be able to do two bottles at a time. If this is the case, ensure the two bottles contain the same substance (e.g. dark soil).
6. Record in an appropriate table the temperatures of each bottle every 2 minutes for at least 20 minutes. Calculate the mean, the median and the mode temperature of each bottle and record it in the table.

Results

1. Record your results in an appropriate table.
2. Draw a graph of time (in minutes) against the mean bottle temperature.

Discussion

1. Identify any outliers that can be seen in your graph. Describe a possible cause for the outliers.
2. Use the graph to compare the rate of increasing temperature for the different bottles.

3 Identify which bottled environment:
   a produced the lowest temperature
   b would lead to the least heating of the atmosphere.
4 Explain the temperature difference between the dark soil and the white sand/perlite.
5 Explain the temperature difference between the water and the white sand/perlite.
6 Explain how this experiment demonstrates the effect of the oceans and dark and light surfaces on air temperature.
7 Explain the temperature difference in the bottles with the "cloud cover" to those without.
8 If the deserts are increasing and ice is melting, exposing dark soil, describe the expected effects this will have on atmospheric temperature.
9 Explain why each bottle filling was duplicated in this experiment.

Conclusion

Summarise your key findings from this experiment. Provide evidence to support each finding.

Lesson 7.6

Investigation: The relationship between industrialisation and the rise in global temperatures

Purpose

To investigate how industrialisation (represented by carbon dioxide emissions) correlates with a rise in global average temperature over the past century

Materials

- Historical data on temperature and carbon dioxide emissions (you can research this yourself or use the additional resource provided)

Additional resource: Temperature and carbon dioxide emissions data

- Graphing tools (Excel, Google Sheets or graph paper)
- Computer or tablet (for accessing data and graphing tools)
- Calculator

Procedure

1 Review the data provided on temperature and carbon dioxide emissions (note the website where each set of data came from) or conduct your own research to access data.
2 Plot two graphs:
   a temperature versus time (the *x*-axis will represent years, and the *y*-axis will represent average temperature, in °C)
   b carbon dioxide emissions versus time (the *x*-axis will represent years, and the *y*-axis will represent carbon dioxide emissions, in metric tonnes or another relevant unit).
3 Overlay both data sets on a single graph to see the relationship visually.

Results

Carefully examine the graphs.

1 Identify any trends or patterns in both graphs.
2 Identify periods of industrial growth and see if there are corresponding increases in average temperatures.
3 Identify any outliers or deviations in the patterns.

Discussion

1 Observe the relationship between industrialisation and temperature change and identify whether there is a clear correlation.
2 Explain how the increase in carbon dioxide emissions contributes to rising average temperatures and consider other factors that might influence temperature changes.
3 Identify specific time periods where there is a significant rise in both industrialisation and global temperature, and analyse possible causes such as major industrial developments or wars.
4 Draw conclusions about the role of industrialisation in current global temperature trends and predict how future industrial development might impact global temperatures.

Conclusion

1 Summarise your findings and draw a conclusion based on your analysis.
2 Determine whether the data shows a clear connection between industrialisation and rising temperatures.
3 Explain how industrialisation has affected climate change.

Lesson 7.7
Investigation: Trends and insights from climate data

Purpose

To determine any trends observed in climate data

Materials

- Laptop computer
- Access to the internet

Procedure

1 Find and gather climate data on temperature, carbon dioxide levels and sea levels from reliable sources such as the Australian Bureau of Meteorology, NASA and the National Oceanic and Atmospheric Administration (NOAA).
2 Create graphs for the data collected using Excel or Google Sheets.
3 Identify the trends in global temperature, carbon dioxide levels and sea levels.
4 Discuss any connections between the data gathered.
5 Examine the data and see if they can be connected to any specific events.

Discussion

1 Explain what patterns are evident in the climate data collected.
2 Discuss the possible causes of the trends observed in the climate data.
3 Examine how these trends might impact Australians and our ecosystems.

Lesson 7.8

Science in context: Humans can reduce greenhouse gas emissions

Introduction

The idea of climate change (previously called "global warming") was first raised by the scientific community in 1977. As a result, scientists around the world began to coordinate their research in the World Climate Research Programme. By 1983, the enhanced greenhouse effect was becoming a political issue. Currently, climate change is seen as a worldwide problem and this has influenced the focus of scientific research.

Kyoto Protocol

In 1997, an international treaty called the Kyoto Protocol was signed by many of the countries that are part of the United Nations. This document stated that global warming exists, and that it is a result of carbon dioxide emissions arising from human activity.

The countries that signed the protocol agreed to start working to reduce carbon emissions by 2005. Australia ratified (made the agreement legally binding) the agreement in 2007. This required the Australian Government to limit its average annual greenhouse gas emissions during 2008 to 2012 to 108 per cent of its emissions in 1990. In 2012, the protocol was amended to allow countries to extend the commitment to 2020, to allow time to create a new comprehensive climate treaty that would require all countries to reduce their emissions of greenhouse gases.

Figure 1 Using renewable energy, such as wind power, is one way to reduce carbon emissions.

Paris Agreement

In 2015, the Paris Agreement was signed by almost all nations (rich, poor, developed and developing) to greatly reduce the amount of greenhouse gases that they produced (Figure 2). The legally binding agreement has a system which, every 5 years, monitors and reports on the targets that individual countries have set. Australia has currently agreed to reduce its greenhouse gas emissions to 26–28 per cent below 2005 levels by 2030.

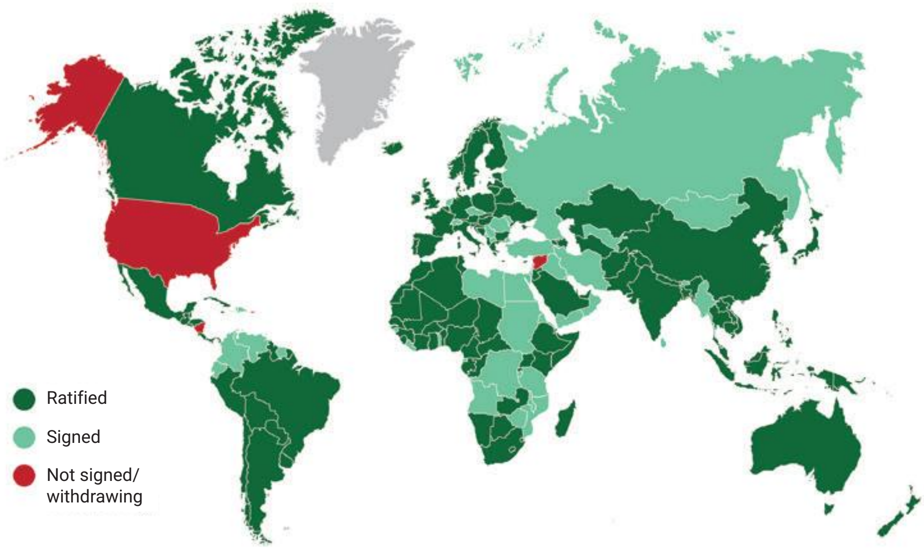


Figure 2 Many countries have ratified the Paris Agreement (made the agreement legally binding), while some have signed the agreement (an initial expression of intent to participate and comply with the agreement). Only three countries are yet to formally join, with the United States withdrawing in 2020.

Reducing carbon emissions

Many governments are encouraging industries in their countries to reduce carbon emissions. Some governments are charging a fee for each tonne of carbon a business emits. This is often called a **carbon tax**.

Other governments have put in place a **carbon trading scheme**, where each business is allowed to release a predetermined amount of carbon emissions. If a company needs to release more carbon dioxide or methane as part of their production process, then they must buy an allocation from another company. This also allows other industries to actively extract carbon dioxide from the atmosphere in order to sell "carbon credits". One carbon credit is often equivalent to 1 tonne of carbon dioxide.

carbon tax a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme the process of allocating a set limit of carbon credits to businesses, which can then trade the credits

Carbon farming

Plants remove carbon dioxide from the air as part of photosynthesis. This carbon dioxide is converted into sugars and proteins that are then used by the plant to grow. During this process, the carbon dioxide becomes part of the plant's structure. The carbon is "locked" in the plant for as long as it lives. For some trees, this can be hundreds of years. Carbon farming is the process of growing plants that are not harvested for firewood, building or any other purpose (Figure 3).

Figure 3 Carbon farming uses trees to remove carbon from the atmosphere and lock it away for hundreds of years.

Figure 4 Turning carbon dioxide into liquid allows it to be stored in old wells.

Geosequestration

The capture and storage of carbon dioxide underground is called geosequestration (Figure 4). This process, often employed by oil companies, involves capturing carbon dioxide from power station chimneys, separating it and compressing it into a liquid. The liquid is then pumped into deep oil or gas wells that are no longer needed (because the oil or gas has been depleted) and then the wells are sealed with a solid plug of thick clay.

Reducing methane production

Methane, another greenhouse gas, is produced when grass ferments in a cow's stomach. Our increasing global population has meant a need for more food (including meat). This has resulted in more cattle being farmed and so more methane being released into the atmosphere.

Microbiologists at the University of Queensland are studying ways to modify the bacteria present in the cow's stomachs so that they do not produce as much methane. The model organism they use is a species of bacteria found in the foregut of kangaroos. This particular species of bacteria produces mainly acetic acid as a waste product. This acetic acid is then digested further by the kangaroo. It is hoped that the way these bacteria digest grasses can be mimicked by the bacteria in a cow, thereby reducing the emission of methane.

Small changes, big differences

There are many ways each person can reduce their impact on the climate. These include:

- using public transport or car pooling
- switching off electrical appliances
- using renewable energy such as solar
- buying local produce, which reduces "food miles" by preventing fossil fuels from being used to transport food long distances
- reducing, reusing and recycling items to prevent them from going into landfill and producing methane.

Our ability to make these changes is affected by social factors. A country with a low socioeconomic population may consider increasing wealth to be more important than future environmental concerns. The challenge is to support all countries to consider larger global issues as well as local issues.

Table 1 Summary of different ways humans can reduce greenhouse gas emissions

Method	How it works	Advantages	Limitations
Carbon tax	Businesses pay a fee for each tonne of carbon they emit	• Encourages businesses to use cleaner technologies • Simple to implement and understand	• Low tax rates may not lead to significant change • High tax rates can financially burden smaller businesses
Carbon trading scheme	Businesses are allocated carbon credits (allowances for emissions) that can be traded	• Creates a financial incentive to reduce emissions • Encourages innovative solutions like carbon capture	• Initial allocation of credits can be unfair • Trading system can be manipulated

Method	How it works	Advantages	Limitations
Carbon farming	Plants absorb carbon dioxide through photosynthesis, storing it in their structures	• Natural process that "locks" carbon away for long periods • Supports biodiversity and soil health	• Requires large areas of land • Limited by the lifespan of plants
Geosequestration	Captures carbon dioxide from power stations and stores it underground	• Prevents carbon from entering the atmosphere • Useful for industries that can't easily reduce emissions	• Expensive to implement • Risk of leaks from storage sites

Test your skills and capabilities

Test your skills and capabilities 7.8

Scientific communication

Presenting data to an audience can take many forms. An increasingly common way to present important information is an infographic. Infographics are visual ways to present data so that the viewer can easily see the patterns. This can be through the use of graphs, images and important figures.

1 Select some of the key information you have learnt about climate change and create an infographic for your peers.

- **a** Decide on one or two key ideas that you want to present in your infographic. This should be reflected in the images and data that you use.
- **b** Identify data (graphs or tables) in this module that support the key ideas.
- **c** Identify how you can present this data in a simple and effective way. By using large and small images, you can represent the size of different values (Figure 5).
- **d** Communicate the key ideas in a short phrase or sentence so that they are clear to the viewer.

Figure 5 Data such as increasing storm strength or biodiversity can be represented in different ways.

Skills builder: Communicating

2 Imagine you are speaking with someone who thinks it is too hard to be environmentally sustainable and that climate change is inevitable.

- **a** Explain why it is important to be sustainable. (THINK: What are the key facts that need to be communicated?)
- **b** Evaluate the impacts of individuals living in a sustainable manner. (THINK: What will change? Will there be bigger impacts?)

Lesson 7.9
Challenge: Measuring carbon stored in trees

Introduction

The key to measuring the amount of carbon stored in a tree is the size of the tree. Bigger trees are usually older and therefore have had more time to photosynthesise (capture carbon dioxide from the atmosphere). The size of the tree can be determined by the girth (circumference) of the tree at chest height (approximately 1.3 metres above the ground)

Aim

To determine the amount of carbon stored in a tree

What you need:

- Tape measure
- Calculator

What to do:

1 Identify a tree in the grounds of your school.
2 Use a tape measure to measure the circumference (in cm) of the tree at 1.3 m above the ground. Repeat this measurement two more times.
3 Calculate the mean (or average) girth of the tree in centimetres.
4 Use Table 1 to determine the dry weight of the tree.
5 Half the dry weight of a tree is carbon. Divide the mean dry weight of the tree by 2.
6 Record the amount of carbon, in kilograms, stored in the tree you measured.

Table 1 The dry weight of trees according to their circumference

Circumference (cm)	Dry weight (kg)
50	106
100	668
150	1,964
200	4,221
225	5,771
250	7,641
275	9,842
300	12,410
325	15,350
350	18,700
400	26,674

Questions

1 Identify the name of the process used by a plant to extract carbon dioxide from the atmosphere.
2 Identify the reactants and products in the chemical reaction you named in the previous question.
3 Calculate the amount of carbon dioxide (in kg) that was absorbed by the tree to create its carbon store by multiplying the amount of carbon stored by 3.67.
4 Describe how the tree you measured does or does not represent all the other trees in the area. Use the term "sample size" to describe how the method you used could be improved.
5 Describe what would happen to the carbon stored in the tree if it was chopped up and burnt as firewood.
6 Describe what would happen to the carbon stored in the tree if it was turned into furniture or used to build a house.

Lesson 7.10
The effects of climate change

Key ideas

→ Data is used to measure and analyse climate change.

→ Climate change has caused increasing global temperatures and extreme weather events, costing people their lives.

→ Climate change has affected the distribution of diseases, with some diseases becoming more prevalent.

→ Climate change is affecting the biodiversity of organisms, with flora and fauna becoming extinct as they are unable to adapt to the climate.

→ Rapid changes in climate have changed where species live.

→ The increasing levels of carbon dioxide in the atmosphere affect the oceans, which absorb more carbon dioxide, resulting in higher ocean acidity. This leads to the destruction of ecosystems and reduces marine species populations.

Learning intentions and success criteria

What is climate change?

Climate change refers to a long-term shift in global average temperature and weather patterns, primarily driven by human activities such as burning fossil fuels, deforestation and industrial processes. These activities increase the concentration of greenhouse gases in the atmosphere, trapping heat and altering the Earth's natural systems. The effects of climate change are far-reaching, including a rise in global average temperature, melting ice caps, sea-level rise and more frequent extreme weather events like droughts, floods and hurricanes. Additionally, ocean acidification, biodiversity loss and ecosystem disruption threaten natural habitats and human livelihoods. Understanding climate change will help us develop strategies to reduce its impact and adapt to the challenges it presents.

Greenhouse gases

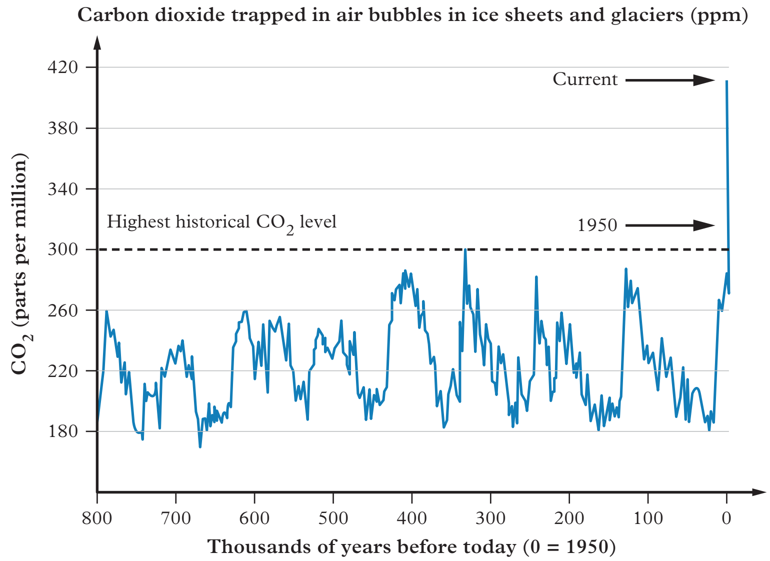
Gases in the atmosphere allow the Earth to maintain a relatively constant environment in which life can survive. The Moon is not large enough to retain a full atmosphere, which means the Moon's temperature can vary from 123°C when in sunlight to –153°C when it is turned away from the Sun.

Gases in the 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 the Earth's surface does not cool too much at night (similar to how a greenhouse retains heat).

Not all atmospheric gases are equal in their ability to retain heat. **Greenhouse gases** such as methane, nitrous oxide and carbon dioxide absorb and emit solar radiation. Atmospheric carbon dioxide has increased significantly because of human-related activities, such as burning fossil fuels and deforestation. The level of carbon dioxide has varied between 180 and 300 ppm (parts per million) over the past 800,000 years. This data was obtained by

greenhouse gas a gas (carbon dioxide, water, methane) in the atmosphere that can absorb heat measuring the amount of carbon dioxide trapped in ice sheets and glaciers (Figure 1A). In 2022, the level of carbon dioxide reached a record high of 419 ppm, which has contributed to the rise in global average temperature (Figure 1B).

A



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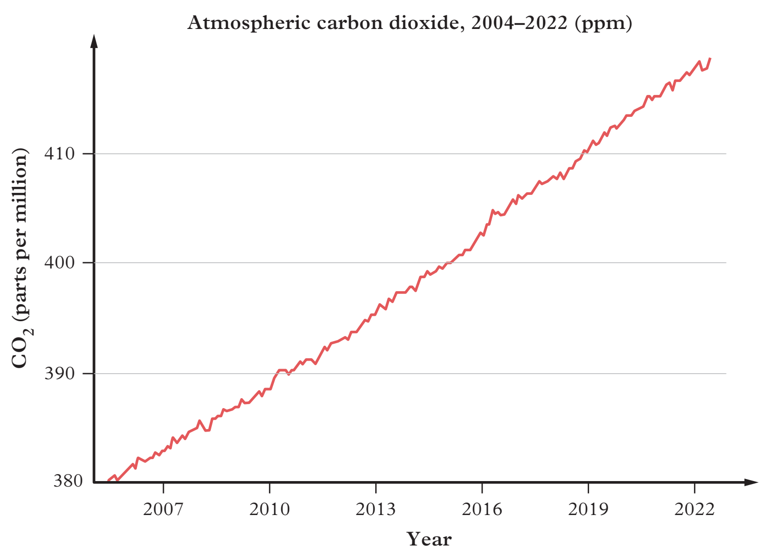


Figure 1 Trends in atmospheric carbon dioxide from (A) air bubbles trapped in ice sheets and glaciers, and (B) atmospheric carbon dioxide recorded by Mauna Observatory, Hawaii

Effects of climate change

One of the most significant climate change issues we are currently facing is the profound and far-reaching effects on the Earth's systems. These effects are driven primarily by our need for places to live, transportation, food to eat and products to keep us entertained, but they come with many negative impacts. Understanding the effects of climate change is crucial to recognising how it influences ecosystems, economies and communities and to exploring ways we can mitigate (minimise) its impact.

Rising temperatures

Increased atmospheric carbon dioxide from human activities has resulted in a rapid increase in the global average temperature. Figure 2 shows that the increase in average temperature is not evenly spread across the 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 1–2°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 icecaps.

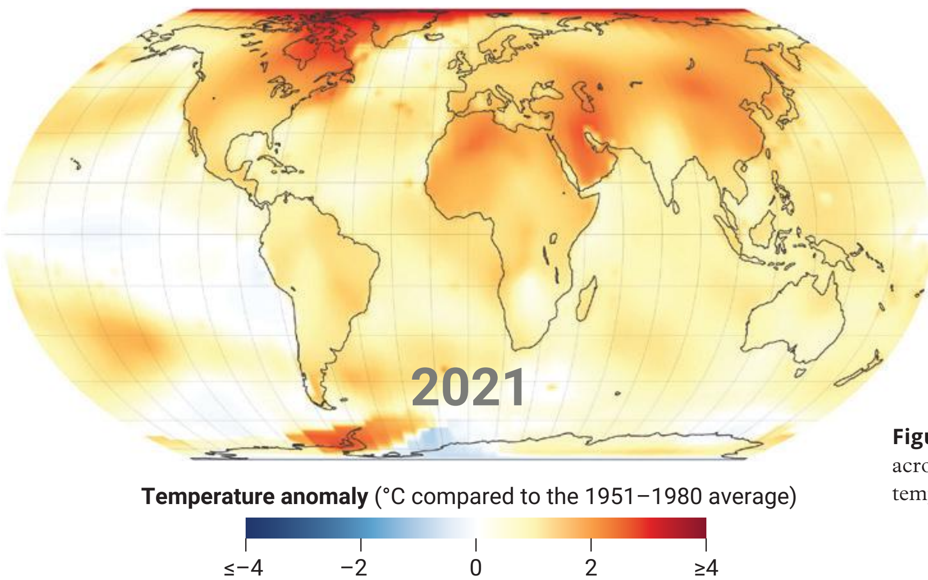


Figure 2 Temperature difference (anomaly) across the world compared to the average temperature between 1951 and 1980.

Extreme weather events

A 2021 report published by the Intergovernmental Panel on Climate Change (IPCC) predicted that without a significant reversal in greenhouse gas emissions, global temperatures could rise by 1.5°C above pre-industrial levels by 2030 and by 2°C or more by mid-century.

With this in mind, the number of extreme weather events such as heatwaves, droughts, floods, cyclones and bushfires are increasing around the world and in Australia. 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, resulting in economic loss and a rise in insurance premiums (or no insurance coverage at all) (Figure 3).

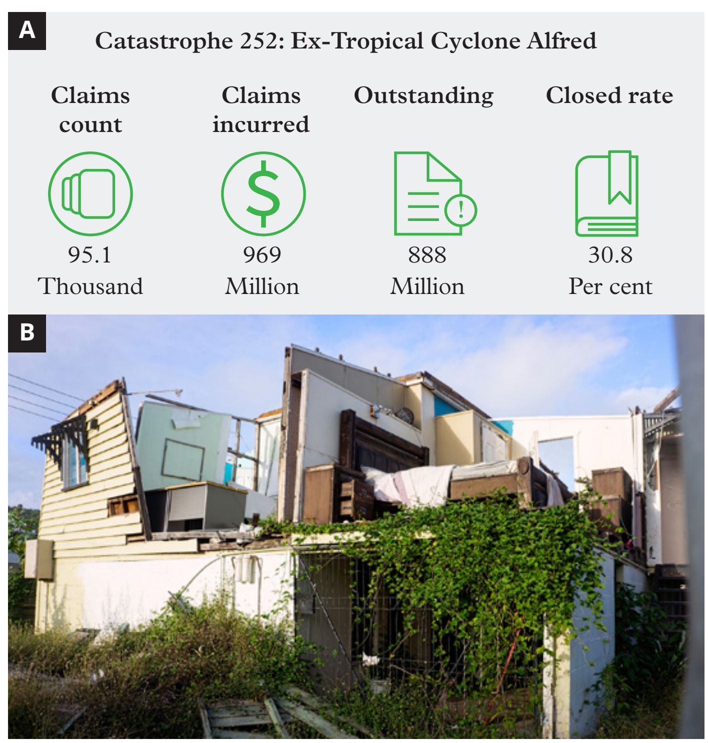


Figure 3 (A) Ex-tropical Cyclone Alfred in March 2025 saw widespread devastation and has had a massive economic impact. (B) The aftermath of a cyclone

In 2022, floods in Lismore, NSW, reached the highest flood level on record at 14.4 m, more than 2.2 m above the previous record set in 1954 (Figure 4). Over 3,000 homes were impacted and four people lost their lives as well as thousands of animals.

While some areas of Australia experience record rainfall, other areas are well below average, increasing the risk of bushfires during the warmer months (Figure 5).

Figure 4 Floods in Lismore, NSW, in 2022

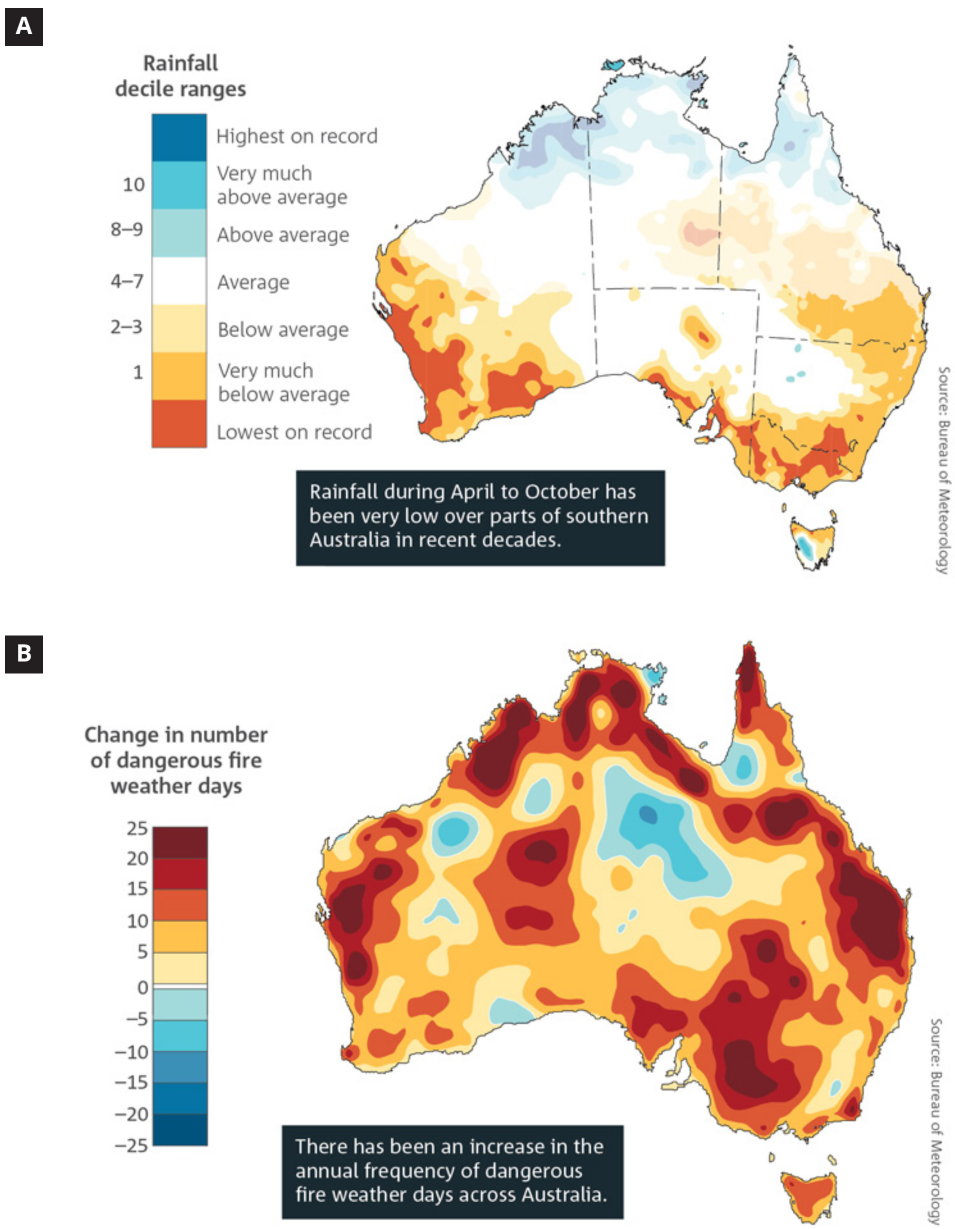


Figure 5 (A) Certain areas of Australia are experiencing record rainfall and (B) a greater number of dangerous fire weather days.

In 2019 and 2020, bushfires destroyed an estimated 79 per cent of the Greater Blue Mountains World Heritage Area in NSW. This area is three times greater than that burnt in any of the previous 48 fire seasons (Figure 6). Thirty-five people lost their lives as well as an estimated 3 billion mammals, birds and reptiles.

Health and disease

Higher temperatures in summer can cause an increase in heat-related deaths. In 2024, the average global temperature was recorded to have risen by approximately 1.1°C since 1880. Heatwaves are now lasting longer, causing people to become more dehydrated, placing more strain on their hearts and causing people to experience sleep deprivation. In 2024, a United Nations report estimated that 175,000 people die from heat-related causes every year in Europe.

Climate change is also causing increased rainfall in some areas. This can extend the zones for infectious diseases, such as dengue fever and malaria, which thrive in warm, moist conditions (Figure 7). This means it is important for people in these areas to be vaccinated against dengue fever and for a vaccine for malaria to be produced. In cities such as Beijing in China, stagnant weather conditions can trap both warm air and pollutants, leading to increased smog which results in serious respiratory problems that contribute to increased deaths.

Figure 6 Bushfires in the Blue Mountains, NSW, in 2020

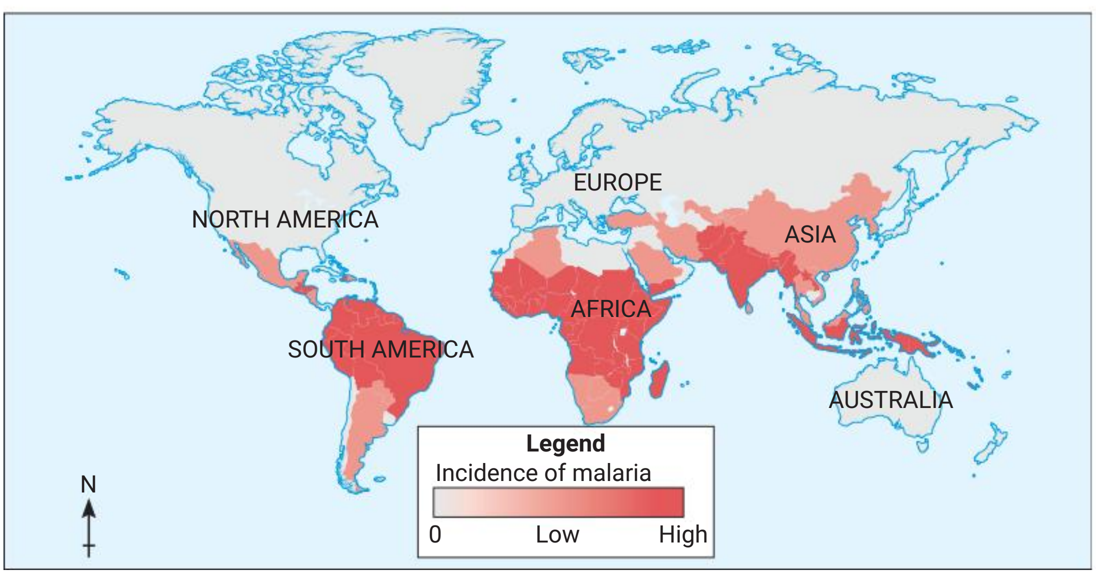


Figure 7 Countries and areas at risk of transmission of malaria

Loss of biodiversity and species distribution

Rapid climate change over the past 50 years has resulted in many changes to the distribution and number of species. Many species are at risk of extinction because they are unable to adapt to the change in conditions. Reductions in populations and the extinction of species lead to a loss of **biodiversity**, which can make ecosystems less stable. Climate change can disrupt seasonal cycles, change migration patterns, cause a loss of habitat, change the amount and types of food available and increase the spread of disease.

biodiversity the variety of life; the different plants, animals and microorganisms and the ecosystems they live in

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 8A and Figure 8B). Other species, such as the lemuroid ringtail possum that is only found in high-altitude areas in north Queensland, can only live within certain temperature ranges (Figure 8C). 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 small numbers were observed recently.

Figure 8 Many animals are at risk of extinction as a result of climate change, including (A) polar bears and (B) emperor penguins, which live in cold climates, and (C) lemuroid ringtail possums, which can only live within a certain temperature range.

Australian native plants and animals are well adapted to year-by-year climate fluctuations, such as floods and droughts; however, they can often only survive within a narrow range of temperatures. This means that many species and ecosystems could be highly vulnerable to the rapid and sustained increase in long-term average temperatures of 1–2°C that are expected because of climate change.

For example, climate change modelling suggests that the extent of highland rainforest ecosystems in 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 (depend on each other), the loss of one species may affect the survival of other species. Even a small decrease in a population may cause a decrease in the number of alleles in the gene pool, making the species more vulnerable to disease in the future.

Ocean acidification

Ocean acidification occurs when excess carbon dioxide in the atmosphere is absorbed by the oceans, causing chemical changes that lower the pH (acidity) of the water. This process threatens marine ecosystems, particularly organisms like corals (causing coral bleaching, as experienced by the Great Barrier Reef), shellfish and some plankton species that rely on calcium carbonate to build their shells and skeletons (Figure 9). As the acidity of seawater increases, these organisms struggle to form and maintain their structures as the acid reacts with the shells of many molluscs, causing them to become thin (Figure 10). This leads to weakened populations and disruptions in marine food chains, ultimately affecting biodiversity and human industries like fishing and tourism.

Oceans are not the only sites that store carbon. It is also stored in:

- decomposed organic matter, such as coal, natural gas, petroleum and shale oil
- rocks, such as limestone, marble, dolomite, chalk and other carbonates
- organic matter in the soil
- dissolved carbon dioxide in other waters
- the shells of marine organisms and some terrestrial organisms.

These carbon sinks could release carbon if their environmental conditions change.

Figure 9 Corals are threatened by ocean acidity, which causes coral bleaching and decay.

Figure 10 Acids in the ocean cause mollusc shells to become thin.

Check your learning 7.10

Check your learning 7.10

Retrieve

1 Define the term “extreme weather event”.

2 Explain the causes of ocean acidification and how it affects marine ecosystems.

3 Discuss how diseases like malaria or dengue fever spread as the global temperature rises.

Comprehend

4 Explain how increasing levels of carbon dioxide have contributed to global climate change.

5 Describe the ways that climate change can affect human health.

6 Explain how the loss of one species can affect other species.

7 Explain why a change of only 1–2°C can be enough to cause problems for species.

8 Summarise why a loss of biodiversity is a problem.

Analyse

9 Assess how the temperature of the Pacific Ocean can affect Australia’s climate.

10 Identify and explain two sets of data that show how the climate has changed over the last 100 years.

11 Research how climate change has altered species migration patterns and identify challenges this might pose for ecosystems.

12 Investigate technologies that are being developed to help reduce the impact of climate change and discuss their effectiveness.

Apply

13 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.

14 Create a poster or webpage that brings awareness to how climate change is affecting the ecosystem in the NSW coastal wetlands.

15 Investigate the economic impact of extreme weather events on businesses, governments and people.

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.

16 Identify the variable that is changing in this situation. (THINK: What is impacting the decline of the North Atlantic cod?)

17 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 7.11

Challenge: Using computer simulations

Introduction

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 (Figure 1).

Figure 1 Computer modelling can be used to represent data from a table.

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 2024. 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 2024.

Identify and use a set of secondary data to make a comparison with the data given in Table 1.

What you need:

- Laptop computer
- Spreadsheet program such as Microsoft Excel

What to do:

1. Enter the information from Table 1 into a spreadsheet program.
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 trend line 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 2024 that you would like to forecast.)
6. Compare the predicted mean temperature difference you generated to that of a secondary source you identified.

Table 1 The mean difference in Australia's surface temperature each year when compared to the mean temperature of 1951 to 1980

Year	Mean difference in temperature (°C)	Year	Mean difference in temperature (°C)	Year	Mean difference in temperature (°C)
1961	0.152	1983	0.609	2005	1.120
1962	0.132	1984	−0.187	2006	0.629
1963	−0.091	1985	0.306	2007	0.842
1964	−0.014	1986	0.347	2008	0.541
1965	0.128	1987	0.329	2009	0.949
1966	−0.255	1988	0.924	2010	0.605
1967	−0.096	1989	0.116	2011	0.140
1968	−0.215	1990	0.517	2012	0.239
1969	0.107	1991	0.781	2013	1.429
1970	0.000	1992	0.238	2014	1.124
1971	−0.034	1993	0.432	2015	1.020
1972	0.089	1994	0.171	2016	1.105
1973	0.834	1995	0.351	2017	1.072
1974	−0.354	1996	0.545	2018	1.059
1975	0.050	1997	0.320	2019	1.360
1976	−0.516	1998	1.028	2020	1.353
1977	0.176	1999	0.512	2021	0.551
1978	0.078	2000	0.085	2022	0.678
1979	0.363	2001	0.281	2023	0.877
1980	0.871	2002	0.664	2024	1.446
1981	0.472	2003	0.770		
1982	0.166	2004	0.649		

Discussion

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.
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 for which you could have used this process.
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.

Lesson 7.12

Effects of climate change on the water cycle

Learning intentions and success criteria

Key ideas

→ Climate change is modelled using scientific methods and data gathered over long periods of time.

→ Increased global temperatures are causing icecaps to melt, resulting in increased sea levels.

→ Deep ocean currents can regulate global climate and affect marine ecosystems.

→ Climate change disrupts the water cycle. This disruption affects ecosystems by altering species distribution, reducing biodiversity and impacting habitats.

Effects of climate change on the water cycle

water cycle the continuous movement of water on, above and below the surface of Earth

The **water cycle** is the continuous movement of water due to the Sun's energy (Figure 1). Climate change significantly disrupts the water cycle by intensifying the natural processes of evaporation, condensation and precipitation.

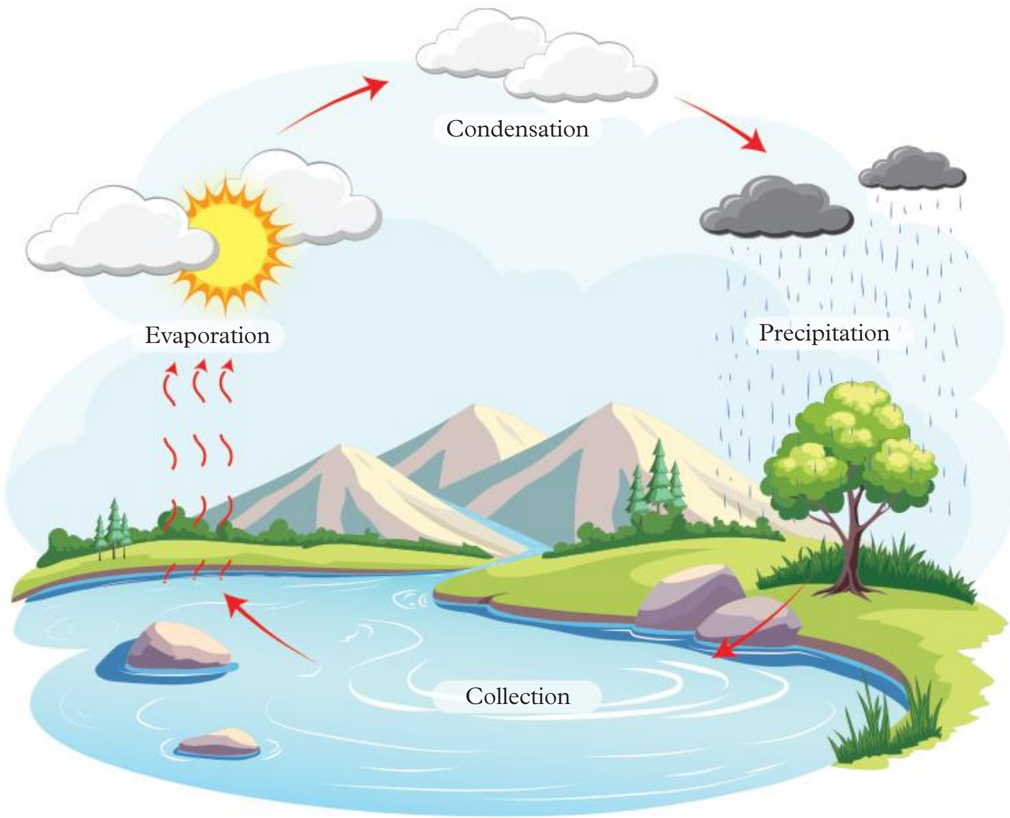


Figure 1 Water moves through a continuous cycle where it is collected, then evaporates and becomes condensation, then becomes precipitation before the cycle starts all over again.

Warmer temperatures lead to increased evaporation from oceans, lakes and soil, causing more moisture to accumulate in the atmosphere. This often results in heavier and more frequent rainfall in some regions, increasing the risk of flooding and soil erosion. In contrast, other areas experience reduced precipitation and prolonged dry periods, exacerbating drought conditions and lowering groundwater levels. These disruptions can strain water resources, affecting agriculture, drinking water supplies and energy production.

Shifts in the water cycle can have widespread effects on ecosystems. Prolonged droughts can dry up rivers, wetlands and lakes, leaving aquatic species without suitable habitats. Plants reliant on consistent water availability may struggle to survive, leading to reduced vegetation cover and biodiversity. Conversely, excessive rainfall can wash away nutrients and destabilise soil structures, which can affect plant growth and reduce food availability for herbivores.

Dams (Figure 2) built to store water or generate electricity can cause shifts in the water cycle and affect ecosystems both upstream and downstream.

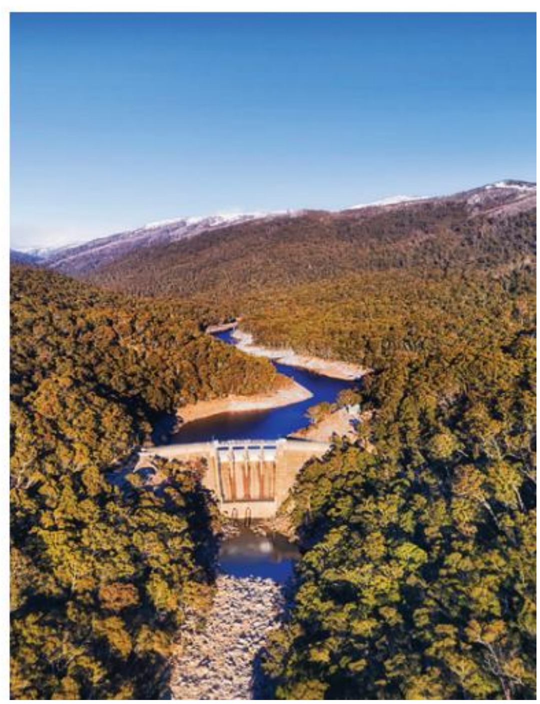


Figure 2 Guthega Dam in the Snowy Mountains

Modelling the future

While climate change has many effects, from increasing global temperatures and extreme weather events to a reduction in biodiversity, scientists can develop models to predict how we can reduce the impact of climate 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 so that the mathematical equations are more accurate. These equations 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 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 (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 3).

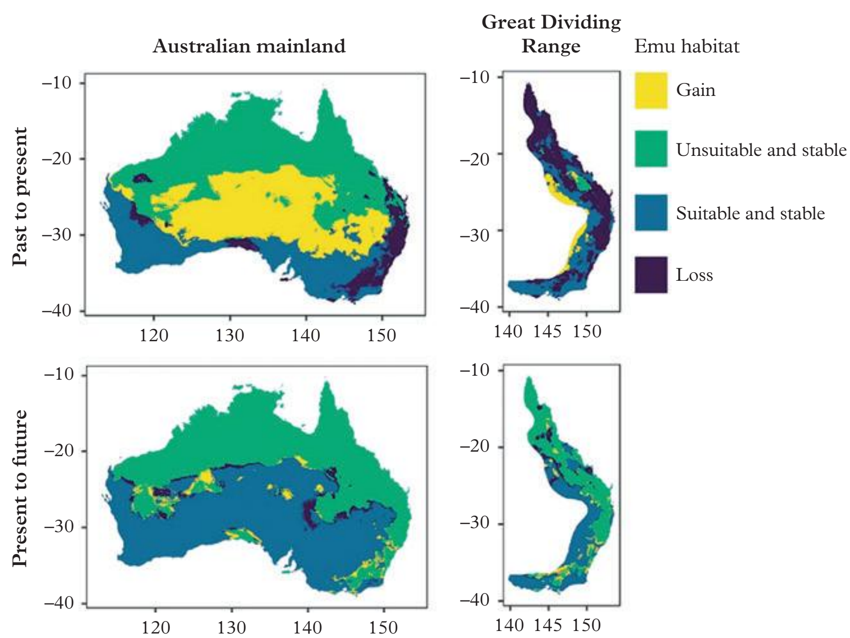


Figure 3 Supercomputers used satellite data to predict how the changing climate in Australia will affect the distribution of emus.

Changing sea levels

The impact of climate change will vary. Some areas of the 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 the Earth). This is due to the increasingly warm ocean currents melting the glaciers and ice sheets (Figure 4). 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. Over the last 100 years, there has been a dramatic change in sea levels as a result of the enhanced greenhouse effect melting ice at the polar ice caps (Figure 5).

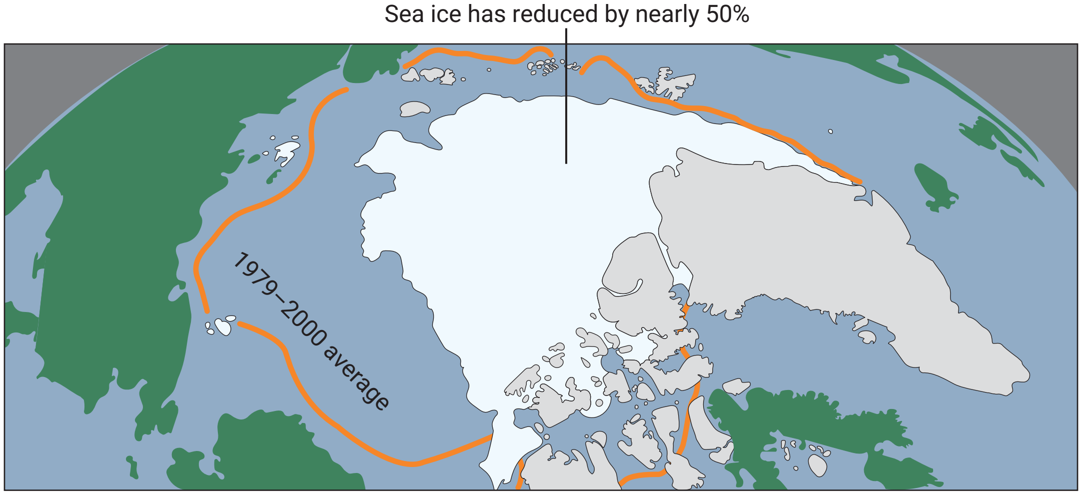


Figure 4 The amount of sea ice at the North Pole has been reduced by nearly 50 per cent in the past 20 years.

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 absorbed by the geosphere and hydrosphere will increase. This may cause the rate of global warming due to climate change to increase further as more heat energy is retained by the 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 6).

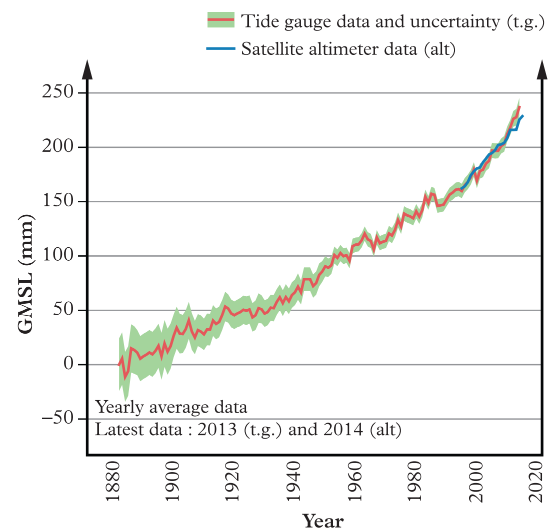


Figure 5 The CSIRO measured the global mean sea level (GMSL) from coastal tidal gauges and satellite data from 1880 to 2014. The overall trend indicates a consistent rise in sea levels.

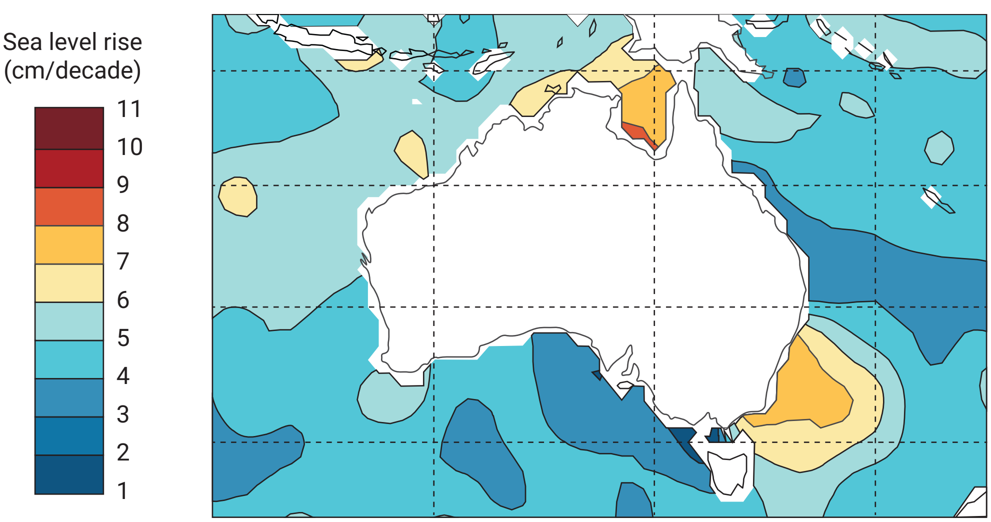


Figure 6 The rate of sea rise around Australia between 1993 and 2017

Deep ocean currents and climate control

Within the oceans are deep ocean currents that act like large conveyer belts, distributing heat through parts of the world and regulating temperature (Figure 7).

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. Water that is less salty is also less dense and rises to the surface, whereas water that is more salty is denser and sinks. Heat from the Sun evaporates the top layer of the ocean, causing 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 fresh water in ice caps. This, in turn, can affect the ocean conveyer belt that controls climate.

Small changes in these large ocean currents can produce large changes in the marine life and the climate. El Niño events occur when the waters of the Pacific Ocean are warmer than normal. This 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.

upwelling a process in which deep, nutrient-rich cold water moves up towards the surface

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

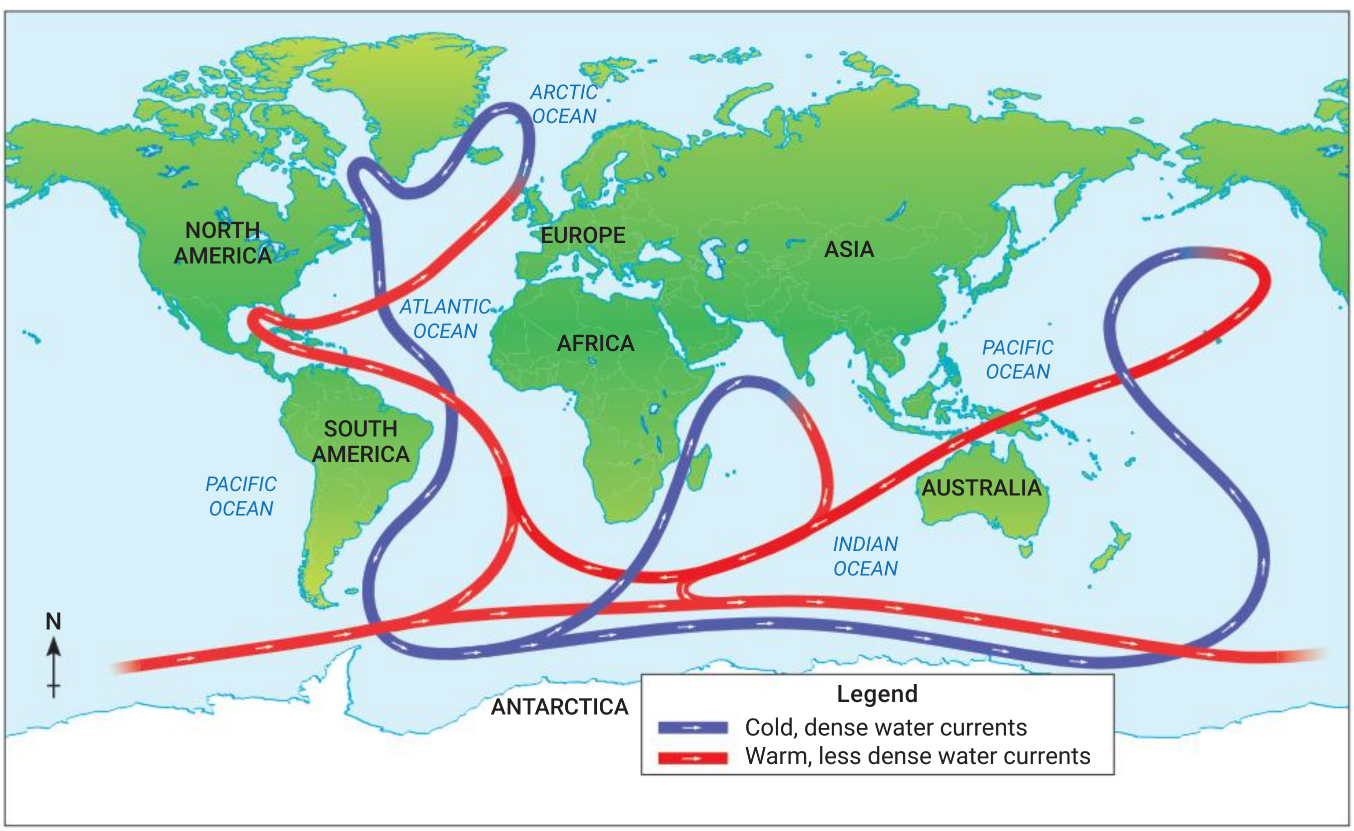


Figure 7 The path of the ocean "conveyer belt", in which differences in temperature and salinity drive the movement of large currents of water

food web of the marine ecosystem. The upwelling process also occurs along the coast of Queensland during monsoon season (Figure 8). Occasionally, the upwelled waters do not completely reach the surface. When this occurs, it is called an **intrusion**.

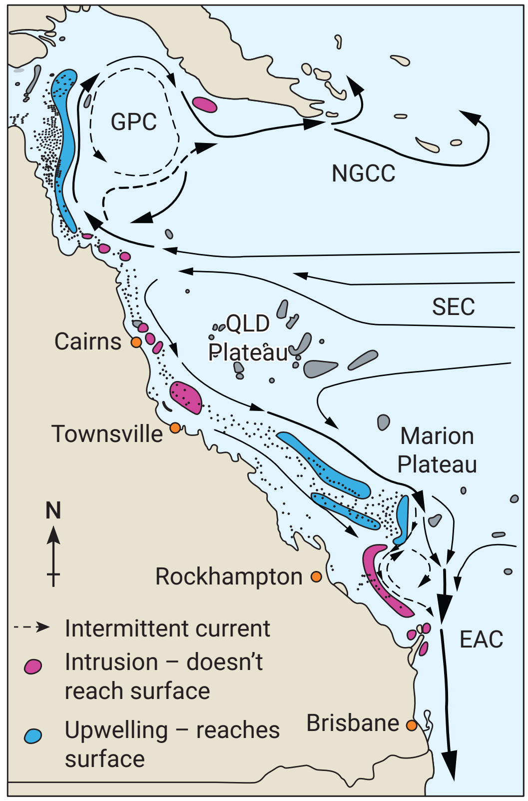


Figure 8 Ocean currents driving marine ecosystems through upwelling and intrusion during monsoon season in Queensland

intrusion when upwelled waters do not reach the surface

Melting sea and land ice

As sea ice (Figure 9A) and land ice (Figure 9B) melt, it impacts the water cycle because it can:

- increase the amount of moisture in the atmosphere, leading to changes in precipitation patterns
- affect the ocean currents
- affect ocean salinity and density.

The sea ice melts because it also absorbs up to 90 per cent of the solar radiation that hits the ocean. When this ice melts, more heat is absorbed by the water, increasing its temperature. The warmer water heats the atmosphere above it, driving a cycle that increases global temperature even further. This is also made worse by the release of any greenhouse gases trapped in the ice.

Land ice melts as the temperature increases, exposing the ground underneath. The darker ground underneath will absorb more heat (whereas on ice, more of it is reflected), which will melt more land ice.

In 2020, a new record was set for the highest temperature ever recorded in Antarctica when it reached 18.3°C, nearly 2°C above the previous record. This warming in Antarctica has contributed to an accelerated loss of ice, particularly from the West Antarctic Ice Sheet.

Not only do changing sea levels affect the water cycle, they also affect communities. Island nations and coastal communities are at risk of flooding, erosion and increased salinity in freshwater sources, which can impact drinking water supplies and agriculture.

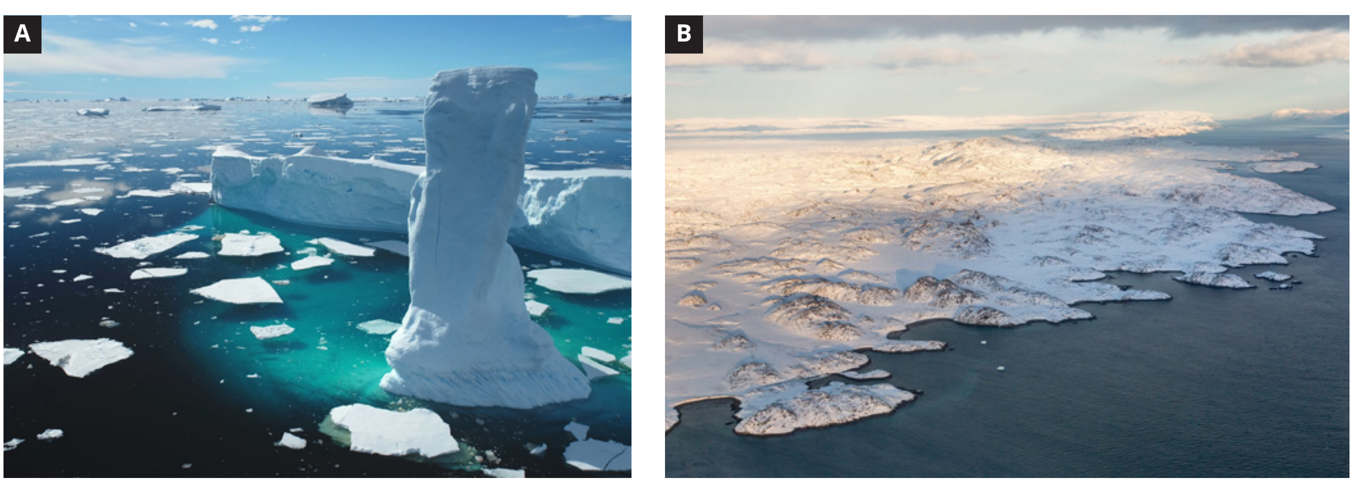


Figure 9 (A) Sea ice floating in the ocean; (B) land ice that is melting and exposing the ground underneath

Small island nations in the Pacific, such as the Marshall Islands and Kiribati (Figure 10), which have an average elevation of just 2 m above sea level, are particularly vulnerable. Rising sea levels driven by global warming and ice melt have contributed to an increase of approximately 3.4 mm per year since 1993, threatening these islands' existence.

Figure 10 Rising sea levels in Kiribati, a Pacific island nation

Melting permafrost

permafrost ground that has been frozen since the last Ice Age; stores carbon

Permafrost is permanently frozen ground that stores carbon from plant material which froze during the last Ice Age (Figure 11). Scientists have been measuring the temperature of the permafrost in Siberia for over 150 years and have noticed an upward trend. This means the ice is getting close to melting temperature (0°C) (Figure 12). Some scientists have predicted that as much as two-thirds of the Earth's permafrost could disappear by 2200. As a result, this melted permafrost can make its way to the ocean, affecting the salinity and making the water less dense, which in turn affects ocean currents.

Figure 11 Melting permafrost in Siberia is releasing carbon dioxide and methane, as well as pathogens such as viruses and diseases.

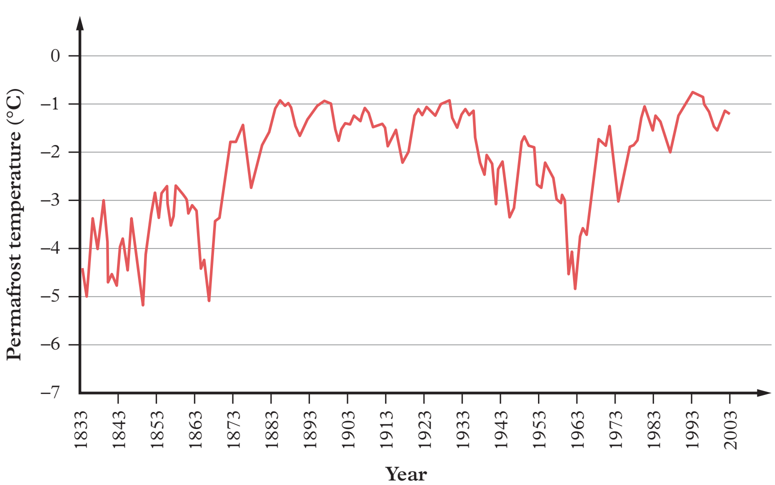


Figure 12 Historical measurements of Siberian permafrost temperatures at 5 m depth suggest that the permafrost is becoming warmer.

Another consequence of melting permafrost is that it will release thousands of years' worth of carbon into the atmosphere. This would roughly equate to half of all fossil fuel emissions to date from when the world became industrialised. In addition to carbon dioxide and methane, the thawing permafrost may also unleash dormant ancient viruses and diseases that have been trapped in the ice. These viruses and diseases could reactivate and pose a risk to all life on Earth.

Check your learning 7.12

Check your learning 7.12

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.

5 Define the term "permafrost" and explain why it will add to greenhouse gas emissions if it melts.

6 Identify two significant impacts of rising global temperatures on island nations.

Analyse

7 Compare the impact of sea ice and land ice on sea levels.

8 Climate change deniers suggest that the increase in sea levels is part of a normal cycle. Investigate and compare the timescale of previous global warming events to current climate change caused by the enhanced greenhouse effect.

Apply

9 Use Figure 6 to determine the expected rise in sea level at the coast closest to where you live.

10 Research strategies that can be adopted at individual, community and global levels to reduce the impacts of climate change on vulnerable regions.

11 Pick an ecosystem and investigate how climate change has altered the water cycle by analysing the changes in water availability and precipitation patterns. Discuss the impacts these changes have had on biodiversity within your chosen ecosystem by considering plant and animal species, food webs and ecosystem health. Propose potential strategies to minimise these impacts and support the resilience of the ecosystem.

Lesson 7.13

Investigation: Exploring the consequences of climate change

Purpose

To observe the effect of melting sea and sheet ice on global sea levels and the effect of ocean acidification

Materials

- Ice cubes
- Water
- Four 50 mL beakers
- Spatula
- Clay or plasticine
- Stopwatch
- Marker pen
- One to two clean and dry eggshells
- White vinegar

Procedure

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 levels (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 levels (e.g. an ice cube resting on clay).

Part C: Ocean acidification

Eggshells are made of calcium carbonate, which is the same compound found in the shells and skeletons of marine organisms such as shellfish and coral. Vinegar (which is a weak acid) can be used to simulate acidic ocean water.

Design an experiment using the listed materials to show the effects that acidic conditions can have on marine organisms.

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 in parts A and B.
2 Explain the differences you noticed between the water levels for each type of ice in parts A and B.
3 Explain the effect that acidified water has on the marine organisms discussed in part C. What could this mean for ecosystems dependent on these organisms?
4 Evaluate the validity of each of these experiments (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

Describe how melting sea ice or melting sheet ice will affect sea levels and how increasing acidification will affect marine systems.

Figure 1 Antarctica is home to both sheet and sea ice.

Lesson 7.14
Challenge: Saltwater density

Aim

To determine how salt affects the density of water

What you need:

- Four 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 salty water from beaker 3 so that it runs down the inside 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 saltwater in the 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 7.15
Pollution damages the natural environment

Key ideas

→ Environmental pollution includes air, water, noise and light pollution as well as radioactive pollution, plastic pollution and eutrophication (when a body of water receives an excess of nutrients).

→ Each type of pollution has distinct negative effects on the environment and living things.

Learning intentions and success criteria

Types of environmental pollution

pollution the introduction of substances to the environment that can cause harm

Environmental **pollution** is caused by a range of human activities and some natural processes that introduce harmful substances into the environment. Urban development, industrial activities and agricultural practices have all contributed significantly to the accumulation of pollutants and waste. These pollutants can degrade air, water and soil quality and can pose a significant risk to human health and ecosystems.

Figure 1 Air pollution in Sydney caused by bushfire smoke

Air pollution

Common air pollutants include particulate matter (PM), volatile organic compounds (VOCs), methane, sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and ground-level ozone. The sources of air pollution are varied and include the burning of fossil fuels, emissions from vehicles, industrial processes, agricultural activities and natural events such as bushfires and volcanic eruptions (Figure 1).

Impacts of air pollution include increased respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD) as well as cardiovascular problems. Air pollution can also have a significant negative impact on the environment. Acid rain and ocean acidification are both linked to the emission of sulfur dioxide and nitrogen oxides, while methane is a significant greenhouse gas. Collectively, air pollutants are extremely damaging to the health of ecosystems and can disrupt nutrient cycles and cause acidification.

Water pollution

The sources of water pollution are diverse, and the impacts vary depending on the type of pollutant. For example, industrial and agricultural run-off, which can include sewage, may contaminate drinking water and lead to waterborne diseases as well as carcinogenic effects. Oil spills cause significant harm to ecosystems (Figure 2), resulting in the death of phytoplankton and other primary producers, reducing food availability across all levels of the ecosystem (trophic levels). Additionally, seabirds and marine mammals can become coated in oil, leading to serious health issues and death.

Figure 2 Water pollution caused by an oil spill

Eutrophication

Eutrophication is a process that occurs when a body of water receives an excess of nutrients, particularly nitrogen and phosphorus. These nutrients often come from agricultural run-off from fertilisers used to promote crop growth. The extra nutrients in the water cause algae to grow rapidly and form algal blooms (Figure 3). The algal blooms block light from reaching aquatic plants and decrease oxygen levels in the water, which can kill aquatic animals. If you see an algal bloom, avoid contact with it, as some blooms can produce toxins that are harmful to your health, as well as to animals and other aquatic organisms.

Figure 3 An algal bloom caused by the run-off of excessive nutrients into waterways

eutrophication excess nutrients in a body of water that can cause the rapid growth of algae (algal blooms) and damage to aquatic ecosystems

Plastic pollution

Plastic pollution is a significant environmental issue (Figure 4). Single-use plastics, such as plastic bags, bottles and packaging materials, are designed for one-time use and are often discarded inappropriately. These plastics are harmful to ecosystems as they can entangle and kill wildlife, disrupt food chains and ultimately threaten biodiversity and the overall health of the environment.

Plastics do not decompose in the traditional sense; instead, they break down over hundreds of years into microplastics. These microplastics, defined as particles less than 5 mm in diameter, enter and can accumulate in the food chain in a process known as **bioaccumulation**. Current research indicates that microplastics adversely affect the fertility of marine life, including seabirds and marine mammals. Concerningly, microplastics have also been detected in humans, with suggested links to a range of health complications, including respiratory issues, hormonal disruptions and potential carcinogenic effects.

Figure 4 Plastic pollution

bioaccumulation the build-up of harmful substances in living organisms

radioisotope an isotope (different versions of the same element due to differing atomic mass) that emits radiation due to an unstable nucleus

Radioactive pollution

Nuclear radiation is used widely in the production of energy and in the creation of **radioisotopes** for medical applications. When managed, it is safe and poses little risk to the environment or to human health. When things go wrong, however, they can go very wrong.

For example, the Chernobyl disaster in 1986 and the Fukushima disaster in 2011 released significant amounts of nuclear radiation into the surrounding environment, resulting in long-lasting impacts on both the environment and human health. These incidents

Figure 5 Radioactive pollution

caused long-term contamination of ecosystems and significant disruption of food chains, adversely affecting biodiversity. The immediate health impacts to humans exposed to radiation include acute radiation sickness, while long-term there is an increased risk of cancer, particularly thyroid cancer.

Noise and light pollution

While not immediately obvious, urban development has led to noise and light pollution; both of which can negatively impact surrounding ecosystems and the health of residents (Figure 6 and Figure 7). For example, noise pollution disrupts animal courtship and foraging behaviours, and can alter population dynamics and reduce biodiversity. Light pollution interferes with natural light cycles, which significantly impacts the behaviour of nocturnal wildlife and can also affect the migratory behaviour of other animals.

Noise and light pollution from traffic, construction and nightlife are linked to increased stress levels and interference with human sleep patterns.

Figure 6 Noise pollution

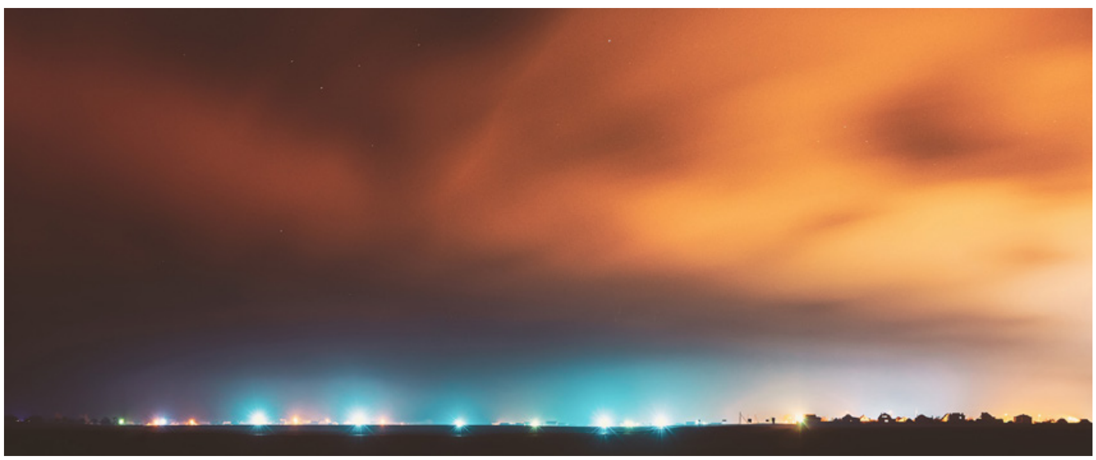


Figure 7 Light pollution

Check your learning 7.15

Check your learning 7.15

Retrieve

1 Define "pollution".

Comprehend

2 Explain bioaccumulation and how it relates to environmental pollution.

3 Explain why carbon dioxide is considered a significant greenhouse gas despite not being classified as an air pollutant.

Apply

4 Construct a table that includes five different forms of pollution and the environmental and human health impacts of each.

5 Research microplastics and analyse their sources, environmental impacts and potential health risks to humans. Discuss the strategies that can be implemented to prevent microplastics entering ecosystems, and explore how to minimise the effects of microplastics on both the environment and human health.

Lesson 7.16

Aboriginal and Torres Strait Islander Peoples have developed sustainable practices

Key ideas

→ Aboriginal and Torres Strait Islander Peoples have developed extensive knowledge of local ecosystems over tens of thousands of years, informing sustainable harvesting practices that maintain environmental health.

→ Incorporating traditional ecological knowledge and cultural protocols into contemporary environmental management can enhance biodiversity conservation and sustainability efforts.

Learning intentions and success criteria

Introduction

Aboriginal and Torres Strait Islander Peoples have developed deep ecological knowledge and sustainable harvesting practices over tens of thousands of years. These practices are based on strong cultural traditions and connection to the land. Extensive knowledge and understanding of animal behaviour, plant life cycles and seasonal changes in the environment have been passed down through generations, informing ongoing practices that promote environmental sustainability.

Seasonal harvesting and selective gathering

While Western cultures typically follow a four-season calendar, Aboriginal and Torres Strait Islander Peoples observe seasons that are specific to their local area. Seasons vary from region to region, differing in number, length and timing. For example, the Noongar people who have lived in South West Western Australia for over 45,000 years have six seasons. In contrast, the Gulumoerrgin people of the Northern Territory and the Wurundjeri people of the Kulin Nation in Victoria have seven seasons (Figure 1), while the traditional landowners of the Tiwi Islands recognise three main seasons and 13 minor overlapping seasons. In all cases, these more detailed seasonal variations are defined by weather patterns and the arrival of specific plant and animal species. These seasonal calendars dictate the availability of plant and animal food sources and the best time to harvest, ensuring that species are not overexploited and can reproduce effectively to replenish numbers for the following seasons.

Selective gathering is a key sustainability practice that involves taking only what is necessary while leaving enough for regeneration. For instance, when collecting bush foods, only mature fruits or seeds are harvested to promote ongoing growth. When collecting bush nuts, such as macadamia nuts, only those that have fallen from the tree naturally are harvested. Similarly, when harvesting seafood such as fish and shellfish, only those above a certain size are kept, allowing younger juvenile individuals to grow and reproduce.

selective gathering the careful removal of specific plants or animals from a population to maintain ecological balance while allowing for resource use

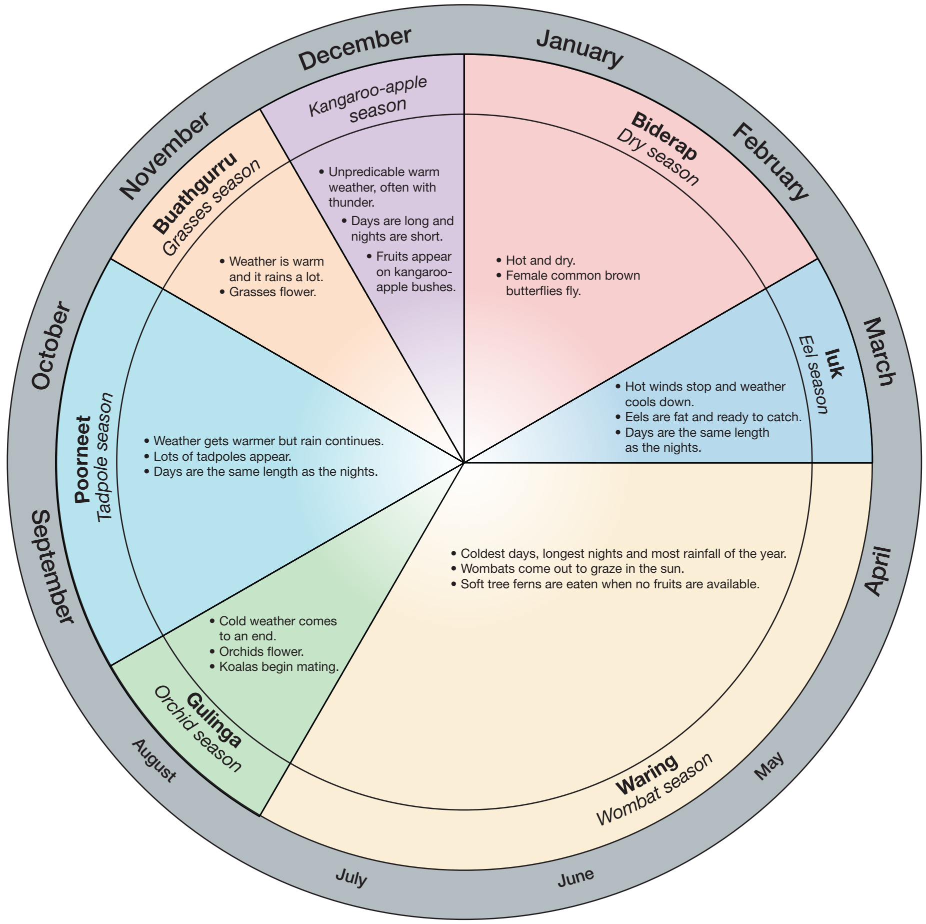


Figure 1 The Wurundjeri people of the Kulin Nation in Victoria identify seven seasons in their calendar. These seasons are marked by changes in the weather, the life cycles of plants and animals and the position of the stars in the sky at night.

cultural protocol the customs, values and guidelines that shape behaviour and interactions within a specific cultural group, ensuring respectful and appropriate interactions

Cultural protocols

Cultural protocols refer to the cultural practices, customs and value systems that are significant to particular Aboriginal and Torres Strait Islander Peoples' cultural groups. These protocols guide how natural resources can be used and often require individuals to seek permission from Elders before harvesting resources, reflecting a deep respect for the land and its resources.

Figure 2 Aboriginal and Torres Strait Islander Peoples' totems on display at the Gallery of Modern Art, Brisbane

Ceremonial practices often accompany certain harvesting methods, acknowledging the spiritual connection to the land and reinforcing the belief that humans are part of the ecosystem and responsible for its wellbeing. In many cases, each Aboriginal or Torres Strait Islander person will have a totem that carries personal or cultural meaning and reflects their identity, family and clan. Each totem, represented by a natural object, plant or animal, is passed down through generations and signifies the roles and responsibilities that each person has in their community and their duty to care for their environment and maintain balance within the ecosystems of which they are a part.

Cultural education plays an important role in passing on sustainable practices to younger generations. Knowledge sharing through storytelling, mentorship and hands-on experiences ensures that ecological stewardship continues and is adapted over time. This helps to preserve the connection to the land and reinforces the value and significance of totems and ceremonial practices.

Fire management

For thousands of years, Aboriginal and Torres Strait Islander Peoples have used fire to hunt animals, maintain ecosystems and manage the land. Traditional fire management practices, often referred to as cool burning, involves the use of controlled burns in targeted areas to reduce the density of understorey vegetation (Figure 3).

Cool burning helps to reduce fuel load, decreasing the risk of uncontrolled, intense wildfires in the dry season when conditions are hotter. Cool burning also promotes the growth of certain plant species that rely on fire for regeneration. The reduced risk and lower burn intensity of cool burning also protects habitats for mammals, reptiles, insects and birds.

Figure 3 Cool burning helps to reduce fuel load.

Check your learning 7.16

Check your learning 7.16

Retrieve

1 Identify two advantages of cool burning.

Comprehend

2 Describe the role of storytelling in transmitting knowledge about sustainable harvesting practices.

3 Explain how traditional ecological knowledge contributes to sustainable harvesting practices among Aboriginal and Torres Strait Islander Peoples.

4 Explain how seasonal changes influence the sustainable harvesting practices of Aboriginal and Torres Strait Islander Peoples.

Analyse

5 Research the different seasons recognised by two different Aboriginal and Torres Strait Islander Peoples' communities. Outline the factors that determine each season.

Apply

6 Western harvesting and use of natural resources usually comes at the expense of the environment.

- **a** Outline two examples of Western natural resource harvesting practices that may cause harm to the environment.
- **b** Explain how the integration of Aboriginal and Torres Strait Islander Peoples' sustainable practices into modern environmental management strategies could benefit the environment.

7 Design an engaging poster to raise community awareness about the sustainable practices employed by Aboriginal and Torres Strait Islander Peoples to conserve biodiversity. The poster should highlight key practices, their cultural significance and the benefits of these methods for both the environment and the community.

Lesson 7.17
Reduce, reuse and recycle

Learning intentions and success criteria

Key ideas

→ The 3Rs (reduce, reuse and recycle) are key strategies for managing resources and reducing waste.

→ Current resource use harms the environment, but sustainable practices can help lessen this damage.

→ Individuals and communities can promote sustainability through local recycling programs and waste reduction initiatives.

→ Exploring alternatives to single-use items, like biodegradable materials and upcycling, supports sustainable living.

Introduction

recycle to turn waste into a new material

Recent government figures estimate that each individual Australian produces 2.95 tonnes of household waste each year. As a country, this equals nearly 76 million tonnes, and of this approximately 60 per cent is **recycled**, leaving over 30 million tonnes to be disposed of in landfill each year. Clean-up Australia suggests that over 130,000 tonnes of waste, much of it plastic, ends up in Australian waterways each year, most of it coming from urban run-off, littering and improper waste disposal.

Now consider the global implications: Australia's population represents only 0.37 per cent of the world population of 8.2 billion, raising significant questions about urgency for more sustainable practices in waste production. This highlights the need for us to reconsider how we manage our resources because many people tend to take them for granted, only acknowledging their value when they are in short supply. Scientists and engineers are very aware of resource shortages and work to optimise the remaining supplies and minimise wastage.

ecological footprint measure of the environmental impact of a person, community or country by calculating the amount of land and water needed to provide resources and absorb waste, especially carbon emissions

Non-renewable resources, such as fossil fuels and metal ores, need to be managed carefully so that our supply does not run out. We are also now aware of the impact of burning fossil fuels on climate change. Carbon emissions from burning fossil fuels can trap heat in the atmosphere, contributing to global warming. Plastic, often derived from non-renewable sources such as oil, poses a significant environmental challenge. Unlike organic waste, plastic does not break down easily, leading to accumulation in landfills and waterways where it can harm wildlife that mistake it for food or become entangled in it.

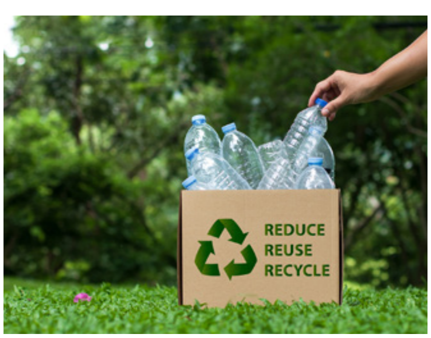


Figure 1 The 3Rs: reduce, reuse and recycle

The 3Rs: Reduce, reuse and recycle

With its origins in the 1970s, the 3Rs slogan of reduce, reuse and recycle has played an important role in highlighting the environmental challenges caused by a growing population and the resource depletion associated with the need to provide housing, food and fuel for more people.

The 3Rs offer viable pathways for individuals, communities and countries to minimise their **ecological footprint** and promote environmental sustainability.

Reducing resource use

Reducing resource use is essential for promoting sustainability and minimising environmental impact. By consciously consuming less and making more sustainable choices, individuals and communities can help conserve valuable natural resources for future generations.

To minimise waste as individuals, it is important to avoid using products like paper plates and plastic cutlery, as they are typically used only once. Additionally, choose products that do not come in plastic packaging and opt for alternatives to plastic, such as reusable bags and metal straws, and do not purchase water in plastic bottles when reusable drink containers are available. Also consider selecting packaging made from natural, biodegradable materials as a more sustainable option.

In the workplace and broader community, reducing resource waste is equally important. Practices that could be considered include:

- using energy-efficient appliances and lighting
- adopting a paperless environment by using digital tools for communication
- establishing community gardens to promote resource sharing and reduce food waste
- encouraging the use of public transport, carpooling or cycling to decrease fuel consumption and lower greenhouse gas emissions.

Reusing resources

Reusing involves finding new or novel ways to use items instead of discarding them after a single use. This extends the lifespan of the product and reduces the demand for new materials, which in turn conserves energy and resources. For example, glass jars can be repurposed for storage, old furniture can be refurbished or upcycled into new pieces, and cloth bags can replace disposable plastic bags.

In the workplace, companies can promote a culture of reusing. This might include adopting policies that ban single-use plastics, encouraging employees to bring their own reusable containers for lunches and donating unwanted office supplies instead of throwing them away.

In the broader community, local initiatives such as swap meets and garage sales can promote the reuse of items that would otherwise be thrown out.

Recycling resources

Recycling involves processing used materials to create new products, which helps divert waste from landfill and reduces the need for raw materials. Recycling conserves natural resources, saves energy and lowers greenhouse gas emissions.

Current recycling processes

Current recycling processes are an important component of waste management and sustainability, focusing on the collection, sorting and reprocessing of materials like paper, plastics, metals and glass into new products.

Increased awareness and more effective recycling help conserve natural resources, reduce landfill waste and lower energy use. By improving recycling processes, communities can support a **circular economy** that minimises waste and maximises resource efficiency, contributing to a healthier planet for future generations.

circular economy a system that minimises or eliminates waste by reusing, recycling and regenerating materials

Plastic recycling

Plastic waste is collected through kerbside recycling programs and delivered to recycling facilities. Plastics are sorted by type and colour before being cleaned and contaminants removed. They are then shredded into smaller pieces before being melted down and formed into pellets or moulded into new products, including outdoor furniture, playground equipment, textiles, containers and packaging (Figure 2).

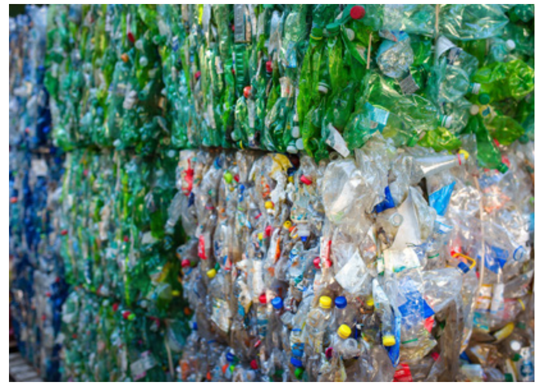


Figure 2 Plastic ready for recycling

Metal recycling

Metal waste, including aluminium cans and scrap metal, is collected through kerbside recycling or industrial sites. To recycle aluminium, products are shredded, melted and formed into ingots. This recycling method saves up to 95 per cent of the energy needed for aluminium production. Like glass, aluminium can be recycled indefinitely without quality loss (Figure 3).

Figure 3 Metal waste being sorted

Paper recycling

Paper products are collected through recycling bins and drop-off sites. Recycling facilities sort the paper into categories such as cardboard, office paper and mixed paper. It is then mixed with water and chemicals to create a slurry, which is agitated to break it down into pulp. Contaminants like staples and inks are removed during this process. The cleaned pulp is collected, pressed and dried to form sheets of new paper, which can be used to produce newspapers, cardboard and other paper products. Recycling paper and cardboard reduces the number of trees cut down for new paper products (Figure 4).

Figure 4 Paper shredded and ready to be recycled into new paper products

Glass recycling

Glass recycling involves sorting the glass by colour, removing contaminants, crushing it and melting it to create new products. This process saves approximately 30 per cent of the energy required for producing new glass and allows for indefinite recycling without quality loss. Glass bottles and jars are collected through kerbside recycling or Return and Earn drop-off centres (Figure 5).

Figure 5 Glass bottles and jars being broken down to be recycled

Electronic waste recycling

Electronic waste (e-waste), including old computers and appliances, is collected through designated council drop-off locations. Components such as circuit boards and batteries are separated for further processing where precious metals (e.g. gold, silver and copper) and plastics are recovered and used in the manufacture of new electronic devices. They also contain valuable materials such as rare earth elements that can be recovered and recycled (Figure 6).

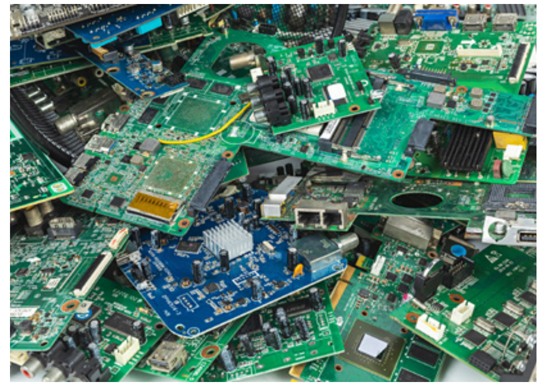


Figure 6 Valuable materials can be recovered from electronic waste (e-waste).

Organic waste recycling (composting)

NSW households, on average, waste 688,000 tonnes of food each year, which contributes to greenhouse emissions. Organic waste, such as food scraps and yard waste, is disposed of through council kerbside collection of designated bins and turned into fertiliser to grow new crops (Figure 7).

Figure 7 Organic waste can be collected to be composted.

The other Rs

While the 3Rs remind us to minimise our ecological footprint, some people recommend that we extend this to include refuse, rot, repair and rethink.

- Refuse: Avoid products that generate waste.
- Repair: Fix broken items instead of throwing them away and buying new ones.
- Rot: Compost organic waste to produce nutrient-rich soil.
- Rethink: Consider the overall impact of your consumption choices.

Check your learning 7.17

Check your learning 7.17

Retrieve

1 Identify and define the 3Rs.

2 Identify common materials that are typically recycled.

Comprehend

3 Describe how population growth can affect waste production.

4 Describe the recycling process used for two common household waste products.

5 Explain the relationship between waste management practices and climate change.

6 Explain why the 3Rs are essential for environmental sustainability.

Analyse

7 Analyse how consumer behaviour influences waste production.

8 Suggest ways that individuals, families, community groups and different levels of government could promote sustainable waste practices.

Apply

9 Explain the concept of a circular economy and its benefits.

10 Apply the principles of the 3Rs to develop a personal or family waste reduction plan.

11 Propose a school or community clean-up initiative based on the 3Rs.

Lesson 7.18

Investigation: How scientists develop ways to recycle materials

Introduction

While the volume of other waste products, such as metal waste, electronic waste and organic waste, present significant environmental concerns, plastic waste is particularly worrying due to its persistence in the environment and the devastating impacts it has on marine and terrestrial ecosystems.

Less than 10 per cent of the plastic used worldwide is recycled, resulting in an estimated 100 million tonnes of plastic currently polluting the oceans. This waste will not decompose and will remain in the environment for generations to come. Microplastics have become so common that they have entered the food chain and have been found in marine and terrestrial animals, and humans as well, which is of great concern. The health effects of microplastics on humans remain unknown.

This reality of population growth and increasing waste production requires innovative solutions across various materials, including plastics, metals, electronics, organics and textiles. To achieve this, scientists are developing several groundbreaking recycling technologies and processes that aim to develop a closed-loop system where these materials never actually become waste.

Purpose

To investigate innovations that scientists have developed to recycle materials

Materials

- Laptop computer
- Access to the internet

Procedure

Research one of the following innovative technologies and present your findings to the class.

Biological recycling

Biological recycling involves the use of enzymes that can break down plastics into their original monomers. Scientists engineered a strain of bacteria, *Ideonella sakaiensis*, that produces an enzyme called PETase that can degrade polyethylene terephthalate (PET), commonly found in plastic bottles.

Chemical recycling

Chemical recycling involves converting waste materials into usable energy sources. For example, pyrolysis decomposes organic materials at high temperatures without oxygen, which produces bio-oil, gas and char, while gasification converts organic materials into syngas, which can be used to generate electricity or produce fuels.

Advanced sorting technologies

Innovations in sorting technologies, such as AI-driven robots and machine learning algorithms, can significantly improve the efficiency of recycling facilities. Different materials can be accurately identified and separated, improving the quality and quantity of recyclables collected.

Plastic roads

Researchers have developed roads made from recycled plastic waste. The recycled plastic pellets are melted and blended with hot asphalt during production. The technology reduces plastic destined for landfill, while also creating durable road surfaces.

Recycled glass aggregates

Researchers are developing new construction materials by using recycled glass as a road base and aggregates in concrete production. This diverts glass waste from landfill and enhances the durability and sustainability of construction projects.

Seabin project

Floating barriers are anchored to the seabed and use natural water currents to funnel plastic waste into a collection trap. A large-scale trial of the technology in the Great Pacific Ocean patch removed thousands of kilograms of plastics from the water (Figure 1).

Figure 1 The Seabin project collected 4.7 million plastics items (including 2.3 million microplastics) in 2023.

Three-dimensional printing with recycled plastics

Researchers have developed a method of processing different types of plastic waste into filaments that can be used in fused deposition modelling (FDM) three-dimensional (3D) printing. This technology reduces the reliance on virgin materials (materials that have never been used before) and promotes a circular manufacturing process.

Converting paper waste to biofuel

Researchers have developed a process that converts paper and cardboard waste into biofuel by treating the waste material and converting it into a slurry. The cellulose fibres in the slurry are converted into glucose, which is then fermented to create a liquid biofuel.

Upcycling textile waste

Worn Again Technologies, founded in London, developed a process that separates, decontaminates and extracts polyester and cellulose from discarded textiles. The separated products can then be reintroduced into the supply chain to create a continual use-reuse cycle.

E-waste precious metal recovery

Companies such as Urban Technologies have developed processes to recover precious metals such as gold, silver and palladium from circuit boards and electronic components. These methods include mechanical separation, hydrometallurgical techniques such as leaching and solvent extraction, and bio-leaching using microorganisms.

Discussion

In your presentation, discuss the following points:

- overview of the technology
- purpose and significance
- impact on the environment
- current applications and examples
- challenges and limitations
- future potential
- community and stakeholder involvement
- conclusion and personal reflection.

Lesson 7.19

Science in context: Human activity and environmental pollution

Introduction

Carbon dioxide is not typically classified as an air pollutant because it is naturally present in high amounts and does not have a directly harmful impact on health at typical atmospheric levels. It is, however, a significant greenhouse gas, and the substantial rise in emissions caused by human activities is linked to climate change and rising global temperature (Figure 1). Methane and nitrous oxide, although present in smaller quantities, are even more potent greenhouse gases. Both are largely emitted through agricultural activities, including livestock farming and the use of synthetic fertilisers.

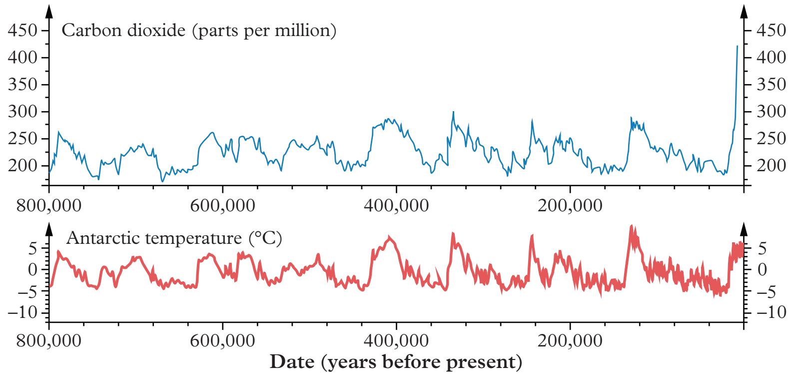


Figure 1 The concentration of carbon dioxide in the atmosphere (ppm) and Antarctic temperature records over the last 800,000 years

Figure 2 Oil refinery processing crude oil into different fuels

Human activities linked to greenhouse gas emissions

Human activities, especially in the industrial, transportation and agricultural sectors, have led to a substantial increase in carbon dioxide emissions.

Burning fossil fuels

The combustion of coal oil and the use of natural gas for energy production are the leading sources of carbon dioxide emissions worldwide. When these fuels are burnt for energy, transportation or industrial processes, carbon dioxide is released into the atmosphere as a byproduct (Figure 2). Fossil fuels contain carbon that has been stored underground for millions of years.

Deforestation

The clearing of forests for agriculture, urban development and logging reduces the number of trees that can absorb carbon dioxide from the atmosphere. When trees are cut down or burnt, the carbon stored in their structures is released back into the atmosphere, further contributing to rising carbon dioxide levels (Figure 3).

Figure 3 Aerial view of a rainforest that has been logged to make way for palm oil plantations

Agricultural practices

Methane and nitrous oxide, although present in smaller quantities, are even more potent greenhouse gases than carbon dioxide. Methane has a **global warming potential (GWP)** over 25 times greater than carbon dioxide over a 100-year period, and nitrous oxide is nearly 300 times more effective at trapping heat in the atmosphere with a GWP of 273. Both gases are largely emitted through agricultural activities, including livestock farming, where ruminant animals such as cows produce methane during digestion, and synthetic fertilisers that release nitrous oxide are applied to crops (Figure 4).

Figure 4 Agricultural sprayers applying fertiliser to crops

global warming potential (GWP) a measure of how much impact a gas will have on atmospheric warming over a period of time compared to carbon dioxide

Test your skills and capabilities

Test your skills and capabilities 7.19

Analysing links

Human activities have significantly impacted the environment, leading to various forms of pollution that threaten ecosystems and biodiversity. This is in part due to our consumer society as well as capitalism. Explore the links between human actions and environmental pollution by investigating current issues. Some guiding ideas have been provided; you can also come up with your own.

1 **Fast fashion**

  a Explain how the production and disposal of clothing contribute to pollution.

  b Investigate the effect textile waste has on landfills, water systems and local ecosystems.

  c Analyse the challenges associated with producing and recycling materials.

  d Propose how the fashion industry could implement sustainable practices to reduce environmental pollution.

Figure 5 Shein is a fast fashion company that produces and sells large quantities of clothing cheaply, using lower-quality materials.

Figure 6 Plastic recycling being shipped to be processed

2 **Plastic recycling**

a Examine the impact of plastic pollution on marine ecosystems and human health.

b Describe why humans are reliant on plastic products.

c Discuss the challenges associated with recycling plastic.

d Investigate why plastic is often sent offshore for recycling and the environmental implications of this.

e Suggest how plastic recycling processes could improve to reduce offshore build-up.

3 **Space junk**

a Examine how the accumulation of debris in the Earth's orbit is due to human activity.

b Discuss the potential risks of space junk on satellites, the International Space Station and current and future space missions.

c Investigate the risk space junk has on global communication and navigation systems.

d Determine the impact that space junk could have on the environment if any of it falls back to Earth.

e Investigate how space exploration could become more sustainable and space junk mitigated.

4 **Ocean garbage patch**

a Determine the human activities that have contributed to the formation of ocean garbage patches and investigate the size and locations of them.

b Discuss the impact the ocean garbage patches have on marine ecosystems, including marine species and food webs.

c Identify solutions that could reduce the size and environmental impact of ocean garbage patches.

Figure 7 Ocean garbage patches pollute and kill the marine ecosystem.

5 **Ocean noise**

a Explain how large ships used for cruises or transportation and submarine operations contribute to ocean noise pollution.

b Investigate and discuss the effect of noise pollution on the communication, navigation and behaviour of marine species.

c Suggest how ocean noise pollution could be mitigated to protect marine ecosystems.

6 **Petrol cars**

a Investigate the impact of environmental pollution from manufacturing petrol cars.

b Discuss technologies that are used to reduce carbon emissions from petrol cars.

c Describe how petrol cars affect ecosystems and biodiversity.

d Examine if hybrid cars are a sustainable way to reduce environmental pollution.

7 **Electric vehicles**

a Discuss the benefits and potential challenges of electric vehicles (EVs) on environmental pollution.

b Examine any advantages and disadvantages in the manufacturing of EVs.

c Investigate what happens to the battery at the end of its life and if it contributes to environmental pollution.

d Describe how the widespread adoption of EVs would affect environmental pollution.

8 **Mobile phones and other technologies**

a Discuss how the materials used in smartphones contribute to pollution.

b Describe the impacts of smartphone production and disposal on the environment.

c Investigate the effect of improper disposal of electronic devices on ecosystems.

d Examine how technological advancements have helped reduce environmental pollution.

Figure 8 The premise of EVs is to help reduce environmental pollution; however, the production and disposal of the battery can be a downside.

Lesson 7.20

Investigation: What does the data collected by satellites tell us?

Introduction

Watch a short video on how Gravity Recovery and Climate Experiment (GRACE) satellites are measuring sea level changes in West Antarctica; the link is provided below.

Video: Sea Level

"GRACE has revolutionised our ability to determine how much glaciers and ice sheets are contributing to sea level rise, and gives insight into how they will respond to future changes in atmosphere and ocean."

Alex S. Gardner, research scientist and member of NASA's Sea Level Change Team

The United States Geological Survey's (USGS) Landsat satellite program has been capturing images of the Australian continent for over 30 years. This data is crucial for land and coastal mapping studies and plays a significant role in monitoring the effects of bushfires. Go to the provided weblink below to view Landsat 7 satellite images showing the difference before and after the northern NSW bushfires in early October 2000 that burnt more than 150,000 hectares of bushland across more than 80 bushfires.

Weblink: Geoscience Australia, Data and publications search

The Enhanced Thematic Mapper Plus (ETM+) sensor on board the Landsat 7 satellite is capable of detecting ambient heat radiation through its thermal infrared channel. In the case of high temperatures, such as those generated by a forest fire, the ETM+ sensor can also detect hot objects.

Purpose

To investigate how satellites collect global data (on ocean temperatures, sea levels, and forest and ice cover) and examine how scientists use this data to assess the impact of climate change

Materials

- Laptop computer
- Access to online satellite data repositories (e.g. NASA Earth Observing System, European Space Agency (ESA) Copernicus data, or NASA Worldview)
- Graphing software for data visualisation

Procedure

Part A: Data exploration

1 Access an online satellite data platform (such as the weblinks provided below) for real-time and historical data from satellites.

Weblink: NASA Worldview

Weblink: Copernicus Data Space Ecosystem

2 Explore the data relating to an area of interest, such as the following.

- Find and download data on sea surface temperatures for a specific region (e.g. the Arctic or Pacific Ocean) over the past 10 years.
- Search for satellite data on forest cover in a specific region (e.g. Amazon rainforest) and observe how it has changed over time.
- Investigate sea level rise using satellite data from the GRACE mission.

3 Look for patterns or trends, such as rising temperatures in oceans, decreasing ice mass in polar regions or shrinking forests in specific regions.

Part B: Data application to climate change

Explain how scientists use satellite data to monitor the impacts of climate change. For example:

- rising ocean temperatures can contribute to more extreme weather events and affect marine ecosystems
- sea level rise due to melting ice caps and glaciers poses a threat to coastal communities and ecosystems
- forest cover changes, particularly deforestation, contribute to the increase in carbon dioxide levels in the atmosphere, exacerbating climate change
- changes in ice cover (e.g. shrinking Arctic ice) are indicative of global warming and contribute to feedback loops, where less ice means more heat absorption by the Earth, leading to further warming.

Discussion

1 Explain how satellite observations help us understand global changes in ocean temperatures, sea levels and land cover, and describe why satellites are crucial for gathering this data.

2 Analyse the trends observed in satellite data and explain how these indicate the impact of climate change.

3 Explain how future satellite missions could help scientists monitor climate change and develop strategies to manage its impacts.

4 Discuss solutions that could be implemented based on satellite data that monitors climate change on temperature, sea levels, animal migration and forest cover.

Lesson 7.21

Review: Environmental sustainability

Summary

Lesson 7.1 Sustainability is a long-term goal to live within our means

- Sustainability is our ability to meet our current needs without compromising the needs of future generations.
- Three key principles of sustainability are environmental sustainability, social sustainability and economic sustainability.
- Our supply of non-renewable resources is limited.
- Strategies to conserve our resources include reducing consumption, reusing materials and recycling.

Lesson 7.2 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 the atmosphere, ocean and land to affect the global climate system.
- Low-pressure and high-pressure systems affect the weather.
- Warm air rises from the Equator and cold air from the poles moves towards the Equator, causing the movement of air (wind).
- The Earth's terrain can affect the speed and direction of the wind.

Lesson 7.4 Evidence supports the enhanced greenhouse effect

- The Earth is surrounded by an atmosphere of natural greenhouse gases that reflect radiation from the Sun and retain the warmth from the Earth.
- Ice core samples are used to analyse the amount of greenhouse gases trapped in the ice over time.
- The enhanced greenhouse effect is the increase in greenhouse gas levels and an increase in the temperature of the land and oceans.
- Evidence for enhanced global warming can be found in higher sea levels and the melting of sea ice and permafrost.

Lesson 7.10 The effects of climate change

- Data is used to measure and analyse climate change.
- Climate change has caused increasing global temperatures and extreme weather events, costing people their lives.
- Climate change has affected the distribution of diseases, with some diseases becoming more prevalent.
- Climate change is affecting the biodiversity of organisms, with flora and fauna becoming extinct as they are unable to adapt to the climate.
- Rapid changes in climate have changed where species live.
- The increasing levels of carbon dioxide in the atmosphere affect the oceans, which absorb more carbon dioxide, resulting in higher ocean acidity. This leads to the destruction of ecosystems and reduces marine species populations.

Lesson 7.12 Effects of climate change on the water cycle

- Climate change is modelled using scientific methods and data gathered over long periods of time.
- Increased global temperatures are causing icecaps to melt, resulting in increased sea levels.
- Deep ocean currents can regulate global climate and affect marine ecosystems.
- Climate change disrupts the water cycle. This disruption affects ecosystems by altering species distribution, reducing biodiversity and impacting habitats.

Lesson 7.15 Pollution damages the natural environment

- Environmental pollution includes air, water, noise and light pollution as well as radioactive pollution, plastic pollution and eutrophication (when a body of water receives an excess of nutrients).
- Each type of pollution has distinct negative effects on the environment and living things.

Lesson 7.16 Aboriginal and Torres Strait Islander Peoples have developed sustainable practices

- Aboriginal and Torres Strait Islander Peoples have developed extensive knowledge of local ecosystems over tens of thousands of years, informing sustainable harvesting practices that maintain environmental health.
- Incorporating traditional ecological knowledge and cultural protocols into contemporary environmental management can enhance biodiversity conservation and sustainability efforts.

Lesson 7.17 Reduce, reuse and recycle

- The 3Rs (reduce, reuse and recycle) are key strategies for managing resources and reducing waste.
- Current resource use harms the environment, but sustainable practices can help lessen this damage.
- Individuals and communities can promote sustainability through local recycling programs and waste reduction initiatives.
- Exploring alternatives to single-use items, like biodegradable materials and upcycling, supports sustainable living.

Review questions 7.21

Review questions Module 7

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 the 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 icecaps.

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.

Figure 1 Polar bears are at risk of extinction.

13 Explain why animals that live in the polar regions of the Earth (the Arctic or Antarctica) are at great risk due to climate change.

14 Describe how high-pressure and low-pressure weather systems are formed.

15 Explain why it is warmer near the Equator than elsewhere on the Earth.

16 Explain why increased melting of sea ice will trigger a more rapid rate of global temperature increase.

Analyse

17 Contrast weather and climate.

18 Compare climate change mitigation with climate change adaptation.

19 Compare ocean currents and air currents.

Apply

20 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 and identify some of the effects of climate change that caused the species to become extinct.

Figure 2 The Bramble Cay melomys

21 Discuss how deep ocean currents can affect climate.

22 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.

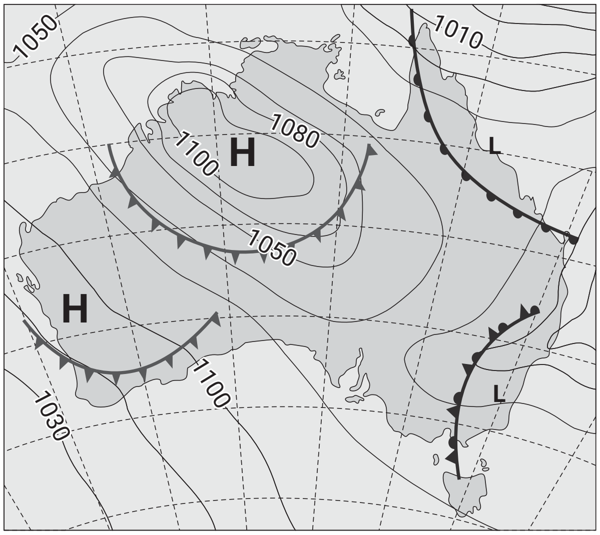


Figure 3 Weather map of Australia

Social and ethical thinking

23 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. The red meat industry in Australia, however, contributes 11.8 per cent of Australia's total greenhouse gas emissions.

Figure 4 Red meat is a popular choice in many Australian households.

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
- justifying your response.

24 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

25 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 change your friend's mind about the climate crisis.

26 Create a concept map that links all the bolded glossary terms in this module together.

27 Create an infographic that explains three different strategies to reduce the impact of climate change and how they work.

28 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

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.

Weblink: Geoscience Australia, Data and publications search

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 a livestock feed called FutureFeed that 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 ruminant (cattle) producers adopt it as feed.

Figure 5 *Asparagopsis* spp. are native to Australia and are used in FutureFeed.

Rising sea level crisis

As the polar icecaps 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 make 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.

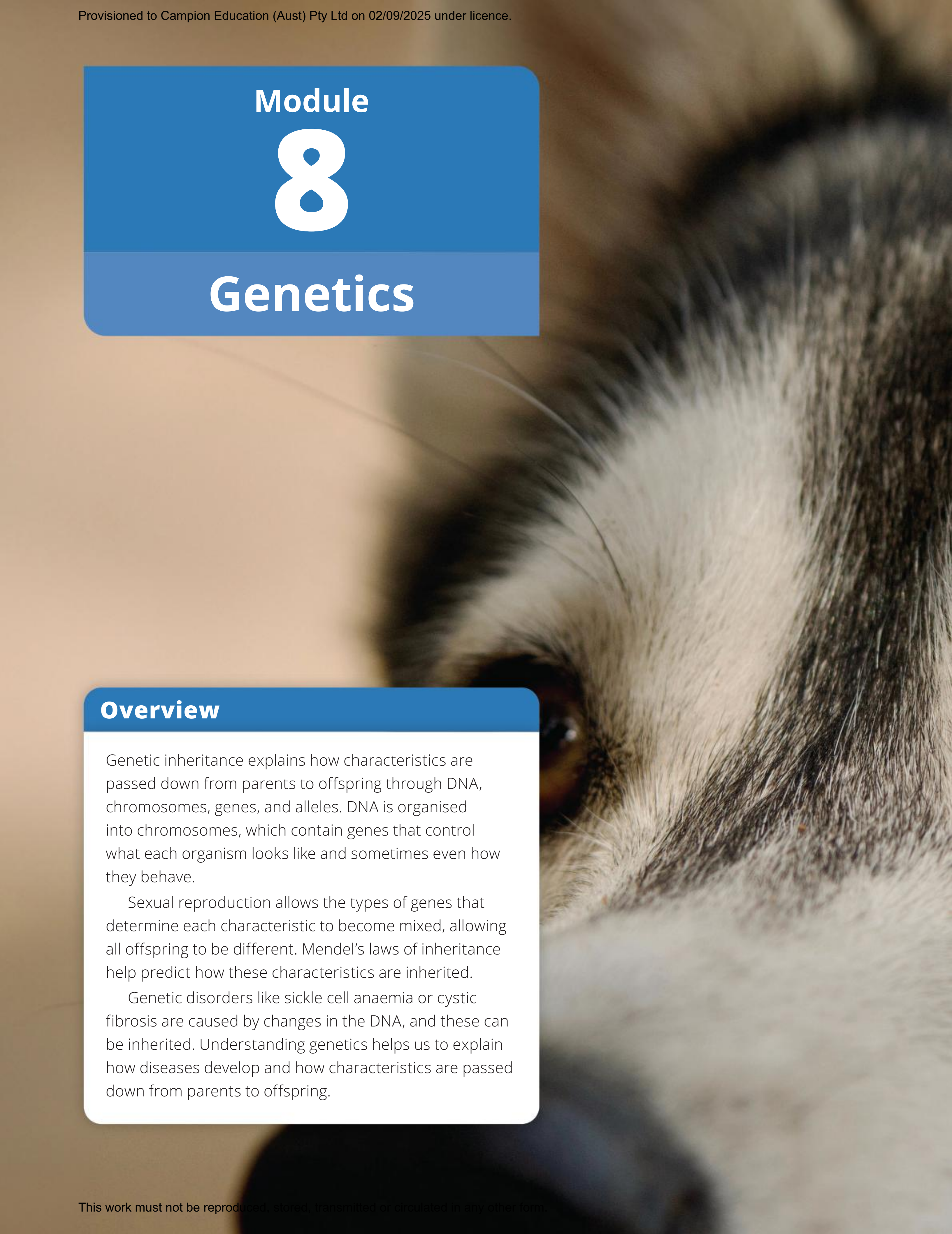
Figure 6 Tabuaeran Beach, Kiribati

Responding to climate change

The Paris Agreement (2025) 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°C 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 result 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.
- Describe how you could contribute to this target.



Module 8

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 8.1
DNA, genes, chromosomes and the genome

Learning intentions and success criteria

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 is 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 unique code that is passed from parents to offspring, generation after generation, with little or no change. Every cell within an organism (except red blood cells and sex cells) contains the same set of DNA molecules.

While DNA is common to every organism on the planet, the specific sequence varies between species. The more closely related two species are, the more similar their DNA sequence.

Within a species, individuals share most of their DNA. For example, 99.9 per cent of your DNA is identical to the person next to you. It is only the very small variations in the DNA code that result in differences to characteristics such as hair, eye and skin colour. These subtle variations make each individual unique, even within the same species.

Understanding the structure of DNA allows us to explain the similarities and differences that exist between and within species.

Structure of a nucleotide

nucleotide the building block of DNA consisting of one deoxyribose sugar, one phosphate group and one nitrogenous base

Each DNA strand is like a necklace of beads. The individual "beads" are called **nucleotides**. These are the sub-units or building blocks of DNA (Figure 1).

A nucleotide is a complex molecule composed of three smaller parts:

- a nitrogenous base (sometimes just called a "base")
- a sugar molecule (deoxyribose)
- a phosphate molecule.

DNA consists of four different types of nitrogenous bases:

- adenine (A)
- guanine (G)
- cytosine (C)
- thymine (T).

These four nitrogenous bases are what define the four different nucleotides (or "beads") that make up the DNA.

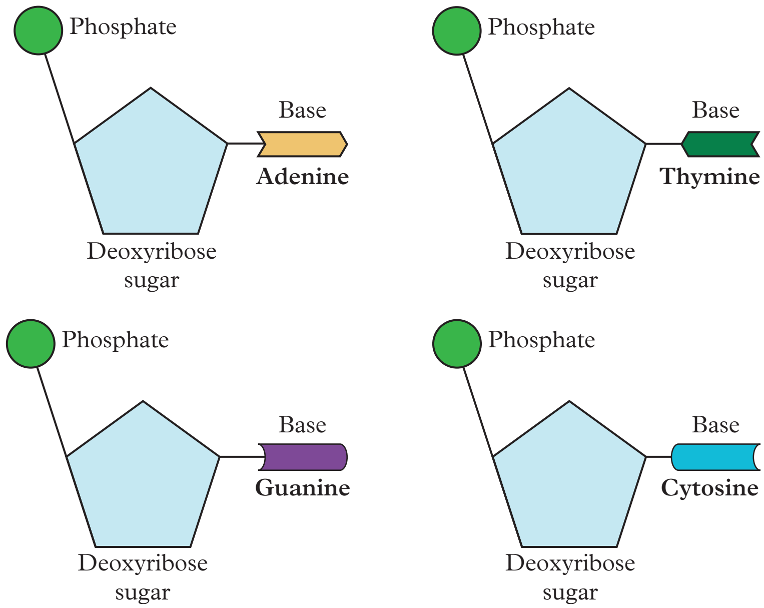


Figure 1 Nucleotides: the building blocks or sub-units of DNA

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. This forms a sugar–phosphate backbone, like the sides of a ladder (Figure 2).

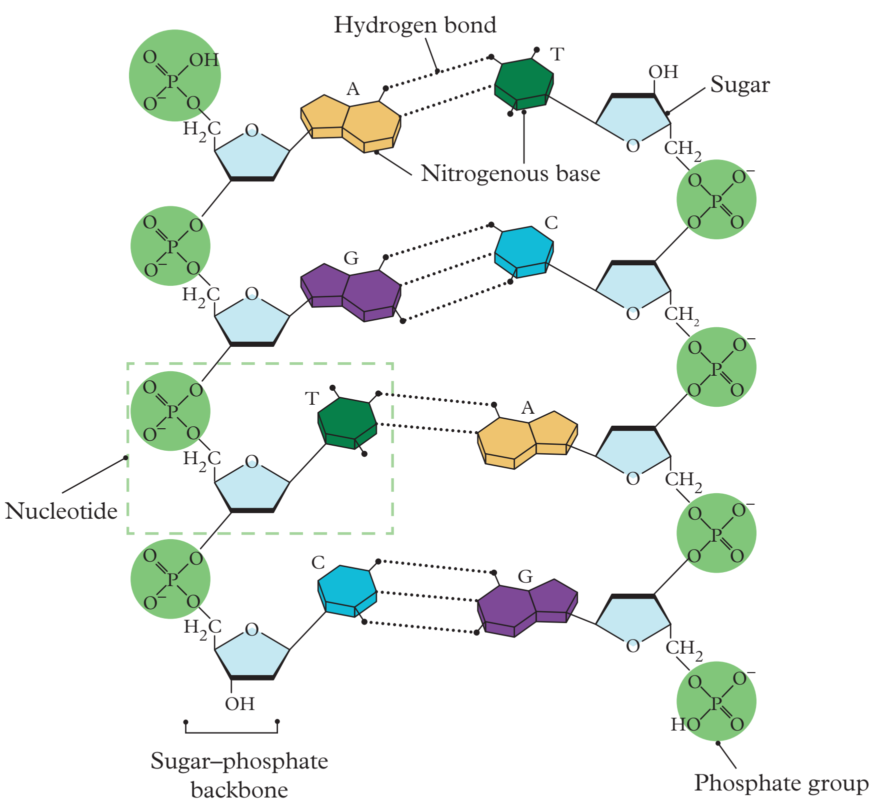


Figure 2 Nucleic acids such as DNA are made of a chain of nucleotides joined together through a sugar–phosphate backbone.

Double helix

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

Each nitrogenous base is attached to a sugar molecule in the backbone of the DNA strand, while the "rungs" of the ladder are formed by the nitrogenous bases from two complementary polynucleotide chains. These bases are bound together by relatively weak **hydrogen bonds**, allowing the DNA strand to separate during DNA replication and protein synthesis.

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

A large nitrogenous base (adenine or guanine) always pairs with a smaller nitrogenous base (thymine or cytosine) to ensure the correct spacing between the DNA strands. The four types of nitrogenous bases follow specific pairing rules: adenine (A) always pairs with thymine (T), and guanine (G) always pairs with cytosine (C) (Figure 3). These pairs, A-T and G-C, are known as **complementary bases**. As a result, one nucleic acid strand is always complementary to its corresponding strand.

complementary base a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand; adenine pairs with thymine, and guanine pairs with cytosine

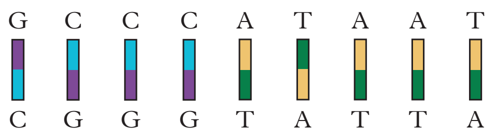


Figure 3 DNA bases always pair as thymine with adenine, and guanine with cytosine.

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 the 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.

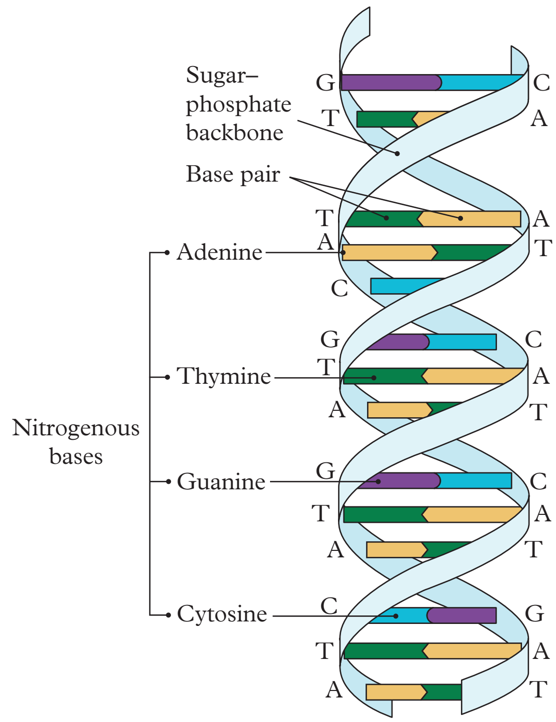


Figure 4 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules, and the rungs are pairs of nitrogenous bases.

DNA, genes, chromosomes and genome

In eukaryotic organisms, chromosomes are always located in the cell nucleus. Chromosomes are composed of DNA molecules tightly wound around small proteins called **histones**, which help to package the DNA efficiently. The DNA unwinds only when the cell needs to access its genetic instructions to synthesise proteins.

histone a protein that helps package and organise DNA in the nucleus of eukaryotic cells

If the DNA from a single chromosome were unwound, it would measure approximately 5 cm in length. With 46 chromosomes present in each human cell, the total length of DNA would be about 2 m. These 46 chromosomes are composed of 23 pairs, with one chromosome of each pair inherited from the mother and the other from the father, forming **homologous chromosome pairs**.

homologous chromosome pairs chromosome pairs – one inherited from each parent – that are similar in size, shape and genetic content

Genes, which are segments of DNA coding for specific traits, are located along the length of each chromosome. Homologous chromosome pairs carry the same genes at the same locations but may have different versions of those genes, known as alleles. A visual representation of all the homologous chromosome pairs, arranged from largest to smallest, is known as a **karyotype**. Figure 5 compares a human and chimpanzee karyotype. The only obvious difference is that humans have 46 chromosomes and chimpanzees have 48. Think about what this might provide evidence of.

gene a segment of DNA that codes for a specific trait

karyotype a way of representing a complete set of chromosomes, arranged in pairs, in order of decreasing

Comparison of human and chimpanzee karyotypes

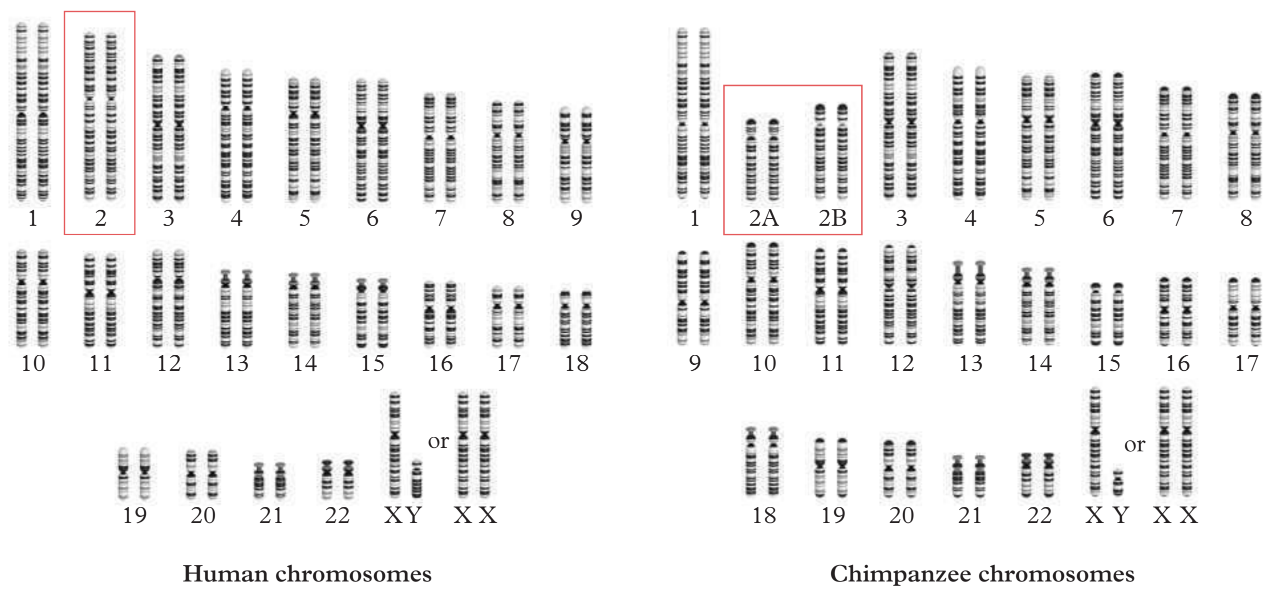


Figure 5 A comparison between the human and chimpanzee karyotypes. Note the only obvious difference is that humans have 46 chromosomes and chimpanzees have 48.

The number of chromosomes an organism has does not indicate how complex the organism is. For example, some species of fern (plant) have 1200 chromosomes, or 600 pairs of chromosomes, compared with kangaroos, which have only six pairs.

How we relate chromosomes to DNA

DNA is found inside a cell's nucleus and appears like a tangled thread. Before a cell divides, the DNA has copied itself, and the chromosomes can clearly be seen under a microscope.

The relationship between a chromosome and DNA is shown in Figure 6A to C. It can be summarised as:

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

Chromosomes may be a single double helix or a pair joined at the **centromere** (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 the centromere (Figure 6B).

centromere the structure in a chromosome that holds two chromatids together

DNA replication the process by which a cell makes an identical copy of its DNA

chromatid one side of the X-shaped chromosome that contains a double helix of DNA

How we relate genes to DNA

DNA in chromosomes is organised into sections called genes (Figure 6D). Each gene consists of a specific sequence of nucleotides, each containing one of the four nitrogenous bases A, T, G or C. Some genes are relatively short, containing as few as 250 nucleotide pairs, while others are much longer, with over 2 million nucleotide pairs.

The sequence of nitrogenous bases within a gene holds the genetic code responsible for producing a specific protein or for performing other important cellular roles. For example, one gene may contain the instructions for making melanin, a pigment responsible for skin colour, while another gene encodes keratin, the protein found in hair and nails.

In a sense, a chromosome, which holds many genes, can be thought of as a long sentence, where each gene is like a word, and the individual nucleotides are like the letters that make up those words.

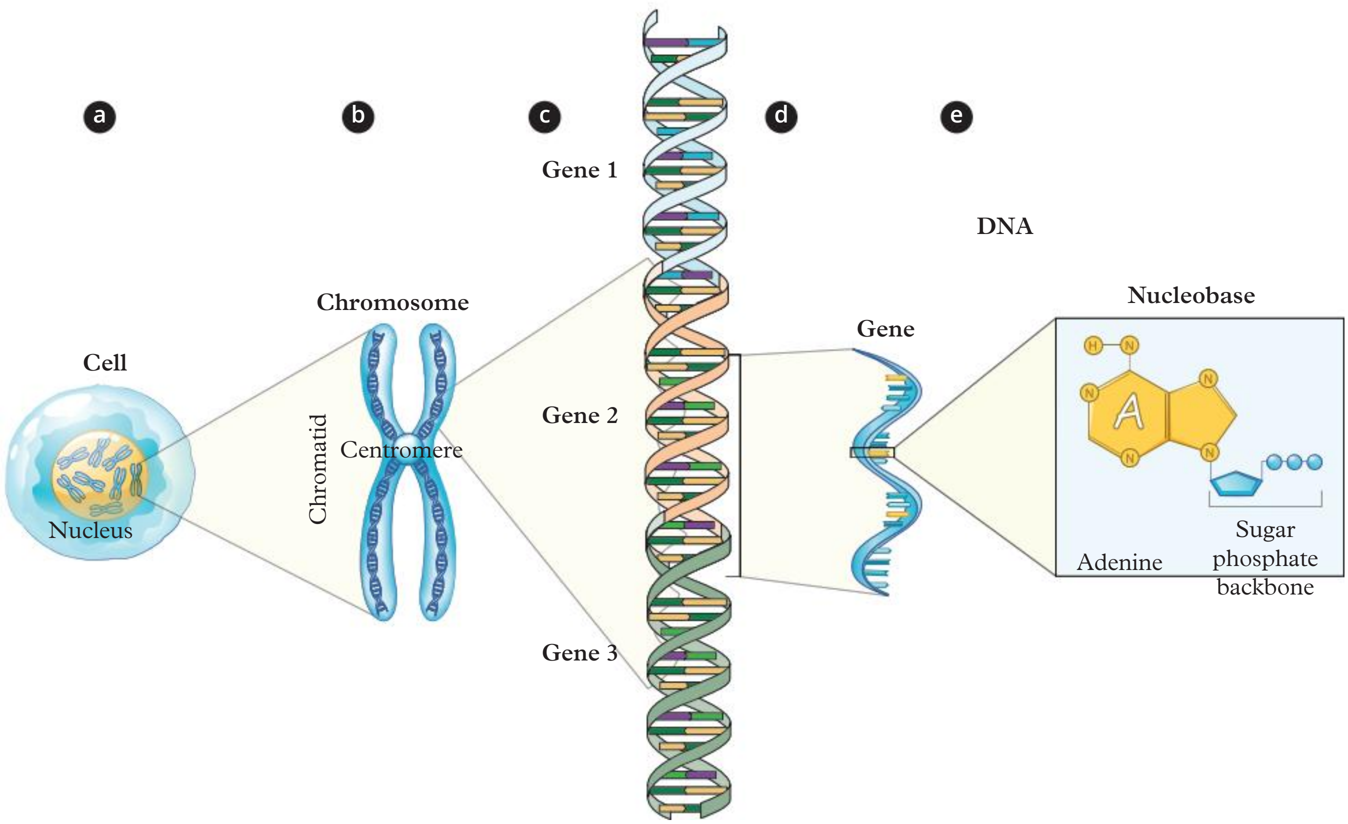


Figure 6 The relationship between chromosomes, DNA and genes. (a) Chromosomes are found in the nucleus of a cell. (b) A chromosome is made of two chromatids joined at a centromere. (c) Chromosomes are made of DNA. (d) Genes are segments of DNA that code for specific traits. (e) Nucleotides are the building blocks of DNA.

How we relate DNA to the genome

genome the complete set of genetic material present in an organism, including both coding and non-coding DNA

Most DNA in eukaryotic organisms consists of long sequences of non-coding regions between the genes. The **genome** of an organism is the complete set of genetic material present in an organism. This includes all of its DNA: both the genes that code for proteins and the non-coding sequences. In most cases, the non-coding DNA is believed to serve no function; however, some regions are known to regulate gene expression.

Check your learning 8.1

Check your learning 8.1

Retrieve

1 Define the term "nucleotide" and identify the three key components that make up a nucleotide.

2 Define the term "karyotype".

3 State the names of the nitrogenous bases that are represented by the letters A, T, G and C.

4 Identify the nitrogenous bases that are complementary to A, T, G and C.

Comprehend

5 Explain how two polynucleotides can twist helically around each other to form the DNA double helix.

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

Analyse

7 Identify the complementary DNA sequence to GTTAGCCAGT.

8 Outline the relationship between DNA, chromosomes and genes.

Apply

9 A student recorded the following answer as the complementary DNA sequence for question **7**: TGACCGATTG. Identify where they went wrong and discuss why this answer is incorrect.

This lesson modelled the structure of chromosomes, genes and nucleotides by comparing them 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.

10 A human karyotype has 46 chromosomes, while a chimpanzee karyotype has 48 (Figure 5). Scientists believe that at some point in human evolution, two smaller chromosomes fused to form human chromosome 2.

a Explain why you think a human has 46 chromosomes and a chimpanzee has 48.

b Explain the difference in the number of chromosomes between a human and a chimpanzee. Compare chromosome pair 2 and discuss what this might indicate.

c Using your answer from part **b**, compare the chromosomes and describe what it tells us about the evolutionary relationship between humans and other great apes. To assist, consider our other close relatives: gorillas and orangutans also have 48 chromosomes.

Skills builder: Planning investigations

11 A student was trying to model the DNA double helix. Their materials include coloured card, scissors, sticky tape and paper clips.

a Propose how they could model DNA using these materials. (THINK: What do they need to represent? How could they show the different bases?)

b Suggest a more specific materials list so that the student can demonstrate the elements of DNA. (THINK: What would benefit their list? Could it be more specific?)

Lesson 8.2
Investigation: Extracting DNA

Caution

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

Purpose

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 iced 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

Procedure

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 over-blend 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 for 8 minutes. Stir gently to avoid making bubbles.
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.

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 coverslip 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

1 Construct a flowchart of the method by drawing a labelled diagram of each step.

2 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 8.3
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:

- Four long pipe-cleaners (two different colours)
- 24 beads (six 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).

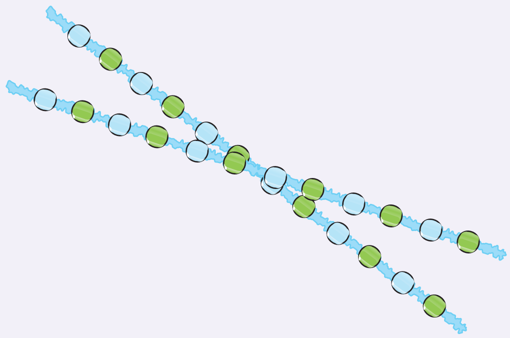


Figure 1 Representation of the sugar–phosphate backbone of DNA molecules

3 Cut the remaining two pipe-cleaners into 5 cm segments. These will be used to create the paired nitrogenous bases A-T and G-C.
4 Choose the two bead colours that represent the adenine and thymine nitrogenous 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).

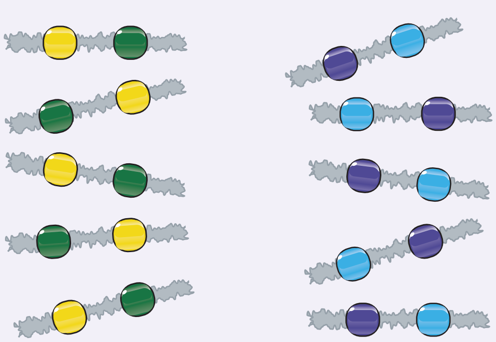


Figure 2 Representation of paired nitrogenous bases A-T and G-C

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 nitrogenous bases onto the backbone of the DNA molecule. Make sure each nitrogenous 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 nitrogenous bases as the rungs of the ladder.
8 Twist your ladder so that it forms a double-helix structure (Figure 3).

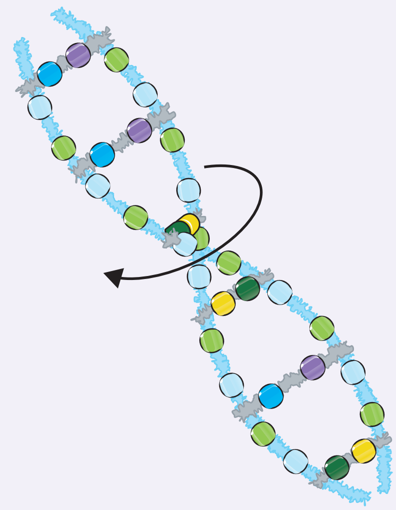


Figure 3 Representation of the DNA double-helix structure

Questions

1 Identify the bead colour that represents the nitrogenous bases:
  a adenine
  b thymine
  c guanine
  d cytosine.
2 Explain what is meant by the term "sugar–phosphate backbone".
3 Describe a "double helix".
4 Identify the base that is complementary to:
  a adenine
  b guanine.
5 Identify the type of bond that holds the complementary nitrogenous bases together.

Lesson 8.4
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 is its capacity to carry the **genetic code** for protein synthesis. The sequence of nucleotides in DNA forms the genetic code that has the instructions to make a **protein** (Figure 1). Proteins can be broadly classified as structural or functional. Structural proteins include collagen, which is found in our skin, bones and connective tissue, and keratin, which is found in our hair and nails. Functional proteins include haemoglobin, responsible for transporting oxygen in the bloodstream; antibodies, which play an essential role in our immune system; and enzymes, which speed up the chemical reactions that drive our metabolism.

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

protein a molecule made of long chains of amino acids, essential for the structure, function and regulation of body tissues and organs

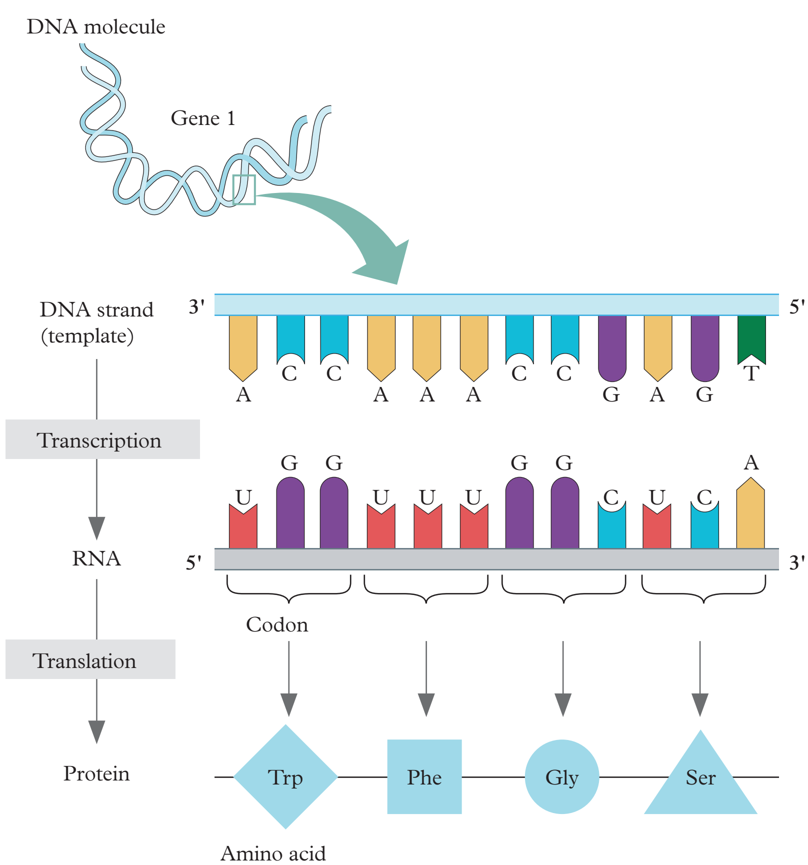


Figure 1 Protein synthesis. A complementary strand of mRNA is made (G-C and A-U). The mRNA leaves the nucleus and is used to form a protein. (Trp = tryptophan; Phe = phenylalanine; Gly = glycine; Ser = serine)

How genes make protein

RNA

mRNA a molecule that carries the coding sequence for protein synthesis

tRNA a molecule that carries amino acids

amino acid the building blocks of proteins, consisting of an amino group, a carboxyl group and a variable side chain

To make a protein, a specific section of DNA (a gene) unwinds, and one strand is used as a template. This template is used to guide the formation of a molecule called messenger ribonucleic acid (**mRNA**). The mRNA carries the genetic code out of the nucleus and to a ribosome, where a second RNA molecule, called transfer ribonucleic acid (**tRNA**), reads the mRNA and drops off specific **amino acids** (the building blocks of proteins) based on the genetic code.

Like DNA, RNA has a backbone of alternating sugar and phosphate groups. Unlike DNA, which contains a deoxygenated ribose sugar (deoxyribose), RNA contains ribose sugar. The nitrogen bases of RNA are adenine (A), cytosine (C), guanine (G) and uracil (U), which replaces thymine (T) (Figure 2).

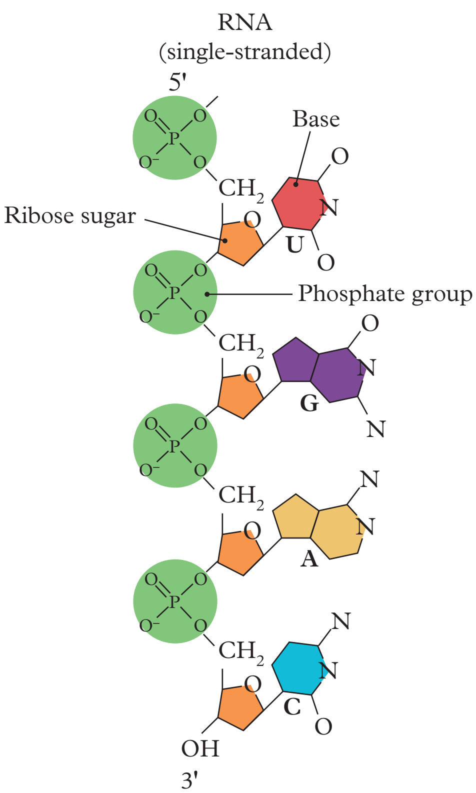


Figure 2 The structure of RNA

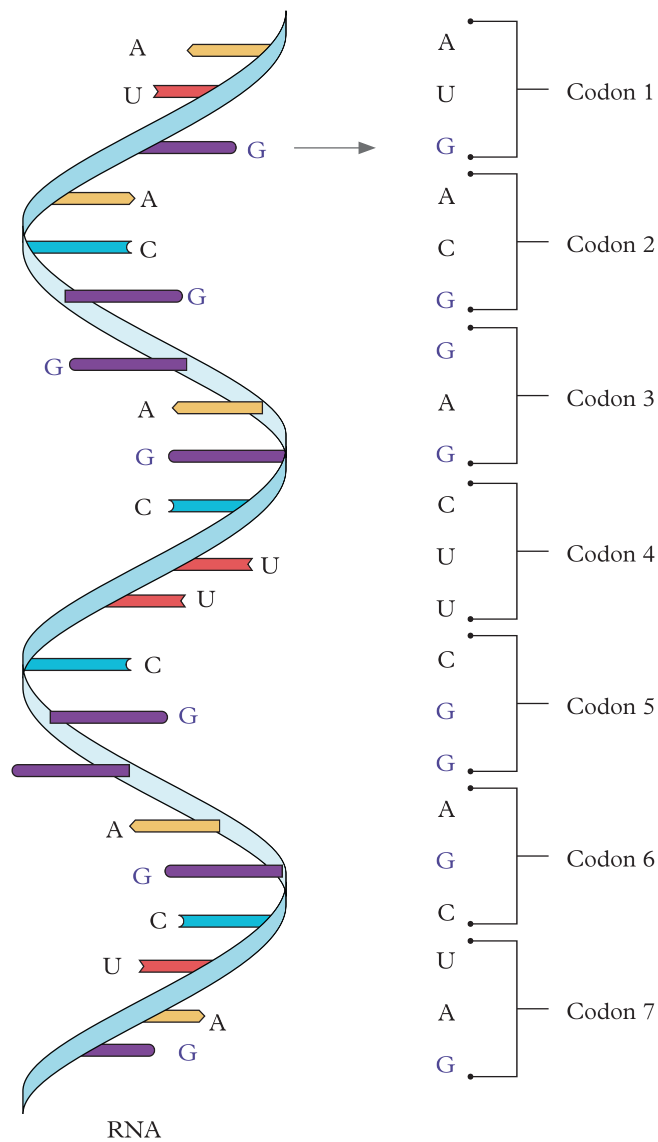


Figure 3 Each codon codes for a specific amino acid. Proteins are made up of long chains of amino acids.

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 The DNA of a gene is "unzipped", unwinding the two strands.
2 An enzyme called RNA polymerase moves along the exposed gene on the DNA strand. As it goes, it joins together free-floating 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.

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

Translation

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

Unlike DNA, mRNA can leave the nucleus and bind to a ribosome in the cytoplasm. Once attached, the mRNA serves as a template, guiding the ribosome in assembling amino acids into a protein. The nitrogen bases on the mRNA are read in groups of three called **codons**. Each codon corresponds to a specific amino acid.

Amino acids are delivered to the ribosome by tRNA. The tRNA recognises the codons on the mRNA and brings the corresponding amino acids. As the ribosome reads the sequence of codons, the amino acids are linked together in a growing chain.

Ultimately, this chain of amino acids folds into a functional protein, completing the process of translation (Figure 3).

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

codon a group of three nucleotides on mRNA

Check your learning 8.4

Check your learning 8.4

Retrieve

1 Identify two differences between DNA and mRNA.

Comprehend

2 Create a flowchart to summarise the process of translation in your own words.
3 Explain the role that mRNA plays in the conversion of DNA information into protein.

Analyse

4 Contrast transcription and translation to highlight the differences between the two processes.
5 Identify the mRNA sequence for the template DNA sequence GTTAGCCAGT.

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.
7 Assess the importance of mRNA and tRNA in producing a functional protein.

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 for 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 8.5
Mitosis produces new somatic cells

Learning intentions and success criteria

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.

Types of cell division

There are two important types of cell division that are essential for sexually reproducing organisms: mitosis and meiosis. Mitosis produces genetically identical daughter cells and is essential for growth, repair and asexual reproduction, ensuring survival of individual organisms. In contrast, meiosis produces genetically unique gametes that ensure genetic diversity within a species, which is important for long-term survival of a species.

While their mechanisms and outcomes differ, both mitosis and meiosis contribute to the continuity of a species.

Mitosis produces genetically identical daughter cells

somatic cell all types of cells in the body except for gametes (egg and sperm)

gamete a reproductive cell (sperm in males and ova in females) that carries half the genetic information necessary for the formation of a new organism

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

diploid containing two complete sets of chromosomes

haploid containing one complete set of chromosomes (n), which is half the diploid number; gametes (sperm and egg cells) are haploid

Every organism needs to grow and repair damaged tissue 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 (**gametes**). When somatic cells reproduce, they undergo a process called **mitosis**.

In each somatic cell, chromosomes are in pairs. The pairs are homologous, meaning they are similar in size, shape and genetic content. One of each pair was originally inherited from the mother via the egg, while the other was inherited from the father via the sperm. In humans, there are the same 46 chromosomes or 23 pairs of chromosomes in every somatic cell. When a cell has these two complete sets of chromosomes, they are described as **diploid** ($2n$). The n in the $2n$ simply refers to a *n*umber, where n is the number of chromosomes in the **haploid** gamete (Figure 1). In the case of humans, $n = 23$; whereas mice somatic cells, for example, contain 40 chromosomes, so $n = 20$ in this case.

So how does a single cell produce two genetically identical copies of itself? Before mitosis begins, the cell undergoes DNA replication within its nucleus. This process makes exact copies of the DNA in each chromosome, resulting in two identical sister chromatids for each chromosome, which are connected at a region called the centromere.

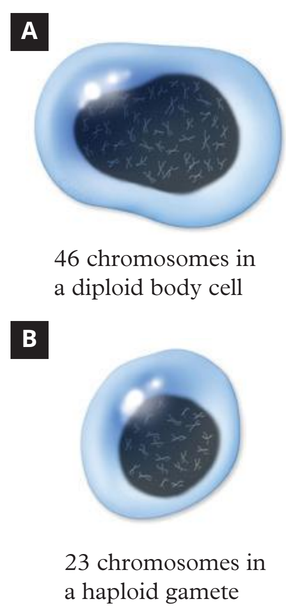


Figure 1 (A) A diploid body cell and (B) a haploid gamete

When the cell undergoes mitosis, the sister chromatids separate and the parent nuclei divide to form two genetically identical daughter nuclei. Following this, the rest of the cell divides in a process called **cytokinesis**, with each resulting daughter cell receiving a genetically identical copy of each chromosome (Figure 2 and Figure 3).

cytokinesis the splitting of a replicating cell into two cells

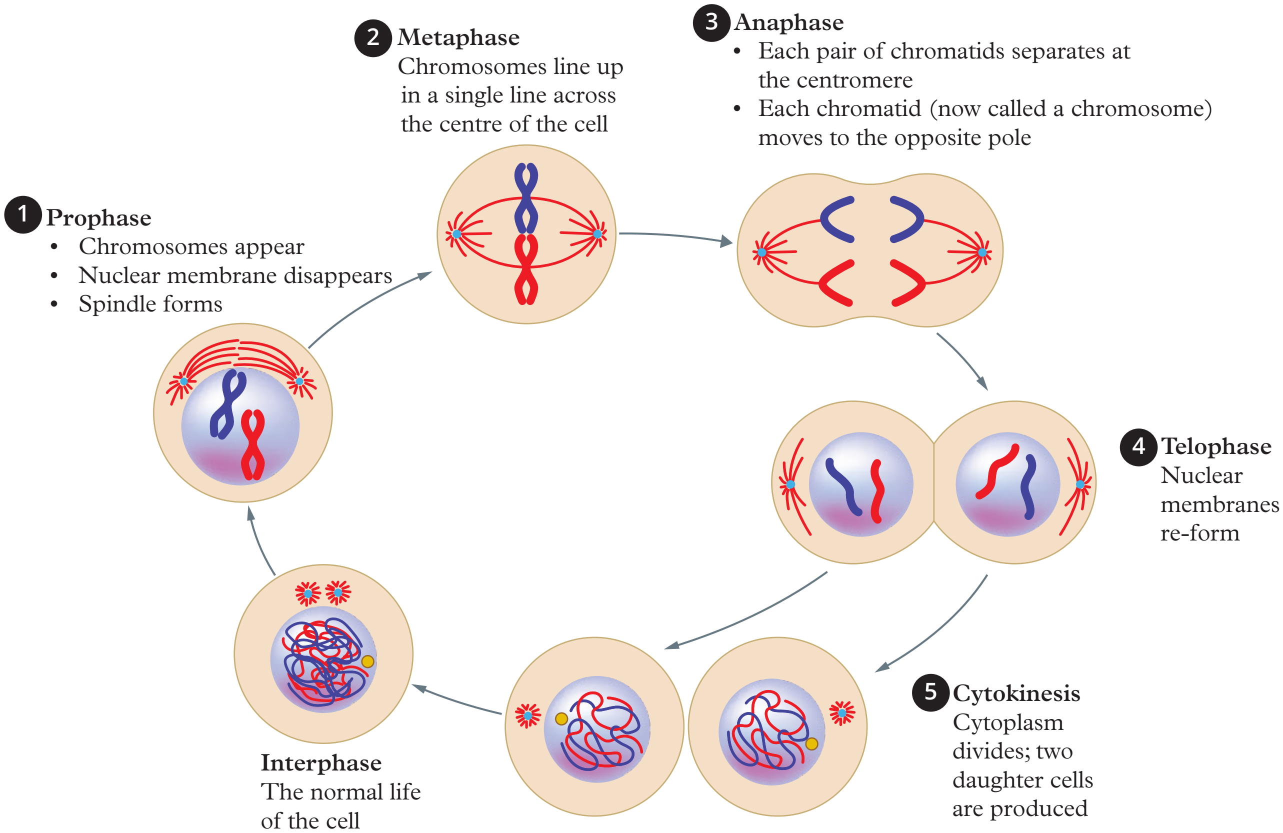


Figure 2 Interphase and the phases of mitosis and cytokinesis. Parent cell and daughter cells have $2n = 2$.

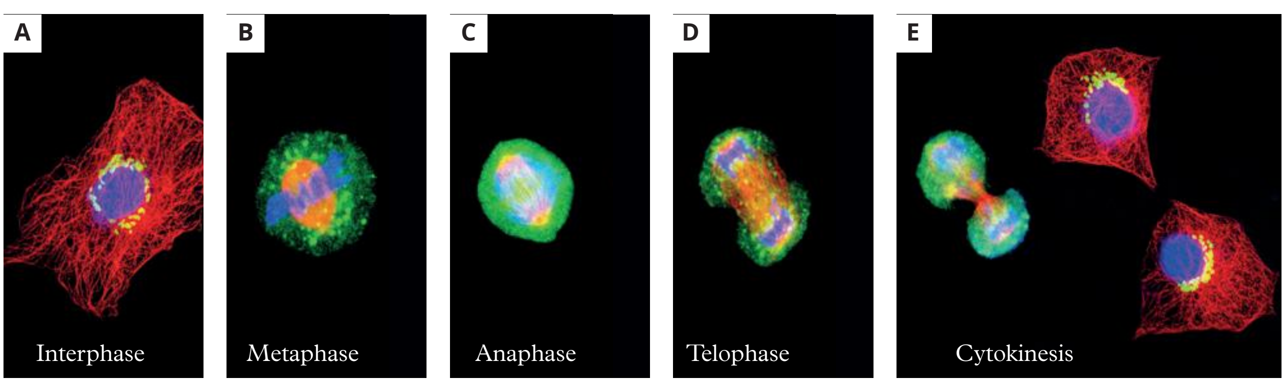


Figure 3 These mitotic cells have been stained with a fluorescent stain to show the separation of DNA. (A) The cell is at the end of interphase: the DNA has been replicated. During prophase, the nuclear membrane breaks down and the red spindle fibres bind to the centromere. (B) The (blue) chromosomes 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.

The importance of mitosis

The cells in your body go through a cycle in which new cells replace old or damaged ones. This process, called mitosis, is important for growth and healing. Cells only begin mitosis when the body signals that new cells are needed. For example, in humans, intestinal cells replace themselves every 4 days, skin cells every 3 weeks and bones every 7 to 10 years. When cells are not dividing, which is most of the time, they are in a phase called **interphase** (Figure 2, Figure 3 and Figure 4). During this phase, cells perform everyday processes such as making proteins. Prior to entering mitosis, DNA replication also occurs during interphase.

interphase a phase of cell life where normal functioning occurs

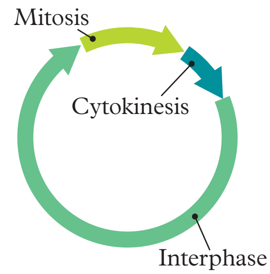


Figure 4 The cell cycle; cells spend most of their life in interphase, when normal cell functioning occurs.

The phases of mitosis are as follows:

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

2 **Metaphase**
- Chromosomes line up in a single line across the centre of the cell

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

4 **Telophase**
- Nuclear membranes re-form

5 **Cytokinesis**
- Cytoplasm divides; two daughter cells are produced

Remember from Lesson 8.3 Challenge: Modelling the structure of DNA (page 331) that the structure of a protein is determined by the exact sequence of nitrogenous bases in the gene that codes for it. If this genetic code is changed, even by as little as one nitrogenous base, it can significantly impact the production of the protein and, therefore, the health of an organism. This is why every time a cell undergoes mitosis, it is vital that the two resulting daughter cells receive the exact same sequence of genetic material as the parent cell.

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.

apoptosis programmed cell death

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

cell mutation a change in a cell's DNA due to exposure to mutagens

Mutagens, such as radiation, viruses or chemicals can lead to a permanent change in the DNA sequence of a cell, resulting in a **cell mutation**. 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. This will be covered in more detail in Lesson 8.20 Mutations are changes in the DNA sequence (page 382).

Check your learning 8.5

Check your learning 8.5

Retrieve

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

Comprehend

2 Explain why cells need to undergo mitosis.
3 Describe the behaviour of the chromosomes through mitosis.

Analyse

4 A cell that is about to undergo mitosis must double its amount of DNA. Explain why this needs to occur.
5 Explain why cytokinesis is often considered the final stage of mitosis.
6 Use Figure 2 to help you identify each of the different stages of mitosis happening in Figure 5.

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".

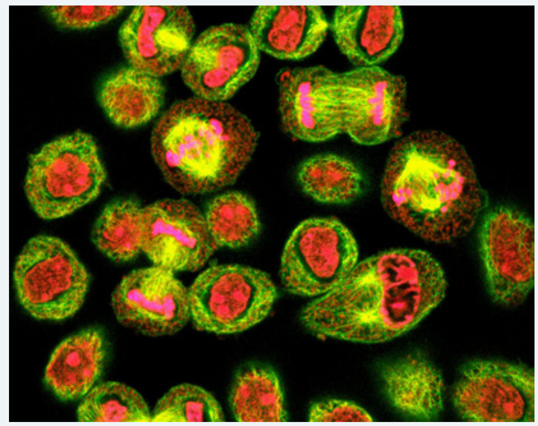


Figure 5 Fluorescent stain showing cells in different stages of mitosis

Lesson 8.6

Skills lab: Cell division in action

Aim

To identify cells undergoing different stages of mitosis

Materials

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

Method

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.

4 Describe an advantage of cellular mitosis for an organism.

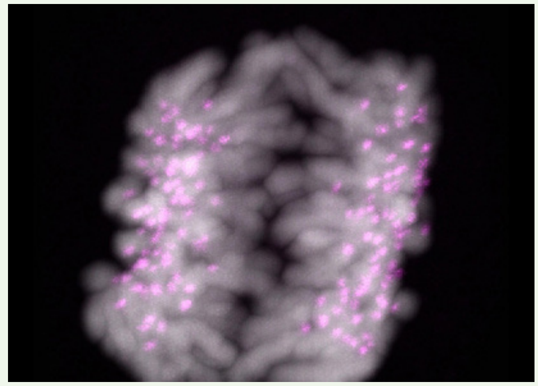


Figure 1 These human chromosomes are in one of the phases of mitosis.

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.

Lesson 8.7
Meiosis produces gamete cells

Learning intentions and success criteria

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 a specialised type of cell division that reduces the chromosome number by half, producing four genetically unique haploid gametes from a single diploid parent cell

sister chromatids identical copies of a chromosome that are formed during DNA replication and are joined together at the centromere; they separate during cell division

Meiosis produces daughter cells with half the chromosomes of parent cells

In sexually reproducing organisms, half of the genetic material in each cell comes from the mother and the other half from the father. Have you ever wondered how the genetic material in one of your parent's cells divided in half? The answer is **meiosis** (Figure 1).

Meiosis is a specialised form of cell division that reduces the chromosome number by half, creating four genetically unique haploid (n) gametes (sex cells) from a single diploid parent cell. In animals (including humans), the male gamete is a sperm and the female gamete is an ovum (egg). In flowering plants, the male gamete is contained in a pollen grain and the female gamete is located in the flower's ovary.

In preparation for meiosis, the cell undergoes DNA replication during interphase, much like in mitosis. This process occurs within the nucleus and results in two identical **sister chromatids** for each chromosome, which remain connected at the centromere.

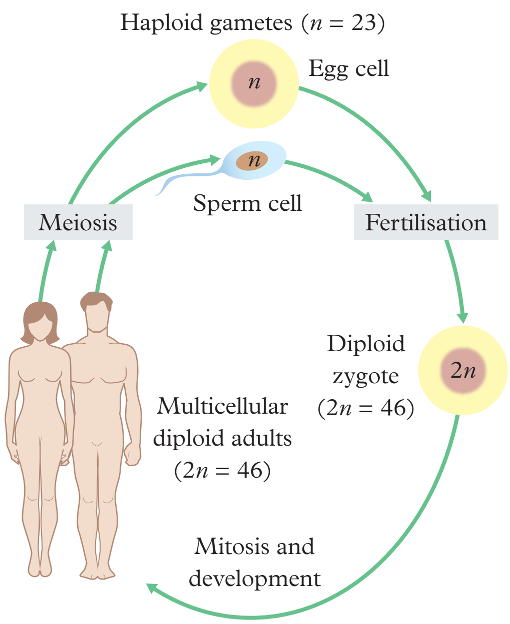


Figure 1 The human life cycle, involving mitosis and meiosis

The process of meiosis itself is divided into two main stages: meiosis I and meiosis II. In meiosis I, homologous chromosomes – each consisting of two sister chromatids – pair up and exchange genetic material in a process known as **crossing over**. This genetic recombination increases variability in the offspring. The homologous chromosomes then align at the cell's equator and are pulled apart to opposite poles. This separation reduces the chromosome number by half, resulting in two haploid cells, each containing one chromosome from each homologous pair, but still consisting of two sister chromatids.

crossing over a process during meiosis where homologous chromosomes exchange segments of genetic material, leading to increased genetic variation in the resulting gametes

Meiosis II resembles a mitotic cell division, where the sister chromatids of each chromosome – now containing different allele combinations – are finally separated. During this stage, the two haploid cells from meiosis I undergo a second division without any further DNA replication. The sister chromatids are pulled apart and segregated into four distinct daughter cells, each with a single set of chromosomes. These haploid cells, now called gametes, are genetically unique due to the crossing over and independent assortment of the chromosomes (Figure 2).

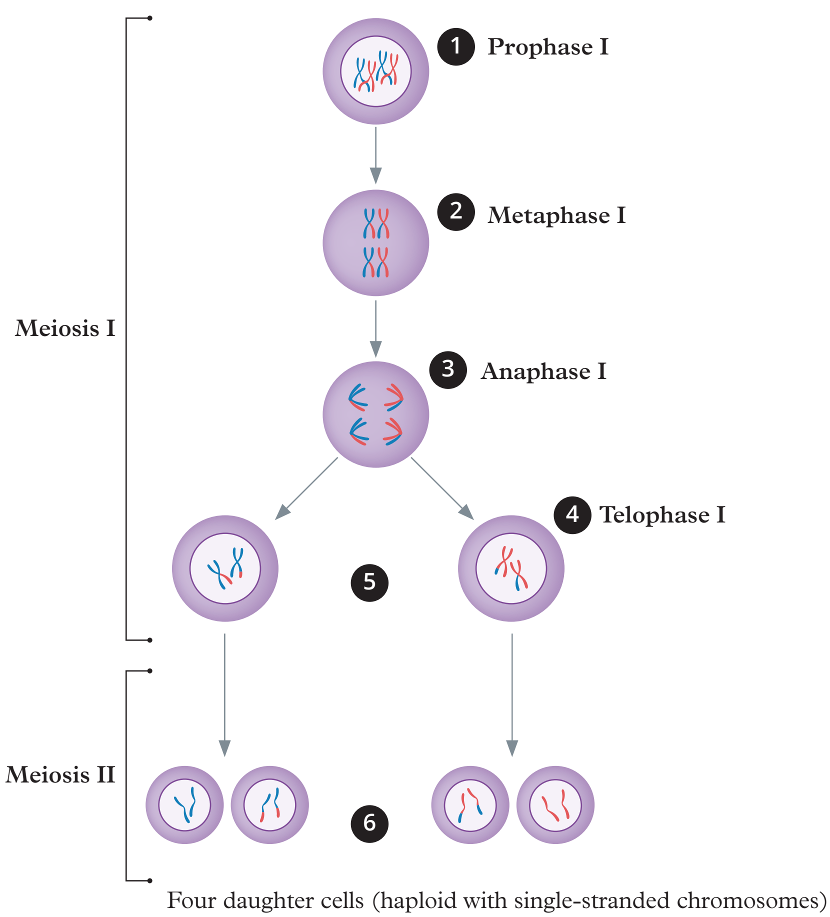


Figure 2 Interphase and the phases of meiosis I and II and cytokinesis. The parent cell has $2n = 4$ and the four daughter cells have $n = 2$. The following parts are labelled.

1. Prophase I
   - Diploid cell ready to undergo meiosis
   - Nuclear membrane will disappear
2. Metaphase I
   - Chromosomes line up in pairs across the centre of the cell
3. Anaphase I
   - One chromosome from each pair is pulled to opposite ends of the cell by the spindle
4. Telophase I
   - Nuclear membrane re-forms and the resulting two daughter cells are haploid
5. Two daughter cells (haploid with duplicated chromosomes)
6. Each daughter cell now undergoes a mitotic-like division (meiosis II) to produce four daughter cells (gametes), each with a single set of chromosomes

The importance of meiosis

zygote the first diploid cell of a new organism that results from the union of two haploid gametes during fertilisation

Meiosis reduces the chromosome number by half, producing haploid gametes from a diploid parent cell. This reduction is essential for maintaining the species' chromosome number across generations. When fertilisation occurs, the diploid state in the resulting **zygote** is restored, ensuring that the offspring have the correct number of chromosomes (Figure 3).

One of the most significant roles of meiosis is the introduction of genetic diversity into a population. Crossing over and independent assortment produce new gene combinations. This diversity is vital for evolution, as it allows populations to adapt to changing environments and increases the chances of survival against diseases and other challenges.

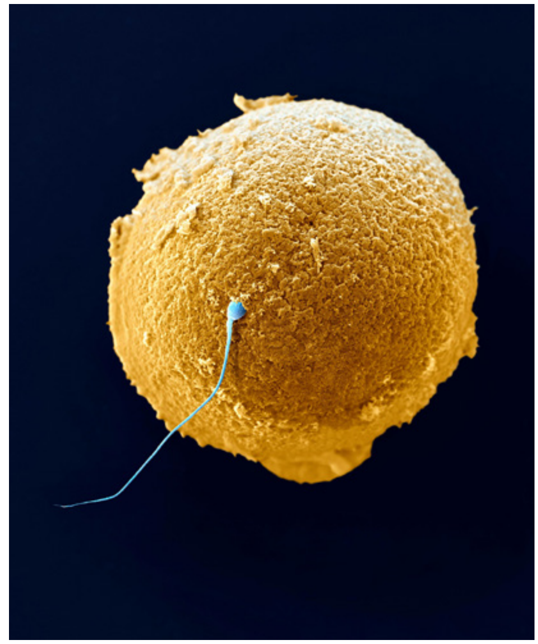


Figure 3 When a haploid sperm cell (n) fertilises a haploid egg cell (n), a diploid somatic cell ($2n$) is formed.

Check your learning 8.7

Check your learning 8.7

Retrieve

1 Identify the number of chromosomes present at each phase of meiosis, as shown in Figure 2.
2 Define the term "gamete".

Comprehend

3 Explain how meiosis and mitosis allow the formation of a zygote and its growth into an embryo.
4 Explain why the offspring of sexually reproducing organisms are not identical to their parents.
5 Explain why it is essential that the number of chromosomes is halved during meiosis.

Analyse

6 Compare a haploid cell and a diploid cell.
7 Construct a table comparing mitosis and meiosis.
8 Explain why interphase is not considered part of meiosis or mitosis.
9 The chromosomes in Figure 4 are separating at the centromere. Use Figure 2 to identify the phase of meiosis that the cell is undergoing.

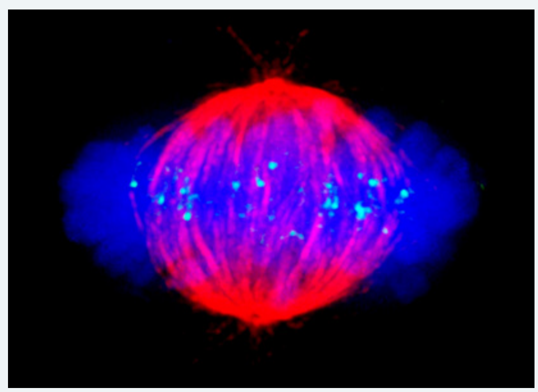


Figure 4 Each stage of meiosis includes prophase, metaphase, anaphase and telophase.

Skills builder: Conducting investigations

10 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 8.8
Skills lab: Modelling meiosis

Aim

To model the stages of meiosis

Materials

- Pipe-cleaners of different colours
- Sticky tape
- Felt-tipped pens
- A3 sheet of paper

Method

1. Draw the outer membrane of a cell on the sheet of paper.
2. Cut two pipe-cleaners of different colours in half and place one half of each colour in the centre of the cell. These represent a homologous pair of chromosomes before starting meiosis ($2n = 2$).
3. Using the other halves, twist each half around the centre (centromere) of the same-coloured chromosome from step 2. This represents the 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.

Extension

Repeat the process, starting with a parent cell with a diploid number of $2n = 4$.

Again, use two different coloured pipe-cleaners. For colour 1, have one long chromosome and one short chromosome. Do the same for colour 2.

Note the two long chromosomes of different colours represent one homologous pair, as do the two short chromosomes of different colours.

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.
5. State what the different colours of the homologous chromosome pairs represent.
6. When modelling meiosis, we typically start with a diploid number of 2 or 4. Suggest a reason for this. (Tip: Consider the diploid number of humans.)

Lesson 8.9

Scientists refine the work of other scientists: Discovering the structure of DNA

Learning intentions and success criteria

Key ideas

→ Scientists build on the work and knowledge of scientists that came before them.

Scientists who contributed to our understanding of DNA

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

Figure 1 Gregor Johann Mendel, 1822–1884, is known as the father of genetics.

heredity the process by which traits and characteristics are passed from parents to offspring through genes

While not specifically involved in discovering the structure of DNA, Gregor Mendel can be considered an important contributor to our understanding of **heredity**, which later paved the way for future discoveries related to DNA and its role in genetics.

In the mid-nineteenth century, Mendel (Figure 1) studied the inheritance of various traits in pea plants. Through his observations, he correctly deduced that offspring inherited two "factors" for each trait: one from each parent.

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 other scientists repeated Mendel's experiments that he was given credit for the two key principles of genetics: segregation and independent assortment (which will be explored further in Lesson 8.13 Mendelian inheritance in plants and animals, page 359).

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

Phoebus Levene

In the 1920s, Phoebus Levene discovered that DNA was composed of units called nucleotides, each consisting of a sugar (deoxyribose), a phosphate group and a nitrogenous base. He proposed, however, that DNA was single-stranded with repeating units of the four nucleotides in a fixed sequence, leading him to believe that each nucleotide should be present in equal amounts within the DNA molecule. Although this theory was later disproven, Levene's work in identifying the components of nucleic acids (sugar, phosphate and nitrogenous bases) laid important groundwork for future discoveries.

Oswald Avery, Colin MacLeod and Maclyn McCarty

In 1944, Oswald Avery – along with his colleagues Colin MacLeod and Maclyn McCarty – demonstrated that DNA, not protein, was the material of genetic inheritance. They isolated DNA from a virulent strain of bacteria (*Streptococcus pneumoniae*) and introduced it into non-virulent strains. In each case, the non-virulent bacteria transformed into virulent ones, confirming that DNA was responsible for heredity.

The group's work shifted the scientific focus to DNA, paving the way for further research that ultimately culminated in the discovery of the DNA double-helix structure.

Erwin Chargaff

In 1950, Erwin Chargaff published his work that established two important principals, known as Chargaff's rules (Figure 2).

Rule 1: The complementary base-pairing rule (A = T, G = C)

In DNA, the amount of adenine (A) is always equal to the amount of thymine (T), and the amount of guanine (G) is always equal to the amount of cytosine (C).

Rule 2: The species variation rule

The ratio of A to T and G to C is always the same within a species, but varies between species.

Chargaff's rules provided the molecular basis for the stability of the DNA structure and supported the idea that DNA carries the genetic code unique to each species.

	A	T	G	C
Human	31.0	31.5	19.1	18.4
Fruit fly	27.3	27.6	22.6	22.5
Wheat	26.8	27.2	22.8	23.2
Fungus	23.0	23.3	27.1	26.6
Rat	28.7	28.4	21.4	21.5
E.coli	24.6	24.3	25.5	25.6

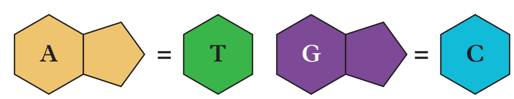


Figure 2 Chargaff's rules. The amount of A is always equal to the amount of T, and the amount of G is always equal to the amount of C. The ratio of A to T and G to C is always the same within a species, but varies between species.

Linus Pauling

Linus Pauling was a highly respected biochemist. In 1953, Pauling proposed a triple-helix model for DNA. His model was flawed, however, because he had incorrectly placed the phosphate groups inside the helix structure and didn't address the correct base-pairing rule demonstrated by Erwin Chargaff. While his model was incorrect, it demonstrated to Watson and Crick the importance of considering the helical nature of DNA.

James Watson and Francis 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. They worked as a team to unravel the secret of the structure of DNA, which they identified as a double helix (two-stranded spiral) in 1953.

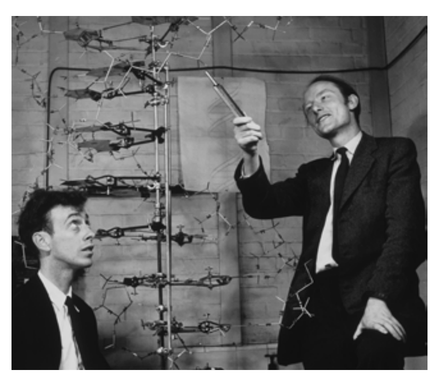


Figure 3 James Watson and Francis Crick with their DNA model

Rosalind Franklin and Maurice Wilkins

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. Franklin developed a technique known as X-ray diffraction, which allowed her to produce high-quality images of DNA fibres.

When Franklin started work in Randall's laboratory, Maurice Wilkins (another scientist working on DNA) was away. When Wilkins returned, he misunderstood her role, treating her as though she were a technical assistant. While she was out of the laboratory, Wilkins showed Watson photograph 51, one of Franklin's best crystallographic images of DNA taken in 1953 (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

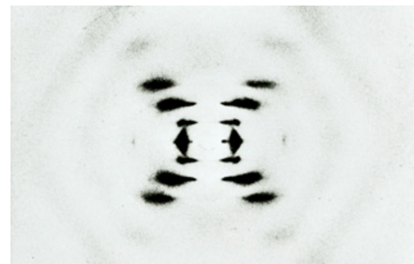


Figure 5 Photograph 51: the X-ray crystallography image of DNA taken by Rosalind Franklin

Check your learning 8.9

Check your learning 8.9

Retrieve

1 Identify the contribution of Erwin Chargaff to our understanding of DNA structure.

2 Identify the scientists ultimately credited with discovering the structure of DNA.

Comprehend

3 A quote by Isaac Newton is as follows: "If I have seen further, it is by standing on the shoulders of giants". With reference to the information in this lesson, explain how this quote can be applied to the discovery of DNA structure by Watson and Crick.

Analyse

4 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 others' 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 photograph 51 to create and publish their DNA model without acknowledging Franklin's contribution.

a Should Wilkins have shown Watson and Crick photograph 51?

b Franklin was a brilliant and kind-hearted scientist, although some colleagues found her difficult to work with. Should she have shared her results with others, had she been given the choice?

c Should all scientists share their results with each other? If so, then how should the work be acknowledged? Provide reasoning to justify your answer.

Evaluate one of the following ethical issues that arose from this discovery by:

» describing the ethical approach you are using (e.g. consequentialist or deontological; refer to Lesson 1.3 Planning investigations (page 10) or Lesson 8.23 Science in context: Using an ethical framework (page 401)
» 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.

Skills builder: Processing and analysing data and information

5 Research Mendel's work. Assess the impact the work had on the science behind DNA and inheritance. (THINK: What aspects of his work are still supported today? What aspects have been refuted? Is his original research reliable?)

Lesson 8.10

Passing on genetic information to offspring

Key ideas

→ All living things reproduce, leaving new organisms to carry on when others die.

→ Asexual reproduction involves a single organism making a copy of itself using its own genetic material.

→ Sexual reproduction involves combining the genetic material from two organisms to produce a new organism.

Learning intentions and success criteria

Types of reproduction

Reproduction is the process by which organisms produce new individuals of the same species. It is essential for the survival and continuation of a species. There are two broad categories: asexual reproduction and sexual reproduction. Both involve the transfer of genetic material from parents to **offspring**, but they have distinct mechanisms and outcomes (Figure 1).

offspring an organism's young, or child

Asexual reproduction

Asexual reproduction involves a single organism producing offspring that are genetically identical to itself, without the involvement of gametes (sperm and egg). This type of reproduction is particularly useful in stable environments where having large numbers of genetically identical offspring can help the species to exploit available resources.

Asexual reproduction allows for rapid population growth and requires less energy and resource investment from the parent as there is no need to search for a mate or engage in

asexual reproduction reproduction that involves a single organism producing offspring that are genetically identical to itself courtship. For many organisms, finding a partner can be challenging and energy-intensive. While some species can easily find mates, others – particularly those that are isolated or immobile – often rely more on asexual reproduction for their survival.

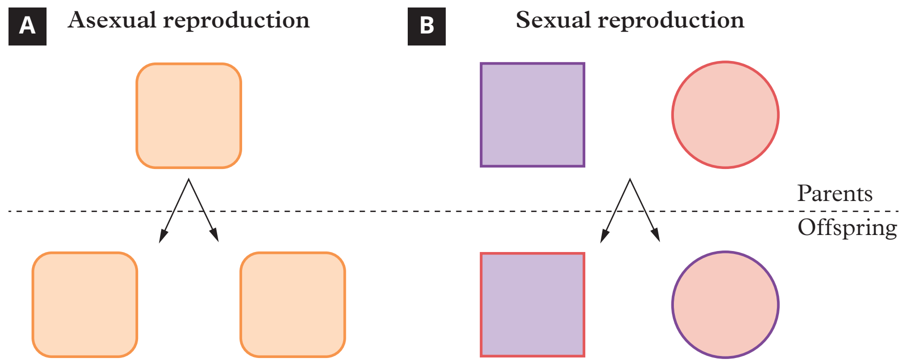


Figure 1 (A) Asexual production results in genetically identical offspring from a single parent. (B) Sexual reproduction produces genetically unique offspring from two parents.

Most environments, however, are not stable. Genetically identical populations are more susceptible to environmental changes and disease. If conditions change too much, the population will struggle to adapt and will face the risk of extinction.

The simplest form of asexual reproduction is **binary fission**, in which a unicellular organism (prokaryotic or eukaryotic) splits in half to form two new organisms. Other common methods observed across the four eukaryotic kingdoms (animals, plants, fungi and protists) include **parthenogenesis**, **fragmentation**, **budding** and **vegetative reproduction**.

binary fission a form of asexual reproduction used by bacteria; the splitting of a parent cell into two equal daughter cells

parthenogenesis asexual reproduction in which an egg develops into a new individual without fertilisation

fragmentation asexual reproduction in which an organism breaks into fragments, each capable of growing into a new individual

budding asexual reproduction that involves a new organism developing from a bud on the parent and eventually detaching

vegetative reproduction asexual reproduction in plants from vegetative parts like roots or stems; examples include runners, tubers and rhizomes

Animal examples

Partheongenesis

Parthenogenesis is an amazing asexual reproductive strategy that involves unfertilised eggs hatching into new organisms (Figure 2 and Figure 3). While usually associated with insects and other invertebrates, there are many known examples in vertebrates, including fish, amphibians and reptiles. In 2012, a reticulated python named Thelma at an American zoo laid 61 eggs, of which six hatched into healthy females. She had no contact with male snakes. Genetic testing confirmed that the baby snakes were genetically identical to the mother, and so parthenogenesis had occurred.

Figure 2 Many species of stick insects, particularly those in the family *Phasmatidae*, can reproduce either sexually or asexually through parthenogenesis.

Figure 3 Water flea (*Daphnia pulex*) with parthenogenic eggs

Fragmentation

Some animals, such as many species of starfish, have the ability to regenerate and form two new individuals when they are split into unequal parts. This is called fragmentation (Figure 4).

Budding

Budding is a process where a bud forms on the parent, which grows and eventually breaks off to become a new, genetically identical organism. An example of this is the hydra, which is a small freshwater animal (Figure 5).

Figure 4 Starfish undergoing fragmentation. The small piece of tissue that broke from the parent organism is growing new arms, while the parent has regenerated the fifth arm.

Figure 5 The hydra uses budding to produce genetically identical hydras.

Plant examples

Vegetative reproduction

In the plant kingdom, asexual reproduction occurs through vegetative reproduction, in which new plants develop from the non-flowering parts of the plant, including stems, roots and leaves. Specific methods of vegetative propagation include runners, tubers, rhizomes and bulbs.

Runners are specialised stems that grow horizontally along the ground's surface. As they extend outward, they produce new plants at their nodes, which take root and develop into independent individuals. Examples of plants that use this method are strawberries and the Sturt's desert pea (Figure 6).

Modified underground stems such as **tubers**, **rhizomes** and **bulbs** store nutrients and energy. When conditions are favourable, they sprout new shoots and roots, giving rise to new

Figure 6 Sturt's desert pea with runners growing horizontally along the ground

Figure 7 Potatoes are examples of modified underground stems called tubers.

runner specialised horizontal stems that grow along the ground's surface; they extend from the main plant and can produce new plants at their nodes

tuber the swollen, fleshy storage organ of a plant that develops from underground stems; serves as a storage organ and a means of vegetative reproduction

rhizome a horizontal, underground stem that grows parallel to the soil surface; serves both as a storage organ and as a means of vegetative reproduction

bulb a short, fleshy stem surrounded by layers of modified leaves; serves as a storage organ and a means of vegetative reproduction plants that are genetically identical to the parent plant. Examples of modified stems include potato (tuber), ginger (rhizome) and onions (bulb) (Figure 7, Figure 8 and Figure 9).

Figure 8 Ginger is an example of modified underground stems called rhizomes.

Figure 9 Onions are examples of modified stems called bulbs.

Sexual reproduction

sexual reproduction the combination of genetic material from two parent organisms, resulting in offspring that are genetically unique

Sexual reproduction involves the combination of genetic material from two parent organisms, resulting in offspring that are genetically unique. This process requires the fusion of gametes (sperm and egg) and is common in many organisms, particularly humans, animals and flowering plants.

Sexual reproduction is beneficial in dynamic or changing environments. The genetic variation that this method of reproduction offers means a population is better able to adapt to changing conditions and resist disease.

It does, however, have its drawbacks. It often requires significant energy and resources for mating, courtship and nurturing offspring, and not all mating attempts result in successful reproduction. Additionally, in some environments, the need for two parents may limit population growth compared to asexual reproduction, where a single organism using asexual reproduction can rapidly produce numerous offspring.

Despite these challenges, the benefits of increased genetic variation often outweigh the costs.

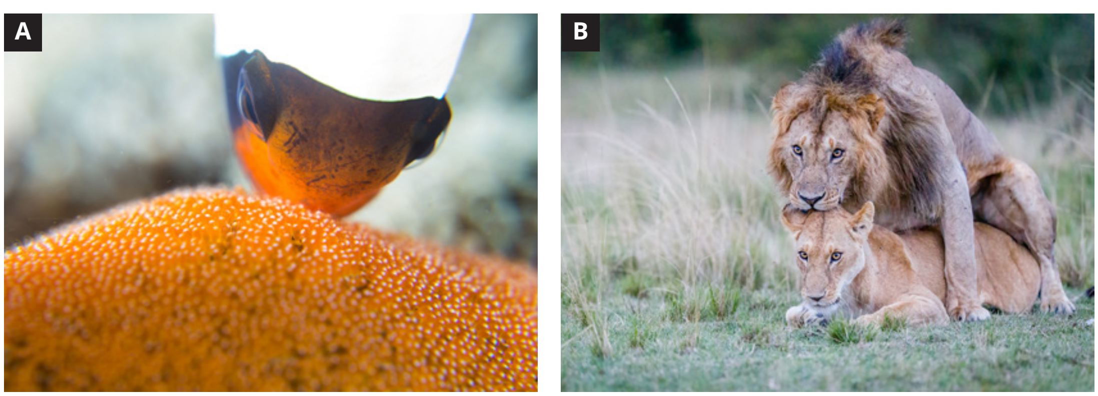


Figure 10 Sexual reproduction involves the union of male and female gametes. (A) External fertilisation: a clown fish guarding her offspring. (B) Internal fertilisation: a male and female lion mating. The female receives male sperm into her reproductive tract.

Humans and animals

In humans and animals, **fertilisation** occurs when a sperm successfully unites with an egg. It can be internal or external, depending on the organism and its environment. **External fertilisation** is common in aquatic environments where eggs and sperm are released in large numbers, relying on chance for fertilisation to occur. Most fish and amphibians use this method. In contrast, **internal fertilisation** is used in terrestrial environments to prevent the eggs and sperm from drying out. Sperm is introduced directly into the female reproductive tract, a process used by all mammals and birds.

Both internal and external fertilisation result in the development of a genetically unique embryo.

Plants

In plants, sexual reproduction begins with **pollination**, where pollen is transferred from the male to the female reproductive structures (**stamen** and **carpel**, respectively). Inside the pollen grains are sperm and tube cells, which help to deliver the sperm to the ovum (egg), where fertilisation occurs. This leads to the development of seeds, ultimately resulting in the next generation of genetically unique organisms.

Sexual reproduction in plants will be covered in more detail in Lesson 8.12 Sexual reproduction in plants (page 355).

Figure 11 Sexual reproduction in flowering plants often requires pollinators, such as bees, to transfer the pollen (containing the sperm) to the female reproductive structure of another plant.

fertilisation the union of male and female gametes

external fertilisation the union of male and female gametes outside the female reproductive tract

internal fertilisation the union of male and female gametes inside the female reproductive tract

pollination the process in which pollen from the male reproductive plant structures is transferred to the female reproductive structure of a plant

stamen the male reproductive part of a flower, consisting of the anther and filament

carpel the female reproductive structure of a flower, consisting of the stigma, style and ovary

Check your learning 8.10

Check your learning 8.10

Retrieve

1 Define the term "reproduction".

2 Identify two methods of asexual reproduction used in plants and two in animals.

Comprehend

3 Describe one situation where an organism might have difficulty reproducing sexually.

4 Explain the challenges faced by populations that reproduce asexually in changing environments.

5 Explain the respective advantages of sexual reproduction and asexual reproduction.

6 Distinguish between pollination and fertilisation in plants.

Analyse

7 Analyse how the mechanisms of internal and external fertilisation influence reproductive success in animals.

Lesson 8.11
The human reproductive system

Learning intentions and success criteria

Key ideas

→ Human females have a uterus, two fallopian tubes and two ovaries.

→ Each month, an ovary produces one ovum (egg) during ovulation.

→ Human males produce sperm in their testes.

→ Sperm will mature in the epididymis and travel along the vas deferens, where the seminal vesicles provide nutrients before the sperm is ejaculated from the penis.

sexually dimorphic describes species in which the male and female organisms look structurally different

sperm the male gamete (sex cell)

testis (plural: testes) the male reproductive organ that produces sperm

testosterone a male hormone involved in the reproductive system

scrotum a sac-like structure that contains the testes

epididymis a coiled tube behind the testes that carries sperm to the vas deferens

vas deferens the tube through which sperm travel from the epididymis to the prostate

seminal vesicles a pair of small pouch-like structures that provide a sugary fluid that assists sperm to travel along the vas deferens

prostate gland a walnut-sized structure surrounding the neck of the male bladder that blocks the flow of urine so sperm can move along the urethra

ovum (plural: ova) the reproductive egg

Introduction

The vast majority of animals reproduce sexually. They are also **sexually dimorphic**, which means that the males look physically different from the females.

The male reproductive system

In fertilisation, a gamete from the father (**sperm**) must meet a gamete from the mother (egg or ovum). Sperm is produced in special organs called the **testes** (singular testis) (Figure 1A). The testes are also responsible for producing a male hormone called **testosterone**. In most mammals, the two testes are kept outside the body in a sack called the **scrotum**. This is to keep the sperm cooler than the 37°C of the rest of the body. If the scrotum gets too hot, sperm production and quality can be negatively affected.

Once sperm are produced in the testes, they move to the **epididymis** to mature. When necessary, the epididymis contracts (squeezes tight) and the sperm is moved into the **vas deferens**. The sperm need energy to be activated. **Seminal vesicles** are small, pouch-like structures that provide a sugary fluid that is needed for the sperm's journey along the vas deferens tube to the **prostate gland**. The prostate gland is a walnut-sized structure that blocks the flow of urine so that the sperm

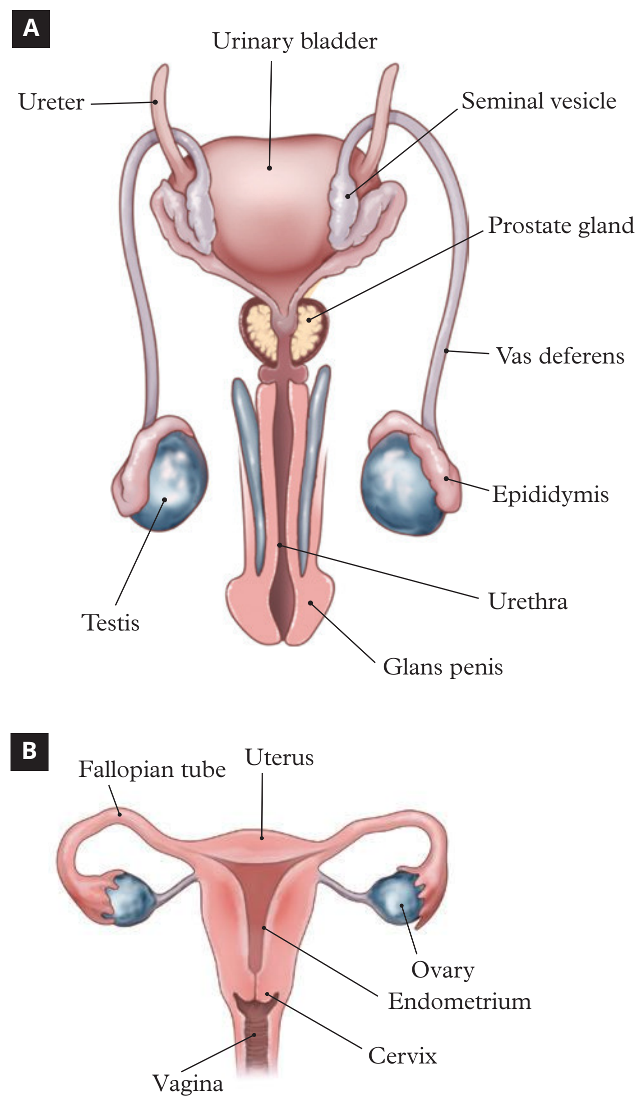


Figure 1 (A) Human male reproductive system. (B) human female reproductive system

can move along the urethra and be ejaculated out through the penis. The function of the penis is to help the sperm reach the eggs. Sperm can survive up to 5 days after ejaculation.

The female reproductive system

In humans, females are born with hundreds of thousands of eggs or **ova** (singular "ovum") partially formed in their **ovaries** (Figure 1B). After puberty, a hormone called **gonadotropin-releasing hormone (GnRH)** from the brain sends a message every month to the ovaries to secrete a second hormone called **oestrogen**, which causes one egg to mature and be released. This process is called **ovulation**.

The egg travels down the **fallopian tubes** to the **uterus**. If sperm are present in the fallopian tubes, the egg may become fertilised. In the three to five days it takes for the egg to travel the fallopian tubes, the lining of the uterus (the **endometrium**) becomes thicker. This is to provide a safe place for the fertilised egg, or zygote, to grow into a **foetus** (Figure 2).

If the egg is fertilised in the first 12–24 hours after ovulation and develops into a zygote, then it attaches to the thick endometrial layer. A special organ called the **placenta** forms between the foetus and the uterus. The placenta allows oxygen and nutrients to pass from the mother to the developing foetus. The length of time between fertilisation and birth is called **gestation** (or pregnancy). In humans, gestation takes 9 months.

Figure 2 A human foetus

If the egg is not fertilised, then the endometrial lining will break down, and 2 weeks after ovulation, it will pass through the **cervix** and **vagina** as a period. This monthly cycle is called **menstruation**. Menstruation usually first occurs in females between 8 and 16 years of age. It can take up to 2 years for menstruation to become a regular cycle. The average length of the cycle is 28 days, but it can vary from 23 to 35 days (Figure 3 and Figure 4).

Sometimes a female produces more than one egg. If the two or more eggs are fertilised, then non-identical twins (with different genetic material) can be produced. Occasionally, a single fertilised egg can be split into two separate cells. This produces two offspring with identical genetic material: identical twins.

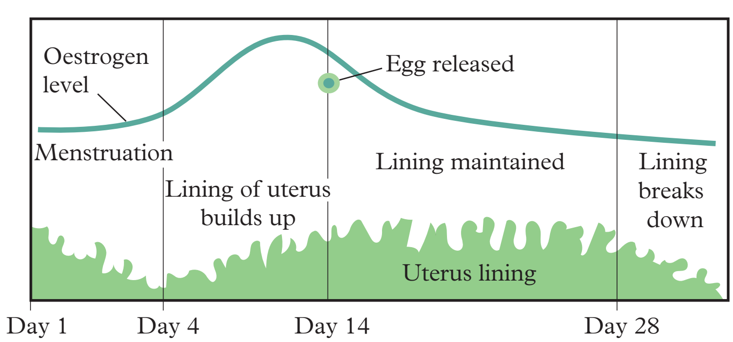


Figure 3 During the average 28-day menstrual cycle, ovulation occurs at day 14.

ovary a female reproductive organ found in both animals and plants; it produces eggs (ova) in animals and ovules in plants

gonadotropin-releasing hormone (GnRH) a hormone produced in the hypothalamus that plays a crucial role in regulating the reproductive system

oestrogen a reproductive hormone in females

ovulation the part of the menstrual cycle when an egg is released from the ovary

fallopian tubes tubes that connect the ovaries to the uterus

uterus an organ in the female reproductive system; where the foetus develops

endometrium the lining of the uterus

foetus an unborn animal or human after the embryo stage; in humans, this is after 8 weeks of development

placenta the organ that connects the developing foetus to its mother

gestation the length of time between fertilisation and birth

cervix the narrow neck connecting the uterus and the vagina

vagina a female reproductive organ; a muscular tube connecting the outside of the female body to the cervix

menstruation also known as a period; the process of the endometrial lining of the uterus breaking down and leaving the vagina

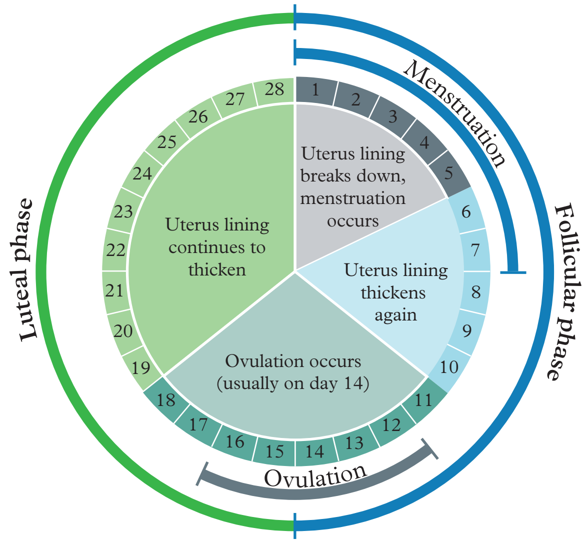


Figure 4 The menstrual cycle begins on the first day of a period.

Giving birth

Mothers go through three stages when giving birth (Figure 5). The first stage involves the muscular walls of the uterus contracting, gently squeezing the baby down against the cervix. This causes the cervix to flatten and start dilating (opening). The cervix must open 10 cm before the baby's head can move through the vagina. This is the second stage of birth. When born, the baby is still attached to the placenta via the umbilical cord, which is inside the mother. When the umbilical cord is cut, it will form the baby's belly button. The third and final stage of birth is the delivery of the placenta. This is important to prevent infections from developing in the uterus.

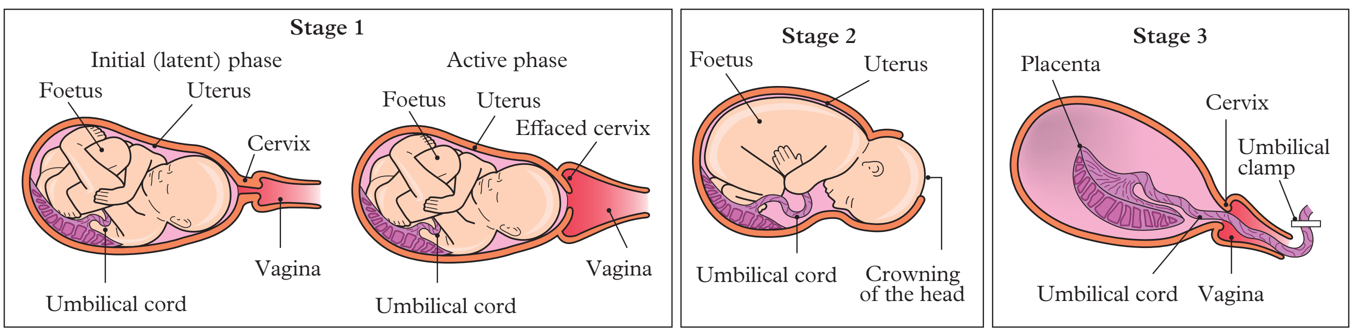


Figure 5 The three stages of childbirth

Check your learning 8.11

Check your learning 8.11

Retrieve

1 Recall one reproductive hormone involved in reproduction in human females.
2 Identify where in the reproductive system the ovum becomes fertilised in humans.
3 Define the term "menstruation".
4 Identify the days (1, 2, 3 …) in the average menstrual cycle when the following occurs:
  a the first day of a period
  b the usual day of ovulation
  c when the ovum can be fertilised.
5 Recall how often menstruation usually occurs.
6 Define "sexual dimorphism" in your own words.
7 Name a hormone involved in male reproduction.

Comprehend

8 Describe the three stages of giving birth.
9 Humans have a relatively long gestation period of 9 months. Explain why this would be an advantage for the baby.

Apply

10 Explain the changes that occur in the uterus during the menstrual cycle and how these changes prepare the body for potential fertilisation.

11 A student said that a baby girl already had all her eggs intact when she was born. Evaluate this claim by:
- describing where all the eggs (ova) are located
- describing when this organ is fully formed
- deciding whether the statement is correct.

12 Some animals, such as rats and rabbits, have a relatively large uterus compared to humans (Figure 6). Suggest a reason why this is advantageous for those species.

13 If an ovum is produced on day 14 of a menstrual cycle, and sperm can survive up to 5 days before fertilisation, determine the days of a cycle that a woman can become pregnant.

14 Imagine a sperm cell is released during human sexual reproduction. Describe the path it must take through the female reproductive system to reach the egg and explain what conditions or events must occur for fertilisation to happen.

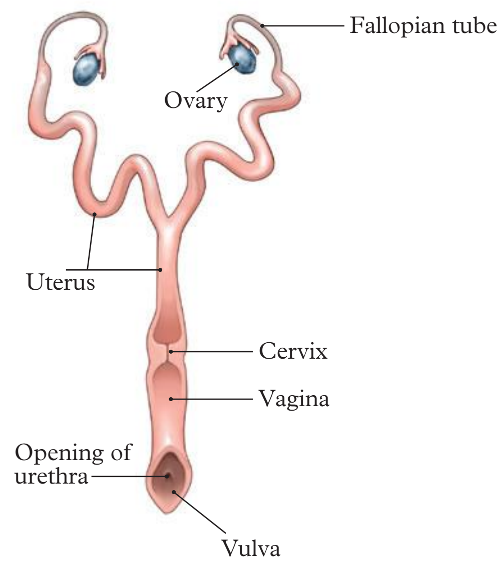


Figure 6 The reproductive system of a female rabbit.

Lesson 8.12
Sexual reproduction in plants

Key ideas

→ Flowers help plants to use sexual reproduction.

→ When the male plant gamete lands on the female plant gamete, pollination has occurred.

→ Plants can self-pollinate or be cross-pollinated by another plant.

→ Insects or birds can help pollinate plants.

Learning intentions and success criteria

Introduction

Flowers come in all shapes and sizes. While some are perfumed, others have no smell, and some have even evolved to mimic the smell of rotting flesh. The primary purpose of a flower, however, is not to look pretty or to smell nice. The flower serves as the sexual reproductive organ of the plant and increases the likelihood of fertilisation.

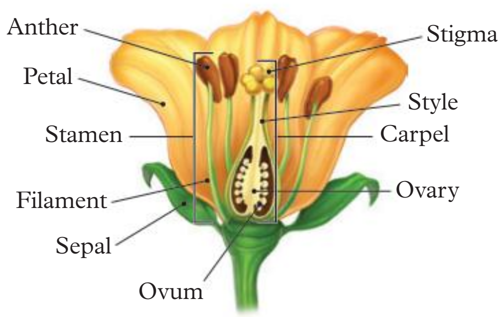


Figure 1 Basic structure of a flower

Flowering plants

Flowers contain both the male and female reproductive structures of the plant (Figure 1). The female carpel consists of three parts: the **stigma** is the sticky top surface that receives pollen, the **style** is a slender stalk that connects the stigma to the ovary, and the ovary is the swollen base of the carpel containing the ovules.

The male stamen consists of two parts: the **anther** produces and contains pollen grains, and the **filament** is a slender stalk that supports the anther, holding it in a position to release pollen effectively (Figure 1).

The pollen grain contains one or more sperm and a tube cell that is required for fertilisation once pollination has occurred.

stigma the top of the carpel; this is where the pollen from the anther begins its journey to the ovary

style a slender, tube-like structure that connects the stigma to the ovary in the carpel

anther the end part of a stamen (male part of a flower); contains pollen

filament the stalk or slender part of a stamen, which holds the anther, where pollen is produced

Pollination

Pollination is the transfer of pollen from the anther (male part) of a flower to the stigma (female part) of the same or another flower. Plants are largely immobile, so they usually require assistance from other organisms (insects, birds or mammals) or the environment (wind or rain) for pollination to occur.

While **self-pollination** (Figure 2) can occur, most plants have evolved so that their stamens and carpels mature at different times. This promotes genetic diversity by encouraging **cross-pollination** between different flowers of the same species (Figure 3).

self-pollination when both gametes come from the same plant

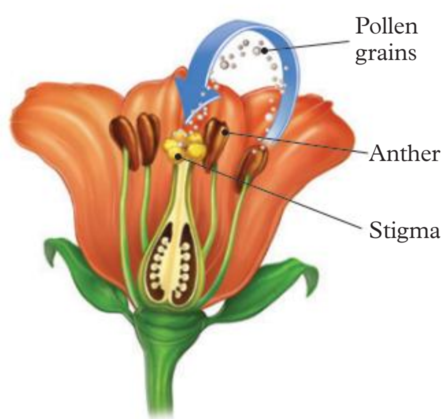


Figure 2 Self-pollination occurs when the pollen grain and ova come from the same plant.

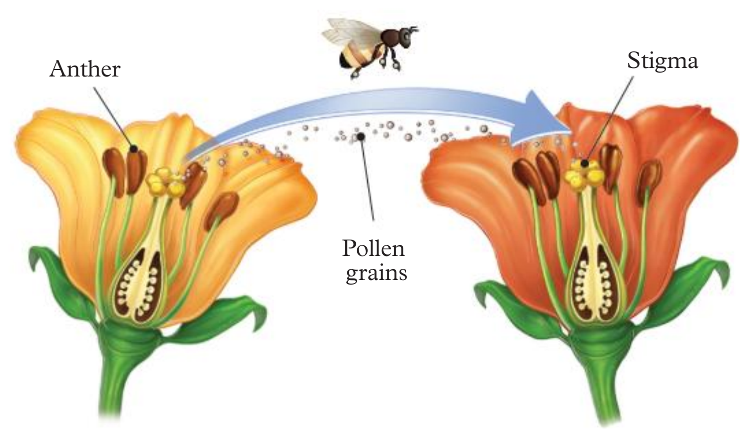


Figure 3 Cross-pollination occurs when the pollen grain and ova come from different plants.

Fertilisation

After pollination, the male gamete (sperm) contained in the pollen grain must travel down the style in order to fertilise the ovum in the ovary. To do this, it needs the assistance of the tube cell, also contained in the pollen grain.

After pollination, the pollen grain germinates on the stigma, forming a pollen tube that grows down the style to reach the ovary. The pollen tube transports the sperm cells from the pollen grain to the ovule, where fertilisation occurs.

cross-pollination the exchange of pollen and ova between different plants of the same species

After fertilisation, the ovary swells to become a fruit, providing nutrition and protection for the zygotes as they grow into embryos inside the seeds (Figure 4).

Reproduction in plants

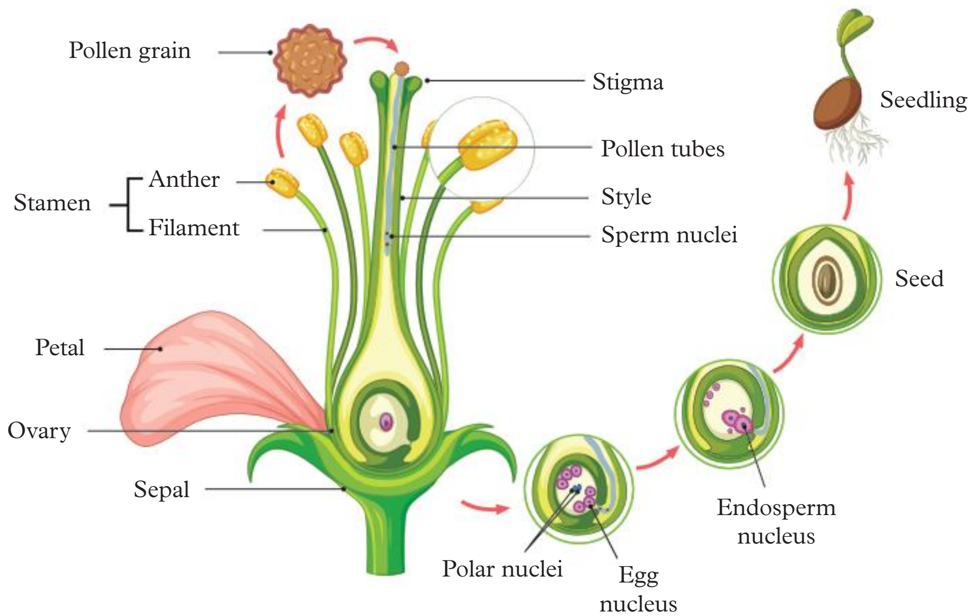


Figure 4 Pollination occurs when a pollen grain from the anther attaches to the stigma. The pollen tube makes way for the sperm to travel to the ovary, where fertilisation of the ovum occurs.

Not all flowers are the same

If a flower smells, it is usually to attract a pollinator – but not all smells are sweet. The flowers of Borneo's *Rafflesia* plant smell like rotting flesh to attract flies for pollination (Figure 5)!

The colour of a flower is also important for attracting pollinators. Birds tend to pollinate brightly coloured flowers, whereas insects may be more attracted to a wide range of colours. Mammals that feed at night will be attracted to strong flower scents and not rely on colour at all.

Some flowers have modified structures to suit their pollinators. Birds may damage flowers with their sharp beaks when they drink nectar, so flowers need to be strong. Insects can be small and need to be forced to brush against pollen and then brush against the stigma, so the flower may be full of obstacles or simply a tight fit.

Figure 5 When in bloom, the *Rafflesia* smells like rotten meat to attract pollinating flies.

Not all plants are the same

When we think of plants, we usually think of flowering plants. There are, however, other groups of plants that never produce flowers and therefore rely on other mechanisms to sexually reproduce.

gymnosperms seed-producing plants that do not form flowers or fruits, and their seeds are exposed on the surface of cones

Figure 6 Pine tree with a male cone at the top and a female cone at the bottom

Gymnosperms and cones

Gymnosperms are seed-producing plants that do not form flowers or fruits. For example, in conifers, which include pine trees and spruces, pollination involves the transfer of pollen from the male cones to the female cones (Figure 6). Male cones produce pollen grains which are carried by the wind to the ovules in the female cones. If fertilisation results, a seed will develop that is eventually released from the female cone to grow into a new conifer tree.

spore a tiny reproductive structure that, unlike a gamete, does not need to fuse with another cell to form a new organism

Figure 7 Fern sori (the brown patches) produce spores for reproduction.

Ferns and sexual spores

If you have ever closely examined a fern, you will have noticed that its leaves are usually quite different from the leaves of flowering plants (Figure 7). You will often see brown patches on the underside of fern fronds. These brown patches, called sori, contain specialised cells that make and release **spores** onto the ground. The spores are tiny reproductive structures that have half the genetic material of seeds. They grow into tiny, heart-shaped plants called prothalli that are made up of male and female reproductive organs. Male and female gametes are produced and released when it rains – hopefully to find a match for fertilisation. The little plant then dies, but the fertilised eggs grow into new ferns.

Check your learning 8.12

Check your learning 8.12

Retrieve

1 Identify the structure that holds a plant's sexual reproductive systems.

Comprehend

2 Explain why some flowers are large and coloured, and others are tiny and plain.

Analyse

3 Contrast the differences between self-pollination and cross-pollination.
4 Compare fertilisation and pollination.
5 Compare a spore with a seed.

Apply

6 Plants that are successful weeds often use both sexual and asexual reproduction. Mint is common in herb gardens and reproduces with little flowers, as well as using vegetative reproduction. Discuss why it would be difficult to get rid of mint once it has spread through a garden bed.
7 Create a circular flow diagram using the following terms: flower, pollen, seed, fruit, pollination, fertilisation, ovum, pollen, ovary, stigma and anther.

Lesson 8.13
Mendelian inheritance in plants and animals

Key ideas

→ Genes can have different versions (alleles) at the same location on 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.

Learning intentions and success criteria

Mendelian (monogenic) inheritance

Gregor Mendel, often referred to as the "father of genetics", was the first person to make accurate conclusions about how genetic information is passed from parents to offspring. He loved experimenting with peas in his garden by crossing one variety with another, and between 1856 and 1863 he performed thousands of crosses before publishing his work in 1866.

Mendel observed the inheritance of seven different traits in pea plants, including seed colour, flower colour and pod shape (Figure 1). He accurately concluded that "factors" (now called genes) exist in pairs, one inherited from each parent.

While he didn't use the terms himself, we now know his work focused on traits determined by single genes with **dominant alleles** and **recessive alleles**, a pattern known as **Mendelian inheritance** or **monogenic inheritance**.

He is credited with the two key principles of genetics: segregation and independent assortment.

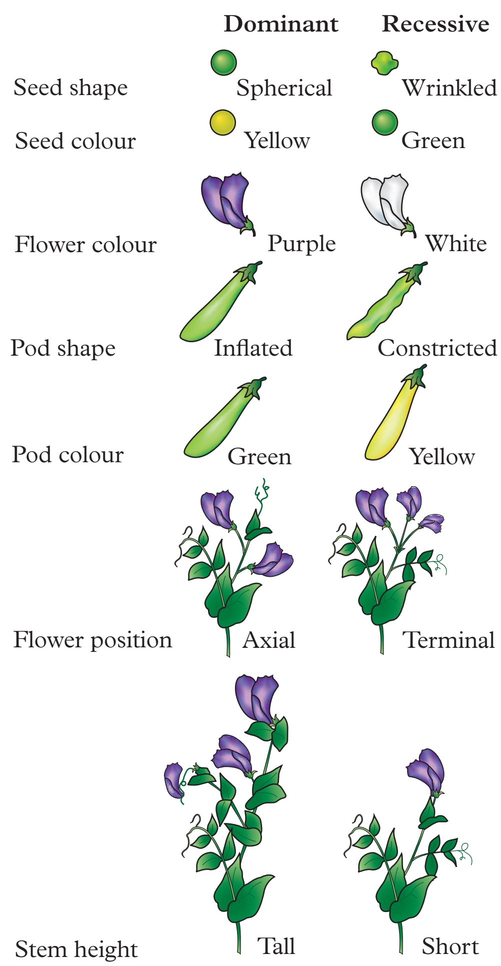


Figure 1 The seven traits, or characteristics, of pea plants studied by Mendel

dominant allele a gene variant that expresses its trait in an organism's phenotype even if only one copy is present

recessive allele a gene variant that only expresses its trait when two copies are present

Mendelian inheritance the inheritance patterns of traits controlled by single genes with two alleles, one dominant and one recessive

monogenic inheritance the inheritance pattern in which a single gene determines traits

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

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

Mendel's work through a modern lens

true-breeding an organism known to be homozygous dominant or homozygous recessive

When Mendel crossed **true-breeding** pea plants (P generation) (Figure 2) with purple and white flowers, all offspring in the F1 generation had purple flowers. When he subsequently crossed two plants from the F1 generation, the F2 offspring from this cross always displayed a 3:1 ratio of purple to white flowers. No matter the trait he crossed, the same 3:1 pattern was always observed (Figure 2).

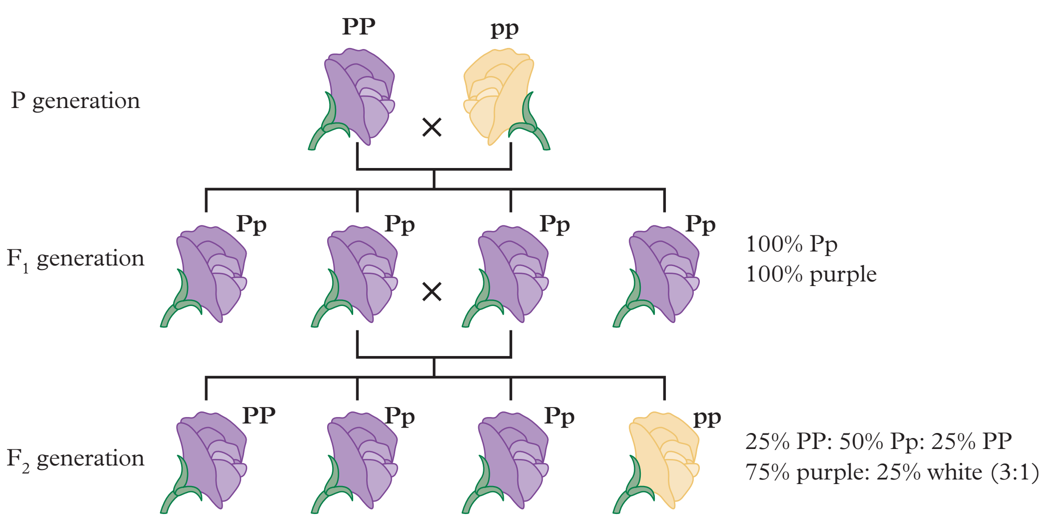


Figure 2 Mendelian inheritance, demonstrating that the purple allele is dominant over the white allele for flower colour

homozygous having two identical alleles for a particular trait

heterozygous having two different alleles for a particular trait; a carrier for a recessive trait

genotype the combination of alleles for a particular trait

phenotype observable physical and physiological traits of an organism, resulting from the interaction between its genotype and environmental influences

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

Dominant and recessive alleles

We now know Mendel's "factors" as genes. Different versions of a gene are known as alleles, located at the same position (or locus) on homologous chromosomes (Figure 3). If an organism carries two identical alleles for a trait, it is said to be **homozygous**. If there are two different alleles for the same trait, it is referred to as **heterozygous**.

Genotype refers to the combination of alleles an organism has for a particular trait, while **phenotype** refers to the observable characteristics or traits of that organism.

Dominant traits require only one copy of the allele to be expressed in the organism's phenotype; they are represented with a capital letter (e.g. T). Both homozygous dominant (TT) and heterozygous (Tt) individuals will exhibit the same appearance for that trait. In contrast, **recessive traits** are represented by lower-case letters (e.g. t) and can only be expressed when two identical copies of the allele are present (homozygous recessive: tt).

Plants

In Mendel's flower experiments (Figure 2), he determined that the purple allele (factor) was dominant (P) and the white allele (factor) was recessive (p). His cross between a homozygous purple (PP) and a homozygous white (pp) plant resulted in all F1 offspring having purple flowers, indicating that they were heterozygous (Pp) and confirming the purple allele to be dominant.

When the F1 generation (Pp) was crossed, the resulting offspring exhibited the 3:1 ratio of purple to white flowers, corresponding to the genotypes 1PP, 2Pp and 1pp. Both the homozygous dominant (PP) and heterozygous (Pp) individuals displayed purple flowers, while only the recessive (pp) individuals had white flowers (Figure 3).

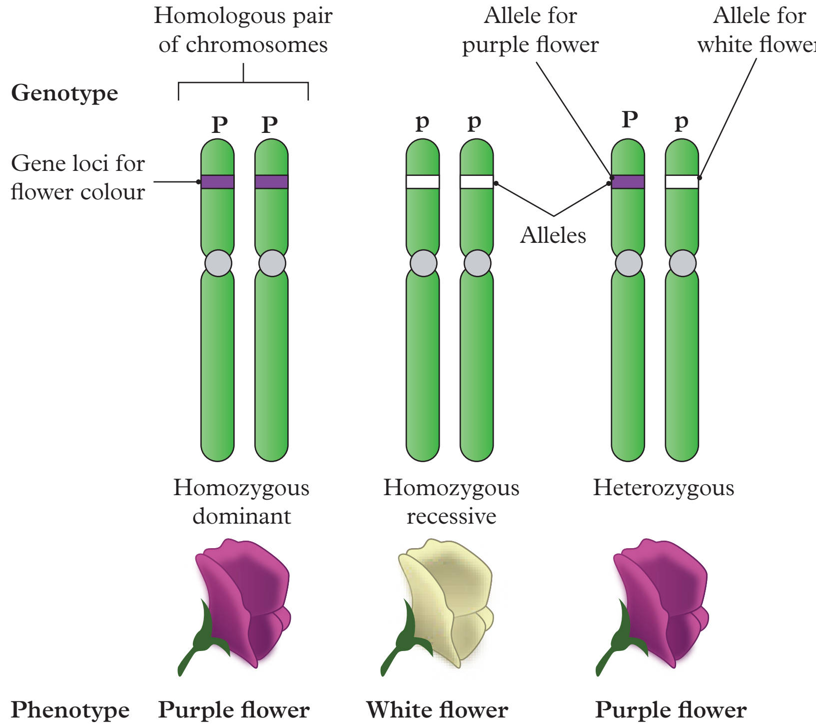


Figure 3 Homologous chromosomes showing possible combinations of dominant and recessive alleles and the effect this has on pea plant flower colour

Animals

In many animals, fur colour is determined by Mendelian inheritance. For example, in guinea pigs, the allele for black fur (B) is dominant over the allele for white fur (b). Similar to Mendel's pea plant experiments, when a homozygous black guinea pig (BB) and homozygous white guinea pig (bb) are bred, all offspring in the F1 generation will have black fur.

If two F1 guinea pigs are then bred, the phenotypic ratio of the second F2 generation will be 3:1, with 75% having black fur and 25% with white fur (Figure 4).

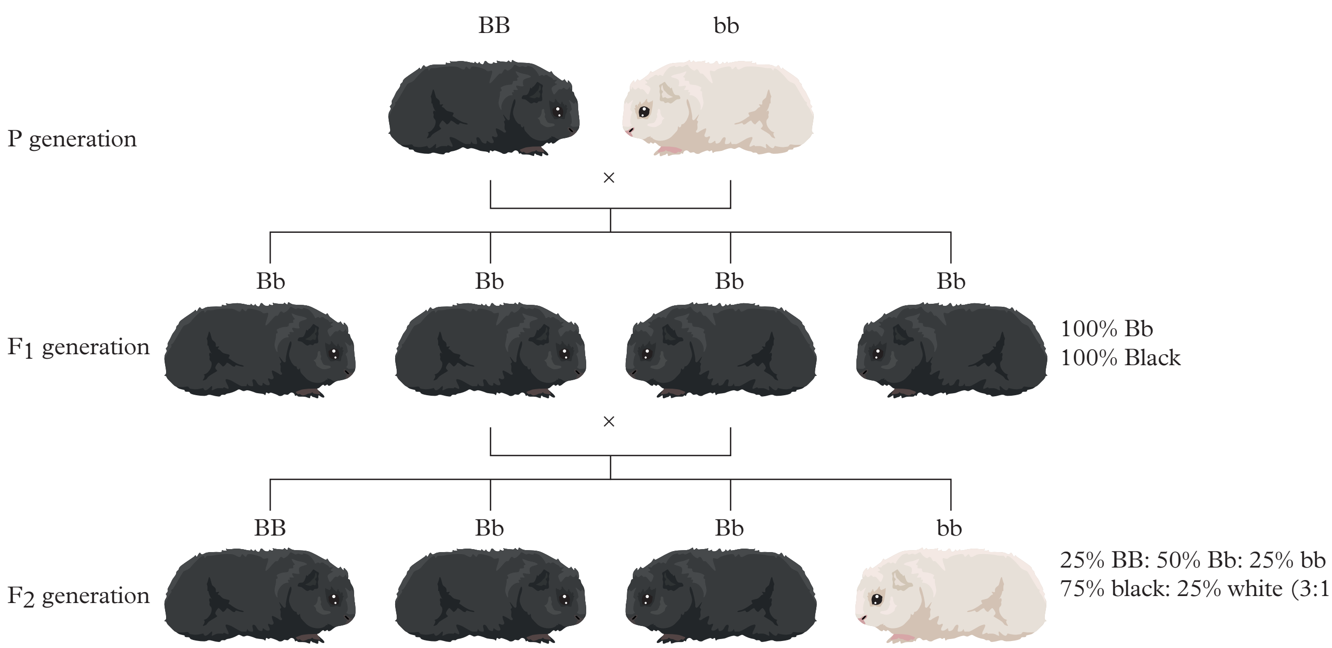


Figure 4 Mendelian inheritance demonstrating that the black fur allele is dominant over the white fur allele for fur colour in guinea pigs

Humans

monogenic trait a trait determined by one gene with two alleles

In humans, an example often treated as a **monogenic trait** is the gene that determines whether earlobes are free-hanging or attached. If your mother has free-hanging earlobes, then you may inherit the allele for free-hanging earlobes from her. If your father has attached earlobes, then you may inherit the allele for attached earlobes from him.

It is known that free-hanging earlobes are dominant over attached earlobes. Therefore, a person with attached earlobes must have two alleles for attached earlobes (ee). In contrast, a person with free-hanging earlobes could be homozygous dominant (EE) or heterozygous (Ee) for the trait. A free-hanging earlobe individual who is heterozygous for the trait is sometimes called a **carrier** for the attached earlobe trait. They have one allele for attached earlobes, but the trait cannot be seen in their appearance (Figure 5).

carrier a person who has the allele for a recessive trait that does not show in their phenotype

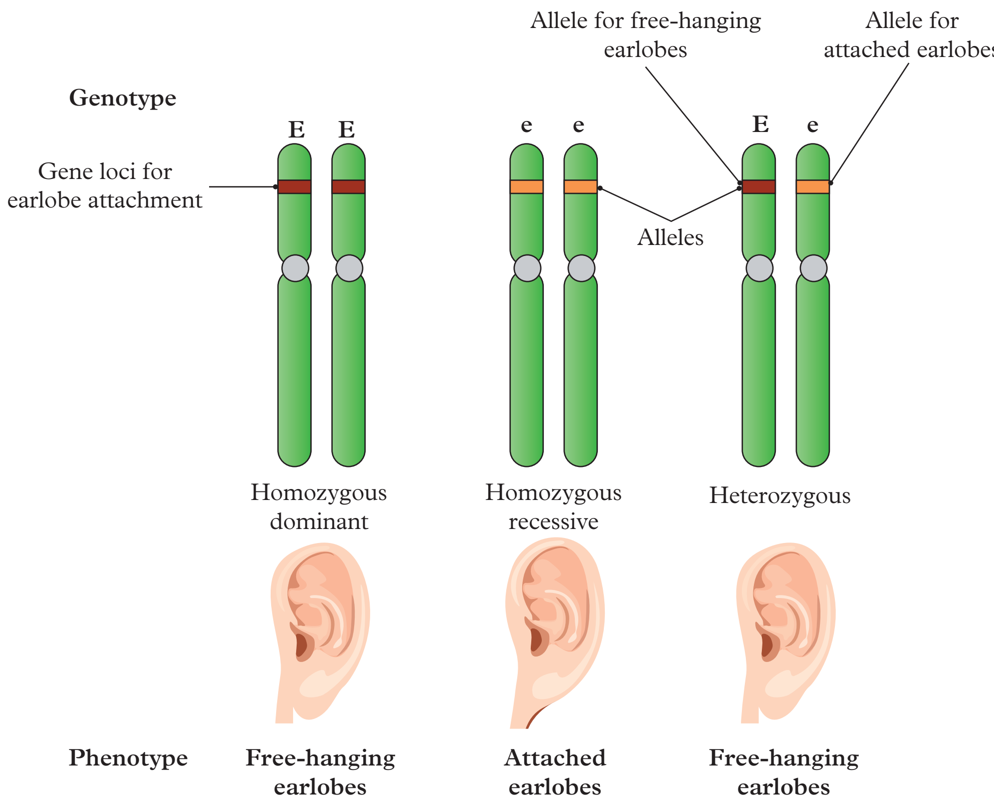


Figure 5 Genotype and phenotype combinations for free-hanging and attached earlobes

Check your learning 8.13

Check your learning 8.13

Retrieve

1 Define the term "carrier".
2 Distinguish between the following terms:
   a gene and allele
   b dominant and recessive
   c homozygous and heterozygous.

Comprehend

3 Having dimples (D) is dominant to having no dimples (d). Identify the genotypes for individuals who:
   a are homozygous for dimples
   b are heterozygous for dimples
   c have no dimples.

4 Compare the genotype and phenotype of a homozygous dominant and heterozygous individual for a specific trait.

Apply

5 In pea plants, yellow seeds are dominant over green seeds. If two plants with yellow seeds are crossed, what are the chances of having green offspring? Justify your response.

6 Mendel established that purple flowers are dominant over white flowers. There will be no difference in flower colour between a homozygous dominant and heterozygous plant. Explain how a cross with a white-flowered plant could be used to determine whether a purple-flowered plant was homozygous dominant or heterozygous.

Skills builder: Processing and analysing data and information

7 A right-handed man and a left-handed woman have children who are all left-handed. Evaluate if this means that left-handedness is dominant. Provide evidence to support your view. (THINK: What tools can I use to investigate this? How can I present this information in a diagram?)

Lesson 8.14

Alleles on sex chromosomes produce sex-linked traits

Key ideas

→ 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

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**) (Figure 2). 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. 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.

autosome a chromosome that does not determine the sex of an organism

sex chromosome a chromosome that determines the sex of an organism

Males tend to show deficiencies in these genes more frequently than females because they only have one X chromosome. In contrast, females have two X chromosomes, increasing the likelihood of having at least one functional allele. As a result, males present with two possible phenotypes: they either have the condition or they do not. In females, however, there is an additional phenotype: heterozygous carriers, who carry one normal dominant allele and one recessive allele (Figure 3).

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 (see also Table 1):

- **autosomal dominant**
- **autosomal recessive**
- **X-linked dominant**
- **X-linked recessive**.

autosomal dominant an inheritance pattern in which only one copy of a gene (from either parent) carried on a non-sex chromosome is sufficient to cause the presence of a trait or disorder

autosomal recessive an inheritance pattern in which two copies of a gene (one from each parent) carried on a non-sex chromosome are required for an individual to express the trait or disorder

X-linked dominant an inheritance pattern in which a gene associated with a trait or disorder is located on the X chromosome, and only one copy of the gene is needed for the trait to be expressed; both males and females can be affected

X-linked recessive an inheritance pattern in which the gene causing the trait or disorder is located on the X chromosome and two copies of the gene are required for females (XX) to express the trait; in contrast, males (XY) will express the trait if they inherit a single copy

Figure 1 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.

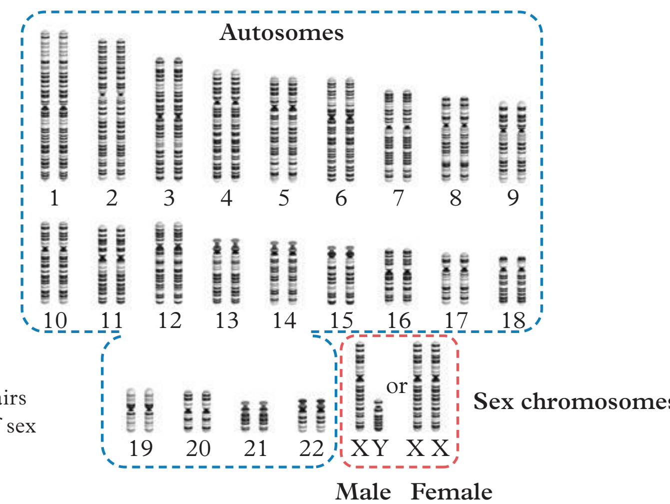


Figure 2 Human karyotype showing 22 pairs of autosomal chromosomes and one pair of sex chromosomes

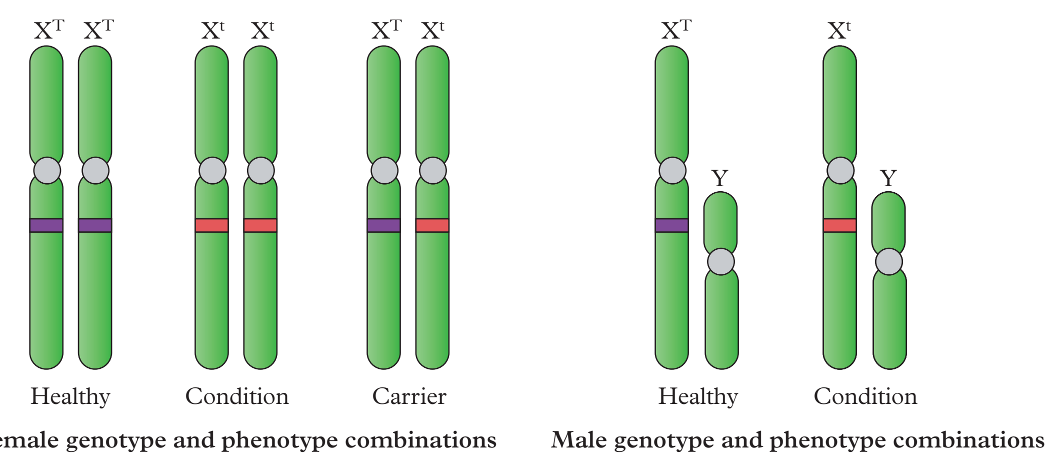


Figure 3 In humans, sex-linked traits are more common in males as they only have one X chromosome. They cannot be carriers.

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). • A carrier mother has a 50% chance of passing the trait on to each son. • Daughters of an affected father will all be carriers.

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.

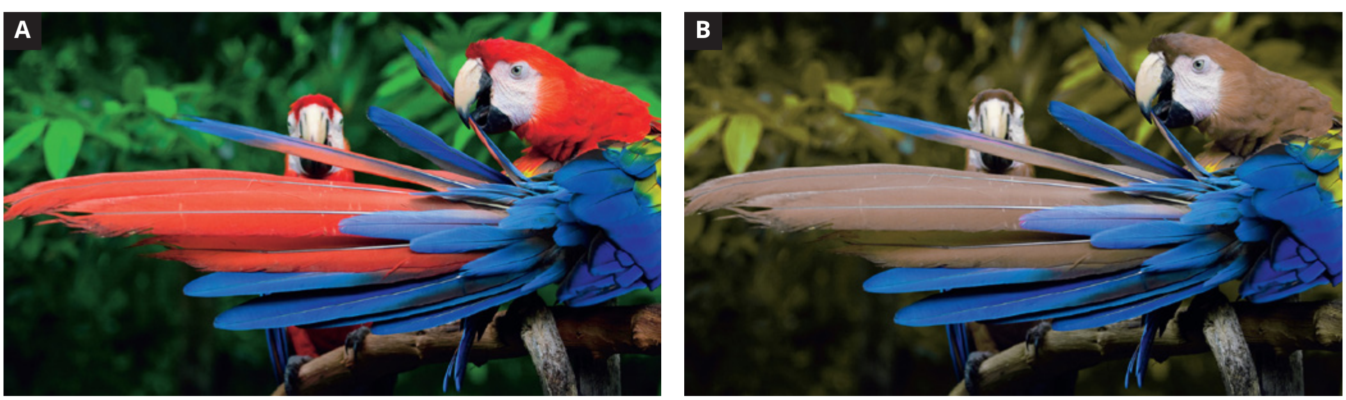


Figure 4 A person with red-green colour blindness will have a very different view of the world. (A) A person with normal vision can see all the colours of these parrots. (B) A person with red-green colour blindness cannot see the colour on the red and green feathers.

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.

mutation a permanent change in a DNA sequence

In the past, there was no treatment for haemophilia. Queen Victoria, Queen of the United Kingdom from 1837 to 1901, appears to have had a spontaneous **mutation** in the gene on the X chromosome responsible for making a blood-clotting factor. As a result, she became a carrier of the gene for haemophilia. 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).

Key: H = normal allele and h = allele for haemophilia

Queen Victoria X^HX^h × X^HY Albert

↓

Carrier daughter X^HX^h × X^HY Her husband

↓

Alexandra X^HX^h × X^HY Nicholas II
(carrier granddaughter) (last Tsar of Russia)

↓

Alexei X^hY
(haemophiliac son)

Figure 6 Genotypes in the family tree of Queen Victoria leading to Alexei

Check your learning 8.14

Check your learning 8.14

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.

2 If a man has a mutated gene on his Y chromosome, identify which grandparent he inherited it from.

Analyse

3 A man and a woman, both with normal vision, had three children: two boys and a girl. One of the boys had normal vision, and the other was colour blind. The girl had normal vision. Calculate the genotypes for this family.

4 The girl from the family in question 3 married a man with normal vision and had a son who was colour blind. Calculate the genotypes for this family.

5 The colour-blind son from the family in question 3 married a woman with normal vision and had a son with normal vision and a colour-blind daughter. Calculate their genotypes.

6 Calculate the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia.

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

Skills builder: Problem solving

9 Colour blindness is a sex-linked trait. If a colour-blind man marries a woman who is not a carrier, calculate the chances that their daughters will be carriers and their sons will be colour blind? (THINK: How can I express this? Is there a scientific diagram I can use?)

Lesson 8.15
Using Punnett squares to predict genotype and phenotype

Learning intentions and success criteria

Key ideas

→ A monohybrid cross examines the inheritance of a monogenetic trait.

monohybrid cross a genetic cross between two individuals that focuses on the inheritance of a single trait, controlled by one gene with two alleles

Punnett square a graphical tool used in genetics to predict the possible genotypes and phenotypes resulting from a cross between two individuals

Monohybrid crosses

In Lesson 8.13 Mendelian inheritance in plants and animals (page 359), the role of dominant and recessive alleles in Mendelian or monogenic inheritance was explored. A **monohybrid cross** examines the inheritance of a monogenetic trait in which one allele is usually dominant and the other is recessive.

We can predict the outcomes of a monohybrid cross by using a **Punnett square**. In a Punnett square, the parents' genotype alleles 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 offspring could inherit. From the genotypes, the possible phenotypes of the offspring can be predicted.

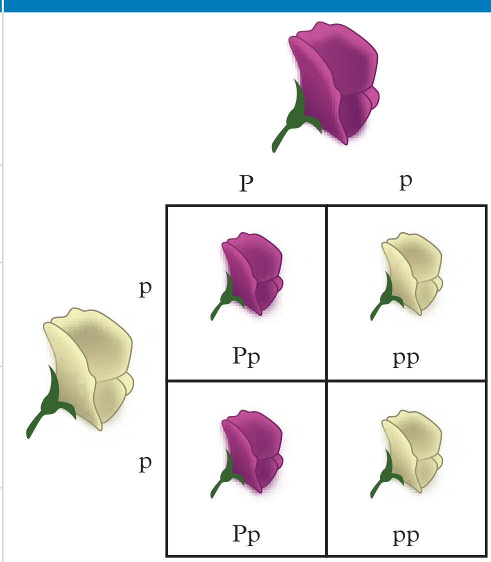
Worked example 8.15A shows how to use a Punnett square to predict the possible genotypes and phenotypes of offspring.

Worked example 8.15A Using Punnett squares

The allele for purple flowers in pea plants is dominant over the white allele. Calculate the probability of the offspring having white flowers if a heterozygous plant is crossed with a homozygous recessive plant for flower colour.

Solution

Steps	What to do	Working out
a.	The symbols for the flower colours need to be selected. Purple flowers is a dominant trait, while white flowers is a recessive trait.	P = Purple flowers p = white flowers
b.	Identify the genotype of the parents from the stem.	Parent 1 (heterozygous) = Pp Parent 2 (homozygous recessive) = pp
c.	A Punnett square can then be constructed.	See figure
d.	Use the Punnett square to determine the offspring's possible genotypes and phenotypes.	Pp : pp purple : white 2:2
e.	Answer the question by stating the probability of the offspring having white flowers.	The offspring have a 50 per cent chance of having white flowers.



Test crosses to determine parent genotypes

Two individuals with the same dominant phenotype may have different genotypes. Remember, in the example of guinea pigs, black fur colour is dominant over white fur colour. Therefore, a homozygous dominant individual (BB) and a heterozygous individual (Bb) will both appear black. So how can their genotypes be determined?

A **test cross** with a white-fur guinea pig, which must be homozygous recessive (bb), can be performed.

test cross a genetic cross used to determine the genotype of an individual with a dominant phenotype; requires a cross with an individual that is homozygous recessive for the trait

A homozygous dominant black fur guinea pig (BB) crossed with a white fur guinea pig (bb) will always produce heterozygous offspring with black fur (Bb). Therefore, if all offspring from the cross have black fur, the parent is most likely homozygous dominant (Figure 1).

In contrast, a heterozygous black fur guinea pig (Bb) crossed with a white fur guinea pig (bb) will result in 50 per cent of the offspring having black fur (Bb) and 50 per cent having white fur. Therefore, if offspring show a 1:1 ratio of black to white fur, the parent with black fur is heterozygous (Figure 1).

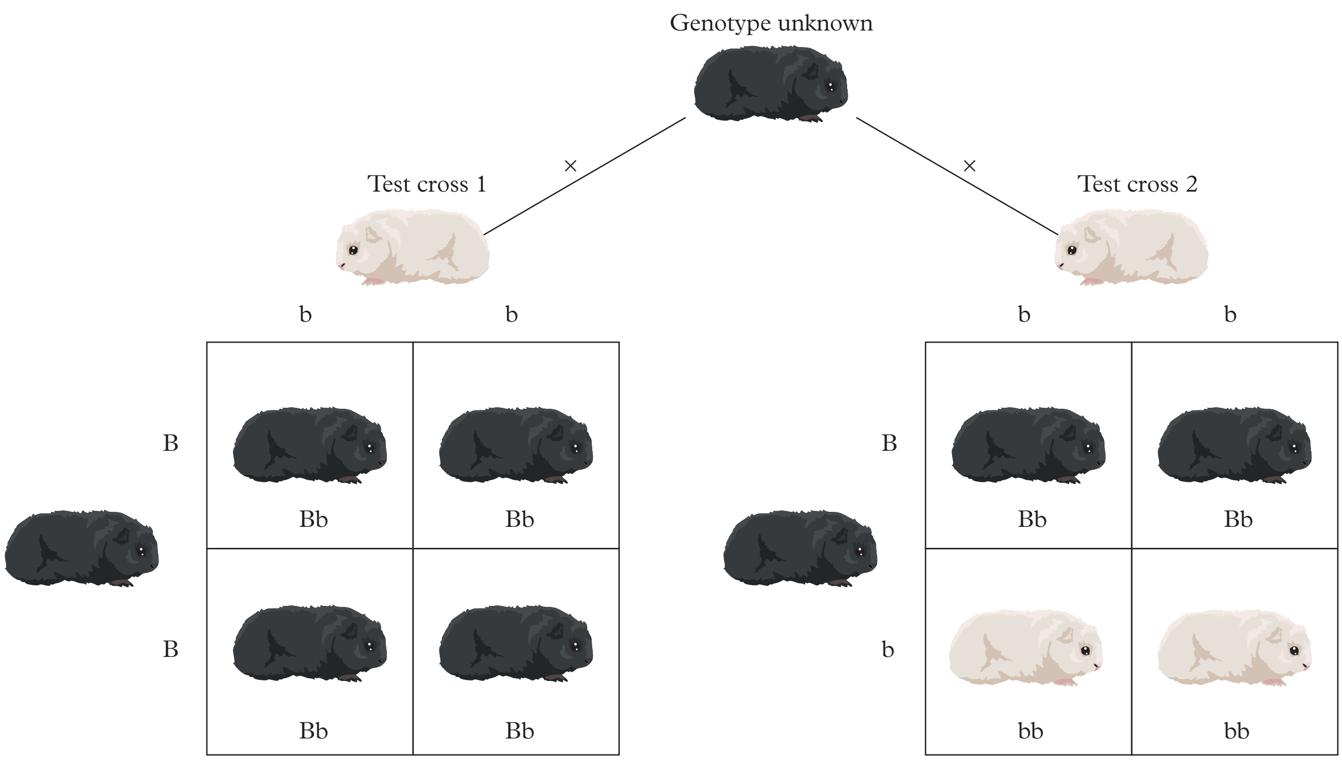


Figure 1 A test cross can be performed between a phenotypic dominant individual and a homozygous recessive individual to determine the genotype of the phenotypic dominant individual.

The role of Punnett squares in assessing disease risk

While it can be fun to use Punnett squares to work out the likelihood of offspring having certain eye colours or hair colours, they can also be used for more serious matters, such as determining the chances of children inheriting genetic diseases. For example, phenylketonuria (PKU) is a recessive genetic disorder caused by a mutation on chromosome 12. The disease results in an inability to break down protein correctly, leading to a build-up of certain amino acids that are toxic. If not detected and managed, PKU can lead to significant brain damage and even death.

While being healthy themselves, if a couple knows they are heterozygous carriers of the recessive PKU allele, there is a 25 per cent chance that each child they have will inherit the life-threatening disease. Additionally, there is a 50 per cent chance that each child will be a carrier of the PKU allele. This is an important consideration for family planning and for their children's future reproductive decisions (Figure 2).

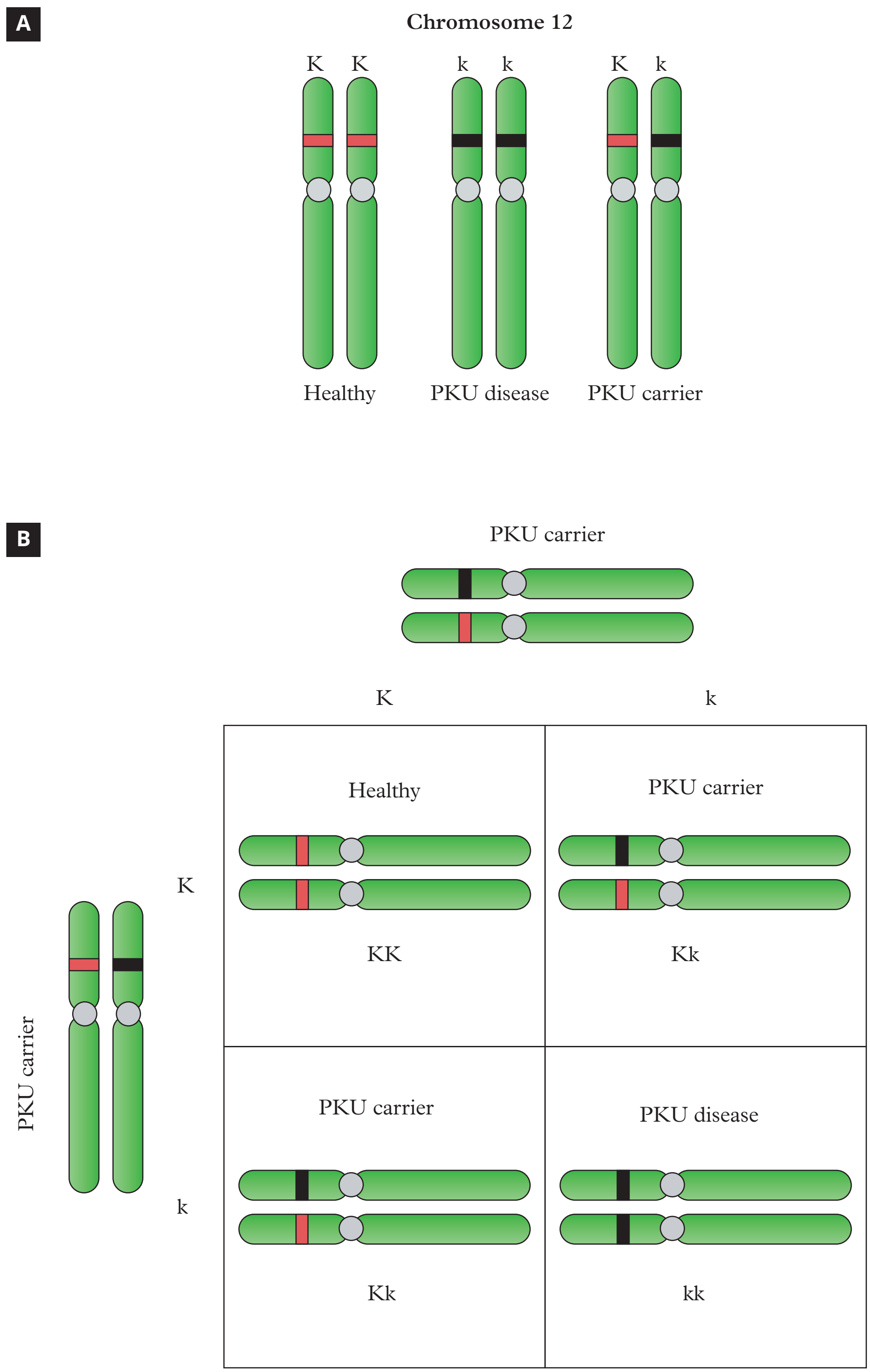
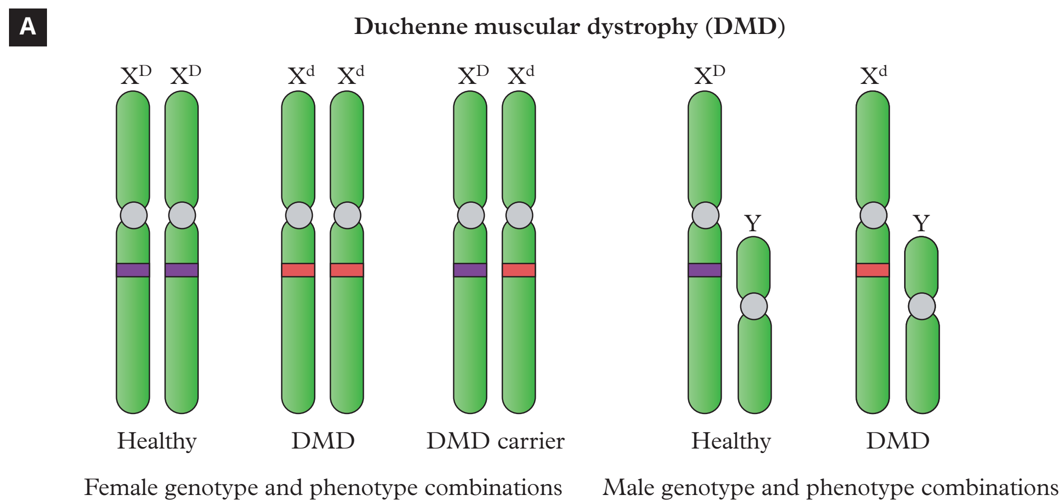


Figure 2 (A) Different genotype and phenotype combinations for phenylketonuria (PKU). (B) Punnett squares can be used to determine the likelihood of children inheriting genetic diseases.

For sex-linked traits, the likelihood of males and females inheriting a condition can vary depending on the genotypes of the parents. For example, Duchenne muscular dystrophy (DMD) is a condition characterised by progressive muscle degeneration and weakness. It is caused by a mutation in the dystrophin gene, which is located on the X chromosome. If a female carrier (heterozygous) has a child with a male who does not have the disease, no female children will have the disease, although 50 per cent are likely to be carriers themselves. In contrast, there is a 50 per cent chance that male offspring will have the disease (Figure 3).



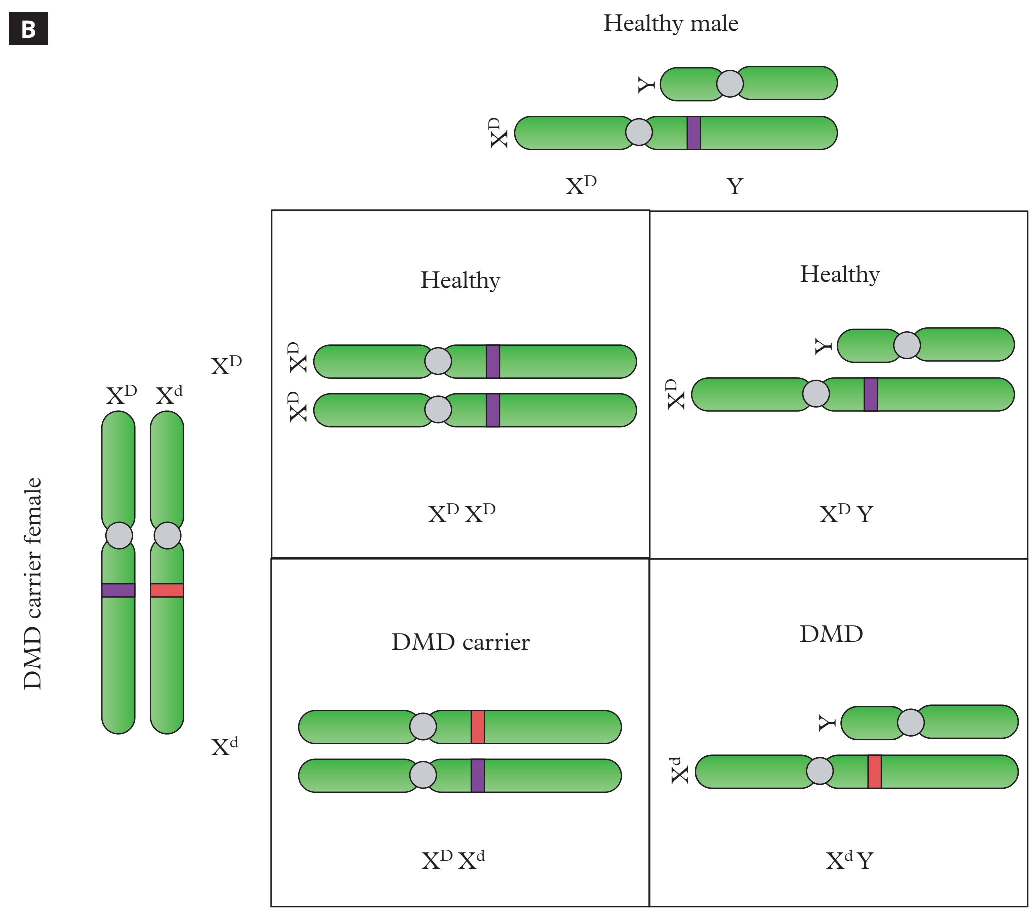


Figure 3 (A) Different genotype and phenotype combinations for Duchenne muscular dystrophy (DMD) in males and females. (B) Punnett squares can be used to determine the likelihood of children inheriting genetic diseases.

Check your learning 8.15

Check your learning 8.15

Retrieve

1 Distinguish between a homozygous and heterozygous genotype.

2 Define monohybrid cross.

Apply

3 Use a Punnett square to determine the genotype and phenotype ratios of the following crosses.

  a In pea plants, the allele for yellow seeds is dominant over the green seed allele. Perform a cross of a heterozygous plant and a homozygous dominant plant for this trait.

  b Cystic fibrosis is a genetic disorder that mainly affects the respiratory system. The disease results in the production of thick, sticky mucus that can clog the airways. It is caused by a mutation in the *CFTR* gene and is inherited in a recessive pattern. Perform a cross of two parents who are carriers of the recessive allele to determine the likelihood that each child will inherit the disease.

  c In fruit flies, eye colour is linked to the X chromosome. The gene responsible for eye colour has different alleles, with red eyes being the dominant phenotype and white eyes being the recessive phenotype. Perform a cross of a female fruit fly with red eyes (heterozygous for the eye colour gene) and a male fruit fly with white eyes.

Lesson 8.16
Investigation: Zazzle genetics

Caution

Do not eat or drink in the laboratory.

Purpose

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

Procedure

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.

Table 1 Alleles inherited from the parent

Gene	Trait and letter representing it	Allele donated by the 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	

Results

Copy and complete Table 1.

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 Assuming each of the traits is carried on a different chromosome, identify the number of chromosomes present in each of the:
   a mother's somatic (non-gamete) cells
   b father's gametes
   c baby Zazzle 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 8.17

Inheritance of traits is shown on pedigrees

Learning intentions and success criteria

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 Strait Islander Peoples have demonstrated an understanding of traits and inheritance without the use of technologies now available to geneticists. Despite living thousands of kilometres away from Gregor Mendel, Aboriginal and Torres Strait Islander Peoples had observed how some recessive traits and illnesses could be inherited in the children of related parents.

The kinship systems of Aboriginal and Torres Strait Islander Peoples is a complex social structure that has key features, which include:

- the regulation of marriage – who can and cannot marry
- defining relationships to determine how people are related to one another
- guiding social behaviour and supporting community cohesion.

Pedigree construction and analysis

pedigree a chart showing the phenotypes of an individual and their ancestors, usually over several generations; also known as a family tree diagram

Today, inheritance of characteristics is 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.

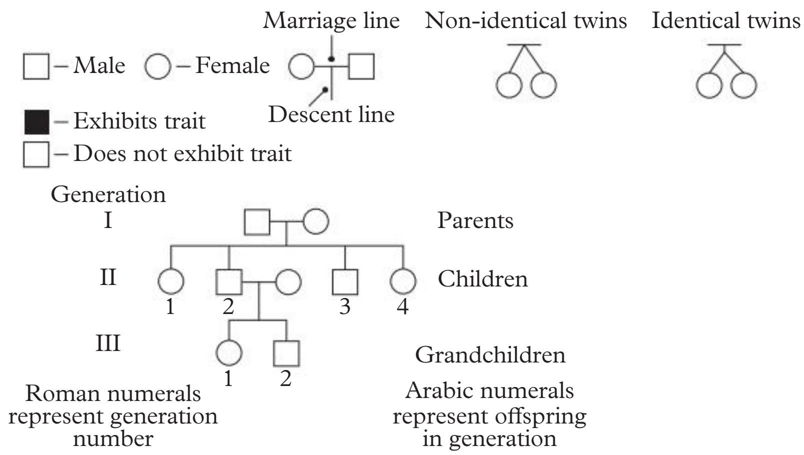


Figure 1 Some symbols used in constructing pedigrees or family tree diagrams

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 have it, then the characteristic is dominant (i.e. both parents are heterozygous).
- If both parents have a characteristic and none of their children have it, then the characteristic is dominant (because if both parents have a characteristic and it is recessive, then all of their children will have that characteristic). Remember, a dominant characteristic is not always the most common 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.

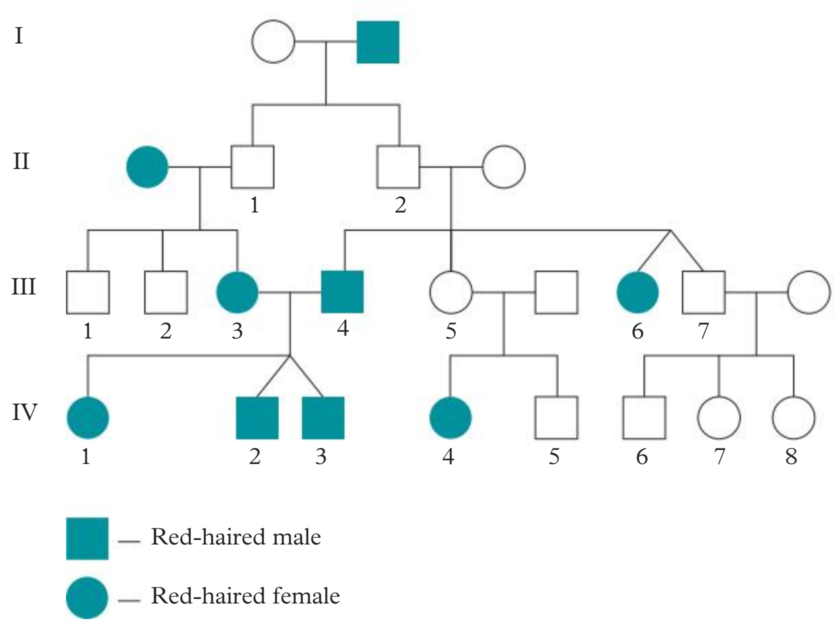


Figure 2 A pedigree for red hair

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.

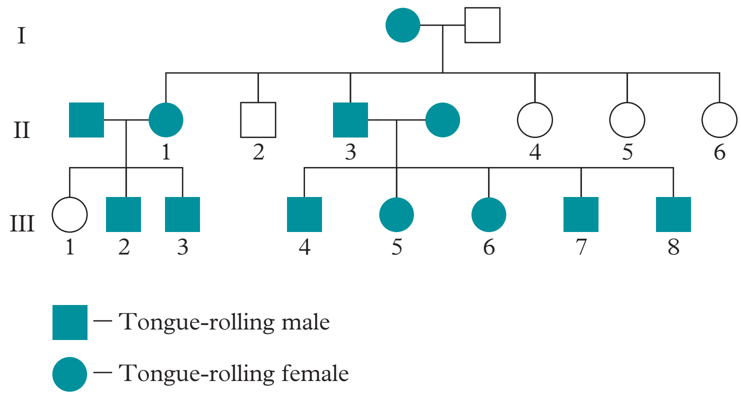


Figure 3 A pedigree for tongue rolling

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a disease. There are 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?
   If YES, go to 2. If NO, go to 3.
2. Do all daughters of affected males have the trait?
   YES = sex-linked dominant. NO, go to 4.
3. Do all affected children have an affected parent?
   YES = autosomal dominant. NO, go to 5.
4. Has a carrier mother passed it on to half/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.

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.

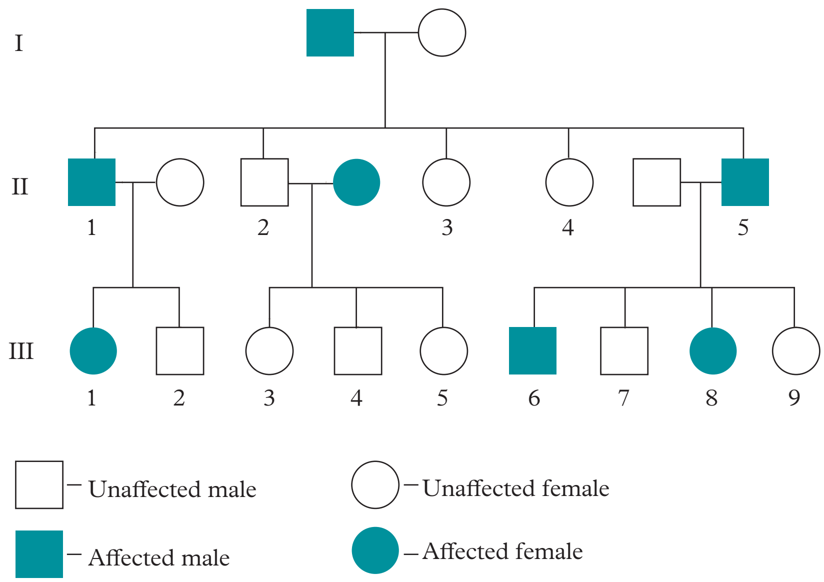


Figure 5 The pedigree chart of a family affected by achondroplasia, showing that some of the children are unaffected.

Check your learning 8.17

Check your learning 8.17

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.

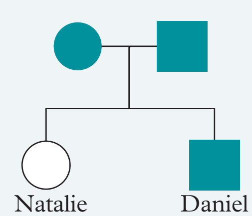


Figure 6 A pedigree showing inheritance of ear lobes

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.

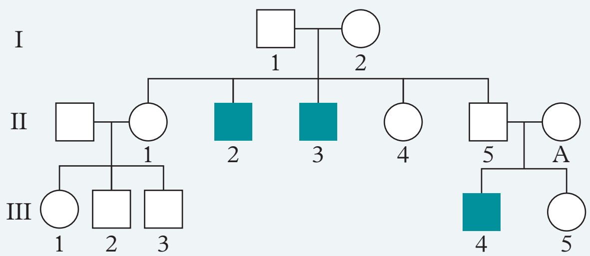


Figure 7 A pedigree showing the inheritance of an X-linked disease

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.

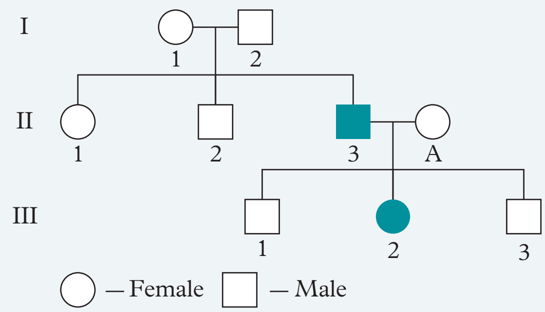


Figure 8 A pedigree indicating the inheritance of a trait

5 The pedigrees in Figure 9 show 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.

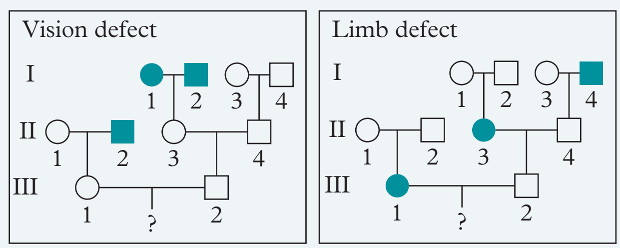


Figure 9 Pedigrees for the inheritance of vision defects and limb defects

Lesson 8.18

Investigation: Colour-blindness inheritance

Introduction

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 because her father is colour blind.

Purpose

To examine the inheritance of X-linked traits

Materials

- Two counters
- Permanent marker

Procedure

1 On one counter, write X^b on one side and Y on the other.
2 On the second counter, write X^b on one side and X^B 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.

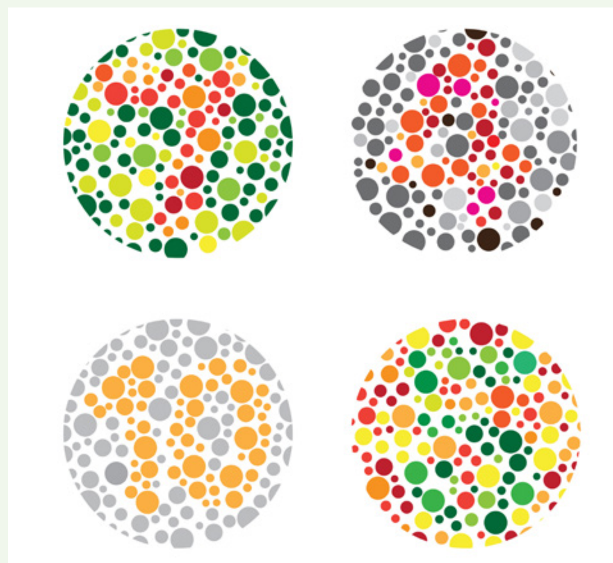


Figure 1 The Ishihara colour test uses coloured dots to identify whether a person is colour blind. The dots in each of these pictures are arranged to represent a number.

Lesson 8.19

Polygenic inheritance and environmental effects on phenotype

Learning intentions and success criteria

Key ideas

→ Polygenic traits are controlled by multiple genes, each contributing to the overall phenotype.

→ The expression of polygenic traits can be significantly influenced by environmental factors.

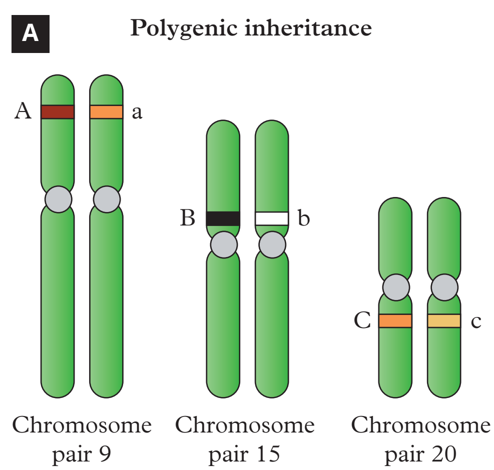
→ The development of traits involves both genetic inheritance (nature) and environmental influences (nurture).

Polygenic inheritance

At an introductory level to genetics, many traits such as eye colour, skin colour and flower colour are often simplified and presented as monogenic traits, determined by one gene with two alleles.

In reality, most traits, including these examples, are **polygenic**. This means that multiple genes, often on different chromosomes, collectively contribute to the observed phenotype (Figure 1). To add further complexity, environmental factors can also influence the expression of these traits.

polygenic inheritance patterns where multiple genes contribute to a single trait, resulting in a continuous range of phenotypes



B	*ABC*	*ABc*	*AbC*	*aBC*	*Abc*	*aBc*	*abC*	*abc*
ABC	6	5	5	5	4	4	4	3
ABc	5	4	4	4	3	3	3	2
AbC	5	4	4	4	3	3	3	2
aBC	5	4	4	4	3	3	3	2
Abc	4	3	3	3	2	2	2	1
aBc	4	3	3	3	2	2	2	1
abC	4	3	3	3	2	2	2	1
abc	3	2	2	2	1	1	1	0

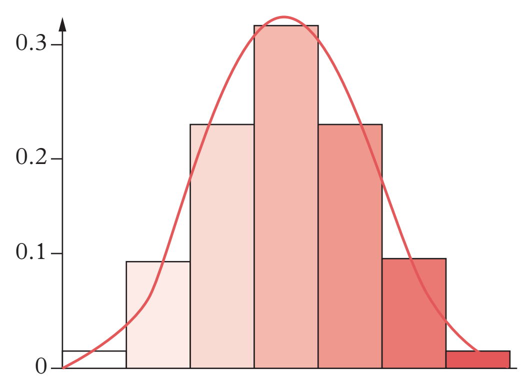


Figure 1 Simplified polygenic inheritance showing skin colour influenced by three genes, each with two alleles. The final skin colour is determined by the number of dominant alleles present.

For example, skin colour is determined by a combination of genetic factors and environmental influences. You inherit a series of genes from your parents that set your potential skin colour, but if you don't receive enough nutrition or are exposed to excessive solar radiation during your development, then your skin colour may be affected.

Effect of the environment on physical appearance

Your genetic material or DNA doesn't control how you cut your hair or what you eat, and the same goes for other organisms. Plants cannot control which leaves get eaten by predators, and animals cannot control the weather. Scientists have often had lengthy discussions about "nature versus nurture": whether DNA is responsible for certain features or whether the features are the result of lifestyle or even upbringing. Your DNA controls your genetic features, such as the colour of your eyes or the length of your nose, whereas the environment (lifestyle, education, etc.) controls everything else and can change regularly. This means genetically identical twins can change slightly (i.e. age faster or slower) if they live in different environments (Figure 2).

For example, genetically identical hydrangeas display different flower colours based on soil pH (acidity), producing pink flowers in alkaline soil and blue flowers in acidic soil. This demonstrates how the environment (nurture) plays a critical role in this trait (Figure 3).

Identical twins develop from a single fertilised egg that splits into two during early embryonic development. This results in two genetically identical individuals who look very similar and are always of the same sex. Despite having identical genomes, environmental factors, such as diet, exercise and sun exposure, can lead to differences in appearance and personality over time.

The NASA Twins Study compared Scott Kelly and his identical twin Mark Kelly who were both astronauts. During the study, Scott was in space while Mark remained on Earth. (Figure 4). The study found the following changes in Scott during this time.

- Gene expression (approximately 7 per cent), which persisted even 6 months after he returned to Earth. These changes were linked to DNA repair, immune system function and responses to environmental stressors.
- Ability to complete cognitive tasks with speed and accuracy post-mission (temporary).

Figure 2 Identical twins are only identical according to their DNA at birth.

Deep blue			Purple -pink			Deep pink
4.5	5	5.5	6	6.5	6.8	7

Figure 3 Effect of soil pH on the phenotype of hydrangea flowers

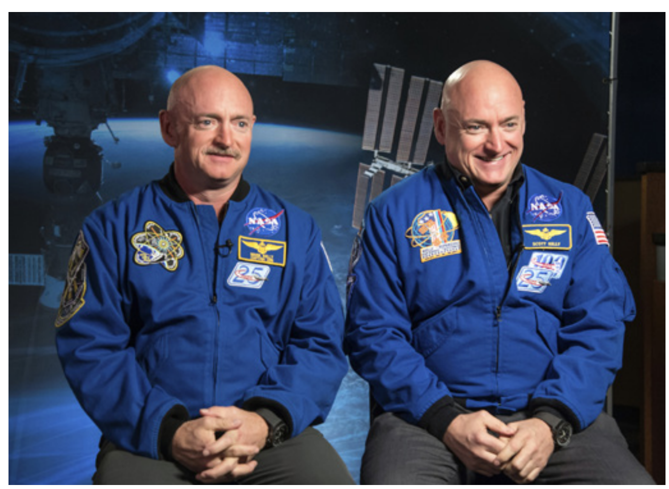


Figure 4 Mark Kelly (left) and his brother Scott Kelly (right), both former astronauts. Scott spent 1 year on the International Space Station as part of the One-Year Mission and participated in NASA's Twin Study in 2015/16.

Figure 5 The effect of the environment they grew up in can be seen in the different physical differences between these identical twins, with one twin growing up in the US (left) and the other in the UK (right).

- Telomeres (protective endcaps on chromosomes) lengthened, making him 6 minutes and 13 milliseconds younger (instead of 6 minutes), which was the opposite of what was expected. These telomeres shortened on his return to Earth.

Another example of environmental factors affecting twins was seen in a study published in 2015 about identical twins, separated soon after birth and reunited at 78 years of age. One twin lived in the UK and the other in the US (Figure 5). Not only were there physical differences, but also differences in their health, cognitive abilities, psychomotor skills and personality.

Check your learning 8.19

Check your learning 8.19

Retrieve

1 Distinguish between monogenic and polygenic inheritance.

Comprehend

2 Two sisters claimed to be identical twins. A classmate didn't believe them because they didn't look exactly the same. Explain whether it is possible for them to still be identical twins. Justify your response.

Analyse

3 Using the polygenic inheritance table in Figure 1, state three possible phenotypes of a child born to parents with the following genotypes: AABbCc × AaBBcc.

Apply

4 Design a valid experiment to test the effect of soil pH on the colour of hydrangea flowers. Clearly identify your dependent and independent variables and ensure your methods address validity, reliability and accuracy.

Lesson 8.20

Mutations are changes in the DNA sequence

Learning intentions and success criteria

Key ideas

→ Mutagens such as chemicals, ultraviolet (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.

Mutations and mutagens

Recall from Lesson 8.4 DNA holds the code for building proteins (page 333) that genes contain the genetic code for making proteins.

Before a new human cell can be produced, the 3 billion nucleotides of the genome need to be copied. Although the aim of copying the DNA is to keep the order of nucleotides the same, occasional errors can occur. On many occasions, these changes can be corrected by the cell; however, if they are not repaired and the change becomes permanent, then it results in a mutation, which can potentially affect the function of genes and the proteins they code for, and they can be passed on to daughter cells.

Mutations may affect one gene or multiple genes, potentially involving part or all of a chromosome. If the mutation occurs in a single gene, it is called a genetic mutation; if it affects multiple genes or most of a chromosome, it is called a chromosomal mutation.

Mutations contribute to genetic variation in populations, and their effects can range from minimal to beneficial or harmful, influencing how organisms adapt and evolve in response to their environments.

If a mutation occurs in non-coding DNA or within a gene but does not change the resulting amino acid produced, then the protein's structure, and therefore function, will be minimally affected – if at all. It is a **silent mutation**.

silent mutation a change in a DNA sequence that does not alter the amino acid sequence of a protein, typically having no impact on its structure or function

If a mutation occurs in a gene that results in an evolutionary advantage to the organism, it will increase the chances of survival and reproduction. This beneficial mutation can become more common in the population through **natural selection**. For example, in humans, a mutation in the lactase gene occurred in Northern Europe around 5,000 to 10,000 years ago, coinciding with the domestication of dairy animals. Normally the gene encoding for this protein, responsible for breaking down the sugar lactose in breast milk, is "switched off" after **weaning**, leading to lactose intolerance in adulthood. The mutation prevented the gene from being "switched off" resulting in lactase persistence. As a result, individuals with this mutation could digest lactose throughout their lives, providing a nutritional advantage by allowing them to benefit from the calories, vitamins and minerals found in milk and dairy products.

Figure 1 A mutation in the lactase gene in humans enabled individuals carrying this mutation to digest dairy products past the childhood weaning stage.

natural selection the process by which traits that enhance survival and reproduction become more common in a population, while less advantageous traits diminish over generations

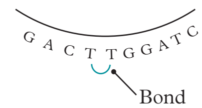
weaning the gradual transition of a young mammal from a milk-based diet to solid food, reducing reliance on maternal milk

Most non-silent mutations, however, have a detrimental effect on an organism's health. A mutation in a gene that leads to the insertion of an incorrect amino acid, or the removal of a correct amino acid, can significantly impair the function of the resulting protein. Examples of diseases caused by harmful mutations include cystic fibrosis, sickle cell anaemia and Tay-Sachs disease.

Natural mutations occur at a continuous low rate, however, environmental factors called **mutagens** can increase the frequency of mutations. Mutagens include radiation, chemicals and UV light (Table 1).

mutagen a chemical or physical agent that causes a change in genetic material such as DNA

Table 1 The effect of mutagens

Radiation	Chemicals	UV light
Ionises biochemical compounds in cells, forming free radicals	Some chemicals insert into DNA instead of bases (i.e. they substitute for bases)	Causes thymines that are close together on a DNA polynucleotide chain to bind together, forming "thymine dimers", leading to problems during DNA replication 
The free radicals cause damage to DNA and proteins (e.g. breakages in chromosomes)	Other chemicals insert between bases, causing problems when the DNA replicates	

Genetic mutations

There are two types of single nucleotide (point) mutations:

- substitution mutations
- frameshift mutations.

substitution mutation a form of mutation where one nucleotide is substituted for another; may or may not result in a deformed protein

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. This is best shown using the sentence:

THE CAT ATE THE RAT AND RAN FAR.

If there was a substitution mutation in this sentence, it might read:

THE CA**R** ATE THE RAT AND RAN FAR.

In this case, the sixth letter, T, was substituted by R. In DNA it might be a G substituted for A. This small change will be passed on to the RNA but may or may not affect the order of amino acids in a protein.

Sickle cell anaemia is an example of a disease caused by a substitution mutation. 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. The protein haemoglobin that is produced is sticky and deformed, and it doesn't carry oxygen as effectively (Figure 2). People with sickle cell anaemia can feel tired, and the sticky haemoglobin deforms the red blood cells, making them a sickle shape.

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.

A deletion of the sixth letter (T) in the example sentence results in the triplet code becoming:

THE CAA TET HER ATA NDR ANF AR.

An addition of an extra R at the same point results in the triplet code becoming:

THE CAR TAT ETH ERA TAN DRA NFA R.

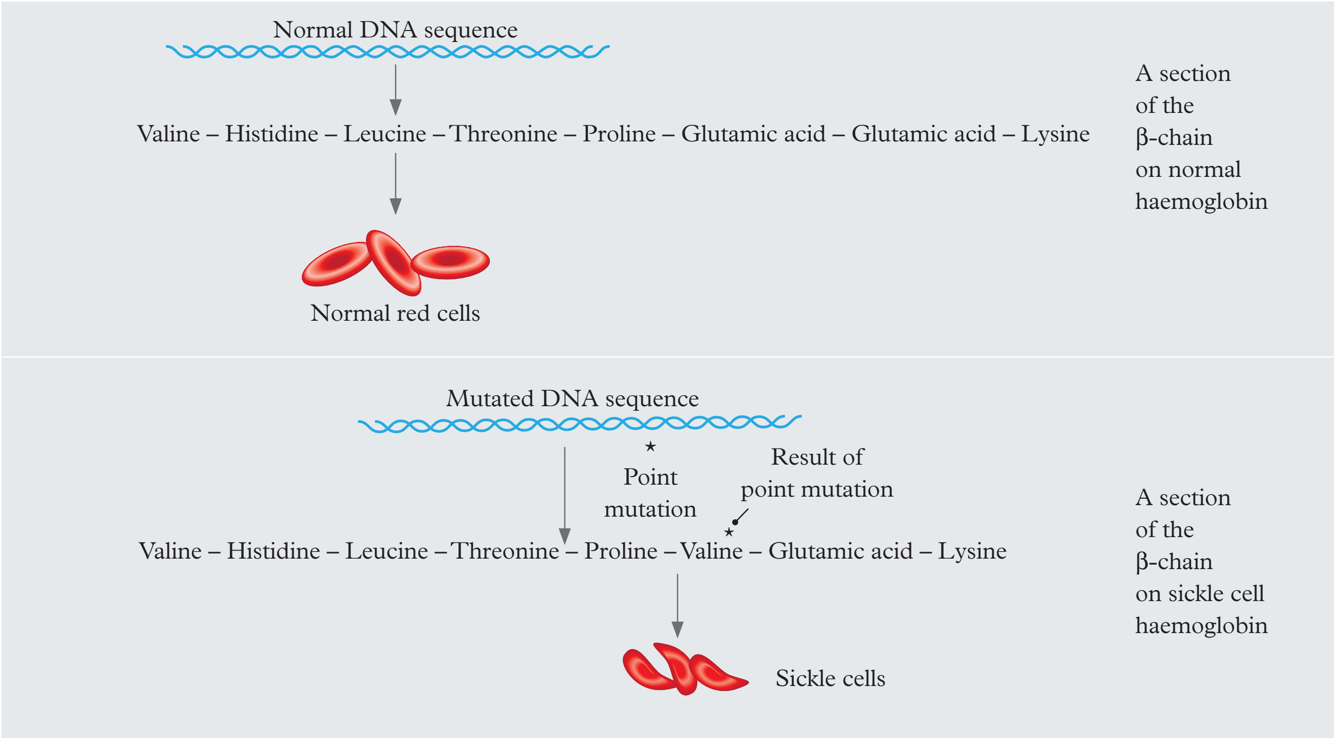


Figure 2 Haemoglobin and sickle cell anaemia, an example of the effects of a point mutation

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 typically result in damaged proteins due to the alteration of the reading frame, leading to incorrect amino acid sequences or premature stop codons.

Tay-Sachs disease, a rare inherited disorder, is often caused by a frameshift mutation that results in a dysfunctional enzyme, crucial for breaking down certain fats in the body. The accumulation of these fats in the brain and nervous system results in significant neurological problems due to the death of nerve cells. Most affected individuals do not survive beyond the age of 4–5 years.

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

Chromosomal mutations

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 3). If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

non-disjunction an error in cell division (meiosis or mitosis), where chromosomes fail to separate properly, resulting in daughter cells with an abnormal number of chromosomes

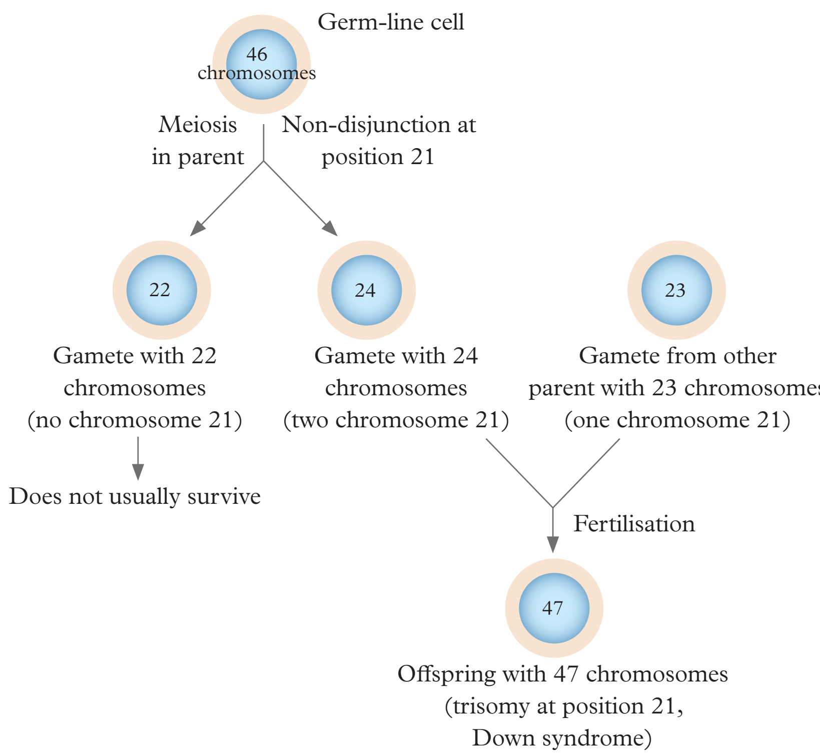


Figure 3 Changes in chromosome numbers due to non-disjunction

trisomy a genetic condition characterised by the presence of an extra chromosome in an individual's cells, resulting in a total of three copies of a particular chromosome instead of the usual two

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 4).

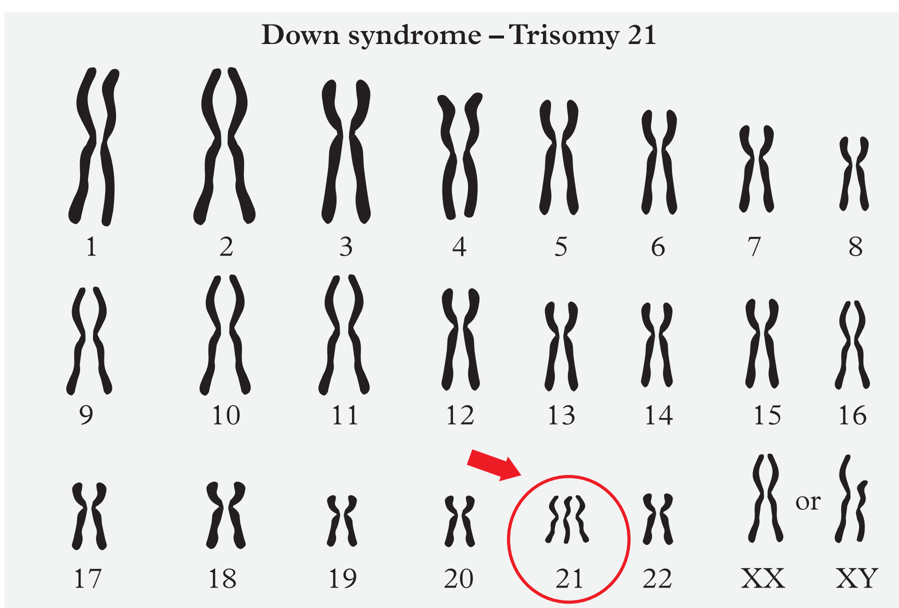


Figure 4 Individuals with Down syndrome have three copies of chromosome 21.

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 5). 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.

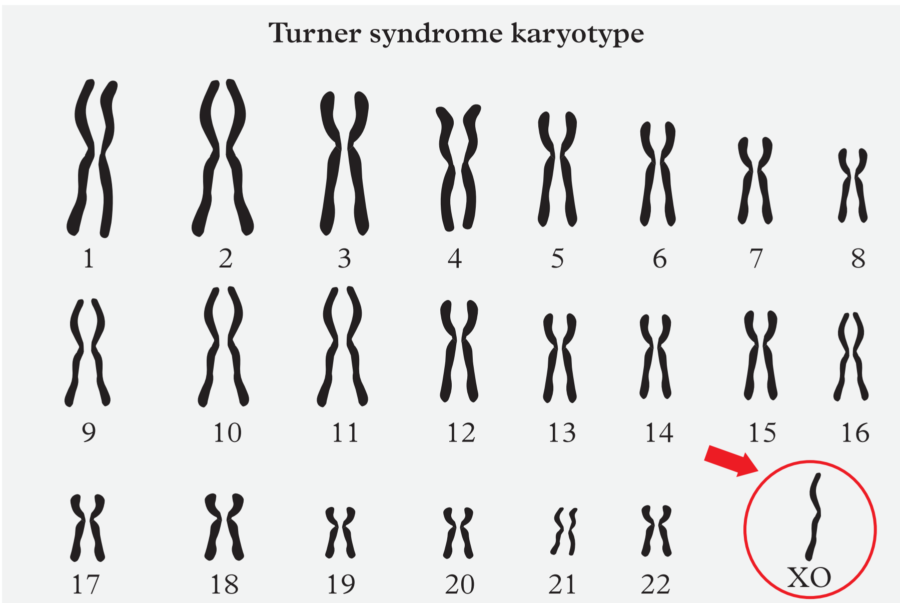


Figure 5 Turner syndrome is a result of non-disjunction of the X chromosome.

Males with Klinefelter syndrome have an extra X chromosome, giving them a total of 47 chromosomes (Figure 6). This can affect their fertility, muscle development and intellectual ability. Many of these individuals will be undiagnosed. Approximately 1 in 660 males are affected.

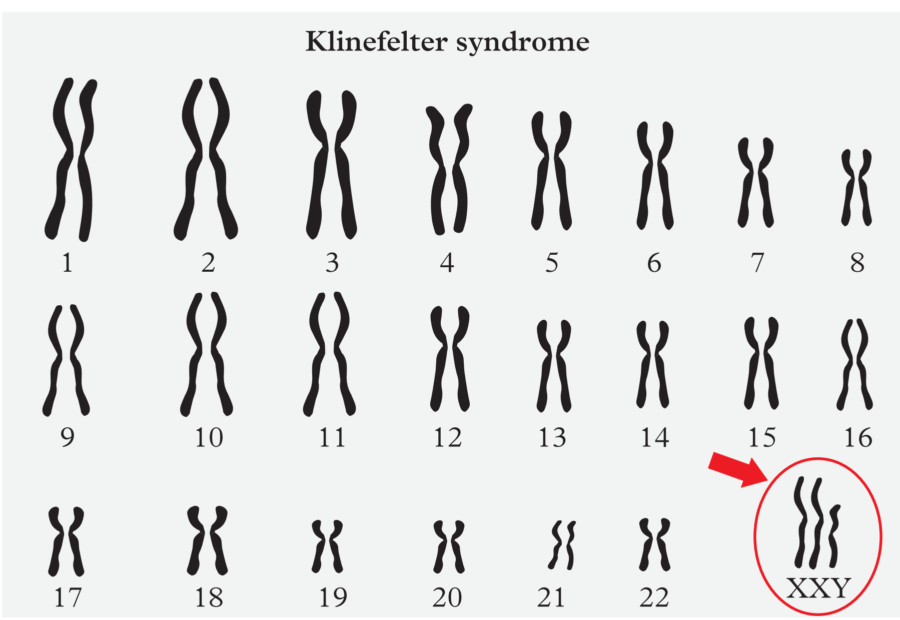


Figure 6 Males with Klinefelter syndrome have an extra X chromosome.

Cri du chat syndrome

Cri du chat syndrome is caused by missing portions of chromosome 5 (Figure 7). 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. Sometimes their fingers or toes can be fused together.

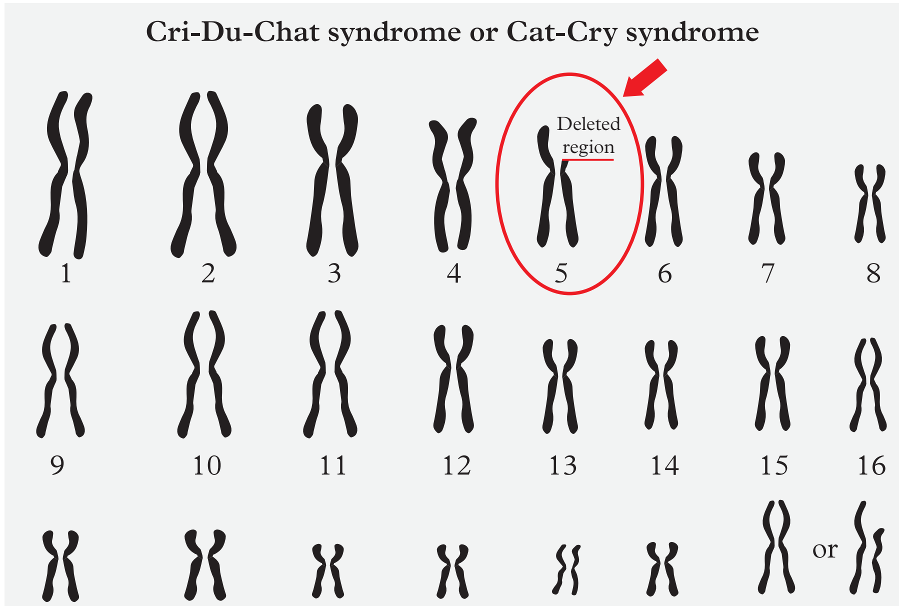


Figure 7 Cri du chat syndrome occurs when part of chromosome 5 is missing.

Check your learning 8.20

Check your learning 8.20

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.

Apply

7 Research and evaluate whether a mutation can be advantageous, with reference to specific examples.

Skills builder: Problem solving

8 The human genome contains 23 pairs of chromosomes with an estimated 20,000 genes that code for approximately 100,000 proteins.

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 8.21
Genes can be manipulated

Learning intentions and success criteria

Key ideas

→ Biotechnology is the use of living organisms or their parts to develop products and technologies for human benefit.

→ Genetic technology specifically involves the manipulation of genetic material.

Biotechnology versus genetic technology

Biotechnology is a broad field that involves using living organisms, cells or biological systems to develop products and technologies for human benefit in fields such as conservation, agriculture, industry and medicine. **Genetic technology** is a specific type of biotechnology that involves the manipulation of genetic material (Figure 1).

Understanding the nature of DNA led to the question, "Can we change it?"

Although biotechnology may sound like a modern scientific term, humans have been manipulating biological processes for thousands of years. Agriculture first emerged 10,000 to 12,000 years ago, requiring the domestication of wild plants and animals. Around 8,000 years ago, **fermentation** was first used to produce alcohol and fermented foods. Approximately 6,000 years ago, selective breeding began, focusing on producing offspring with desirable traits.

These practices laid the groundwork for modern biotechnologies, such as artificial insemination and cloning. Today, current and emerging genetic technologies include the use of recombinant DNA to produce **genetically modified organisms (GMOs)** and gene editing tools such as **CRISPR-Cas9**, which is used in **gene therapy**.

Fundamental to the success of genetic technologies is that the hereditary material of all organisms on the planet shares the same basic building blocks: DNA, which is composed of nucleotides with one of four nitrogenous bases: adenine (A), thymine (T), guanine (G) and cytosine (C).

Figure 1 A novel approach to showing how organisms can be genetically modified. In this case, the gene responsible for producing fluorescence in a species of jellyfish was inserted into mouse embryos. As a result, every cell in their bodies now contains the jellyfish gene, which produces the protein that causes them to glow under UV light.

Genetic technologies in conservation

Historically, biotechnologies that did not involve genetic manipulation have been used in conservation efforts. In recent years, however, there has been an emergence of genetic technologies, including **transgenesis** and **gene editing** tools, aimed at introducing genetic resilience into populations. For example, the gene editing tool CRISPR-Cas9 can be used to "knock-out" genes to better understand their importance to a species' survival, or to "knock-in" genes known to be advantageous.

biotechnology the use of living organisms or their parts to develop products and technologies, often to improve human life or the environment

genetic technology techniques that involve manipulating the genetic material (DNA) of organisms to change their characteristics or functions

fermentation an anaerobic process of breaking down sugars

genetically modified organism (GMO) an organism that has had its DNA changed in a laboratory

CRISPR-Cas9 a gene-editing tool that allows for easy and accurate modifications to DNA, enabling researchers to "cut" and "paste" genes in a way that can change how an organism functions

gene therapy a medical technique that involves altering the genes inside a person's cells to treat or prevent disease; it aims to correct or replace faulty genes with healthy ones to improve health outcomes

transgenesis the process of introducing a gene from one species into the DNA of another species, creating a genetically modified organism (GMO)

gene editing a method that allows scientists to make precise changes to an organism's DNA to alter its traits

Coral reefs around the world are at risk from climate change and increasing water temperatures. When corals are stressed, they expel the symbiotic algae that provide nutrients (and colour) to the coral, leading to coral bleaching (Figure 2). In 2016, 90 per cent of the Great Barrier Reef was impacted by coral bleaching. In 2018, scientists demonstrated that they could easily modify targeted genes in corals using CRISPR-Cas9. Current research is now exploring the "knocking-in" of genes that will make the corals more resistant to increased water temperature.

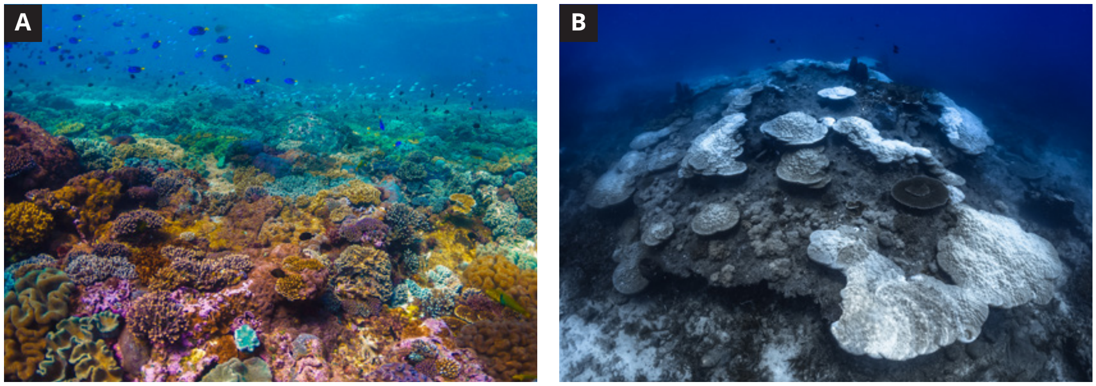


Figure 2 (A) Healthy coral and (B) bleached coral caused by increasing water temperatures

The southern corroboree frog is one of the most critically endangered species on the planet, with only 50 individuals remaining in their natural Alpine habitat in the Snowy Mountains of NSW (Figure 3). Experts say they are functionally extinct. The main reason for their decline, and that of over 200 species of other frogs worldwide, is an introduced fungus called chytrid fungus (*Batrachochytrium dendrobatidis*), which causes the disease chytridiomycosis. The fungus blocks pores in the frogs' skin, preventing them from breathing, hydrating (yes, frogs breathe and drink through their skin!) and regulating their body temperature.

Figure 3 The southern corroboree frog; one of the most endangered species on the planet

Scientists at the University of Melbourne are currently exploring a combined approach of selective breeding and gene editing to ensure the survival of the species. A small number of southern corroboree frogs have proven to be immune to the effects of the chytrid fungus. It is hoped that selective breeding of these individuals will pass on the necessary "resistance genes" to offspring and produce a resistant population over several generations.

The scientists are also creating DNA profiles of the resistant frogs in the hope of identifying the gene or genes responsible for their resistance to the pathogen. Once identified, one option being considered is the use of CRISPR-Cas9 to edit the genomes of offspring to make them immune to the effects of the fungus.

Genetic technologies in agriculture

Genetically modified organisms (GMOs) have had their DNA changed or modified in the laboratory. This is done by changing nucleotides to stop genes making certain proteins or by adding 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 with the desired traits and hope that the offspring inherited those traits.

Today, **genetic engineering** can create plants with the exact desired traits 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.

genetic engineering the deliberate engineering of change in the DNA of an organism

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.

transgenic organism an organism that has a gene from another organism inserted into its own chromosomes

Agriculture has been significantly affected by the introduction of transgenic animals and GM crops and 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 fewer pesticides and herbicides when growing them, which in turn reduces production costs and environmental pollution.

Figure 4 shows the process of introducing a gene from a daffodil into corn. The following parts are labelled.

1 The gene that produces vitamin A is isolated from a daffodil.
2 This gene is added into a plasmid, which is a small loop of DNA that acts as a vector, transporting the gene into a bacterial cell.
3 The bacterial cells containing the plasmid are added to the embryonic corn plant.
4 The transgenic corn plant grows. The introduced genes produce high levels of vitamin A.

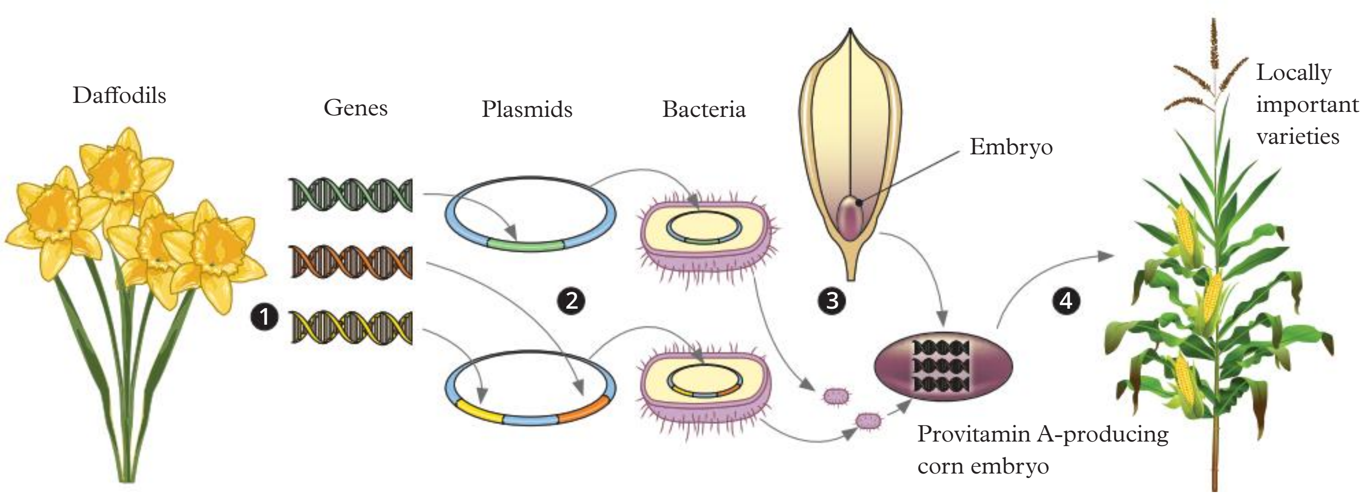


Figure 4 Scientists can grow transgenic corn that produces high levels of vitamin A.

Examples of plants that have been genetically engineered are shown in Figure 5, Figure 6 and Figure 7.

Figure 5 A transgenic variety of cotton that is pest resistant. Genes that make a protein which is toxic to insect pests (from the bacterium *Bacillus thuringiensis*) have been introduced into the DNA of this plant. The protein is called Bt (*B. 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 6 Transgenic papaya plants in Hawaii are resistant to the ring spot virus. Genetically engineering papaya has saved the industry. The technology has also been exported to other countries where ring spot virus is damaging papaya plants.

Figure 7 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.

enzyme a protein-based catalyst

GM salmon have now been approved for commercial production and human consumption in some countries. The fish are genetically modified by inserting two genes from other fish species into Atlantic salmon. The fish grow faster and reach adult size significantly faster than the "normal" salmon. The aim is to improve food security and reduce the environmental impacts of fish farming.

Genetic technologies in industry

Industrial bioprocessing involves the use of GM microorganisms to produce products on a large scale.

Detergent enzymes

Many **enzymes** used in detergent and textile manufacturing are now produced by GM microbes. For example, Savinase® is an enzyme naturally produced by bacteria to break down proteins in their environment, making it useful for removing protein-based stains on clothes. Scientists have genetically modified the bacterium *Bacillus licheniformis* to produce larger quantities of the enzyme. After cultivating large quantities of the bacteria through fermentation, the enzyme is separated from the bacterial cells, purified and added to the detergent.

Textile enzymes

Figure 8 Stone-washed jeans; the effect is produced by GMOs

In the textile industry, stone washing of denim traditionally involved the use of abrasive stones, but now uses cellulase enzymes produced by GM microbes. The enzyme breaks down cellulose in the cotton fabric of the jeans (Figure 8). This softens the fabric, leading to the release of the dye and creating the faded stone-wash appearance. The fungal species *Aspergillus niger* and *Trichoderma reesei*, along with the bacterium *Bacillus subtilis*, have all been genetically modified to produce higher levels of cellulase used in textile manufacturing. The process provides increased efficiency and is more cost-effective than traditional methods.

Biofuels and bioplastics

The majority of the world's fuel sources (including petrol and diesel as well as many plastics) are derived from crude oil, a significant contributor to global climate change. To reduce these impacts, genetic technologies in biofuel and **bioplastic** production are rapidly advancing, driven by an urgent need to reduce our reliance on fossil fuels (Figure 9).

bioplastic a type of plastic made from renewable biological sources, such as plants, rather than fossil fuels

Biofuels are renewable energy sources derived from organic materials, including plants and animal waste. One example is bioethanol, an alcohol produced by the fermentation of sugars found in crops like corn and sugar cane. Both the crops and the microbes used in the fermentation process are genetically modified. For instance, CRISPR-Cas9 is used to "knock-out" genes in the plants that break down sugars, therefore increasing the sugar content of the crops. Historically, alcohol production has used *Saccharomyces cerevisiae* (baker's yeast) to ferment these sugars. This process is relatively slow, however, because *S. cerevisiae* does not produce its own cellulase enzymes.

Figure 9 Both (A) biofuel and (B) bioplastic are produced by the fermentation of plant-based sugars by GM microorganisms.

Despite this limitation, *S. cerevisiae* remains a preferred microorganism in industrial applications due to its established role in ethanol production and ease of genetic manipulation. To overcome its lack of cellulase production, GM strains of *S. cerevisiae* have been developed by inserting the cellulase genes from *A. niger*, *T. reesei* or *B. subtilis*.

As for biofuels, bioplastics originate from plant-based materials. Polylactic acid (PLA) is a bioplastic produced by GM strains of *S. cerevisiae* or the bacteria *Escherichia coli* (*E. coli*) that are engineered to convert sugars more efficiently into lactic acid during fermentation. This lactic acid is then isolated and polymerised to create PLA, which is **biodegradable** and **compostable**.

biodegradable a material that can be broken down naturally by living organisms, like bacteria, into harmless substances over time

compostable a material that can break down into rich soil (compost) under specific conditions, without leaving harmful residues

Genetic technologies in medicine

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**.

gene cloning the production of identical copies of a gene

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 bacterium (Figure 10). The bacterium used the gene to produce multiple copies of the human insulin protein, which was purified and used to treat a person with diabetes. This production method avoids the complications caused when insulin is made from pig or sheep genes, because it is human insulin made from the human gene.

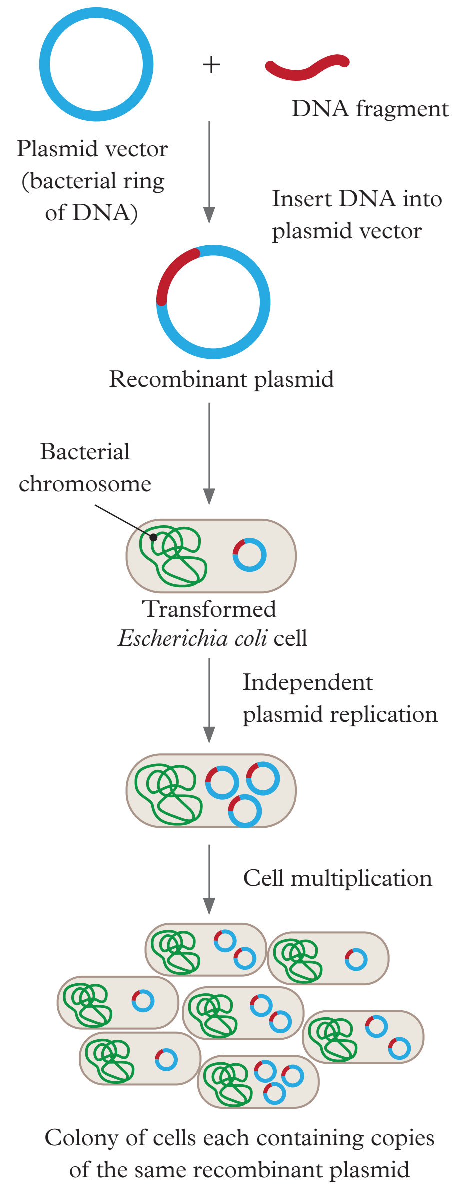


Figure 10 Gene cloning

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 challenges, gene therapy (particularly through **recombinant DNA technology**) has shown promise in the treatment of cystic fibrosis (CF). CF is caused by a deficiency in the *CFTR* gene, which regulates the movement of chloride ions across cell membranes. A major symptom of CF is the accumulation of thick mucus, which can severely damage lung tissue and significantly shorten a patient's lifespan.

recombinant DNA technology a range of techniques that use enzymes to cut and join the DNA from different organisms

In the 1990s, medical researchers successfully cloned the healthy *CFTR* gene in bacteria. Once cloned, the purified gene is linked to a carrier molecule called a vector; in this case, a harmless virus. The viral vector is then administered to patients via a nasal spray.

When inhaled, the virus enters many of the lung cells and delivers the healthy *CFTR* gene into the cell nuclei. When the lung cells divide, the newly formed cells inherit the healthy *CFTR* gene, potentially alleviating the symptoms of the disease (Figure 11).

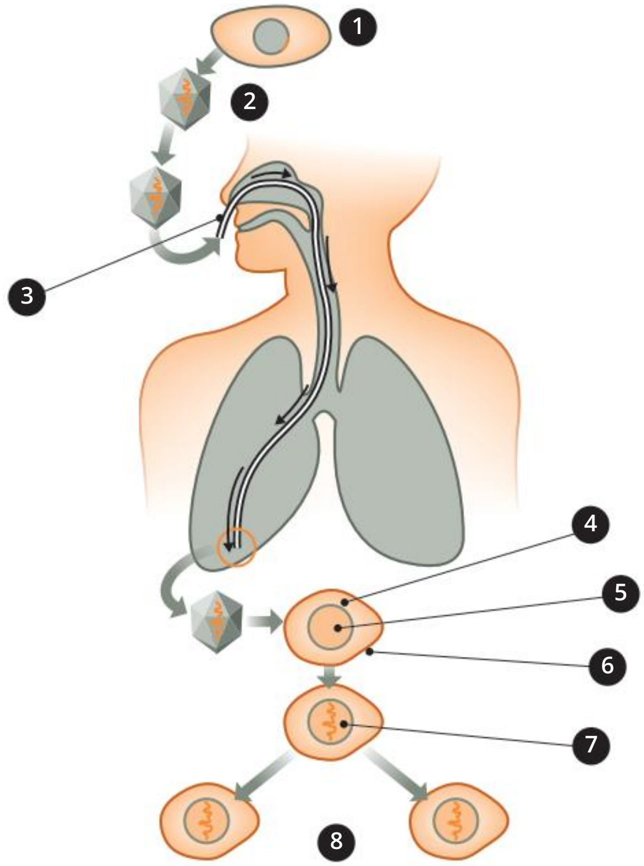


Figure 11 Gene therapy for cystic fibrosis; the following parts are labelled:

1. Normal human gene cloned in bacterium
2. Normal gene (DNA sequence) inserted into harmless virus (AAV, Aden-associated virus)
3. Virus dripped into lung through a thin tube inserted in the nose
4. Lung cell
5. Nucleus
6. Virus enters lung nucleus
7. Normal gene (DNA sequence) inserted into lung cell DNA by virus
8. Cells now with normal genes function properly.

More recently, in 2019, CRISP-Cas9 was used to effectively cure sickle cell disease. The disease is caused by a mutation in the HBB gene that produces a subunit of the protein haemoglobin. The mutation causes the red blood cells to become rigid and sickle-shaped, causing a range of symptoms including anaemia and sharp, intense, throbbing pain throughout the body.

Blood stem cells were collected and isolated from a patient. CRISP-Cas9 was used to cut out the specific HBB mutation and correct the sequence by inserting a "healthy" version of the gene. The edited cells were then grown in culture to increase their numbers before they were reintroduced back into the patient's bone marrow. Being stem cells, they continued to divide and produce red blood cells with the correct haemoglobin protein (Figure 12).

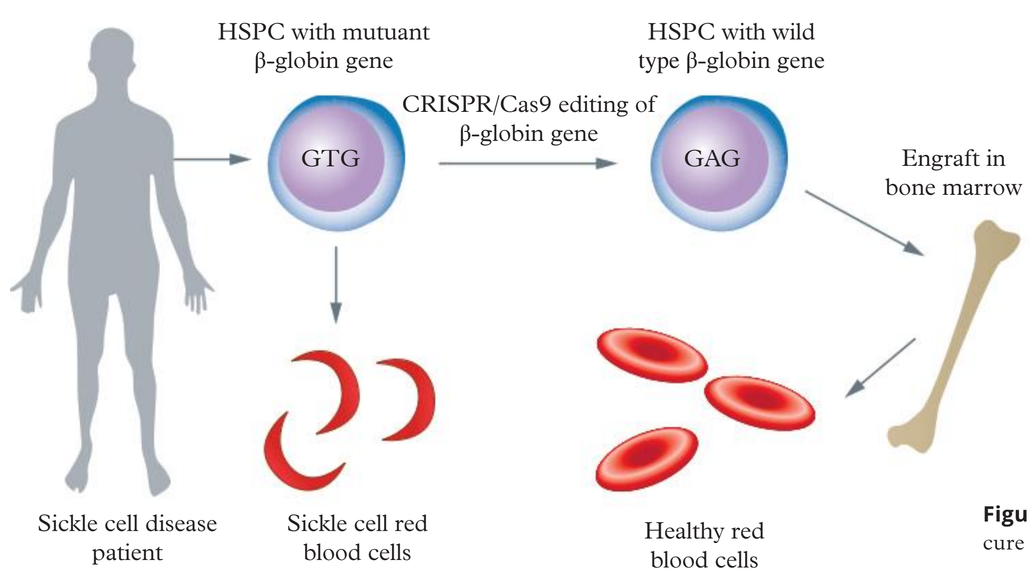


Figure 12 CRISPR-Cas9 was used to cure a patient of sickle cell disease.

Check your learning 8.21

Check your learning 8.21

Retrieve

1 Distinguish between biotechnology and genetic technology.

2 Identify what GMO stands for.

Comprehend

3 Describe how genetic technologies can potentially aid in the conservation of the southern corroboree frog.

4 Describe a genetic technology used in industry.

5 Explain the environmental benefits of using GM crops that are resistant to herbicides.

6 Explain the process of gene cloning used to produce insulin.

7 Explain how gene therapy differs from gene cloning in terms of application and purpose.

Analyse

8 "Since the introduction of GMOs in America in 1996, there has been an increase in chronic illness, food allergies, autism and digestive problems."
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.

Apply

9 Research an endangered Australian species and propose a conservation project that combines selective breeding and genetic engineering, explaining how each method will contribute to the species' survival.

10 Evaluate the potential benefits and challenges of developing a new GM crop aimed at increasing food security in regions affected by climate change.

Skills builder: Planning investigations

11 Your school is investigating the use of GM strawberries. Assess whether it would be better to use secondary or primary data in this investigation. (THINK: Which would contribute more to the area of science? Do you have access to the necessary equipment and materials to conduct an investigation?)

Lesson 8.22
Genetic testing

Learning intentions and success criteria

Key ideas

→ Genetic testing is a diagnostic tool used for individuals with specific symptoms or a family history of disease.

→ Genetic screening targets broader populations to identify asymptomatic individuals who may be at risk.

→ Both genetic testing and screening involve analysing DNA, obtained from blood samples, to identify genetic mutations.

→ Both techniques raise important social implications, such as privacy concerns and mental health impacts, as well as economic considerations.

Genetic testing and screening

There are subtle differences between **genetic testing** and **genetic screening**. Genetic testing is used primarily as a diagnostic tool for individuals presenting with specific symptoms or who have a family history of a particular disease.

In contrast, genetic screening is performed on a larger, broader population, focusing on identifying individuals who do not show symptoms and may not have a family history but could still be at risk of developing certain diseases. The focus is on prevention rather than diagnosis.

The science behind each process is the same. The genetic material of a person is obtained through a blood sample. DNA from the white blood cells (red blood cells do not have a nucleus) is isolated and replicated for analysis.

Mutations in genes can be identified using **probes**, short sections of complementary nucleotides that can bind to mutated alleles. For example, if the mutated allele is TAA CAG TAT, the complementary probe will be ATT GTC ATA. These probes bind to the target DNA and can be detected using a range of methods, including fluorescence. Sequencing is another method used to read the DNA sequence directly and identify mutations. By employing these techniques, genetic testing and screening can confirm the diagnosis of a specific disease or whether individuals are at an increased risk of developing a disease.

Genetic testing and screening 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 PKU, hypothyroidism and Cystic Fibrosis (Figure 1)
- **early detection and predictive testing for adults** – the screening of adults to detect existing diseases, those who have a high chance of the disease or those who are carriers with a reproductive genetic risk.

Figure 1 A blood sample is collected from a newborn baby to screen for PKU, a disease that affects the way the body breaks down proteins.

genetic testing testing that examines an individual's genetics to identify changes or mutations that may indicate a genetic disorder or an increased risk of developing certain diseases

genetic screening the testing of populations or groups to identify individuals at risk of genetic disorders, even if they do not show symptoms

probe a DNA or RNA fragment used to detect complementary sequences in a sample through hybridisation

maternal serum screening (MSS) the genetic testing of fetal 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

Social, economic and ethical considerations

Genetic testing and screening offer individuals the opportunity to make informed decisions regarding their health and lifestyle choices. By understanding their genetic risks, individuals can take proactive measures, pursue personalised treatment options and engage in discussions about family planning with greater awareness.

For example, individuals who are carriers of genetic mutations face challenging decisions about having children who may inherit these conditions. Genetic screening can help prevent genetic diseases from being passed on to the next generation, but this often involves difficult decisions for parents to make. Additionally, important social, economic and ethical considerations surround the use of genetic testing and screening.

Social implications

Genetic testing and screening offer significant benefits to individuals and society. They enable early diagnosis, personalised treatment options and informed lifestyle and medical choices; however, concerns about privacy, stigma, impacts on mental health and family dynamics must also be considered.

For example, an individual testing positive for a homozygous mutation in the *BRCA1* gene faces a lifetime risk of developing breast cancer of up to 85 per cent. Similarly, individuals who are homozygous for the *APOE4* allele have a comparable risk of developing Alzheimer's disease. While lifestyle changes can potentially reduce the risk of disease onset, early detection is crucial for enabling proactive management decisions.

Some women with the *BRCA1* mutation will choose a double mastectomy, which lowers the risk of breast cancer by 95 per cent. This decision is made knowing there is still a 15 per cent chance of not developing cancer without surgery. The implications of such a decision can affect family dynamics, as relatives may grapple with their own risk and the choice of whether to be tested themselves.

The outcomes of genetic testing can also have profound impacts on mental health, affecting not only the individual but also their friends and family. Individuals may experience anxiety or depression upon learning about their genetic risks, which can impact their overall wellbeing and relationships.

Ethical implications

Ethical considerations examine the appropriateness (right versus wrong) of decisions related to the use of genetic testing and screening, as well as the implications of the results obtained.

Concerns often arise regarding informed consent, privacy and confidentiality of results, and disparities in access to genetic testing technology. It is crucial for individuals undergoing genetic testing to make informed decisions that consider potential risks, benefits, limitations and accessibility of the results. Ensuring that individuals are fully aware of these factors helps promote responsible use of genetic testing and protects their rights and interests.

Privacy and confidentiality must be prioritised to protect individuals' genetic information from unauthorised access and potential misuse, which could lead to discrimination in employment and insurance.

Addressing disparities in access to genetic testing and follow-up health services is also important to ensure that marginalised and low-income populations are not disadvantaged.

Finally, the psychological impact of receiving genetic information, be it good or bad, must be considered, with appropriate access to support and counselling.

Case study Prenatal genetic testing

"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 fetus or the placenta, NIPT picks up traces of fetal 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 $1400 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."

Source: O'Leary, C. (2015, November 7–8). *Sex, Down syndrome tests popular. The Weekend West*, p. 17.

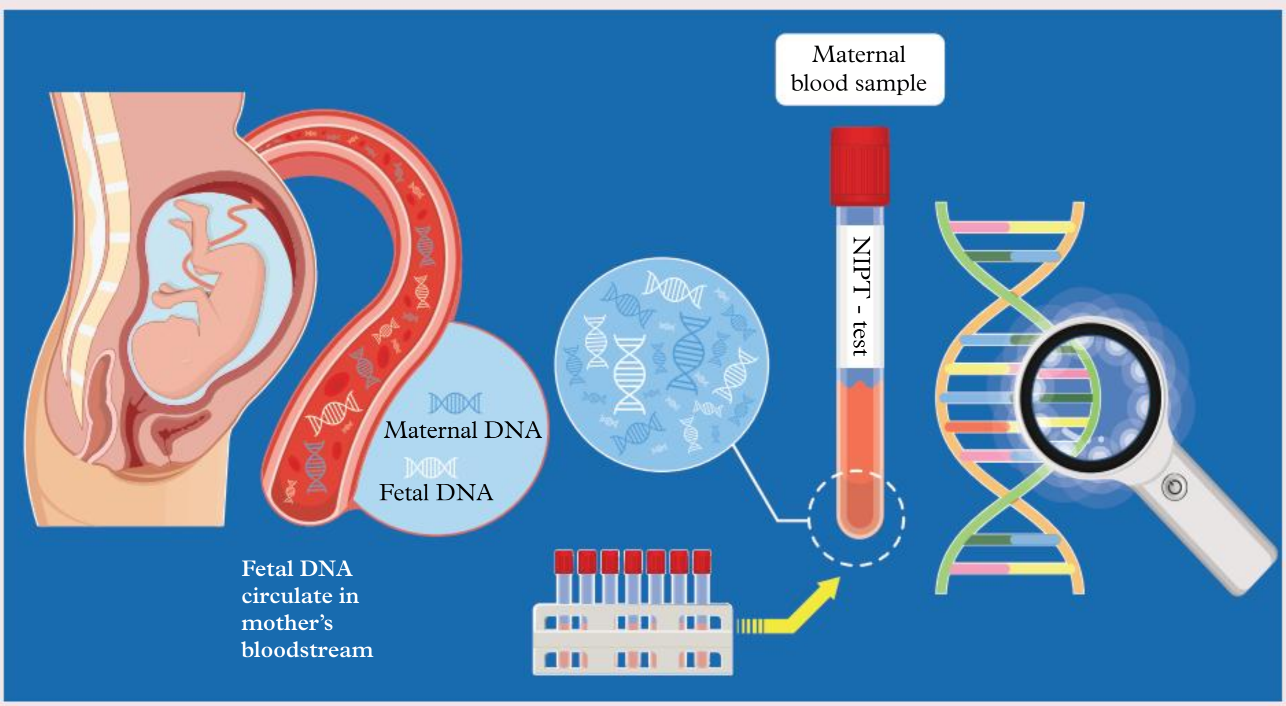


Figure 2 NIPT is a non-invasive way to conduct prenatal testing that will not harm the mother or baby.

What is non-invasive prenatal testing (NIPT)?

- Non-invasive prenatal testing is a new way to screen for genetic abnormalities (Figure 2)
- 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.

Check your learning 8.22

Check your learning 8.22

Retrieve

1 What is the main difference between genetic testing and genetic screening?

2 What is one economic concern related to genetic testing?

3 Describe how genetic probes are used to identify mutations.

4 Describe how NIPT detects genetic abnormalities.

Comprehend

5 Explain the ethical considerations associated with genetic testing.

6 Explain why genetic discrimination is a concern in employment and insurance.

7 Explain why informed consent is a critical ethical issue in genetic testing and screening.

Analyse

8 There are many social, economic, ethical and legal issues raised by genetic testing.

  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 are 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 asks for your advice about terminating the pregnancy.

  Select one of the issues listed below and use an ethical approach to evaluate the issue by:

  » describing the people affected by the issue (including individuals, their families and medical, personal and societal costs)
  » describing how they are affected
  » describing the ethical framework you will use (refer to Lesson 8.23 Science in context: Using an ethical framework (page 401)
  » using the ethical framework to describe the issue
  » describing an alternative view that could be used by someone else
  » describing the decision you would make if faced by the issue.

Lesson 8.23
Science in context: Using an ethical framework

Ethical frameworks

Scientific research often involves controversial ethical dilemmas, particularly when the research involves human or animal subjects or biological material obtained from them. To address concerns around informed consent, patient rights and welfare, research groups and institutions will use an **ethical framework** to guide discussions and the decision-making process.

While many ethical frameworks have been published, most of the time, a single one will be chosen that aligns with the values and belief system of those involved, ensuring that all stakeholders have a voice in the process. The three main ethical frameworks used are **consequentialism**, **deontology** and **virtue ethics**, each offering different perspectives on how to determine what is right or wrong.

ethical framework a structured system of principles and values that guides individuals and organisations in making decisions about right and wrong

consequentialism an ethical framework focused on the outcome of an action or decision

deontology an ethical framework focused on the intent of an action or decision

virtue ethics an ethical framework focused on the character of the individual(s) making the decision

Consequentialism

The consequentialism framework focuses on the outcome or consequences of an action or decision. The most well-known form of consequentialism is utilitarianism, which determines value based on the greatest overall good for the greatest number of people.

Deontology

Deontology focuses on the intent of the action or decision and not on the outcome. Rules and duties must be followed. The actions themselves are either right or wrong, regardless of the consequences.

Virtue ethics

Virtue ethics emphasises the character of those making the decisions; that is, whether they are good people, with positive attributes such as honesty, courage, compassion, generosity and empathy. It maintains that virtuous people will make ethical decisions. Both the actions and the consequences are secondary.

Case study The controversy of the immortal HeLa cell line

Each of the ethical frameworks discussed offers advantages, but they also have flaws, which is why there will never be one universal framework. Consider the following case study on the use of HeLa stem cells in scientific research and discuss as a class how each of the ethical frameworks mentioned above would evaluate their use.

HeLa cells are an immortal **cell line** used widely in biomedical research (Figure 1). They are termed “immortal” due to their unique ability to divide indefinitely, which allows for continuous growth and easy maintenance in culture. Their uniform genetic make-up and consistency between generations has made them invaluable in the development of new treatments and the advancement of biomedical research. To date, they have been used in over 100,000 publications.

cell line a cell culture developed from a single cell and therefore consisting of cells with a uniform genetic make-up

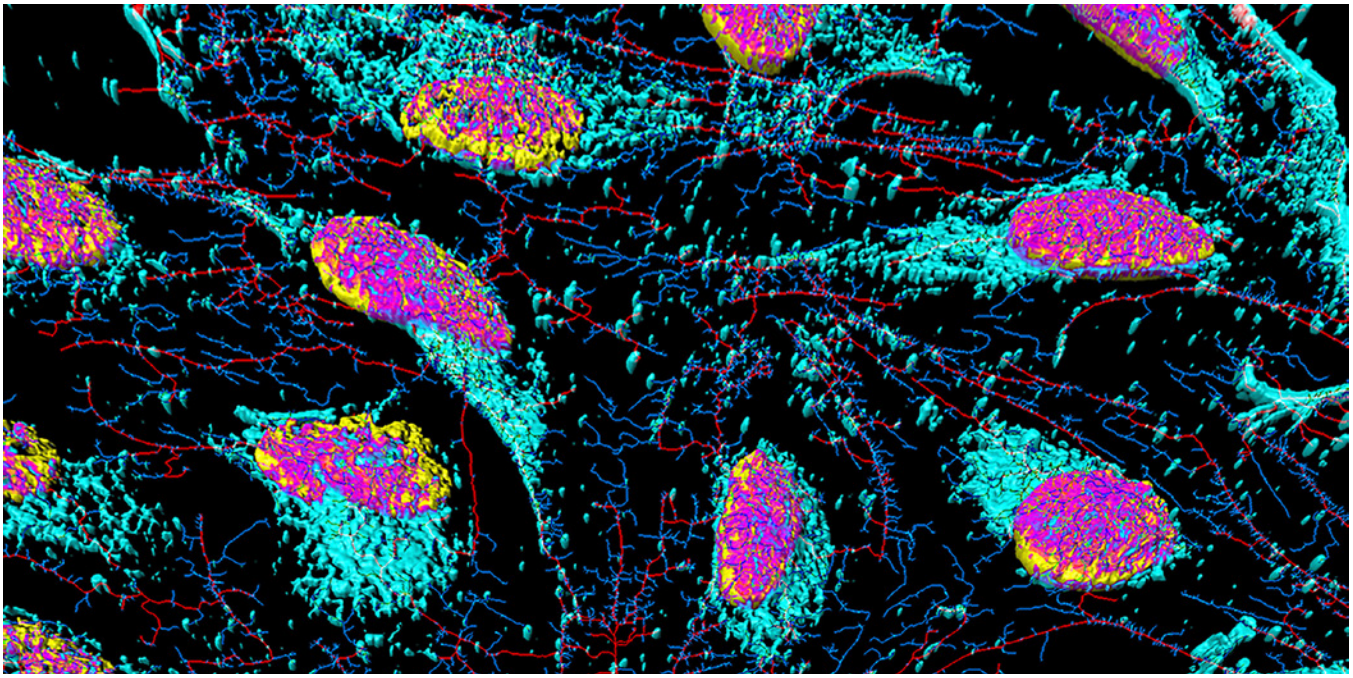


Figure 1 Stained nuclei in HeLa cells

For example, the HeLa cell line played a central role in the development of many vaccines. The polio vaccine, created in the 1950s, used HeLa cells to cultivate the polio virus and test the vaccine. Their ability to divide indefinitely allowed researchers to produce large quantities of the virus required for vaccine development. Similarly, in the 1960s, the development of the measles, mumps and rubella (MMR) vaccine used a similar approach.

HeLa cells are also used widely to study and develop treatments for a wide range of infectious diseases, including HIV and influenza. They were instrumental in understanding the mechanisms used by these viruses to infect host cells. This understanding has led to the development of innovative therapeutic drugs that enable HIV-positive patients to achieve a near normal life expectancy. Additionally, HeLa cells have played a crucial role in the formulation of vaccines against the various influenza strains, contributing significantly to public health efforts.

More broadly, HeLa cells continue to be used by researchers to better understand fundamental cellular processes, including cell division, gene expression and cellular responses to different stimuli. This has led to significant advancements in our understanding of genetics, the impact of mutations, and the origins and progression of cancer.

Additionally, HeLa cells serve as a crucial platform for drug testing, allowing scientists to screen potential drugs for effectiveness and safety.

HeLa cells were taken from Henrietta Lacks, an African American woman undergoing treatment for cervical cancer at Johns Hopkins Hospital shortly before her death in 1951. Despite their profound impact on science and medicine, the use of HeLa cells remains controversial, primarily due to ethical concerns

Figure 2 Henrietta Lacks died at the age of 31. Her legacy lives on through ethical frameworks that are now in place to ensure informed consent and protect patient rights.

surrounding their origin – particularly the lack of informed consent and the influence of racial and socioeconomic inequality. These cells raise important questions about patient rights and the ownership of biological material (Figure 2). They also highlight issues regarding the distribution of any financial benefits or research developments that arise from their use.

The family of Henrietta Lacks only learnt about the use of her cells in research in the early 1970s when ethical conversations around informed consent became more central to decision-making. Scientists wanting to use the cells in cancer research reached out to the family for consent. While this was a positive ethical move forward, the family had no understanding of the impact the HeLa cells had already had or the future breakthroughs that would occur as a result of Henrietta Lacks' unknowing contribution.

More recently, in 2013, the full genome of the HeLa cells – and therefore of Henrietta Lacks – was published in one of the world's most reputable scientific journals. This development further complicates the ethical landscape surrounding the use of HeLa cells, as it involves the release of the genome from a person without their consent. This has far-reaching implications, as her genome could offer insights into genetic conditions to which she was predisposed, and, by extension, those that may affect her descendants.

While the family considered legal action given the significant financial and medical gains that have been made from the HeLa cell line, they ultimately decided against it, instead choosing to advocate for ethical standards in medical research that prioritised informed consent and patient rights. In doing so, they ensured Henrietta Lacks' positive legacy would continue. Henrietta Lacks' story, along with the ethical issues faced by her and her family, was brought to light in Rebecca Skloot's book *The Immortal Life of Henrietta Lacks,* which was later adapted into a film of the same name.

Test your skills and capabilities

Test your skills and capabilities 8.23

Applying an ethical framework

1 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.

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 framework you will use
- using the ethical framework 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.

2 Research each of the ethical frameworks above in more detail, or another of your choosing, and select the one that best aligns with your belief system.

Investigate a specific genetic technology and apply your chosen ethical framework to construct an evidence-based written argument evaluating its use.

When constructing your written argument, address the following.

a Introduction
- » Introduce the ethical framework you've chosen.
- » Briefly state the genetic technology you'll be discussing.

b Overview of the ethical framework
- » Explain the key ideas of your chosen ethical framework.
- » Share why this framework resonates with you.

c Identify ethical issues
- » List the main ethical issues related to the genetic technology.
- » Give examples to clarify these issues.

d Stakeholders
- » Identify who is affected by the technology (e.g. patients, animals, researchers, society).
- » Mention their interests or concerns.

e Positive and negative outcomes
- » Discuss the potential positive and negative outcomes of using the technology.
- » Use examples to support your points.

f Your argument
- » Present your main argument about the use of the technology based on the ethical framework.
- » Explain how the framework guides your viewpoint.

g Consider alternatives
- » Suggest other ways to approach the ethical issues.
- » Briefly discuss the pros and cons of these alternatives.

h Conclusion
- » Summarise your main points.
- » Highlight the importance of ethics in using genetic technology.

Lesson 8.24
Review: Genetics

Summary

Lesson 8.1 DNA, genes, chromosomes and the genome

- 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 is a double-helix shape.

Lesson 8.4 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 8.5 Mitosis produces new somatic cells

- 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 8.7 Meiosis produces 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 8.9 Scientists refine the work of other scientists: Discovering the structure of DNA

- Scientists build on the work and knowledge of scientists that came before them.

Lesson 8.10 Passing on genetic information to offspring

- All living things reproduce, leaving new organisms to carry on when others die.
- Asexual reproduction involves a single organism making a copy of itself using its own genetic material.
- Sexual reproduction involves combining the genetic material from two organisms to produce a new organism.

Lesson 8.11 The human reproductive system

- Human females have a uterus, two fallopian tubes and two ovaries.
- Each month, an ovary produces one ovum (egg) during ovulation.
- Human males produce sperm in their testes.
- Sperm will mature in the epididymis and travel along the vas deferens, where the seminal vesicles provide nutrients before the sperm is ejaculated from the penis.

Lesson 8.12 Sexual reproduction in plants

- Flowers help plants to use sexual reproduction.
- When the male plant gamete lands on the female plant gamete, pollination has occurred.
- Plants can self-pollinate or be cross-pollinated by another plant.
- Insects or birds can help pollinate plants.

Lesson 8.13 Mendelian inheritance in plants and animals

- Genes can have different versions (alleles) at the same location on 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 8.14 Alleles on sex chromosomes produce sex-linked traits

- 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 8.15 Using Punnett squares to predict genotype and phenotype

- A monohybrid cross examines the inheritance of a monogenetic trait.

Lesson 8.17 Inheritance of traits is 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 8.19 Polygenic inheritance and environmental effects on phenotype

- Polygenic traits are controlled by multiple genes, each contributing to the overall phenotype.
- The expression of polygenic traits can be significantly influenced by environmental factors.
- The development of traits involves both genetic inheritance (nature) and environmental influences (nurture).

Lesson 8.20 Mutations are changes in the DNA sequence

- Mutagens such as chemicals, ultraviolet (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 8.21 Genes can be manipulated

- Biotechnology is the use of living organisms or their parts to develop products and technologies for human benefit.
- Genetic technology specifically involves the manipulation of genetic material.

Lesson 8.22 Genetic testing

- Genetic testing is a diagnostic tool used for individuals with specific symptoms or a family history of disease.
- Genetic screening targets broader populations to identify asymptomatic individuals who may be at risk.
- Both genetic testing and screening involve analysing DNA, obtained from blood samples, to identify genetic mutations.
- Both techniques raise important social implications, such as privacy concerns and mental health impacts, as well as economic considerations.

Review questions 8.24

Review questions Module 8

Retrieve

1 Identify which of the following is not a smaller part of all DNA nucleotides.
  A Deoxyribose
  B Nitrogenous 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 of DNA molecules.
  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 nitrogenous bases found in DNA.

8 Define the term "monohybrid cross".

9 Define the following terms:
  a GMO
  b transgenic organism.

10 Recall the two main categories of mutation.

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 following processes:
  a gene cloning
  b gene therapy.

15 Describe the sort of information that can be determined from the pedigree shown in Figure 1.

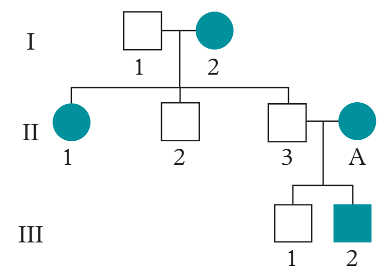


Figure 1 A pedigree

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 nitrogenous 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).

c As the geneticist, discuss what you could tell the parents about their baby.

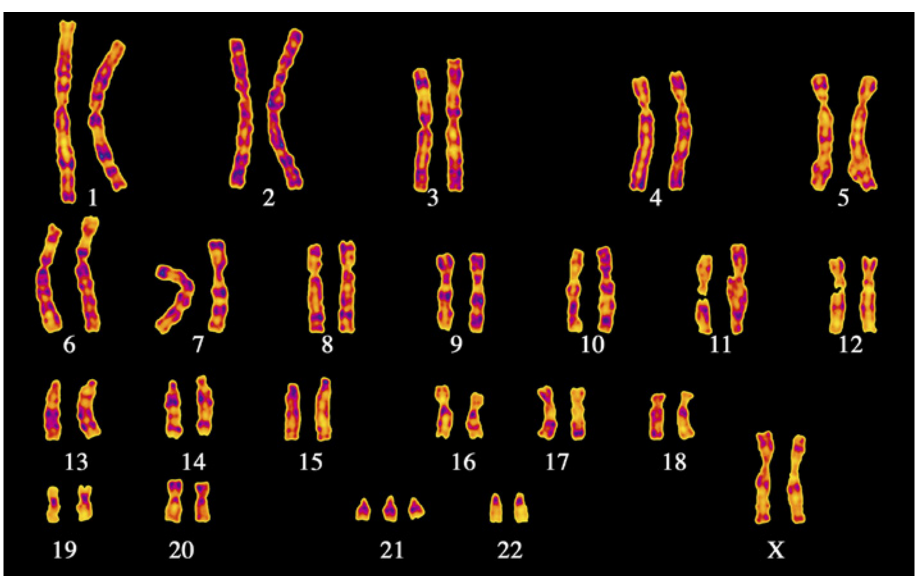


Figure 3 The newborn baby's karyotype

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 (PKU) 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.

Stem cell survival technique

Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them.

- Explain why this technique is important.
- Describe the technique used to keep the stem cells alive.
- Describe the immediate uses of this technique.

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.

Cloning

An understanding of how cells replicate has allowed scientists to clone animals.

- Define the term "clone".
- Identify three animal clones that have been developed since Dolly the sheep in 1997.
- Evaluate the benefits of cloning (by describing the advantages and disadvantages of cloning animals, comparing the costs of cloning and the benefits of cloning, and deciding if the cost is equivalent to the benefits).

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.

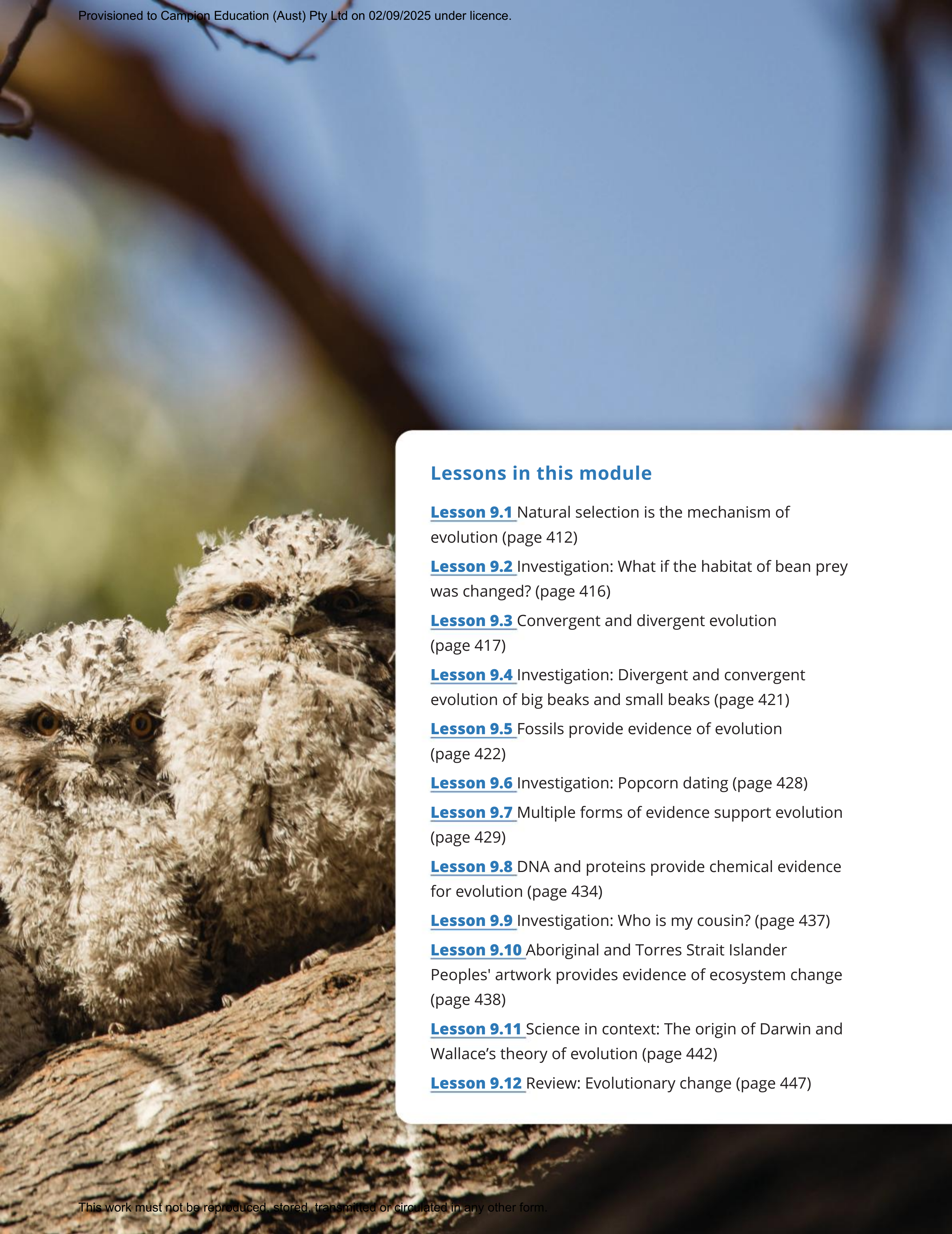
Module 9

Evolutionary change

Overview

The theory of evolution by natural selection explains how plants and animals change over time. Evidence for evolution comes from the fossil record, which shows past life forms, and biogeography, which shows where species live around the world. Evidence is also found when we compare how embryos develop over time. The theory of evolution explains why there is so much biodiversity, and it shows that all organisms are related to some degree.

The artwork of Aboriginal and Torres Strait Islander Peoples provides evidence of ecological changes over time, including significant shifts in plant and animal life and evidence of now-extinct species. These include megafauna, which are large animals that coexisted with Aboriginal and Torres Strait Islander Peoples for an extended period of time.



Lessons in this module

Lesson 9.1
Natural selection is the mechanism of evolution

Learning intentions and success criteria

Key ideas

→ Evolution is the permanent change in the number of alleles in a population due to natural selection.

→ Natural selection is the process whereby selection pressures (environmental factors affecting an organism's survival) choose a trait or characteristic (or do not choose it) so that a species becomes better suited to its environment. The concept of "survival of the fittest" drives natural selection.

→ All scientists make observations of the world around them; they then use these observations and reasoning to draw conclusions (inferences).

Introduction

evolution the process by which populations of organisms change over successive generations through variations in their genetic material

Evolution is the process by which populations of organisms change over successive generations through variations in their genetic material. The process is driven by natural selection where organisms with traits that help them survive in their environment are more likely to live longer and pass these traits on to their offspring.

Observations that led to the theory of evolution by natural selection

observations facts or details based on actual sensory information

species a group of organisms that can breed with each other in natural conditions to produce offspring that are viable (alive) and fertile (able to have children of their own)

inference a conclusion based on evidence and reasoning

competition the struggle between individuals or groups for limited resources

Although scientists knew that living organisms changed over time, the mechanism of how this occurred was first fully described by Charles Darwin and Alfred Wallace through their theory of evolution. They made several key **observations**.

- Members of a **species** exhibit variations between one another.
- More organisms are born than are able to survive into adulthood.
- Despite high reproductive rates, population sizes tend to remain relatively stable over time.
- Many offspring do not survive due to limited resources and other environmental pressures (survival of the fittest).
- Offspring tend to resemble their parents, inheriting traits from them.

Darwin and Wallace independently made the following **inferences** based on their observations, now known as the theory of evolution by natural selection. The key points are as follows.

- Variation in traits: Within a population, individuals exhibit variations in traits, such as size, colour and behaviour, which can influence their survival and reproduction.
- Overproduction and natural selection: Species produce more offspring than the environment can support, leading to resource **competition**. Individuals with advantageous traits are more likely to survive and reproduce. This concept of "survival of the fittest" drives natural selection.

- Inheritance of traits: Advantageous traits are passed down from generation to generation, gradually increasing their prevalence in the population over time.
- Adaptation and speciation: Over many generations, natural selection promotes adaptations that enhance survival and reproduction, potentially resulting in the emergence of new species as populations diverge and become isolated.

Figure 1 These Siberian huskies have different versions, or alleles, of the gene for fur colour.

Variation in populations

Natural selection cannot occur without biodiversity (genetic diversity) in a population. A biodiverse population has a wide range of traits, such as camouflage, predator detection and defence, as well as varying temperature tolerance. 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.

Recall from Module 8 Genetics (page 322) that individuals of the same species have the same number and types of genes but different alleles (gene variants). For example, all humans will have the same genes for eye colour, but the alleles they have for each gene may be blue, brown or hazel. New alleles arise due to mutations; small changes in the DNA sequence. Some mutations are not obvious in an organism's appearance, while others result in noticeable physical differences (phenotype). For example, a single mutation around 6,000 to 10,000 years ago led to one of our ancestors having blue eyes.

All the different types of genes in the entire population can be thought of as a **gene pool**; a pool of genetic information. The gene pool includes all the alleles for all the genes in the population.

gene pool all the genes or alleles in a population

A mutation may produce a variation that gives an individual an advantage, making them better able to survive than others in their population. **Selection pressures** determine which variations survive and which do not. These pressures include any environmental factor affecting an organism's chance of survival. For example, advantages might include the ability to withstand hot weather or outpace a predator. If an organism is better suited to its environment, it has a higher likelihood of mating and passing the advantageous genetic traits to its offspring.

selection pressures environmental factors that affect an organism's ability to survive

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.

Allele frequencies

The frequency of an allele refers to 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 Black-flanked rock-wallaby (*Petrogale lateralis*), which is found in rocky, mountainous areas of Australia. Different populations of the species have developed variations in fur colour, which help them blend into their specific environments. In lighter, sandy-coloured rock habitats, wallabies with lighter-coloured fur are better camouflaged from predators. In darker, volcanic rock regions, wallabies with darker fur have an advantage. These differences in fur colour are due to variations in their genes (alleles). Since camouflage increases the chances of survival and reproduction, the allele for the fur colour that best matches the local environment becomes more common in each population over time. This is an example of natural selection, where environmental factors influence which alleles are advantageous, causing changes in allele frequencies within populations. Over generations, this process contributes to evolution.

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 due to soot, exposing lighter moths to predation from birds (Figure 2).

Figure 2 Dark-coloured moths of the species *Biston betularia* increased in numbers when air pollution killed lichen on trees. Lighter-coloured moths (such as the one on the right side of the image) became more visible to predators on the dark-coloured trees and were selected against.

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.

In 1952, strict pollution controls were introduced in England, the lichens returned and the tree trunks became mostly free of soot. Predictably, selection pressures started to operate in the reverse direction. In areas where pollution levels decreased, lighter moths were selected for and darker 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 (i.e. pesticides or antibiotics) has selected for variants that are resistant to the chemicals.

Check your learning 9.1

Check your learning 9.1

Retrieve

1 Identify the source of all new alleles.

2 Summarise in your own words the inferences Darwin and Wallace made that underpin the theory of evolution.

3 Define “biodiversity”.

Comprehend

4 A student was heard to say that mutations are bad. Explain whether this is true.

5 Describe the selection pressures that caused the allelic frequency of light-grey moths to decrease in England in the 1950s.

6 Explain the relationship between phenotypic variation (physical differences) and survival advantages in a population.

Analyse

7 Doctors are concerned about the rising issue of antibiotic resistance in bacterial populations, as it poses a significant challenge to public health and the effectiveness of medical treatments. Discuss how antibiotic resistance in bacterial populations illustrates Darwin’s theory of evolution, particularly the principles of natural selection and adaptation, and what implications this has for public health and the effectiveness of medical treatments.

Apply

8 Create a series of labelled diagrams that illustrate the process of natural selection of the moth species *Biston betularia* in England.

Skills builder: Planning investigations

9 An experiment aims to model the effects of natural selection on the allele frequency of a population. The experiment lists the following materials: 30 red counters, 30 yellow counters and 30 blue counters, and a six-sided die.

a Propose a hypothesis for this experiment. (THINK: What would the coloured counters represent? What are you testing?)

b Write a brief method based on this hypothesis. (THINK: How will you use the die to simulate the effects of natural selection? What steps could you achieve with the materials listed?)

Lesson 9.2

Investigation: What if the habitat of bean prey was changed?

Purpose

To examine the selection pressures involved in hunting prey

Materials

- Paper cups
- Tools: knives, forks, 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

Procedure

1. The class divides 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, 20 of each bean type are randomly spread out.
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 six white beans were collected, then 14 remain, and another 14 white beans need to be added 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 the 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.
- Record your results in tables as outlined below.
- Show your teacher your planning for approval before starting your experiment.

Results

1. Copy and complete Table 1 to record your results for generation 1.
2. 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	Totals
Red-butted beans						
Long-toothed yellow beans						
Panther-toothed black beans						
Wicked white beans						
Totals						

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 9.3
Convergent and divergent evolution

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

Introduction

A species is a group of organisms that can 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

Figure 1 *Magicicada cassini* emerge from the ground every 17 years to mate. Other closely related species from the same genus emerge every 13 years.

Genetic isolation

In order for new species to evolve, populations of a species must first be genetically isolated from one another. This genetic isolation can occur through various mechanisms, such as geographical isolation, temporal isolation, behavioural isolation or ecological isolation.

Geographical isolation includes physical barriers, such as mountains or rivers, that separate populations. This can lead to different evolutionary paths as each group adapts to its unique environment. Darwin's finches are an example of geographical isolation leading to speciation (Lesson 9.11 Science in context: The origin of Darwin and Wallace's theory of evolution, page 442).

Temporal isolation occurs when populations of the same species breed at different times. This could be a different time of the day, different seasons, or in some cases, different years. The isolation prevents interbreeding, even when they occupy the same area. For example, cicadas from the genus *Magicicada* emerge every 13 or 17 years (Figure 1).

Behavioural isolation involves differences in mating behaviours or rituals that prevent populations from recognising each other as potential mates. It is believed that slight differences in mating calls and courtship dances led to the origins of three distinct species of booby (the blue-footed booby, the Nazca booby and the masked booby) despite them all living in the same area of the Galapagos Islands (Figure 2).

Figure 2 The blue-footed booby, Nazca booby and masked booby have different mating calls and courtship dances.

Ecological isolation occurs when populations inhabit different habitats within the same area, reducing the likelihood of mating. For example, many species of closely related cichlid fish from the African Great Lakes occupy different ecological niches (Figure 3). Some species thrive in shallow rocky areas, while others prefer deeper waters with sandy bottoms. Over time, the different habitat preferences minimise competition for resources, reducing the interaction between populations.

Figure 3 Cichlid fish from the African Great Lakes. Closely related species occupy different ecological niches in the same area.

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

Speciation

Once isolated, alleles no longer flow between the two gene pools. Over time, as new mutations arise, genetic differences accumulate, especially as each population encounters different selective pressures. Natural selection will ultimately lead to the emergence of distinct species.

When a variant 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**. 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.

Over time, different selection pressures act on the two groups, leading to the selection of distinct characteristics. Given sufficient time for evolution to occur, the two populations may become so genetically distinct that they are incapable of interbreeding if they ever come together again. This reproductive isolation results in the formation of two separate species by the process of speciation. As a result, the two species have undergone **divergent evolution**.

isolation the division of a population into two groups

divergent evolution the process whereby related species become more dissimilar over time due to different environmental pressures, resulting in distinct traits from a common ancestor

allopatric speciation a mode of speciation that occurs when a population is geographically separated into two or more isolated groups, preventing gene flow between them

homologous structures structures that are 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

Divergent evolution

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.

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 are known as **homologous structures**. The most commonly discussed homologous structure is the pentadactyl limb, which is the pattern of limb bones in all groups of tetrapods (four-legged vertebrates) that ends in five digits (Figure 4). 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 the organisms originated from a common ancestor. During the course of evolution, however, mutations and different selection pressures modified these structures and they are now used for different purposes.

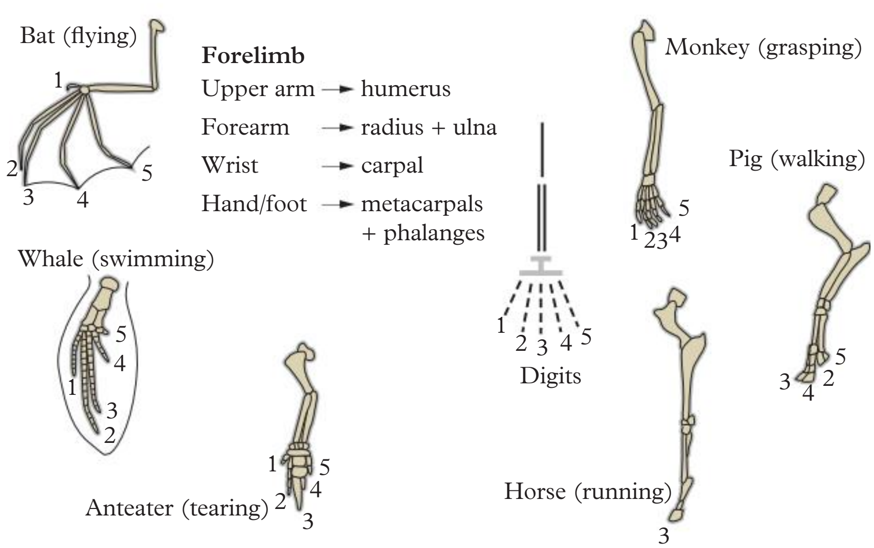


Figure 4 The homologous forelimbs of different mammals show the same basic structure, with a single upper bone, two lower limb bones, small wrist or ankle bones and five digits that are adapted to different uses.

Figure 5 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.

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

Convergent evolution

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. As a result, they both have a streamlined body with analogous structures, such as fins and a tail, which enable them to move through the water quickly enough to catch prey and escape predators. This is an example of **convergent evolution**. The wings of birds and butterflies are also analogous structures (Figure 5).

Check your learning 9.3

Check your learning 9.3

Retrieve

1 Define the term "homologous structure".

2 Identify an example of an analogous structure and the animals on which they are found.

3 Define the term "speciation".

4 Construct a table to summarise the different types of isolation.

Comprehend

5 Use an example to describe how a permanent barrier could create a new species.

6 Describe how gene flow influences the process of speciation.

Analyse

7 Contrast the differences between how an individual organism adapts to living in a hot environment and how an entire species adapts if conditions gradually become hotter over time.

Apply

8 Dolphins descended from terrestrial mammals, and these ancestors underwent significant evolutionary changes as they adapted to a fully aquatic lifestyle. Discuss how the land-dwelling ancestors of dolphins evolved into the streamlined mammals we see today, focusing on the key adaptations that occurred over millions of years.

9 Research an example, other than those provided in the lesson, of geographical isolation, temporal isolation, behavioural isolation or ecological isolation. Use your chosen example to assess the importance of isolation in speciation.

Skills builder: Questioning and predicting

10 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 the other 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 individuals who are both colours. Predict the type of speciation that has occurred here. (THINK: What are the similarities and differences? What key information do you have?)

Lesson 9.4

Investigation: Divergent and convergent evolution of big beaks and small beaks

Caution

Do not eat or drink in the laboratory.

Purpose

To model divergent and convergent evolution in beak size

Materials

- Six 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-sized bulldog clips
- 20 small bulldog clips
- 30 plastic cups
- Two large trays
- Six plastic bags
- Timer

Procedure

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-sized 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 (two giant birds, two midbill birds and two babybill birds) in each. Place the trays at opposite ends of the classroom.
3. Place the first season's food for each population on 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 (kJ) each bird has consumed if popcorn = 2 kJ, beans = 5 kJ and marbles = 10 kJ. 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. 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 on each tray. Repeat steps 3 to 6.

8 Remove any remaining food from the trays and place the food for season 3 on 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 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 9.5
Fossils provide evidence of evolution

Learning intentions and success criteria

Key ideas

→ Fossils are the 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.

Evidence for evolution

Support for any theory, including evolution, requires evidence from a range of sources that all points 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 animals in fossils reinforced the fact that life forms change with changing environmental pressures – even if that simply means that many die and only a few survive.

extinct refers to when there are no living members of the species left

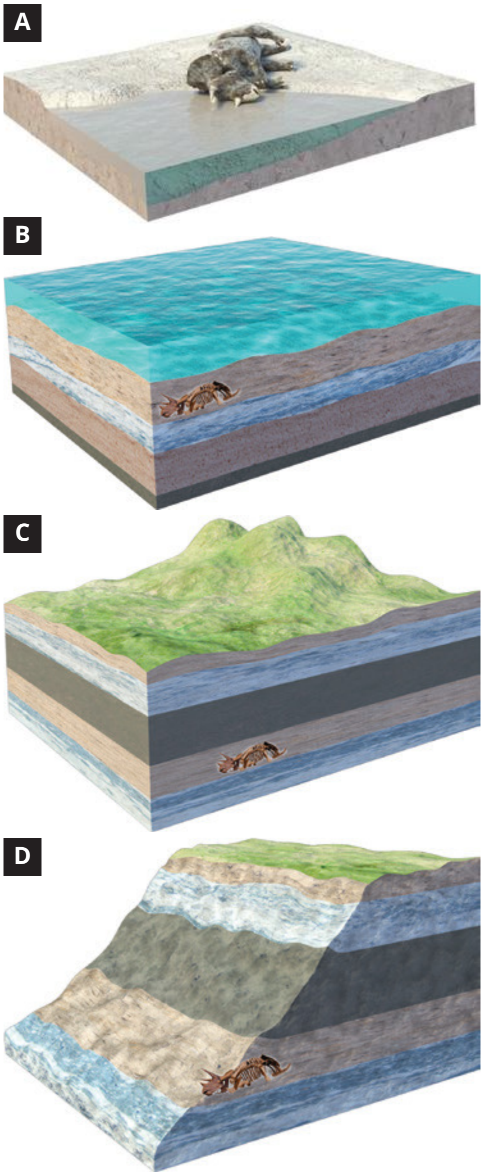


Figure 1 Formation of a fossil: (A) and (B) If an organism dies near water, it has a greater chance of being covered by sediment. The sediment protects the body from predators and weathering. (C) Over millions of years, more sediment is deposited, replacing the remains, so they are transformed gradually into sedimentary rock. (D) Years of geological movement, weathering and erosion may eventually expose the fossil.

What are fossils?

Fossils are the remains or traces of organisms, such as footprints, imprints or coprolite (fossilised faeces), from a past geological age, embedded in rocks or other substances by natural processes.

fossil the remains or traces of an organism that existed in the past

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 forms of fossilised remains. Figure 1 shows how the process of fossilisation occurs.

fossilisation the process of an organism becoming a fossil

Transitional fossils

Darwin's theory suggests that life originated in the sea, crawled onto land and then took to the skies or grew fur. The evidence that links these stages is in the form of **transitional fossils**, which are sometimes referred to as "missing links". Transitional fossils will often display some characteristics of two different species.

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"

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.

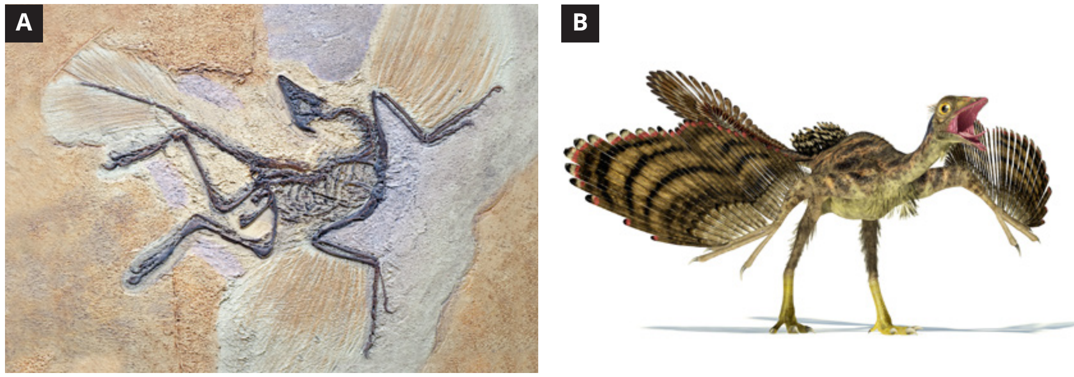


Figure 2 (A) *Archaeopteryx* is an important transitional fossil. (B) Artist's impression. It displays a number of features common to birds (hollow wishbone and feathers) and reptiles (teeth, flat sternum/breastbone, three claws on the end of its wings and a long bony tail).

relative dating a method of determining the age of an object relative to events that occurred before and after

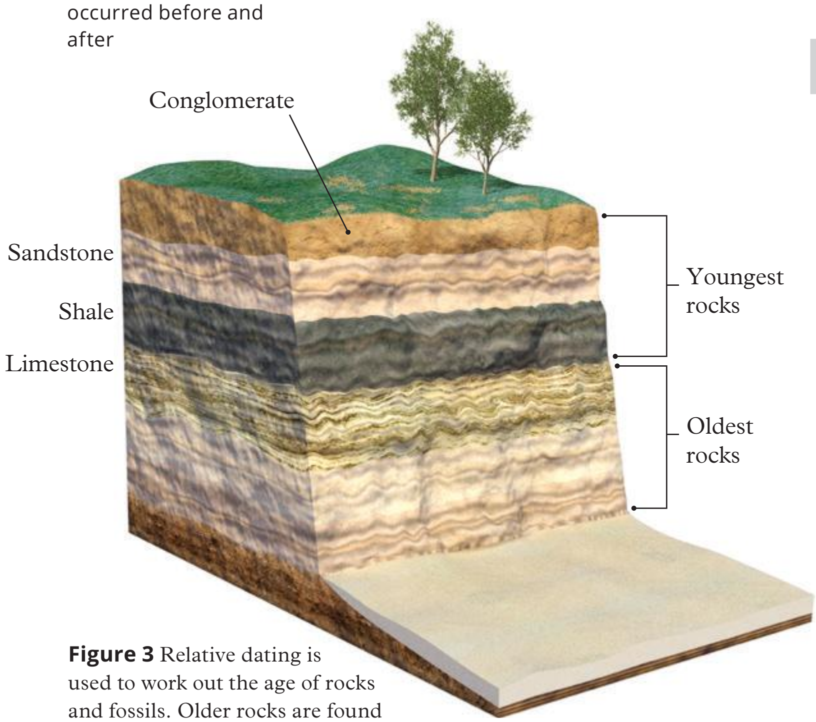


Figure 3 Relative dating is used to work out the age of rocks and fossils. Older rocks are found below younger rocks.

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

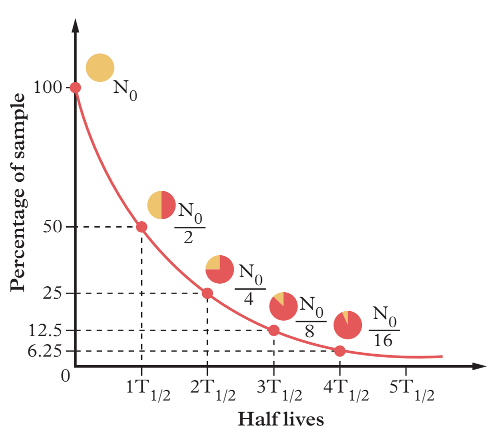


Figure 4 Half-life graph. Scientists are able to determine the absolute age of a fossil by analysing the decay of radioisotopes.

Dating fossils

It is possible to find out how a particular group of organisms evolved by arranging its fossil record 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.

Advances in our understanding of matter have led to technologies that can provide more accurate time frames for fossils. **Absolute dating** relies on the level of radioactivity in the fossil.

Every living organism contains a constant low level of radioactive isotopes. When an organism dies, the radioactive isotopes begin to undergo radioactive decay. The time it takes for half of the radioactive nuclei in a sample to decay is called the **half-life**. For example, in the case of uranium-238, a common isotope used in dating, the half-life is approximately 4.47 billion years. During the first half-life, the level of radioactivity decreases by 50 per cent. In the second half-life, the remaining radioactive nuclei decrease by half again, leaving only 25 per cent of the original level. This process continues until only very small levels of radioactivity remain.

If scientists know an element's half-life, they can determine how many half-lives have passed by measuring the remaining radioactivity in a sample (Figure 4). Therefore, they can determine the age of the fossil or rock.

Worked example 9.5A illustrates how to calculate the number of half-lives that have passed in a fossil.

Worked example 9.5A Calculating half-lives

A fossilised piece of coral was found at Bondi Beach in Sydney. Scientists at the Australian 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 one half-life = 5,730 years, calculate the age of the fossil.

Solution

Steps	What to do	Working out
a.	For part **a**, starting with one whole, halve it repeatedly until you reach $\frac{1}{8}$. The number of times you divide by two is the number of half-lives that have passed.	• 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 ($\frac{1}{2} \times \frac{1}{2}$). • After 3 half-lives, $\frac{1}{8}$ of the radioactive material will remain ($\frac{1}{2} \times \frac{1}{4}$). Therefore, 3 half-lives have passed.
b.	For part **b**, to calculate the age of the fossil, you know three half-lives have passed, so you multiply that by the value of one half-life in years.	3 half-lives = 3 × 5,730 = 17,190 years old

The history of life on Earth

The combination of relative and absolute dating has provided scientists with a good understanding of the history of life on Earth (Figure 5).

Key events include the origin of life around 3.5 billion years ago when the first simple prokaryotic organisms emerged. The first photosynthetic organisms emerged 2.4 billion years ago, which gave rise to increased atmospheric oxygen. In turn, this allowed for the evolution of the first eukaryotic cells approximately 2 billion years ago, followed by more complex multicellular organisms 600 million years ago.

The Cambrian "explosion", 540 million years ago, gave rise to a rapid diversification of life forms, resulting in the emergence of most major animal groups. An estimated 420 million years ago, plants and fungi began to colonise terrestrial environments, followed by animals. Dinosaurs became the dominant terrestrial vertebrates between 230 to 66 million years ago.

Major extinction events led to the demise of the dinosaurs and the rise of mammals, which diversified and became the dominant land animals 66 million years ago, with humans first appearing relatively recently around 2 million years ago.

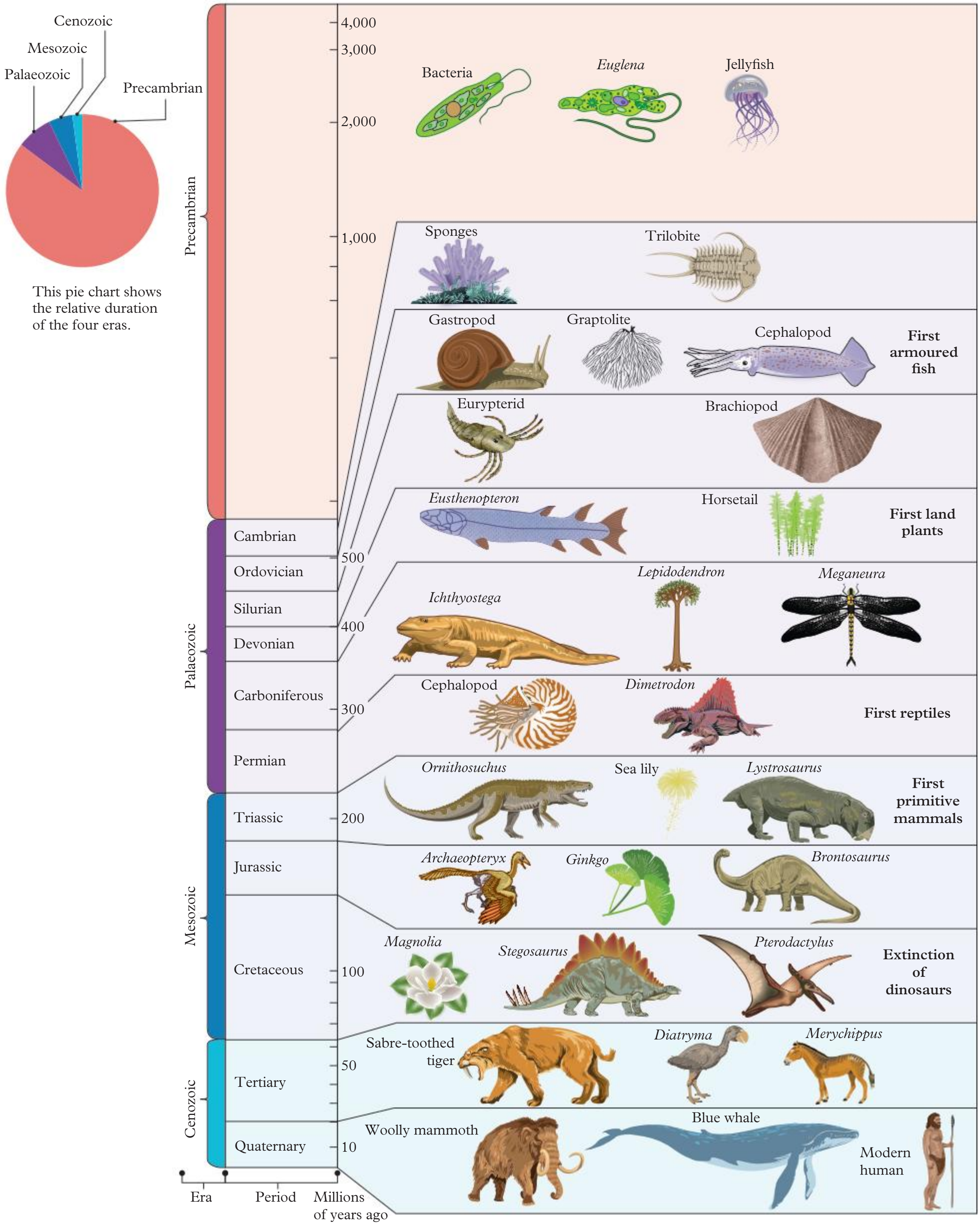


Figure 5 The history of living things (mya = million years ago), as determined by palaeontology (the study of fossils)

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 (Figure 6).

Figure 6 Unique in the animal kingdom, the coelacanth is a 400-million-year-old species of living fossil fish. The coelacanth pre-dates dinosaurs by millions of years and was thought to have become extinct with them. In 1938, the coelacanth was discovered living in caves off the continental shelf. This environment has changed little over the past 400 million years and, as a result, neither has the coelacanth.

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** (Figure 7).

Figure 7 Ammonite trace fossil. Only the imprint remains.

living fossil an existing species of ancient lineage that has remained unchanged in form for a very long time

trace fossil a geological record of biological activity, distinct from body fossils; includes footprints, burrows, nests, fossilised dung and bite marks

Check your learning 9.5

Check your learning 9.5

Retrieve

1 Define the term "transitional fossil" and provide an example.

Comprehend

2 Describe the process of relative dating of a fossil.

3 Living fossils have remained relatively unchanged, often for millions of years, while other species have adapted or become extinct. Explain why some species are able to remain unchanged for such a long period.

Analyse

4 A well-preserved fossil of a sawfly was discovered at McGraths Flat, NSW. The age of the fossil could be determined using absolute dating. If the amount of hafnium-182 (half-life approximately 8.5 million years) remaining had decreased from 100 to 25 per cent, calculate the age of the sawfly.

5 Contrast relative dating and absolute dating to show the differences between the two processes.

Apply

6 Compare the terms "scientific fact" and "scientific theory". Evaluate whether the theory of evolution could ever become a fact.

7 Fossils were found at four locations (Figure 8). Use relative dating to determine which location had the oldest fossils.

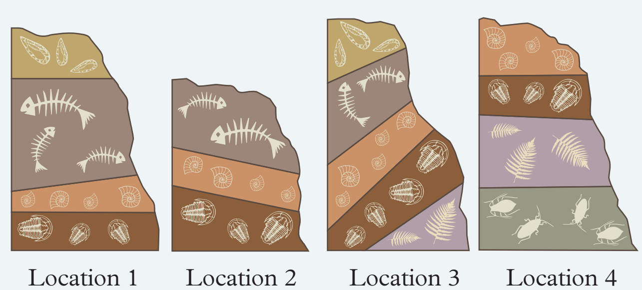


Figure 8 Fossils found at four different locations

Lesson 9.6
Investigation: Popcorn dating

Caution

Do not eat or drink in the laboratory.

Purpose

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)
- Four large trays

Procedure

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

1 Copy and complete Table 1.

2 Draw a graph of your results.

Discussion

1 Define the term "half-life".

2 Calculate the half-life of your popcorn kernels.

3 Identify how long the mystery bag D was heated in the microwave oven.

a Compare your answer with that of other students.

b Compare your answer with the actual time provided by your teacher.

4 Explain why the absolute 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).

5 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.

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				

Lesson 9.7
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

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 puzzle (Figure 1). Since then, our understanding of the structure of the Earth has advanced, and the theory of **continental drift** through plate tectonics has been supported by observations of various phenomena around the planet. It is now believed that all the continents were once connected in a single land mass known as Pangaea (Figure 2). This supercontinent eventually broke into two landmasses, forming Gondwana in the south and Laurasia north of the Equator. Over a long period, these landmasses drifted apart, and some later re-joined to form the continents that we now know. During this drift, populations of organisms were separated, leading to the formation of new, diverged species.

continental drift the continuous movement of the continents over time

This theory of continental drift is supported by identical fossils buried on the land masses that used to be joined (Figure 3). An example of this is fossilised pollen that has been found in Antarctica, India and Australia. 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.

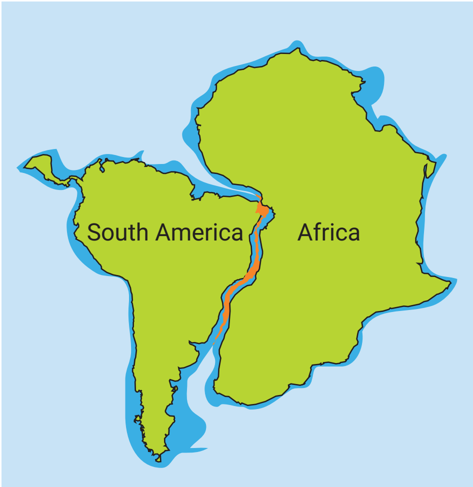


Figure 1 The jigsaw fit of Africa and South America supports the theory of continental drift.

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.

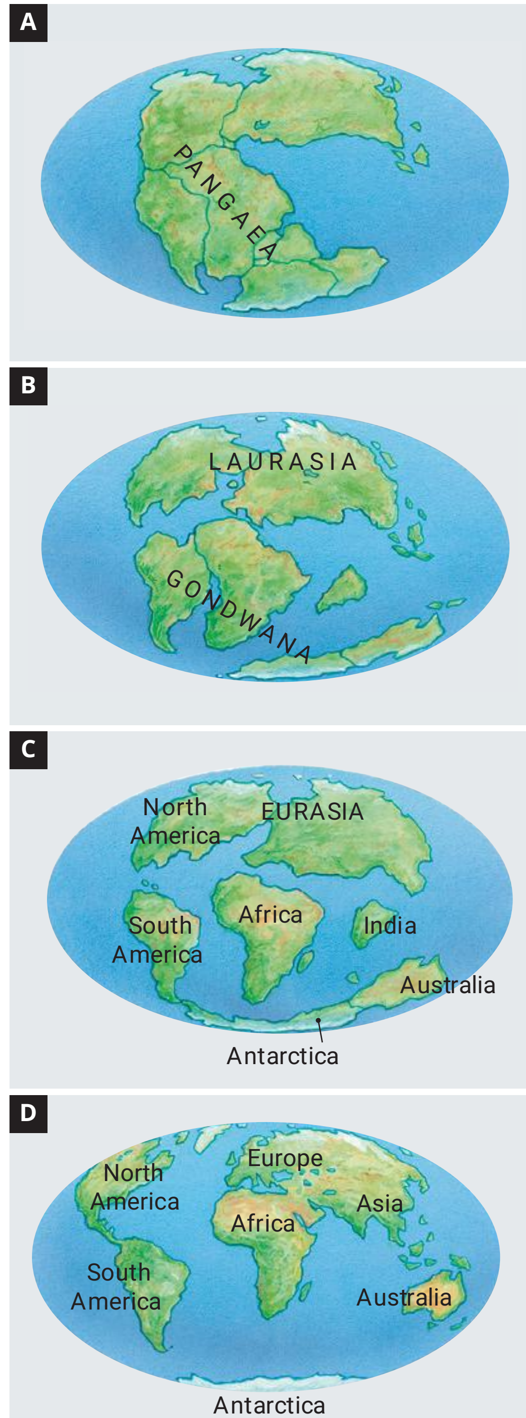


Figure 2 How the continents have drifted: (A) 220 million years ago; (B) 135 million years ago; (C) 65 million years ago; and (D) today

Vestigial structures

vestigial structure a structure in an organism that no longer has an obvious purpose

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. 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 (i.e. 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 hind-limb 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.

Vestigial structures are now interpreted as evidence of an ancestral heritage. 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.

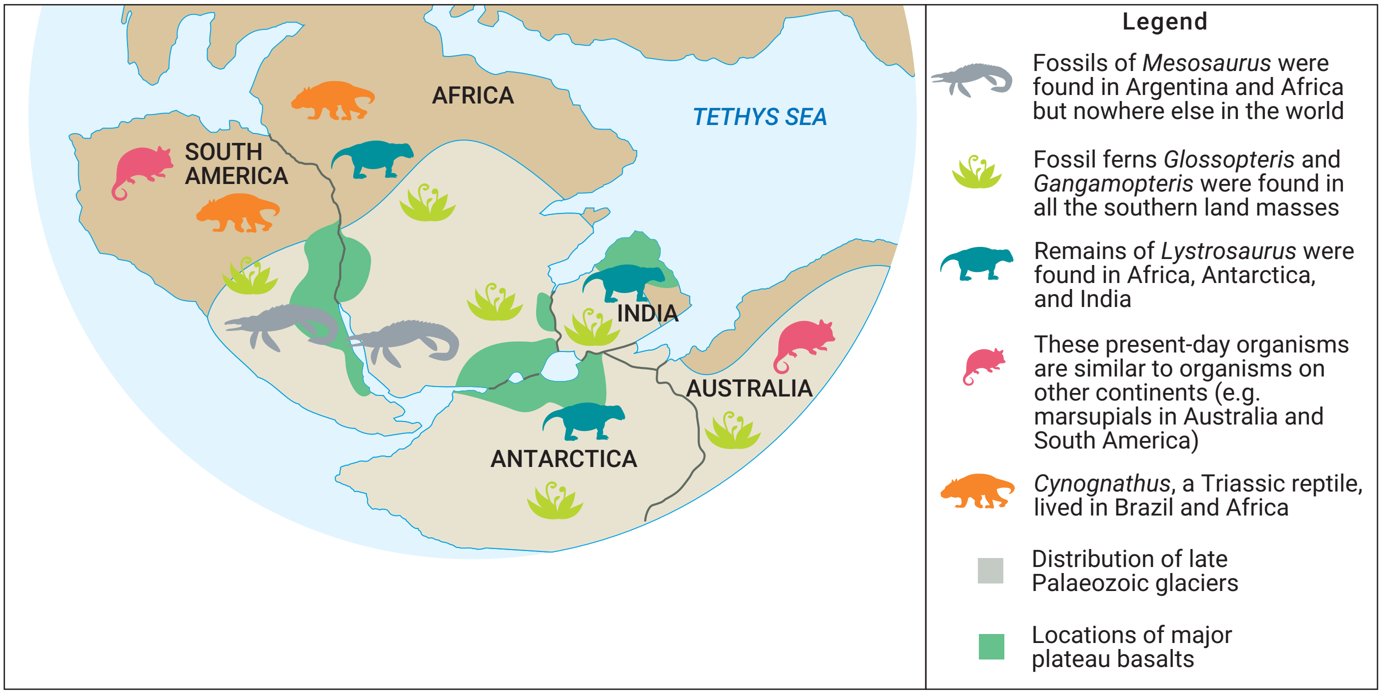


Figure 3 Evidence for the existence of the supercontinent Gondwana is provided by the similarity of fossils on different continents.

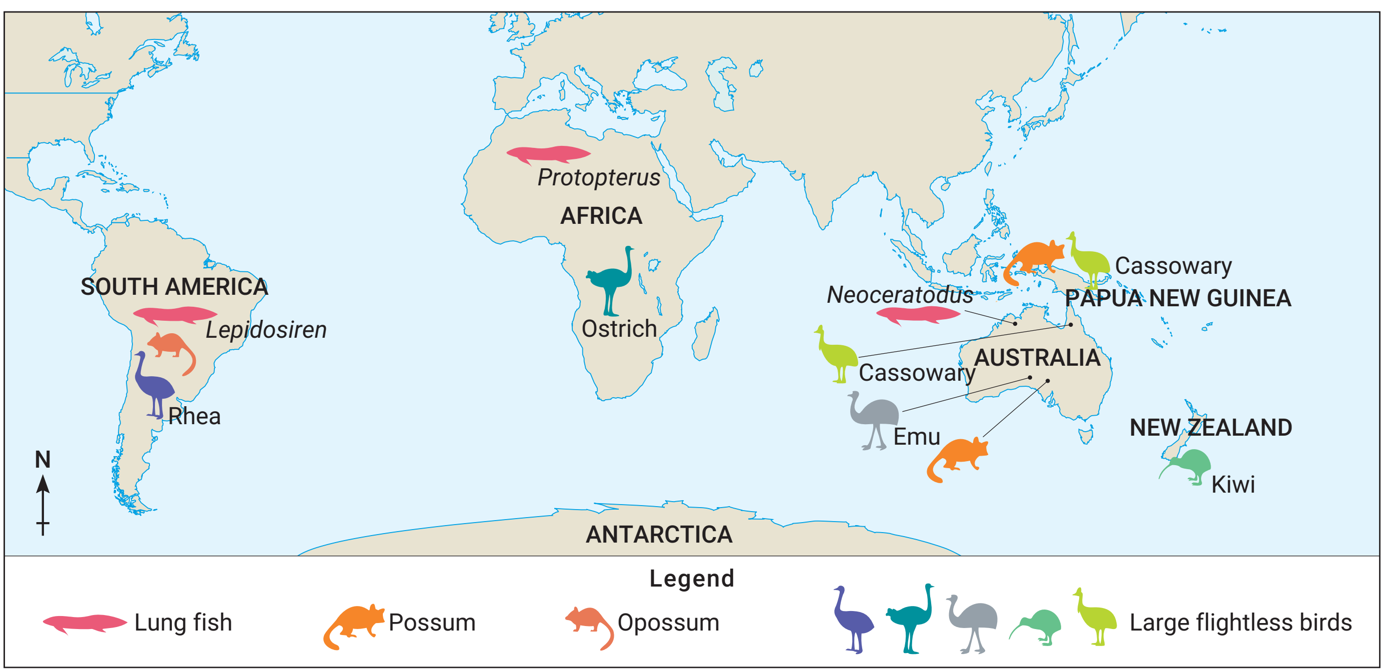


Figure 4 Similar lungfish are found in South America, Africa and Australia. Similar marsupials are found in South America and Australia.

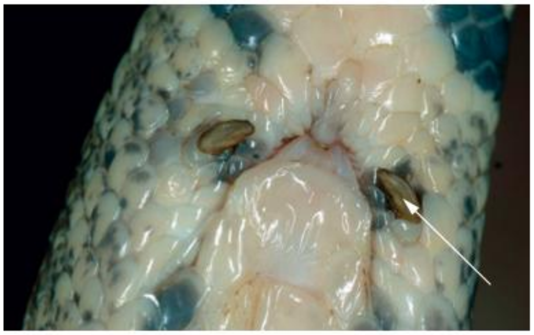


Figure 5 The rear legs on a snake (as shown by the arrow) are an example of a vestigial structure.

Analysing embryos

Scientists have observed that although adults from the five classes of vertebrates exhibit obvious differences when fully formed, a comparison of their embryos shows striking similarities during the early stages of development (Figure 6). To the untrained eye, it is nearly impossible to distinguish between an early embryonic fish, chicken or human, as they share many interesting homologous structures, such as gill slits and a tail, that are not present in the fully developed animals.

As embryonic development progresses, the similarities between the more closely related vertebrate classes continue. For example, the fish and amphibian (salamander) in Figure 6 appear similar late in embryonic development, as do the reptile (tortoise) and bird (chicken). The similarities within the same class are also clear when observing the pig, rabbit and human.

The embryological similarities can only be explained by inferring that these organisms all share a common ancestry with common genes. 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, turned 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.

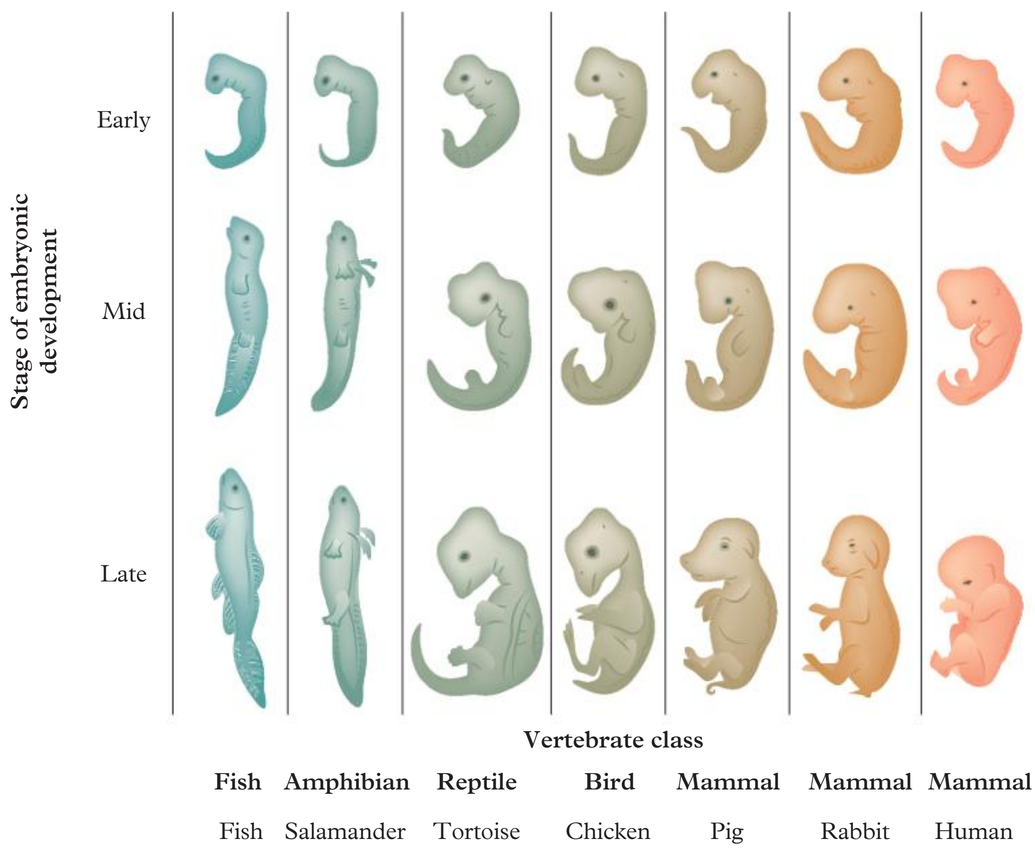


Figure 6 Common structures in the early stages of embryonic development of vertebrates indicate the existence of common genes.

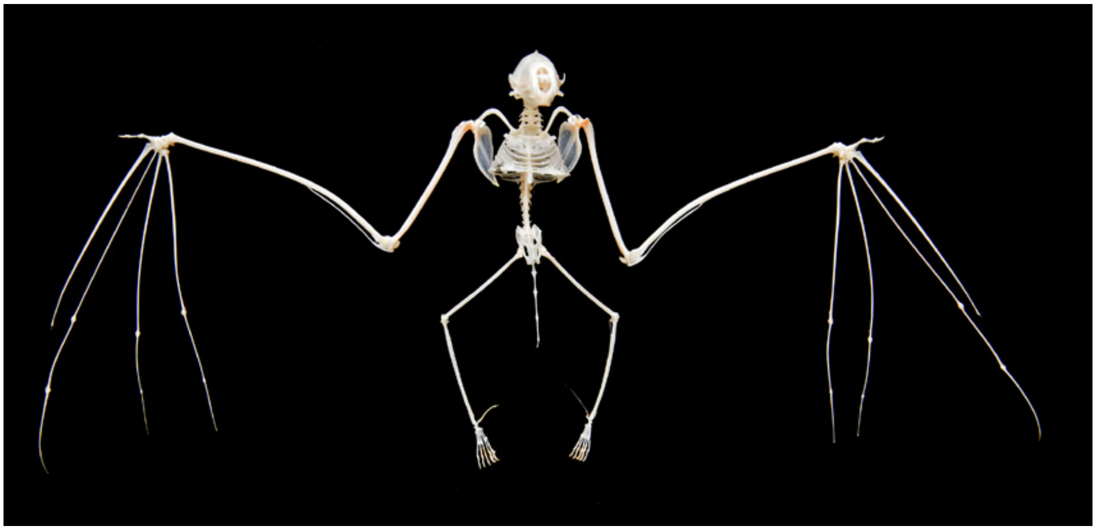


Figure 7 As an embryo, the "finger genes" of the bat become more active. As a result, the bat's fingers grow much faster than the fingers of other embryos.

Check your learning 9.7

Check your learning 9.7

Retrieve

1 Outline the observation made by Francis Bacon that was later used as evidence of continental drift.

2 Describe how the gene that forms fingers changes to form the wings on a bat.

Comprehend

3 The frogs in Australia show their closest evolutionary relationships to frogs in Africa and South America. Explain how this is possible.

4 Explain how the presence of vestigial structures supports the theory of evolution.

5 Explain why human embryos temporarily develop gill-like structures.

Analyse

6 Compare and contrast the embryological development of vertebrates mentioned in the text. What do these similarities reveal about the evolutionary relationships among different species, and how do they challenge the idea of independent evolution?

Apply

7 A student thinks that if native Australian marsupials were found in North America, this would support the theory of continental drift. Evaluate their claim by:
- describing two reasons that support their claim
- describing two reasons that refute their claim
- deciding which reasons are most convincing.

Skills builder: Problem solving

8 Geologists are identifying ancient magnetic rocks that suggest magnetic north has moved over millions of years.
  a Explain how this information could be used to support the theory of continental drift, and how this could impact the theory of evolution. (THINK: What does this evidence suggest? Can you think of a scientific theory to apply to this evidence?)
  b Identify the information that would support how this could change the theory of evolution. (THINK: What is the theory of evolution based on? Is this information more likely to support or refute the theory of evolution?)

Lesson 9.8

DNA and proteins provide chemical evidence for evolution

Learning intentions and success criteria

Key ideas

- → The basic structure of DNA and proteins is identical for all species on the 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

Recall from Module 8 Genetics (page 322) that DNA (deoxyribonucleic acid) is the hereditary material in all organisms and is composed of two long strands that form a double-helix structure. Each strand consists of a sequence of nucleotides, which are the building blocks of DNA.

The best evidence in support of evolutionary theory comes from comparing the DNA sequences of different organisms. For example, in a study comparing the DNA sequences of chimpanzees and humans, researchers found that 97 per cent of the nucleotide sequence is identical between the two species. This similarity suggests that millions of years ago, humans and chimpanzees shared a common ancestor. Over time, a separation in the population of these 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, which contributed to the divergence and formation of distinct species: humans and chimpanzees.

evolutionary relationship the way in which two species or populations are related with respect to their evolutionary descent

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 (Figure 1).

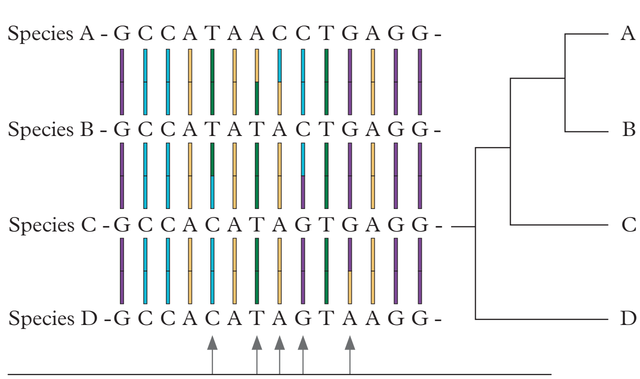


Figure 1 Comparing DNA sequences allows scientists to determine the evolutionary relationship between different species. Species A is most closely related to B. Species D is the most distant relative of A. A phylogenetic tree for the four species is shown on the right.

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. Recall from Module 8 Genetics (page 322) that 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.

amino acid the building blocks of proteins, consisting of an amino group, a carboxyl group and a variable side chain

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, which 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.

The same type of proteins can be remarkably similar across different species. Cytochrome c, a protein involved in energy production during cellular respiration, is one such example (Figure 2). 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 reveal 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. As the two species diverge, the number of mutations gradually accumulates. While these mutations may not alter the protein's structure or function, they can change a few amino acids in the long chain. Over time, the number of changes in the amino acid sequence increases. Therefore, the more similar the protein sequences are between two species, the more closely related they are. This indicates that organisms with similar proteins share a recent common ancestor.

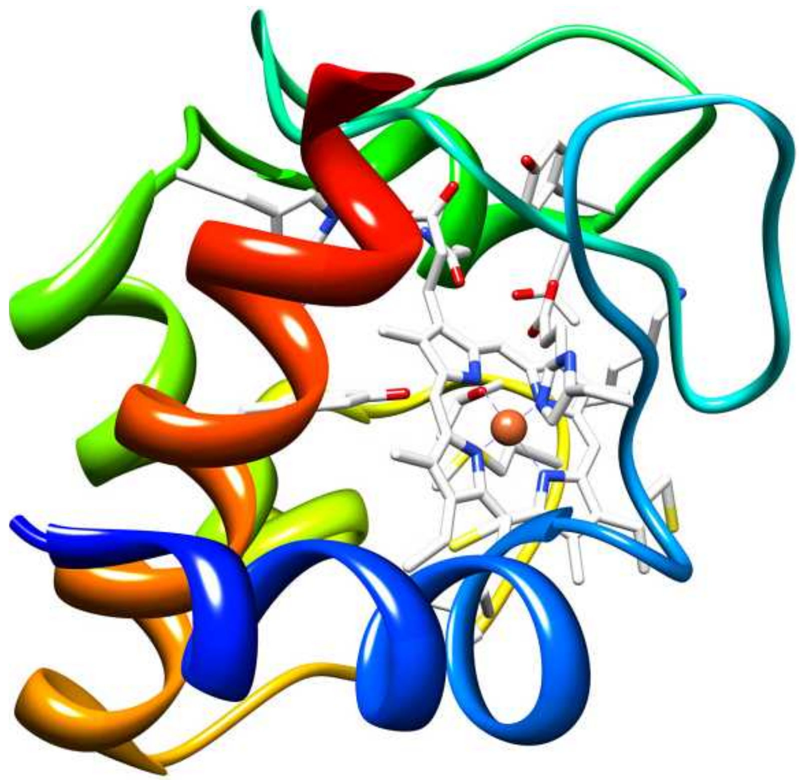


Figure 2 There are many sequences of amino acids that could make a functional cytochrome c molecule.

Table 1 The sequence of amino acids that make up cytochrome c protein in different animals. Note: Amino acids are identified by a three-letter code: Val = valine; Glu = glutamic acid; Lys = lysine; Gly = glycine; Ile = isoleucine; Phe = phenylalanine.

Human	Val	Glu	Lys	Gly	Lys	Lys	Ile	Phe	Ile
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

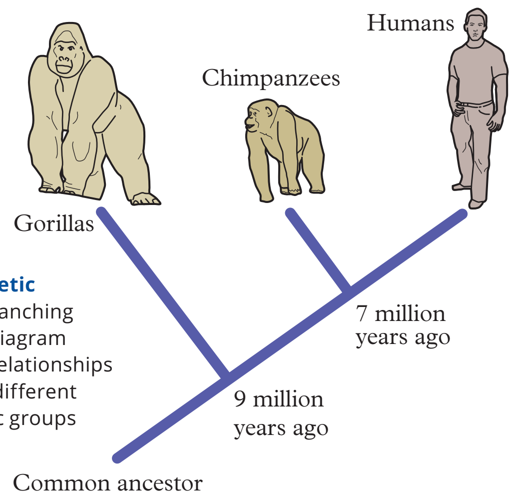


Figure 3 Gene sequencing has shown that humans, gorillas and chimpanzees all evolved from a common ancestor.

phylogenetic tree a branching tree-like diagram showing relationships between different taxonomic groups

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.

One way of showing how closely related different organisms are is through a **phylogenetic tree** (Figure 3). 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.

Check your learning 9.8

Check your learning 9.8

Retrieve

1 Identify the smaller (bead-like) structures that make up proteins.

2 Identify the original cause of changes to the amino acid sequence of a protein.

Comprehend

3 Cytochrome c is of interest to biologists studying evolution. Describe how the study of the 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
   - 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
   - explaining how this is an indication of evolutionary relationships.

6 Use the phylogenetic tree in Figure 4 to determine:
   - which species is most closely related to species A
   - which species are most closely related to species C.

   Justify your answer.

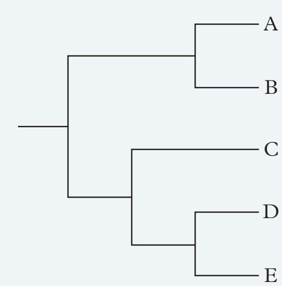


Figure 4 A phylogenetic tree

7 A student claims that sharks and dolphins are closely related because they both live in the ocean and have similar body shapes.
   a Explain why this belief is incorrect, focusing on the evolutionary relationships between sharks and dolphins.
   b Describe the key differences in the classification of sharks and dolphins that highlight their distinct evolutionary pathways.
   c Provide examples of two features that support the idea of convergent evolution in this context.

Lesson 9.9
Investigation: Who is my cousin?

Purpose

To determine the evolutionary relationship between different species

Materials

- DNA sequences, listed below:
  - hippo: AGTCCCCAAAGCAAAGGAGAC TATCCTTCCTAAGCATAAAGAAATG CCCTTCTCTAAATC
  - giraffe: AGTCTCCAAATGAAAGGAGA CTATGGCTCCTAAGCACAAAGAAAT GCCCTTCCCTAAATA
  - rhino: AGTCCTCCAAACTAAGGAGACC ATCTTTCCTAAGCTCAAAGTTATGC CCTCCCTTAAATC
  - pig: AGATTCCAAAGCTAAGGAGACCA TTGTTCCCAAGCGTAAAGGAATGCC CTTCCCTAAATC
  - cow: AGTCCCCAAATGAAAGGAGACT ATGGTTCCTAAGCACAAGGAAATGC CCTTCCCTAAATA

Procedure

Compare the DNA sequences with each other and determine the number of differences between each pair.

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

Animal	Hippo	Cow	Giraffe	Rhino	Pig
Hippo					
Cow					
Giraffe					
Rhino					
Pig					

Discussion

1 Understanding the genetic similarities and differences among various species can provide valuable insights into their evolutionary relationships.
   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 By comparing DNA sequences, we can determine how closely related different animals are and infer their common ancestry.
   a Identify the animal that has the greatest 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.

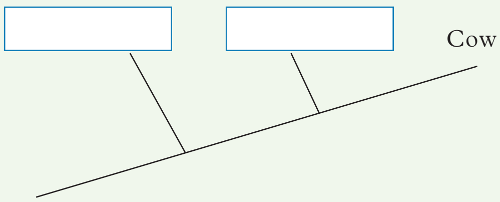


Figure 1 Phylogenetic tree

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 9.10

Aboriginal and Torres Strait Islander Peoples' artwork provides evidence of ecosystem change

Learning intentions and success criteria

Key ideas

→ Aboriginal and Torres Strait Islander Peoples have inhabited Australia for at least 65,000 years.

→ Rock paintings dated to over 10,000 years old show evidence that megafauna coexisted with Aboriginal and Torres Strait Islander Peoples.

Historical significance of Aboriginal and Torres Strait Islander Peoples in Australia

Aboriginal and Torres Strait Islander Peoples have inhabited Australia for at least 65,000 years, making them one of the world's oldest continuous cultures. Archaeological evidence suggests a rich tapestry of cultural, spiritual and social practices, which can be observed through ancient rock and bark paintings, as well as rock and tree carvings. These paintings provide valuable insights into ecological changes over time, including significant shifts in plant and animal life and evidence of now-extinct species believed to have disappeared around the end of the last Ice Age, likely due to a combination of climate change and human impact.

Megafauna

The term **megafauna** refers to large animals, typically extinct species that were significantly larger than modern-day relatives. In Australia, examples include:

- *Diprotodon*, the largest marsupial to ever exist, resembling a giant wombat and weighing up to 3000 kg
- *Megalania*, a giant monitor lizard that grew up to 7 m long
- *Procoptodon*, a large species of kangaroo that stood over 2 m tall
- *Genyornis*, a large flightless bird, similar to an emu, that stood 2.5 m tall.

Fossil evidence of megafauna indicates that they were present in Australia from 2.5 million to 11,700 years ago, suggesting they coexisted with Aboriginal and Torres Strait Islander Peoples for an extended period. This is further supported by rock paintings depicting a range of megafauna, particularly across Northern Australia.

megafauna large animals, typically extinct species that were significantly larger than modern-day relatives

Procoptodon goliah

The short-face kangaroo, *Procoptodon goliah*, is the largest kangaroo known to have existed, standing up to 2 m tall and weighing over 200 kg (Figure 1). Fossil sites in South Australia, NSW and Queensland indicate that *Procoptodon* species were widespread across Australia.

Initial dating of *Procoptodon* fossils suggested they went extinct 65,000 years ago; however, more recent evidence, including rock paintings, indicates they may have survived much longer. While dating rock paintings directly is difficult, due to their lack of organic pigments suitable for carbon dating, current estimates suggest that these paintings were created around 10,000 years ago, potentially indicating the survival of *Procoptodon* closer to that time.

Figure 1 A recreation of *Procoptodon* based on available fossil evidence

Diprotodon species

There are at least four recognised species of *Diprotodon* identified from fossil records. The largest of these was *Diprotodon optatum*, reaching a length of up to 4 m and weighing up to 3,000 kg. Like *Procoptodon*, *Diprotodon* species were widespread across Australia, with fossil sites found across the country.

Diprotodon went extinct approximately 25,000 years ago. Some rock painting sites in northern Australia, estimated to be as old as 40,000 years, include paintings of *Diprotodon*, such as those found in Cape York, Queensland. They provide evidence that *Diprotodon* coexisted with Aboriginal and Torres Strait Islander Peoples (Figure 2).

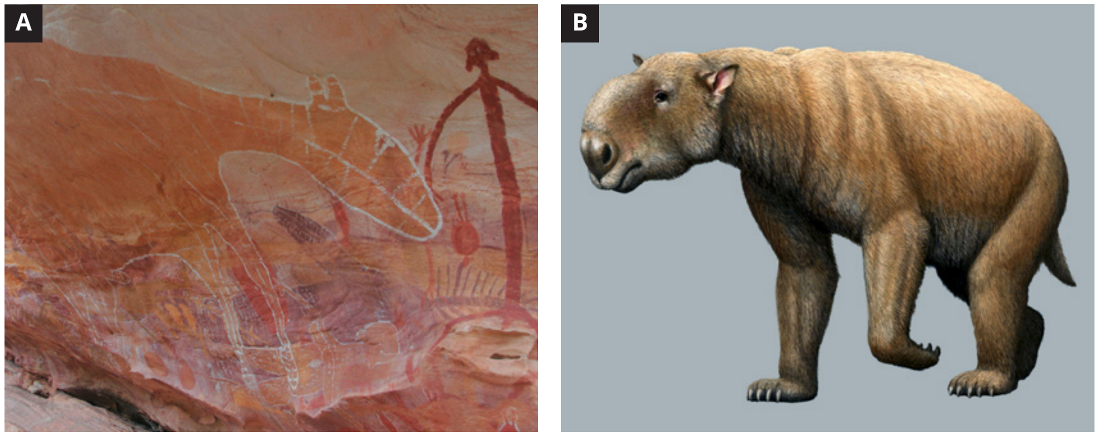


Figure 2 (A) Rock painting from Cape York, Queensland, showing what appears to be a *Diprotodon* encountering a human; (B) Recreation of *Diprotodon* based on available fossil evidence

Thylacinus cynocephalus

More commonly known as the thylacine or Tasmanian tiger, *Thylacinus cynocephalus* was a large carnivorous marsupial weighing up to 30 kg. Thylacines were once widespread across mainland Australia, Tasmania and New Guinea. They went extinct in mainland Australia and New Guinea approximately 2,000 to 3,500 years ago, however, likely due to competition from the introduction of the dingo.

Prior to European arrival, an estimated 5,000 thylacines remained in the wild in Tasmania. Unfortunately, a perceived threat to the livestock of farmers resulted in them being hunted to extinction. The last known wild thylacine was killed in 1930 and the last captive animal, Benjamin, died in Hobart Zoo in 1936.

Rock paintings that clearly depict thylacine have been discovered across northern Australia and are dated to around 3,000 years old. This serves as compelling evidence that Aboriginal People coexisted with this species, and further highlights the dynamic changes in Australia's fauna over time (Figure 3).

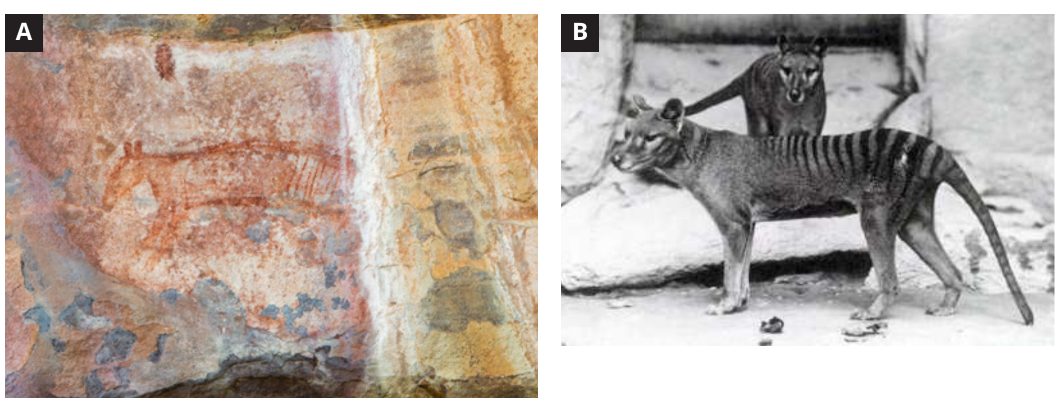


Figure 3 (A) Rock painting of *Thylacinus cynocephalus* from Kakadu, Northern Territory; (B) Photograph of two of the last remaining thylacines in captivity

Plants

The number of rock paintings of plants – particularly extinct plants – is far less than those of animals, possibly indicating the greater cultural and spiritual significance of animals to Aboriginal and Torres Strait Islander Peoples. The examples that do exist offer valuable insights into the plant life that Aboriginal and Torres Strait Islander Peoples interacted with, particularly those that served as important food sources or were used for medicinal purposes. Changes in the representation of plants in rock paintings can indicate shifts in plant species abundance, ecological conditions and cultural significance (Figure 4). Identified examples include yams, various fruits, native grasses, water lilies and ferns.

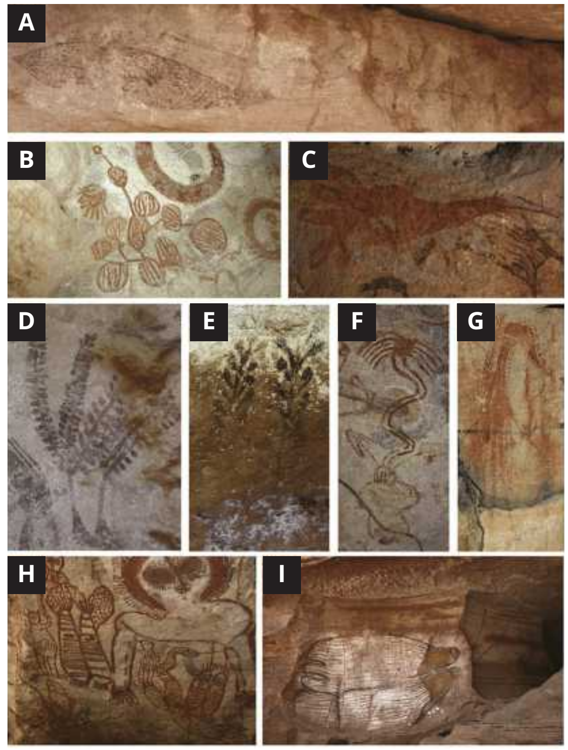


Figure 4 Plants depicted in Kimberley rock art: (A) Irregular-infill-animal period tuber with tendrils, vine and leaves; (B) Wanjina-style string of yams; (C) Painted-hand-style yam; (D) Gwion-style plant; (E) Painted-hand-style sprig of fruit motifs; (F) Painted-hand-style lily; (G) Gwion-style human figure with fern leaf; (H) Wanjina-style "yams with eyes" associated with human figures; (I) Wanjina-style yams with tendrils, vine and leaves

Check your learning 9.10

Check your learning 9.10

Retrieve

1 Define "megafauna".

2 Identify two species of megafauna known to coexist with Aboriginal and Torres Strait Islander Peoples.

Comprehend

3 Explain how the rock paintings of the thylacine in the Northern Territory provide evidence of changing ecosystems.

4 Explain why direct dating of rock paintings is challenging.

Analyse

5 Analyse the significance of rock paintings depicting megafauna in understanding the ecological changes and environmental conditions experienced by Aboriginal and Torres Strait Islander Peoples over time.

Apply

6 Assess the impact of European colonisation on the extinction of the thylacine.

Lesson 9.11

Science in context: The origin of Darwin and Wallace's theory of evolution

Figure 1 These layers of rock are an indication of different time periods. Pale layers can sometimes represent volcanic ash released during an eruption.

Figure 2 Lamarck believed that giraffes stretched their necks to reach food, and that their offspring and later generations inherited the resulting long, stretched necks.

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. 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. Natural phenomena, including volcanic eruptions and earthquakes, were considered to be manifestations of the gods' emotions. Societies typically worshipped one or more gods, who were depicted with either human or animal-like characteristics.

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 he was able to "date" them by the layer of rock in which they were found (Figure 1). This later became known as relative dating.

Georges Cuvier, a French zoologist, collected and studied many fossils, ultimately concluding that many of the specimens belonged to species that are now extinct.

Mary Anning, a palaeontologist, collected and sold fossils to support her family, gaining recognition for her groundbreaking discovery of a five-metre-long *Ichthyosaurus* fossil. Despite her contributions, Anning faced significant barriers due to the gender norms of her time, as women were excluded from scientific societies. Consequently, many of the fossils she unearthed were often credited to male colleagues, overshadowing her vital role in the field of palaeontology.

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, and because their necks were strong, their children were born with long and strong necks.

Lamarck's hypothesis faced several significant challenges. For example, it implied that a man who had lost his arm would have children with weak or deformed arms, which is clearly contradicted by observed reality. The scientific evidence that disproved the idea of inheritance of acquired characteristics was provided by August Weismann. He performed an experiment, cutting the tails off 22 generations of mice, while allowing them to breed with each other. Unsurprisingly, all the offspring were born with tails.

Charles Darwin

Charles Darwin (1809–1882, Figure 3) was well educated and had been exposed to the sciences from an early age through his father and grandfather, who were both physicians. Darwin had also read the works of Lamarck. In 1832, the young 23-year-old set sail on a five-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 a diverse range of specimens, trying to obtain at least one of each species. Among the specimens collected were 13 finches that – despite their remarkable similarities in beak structure, body shape and plumage – were each classified as

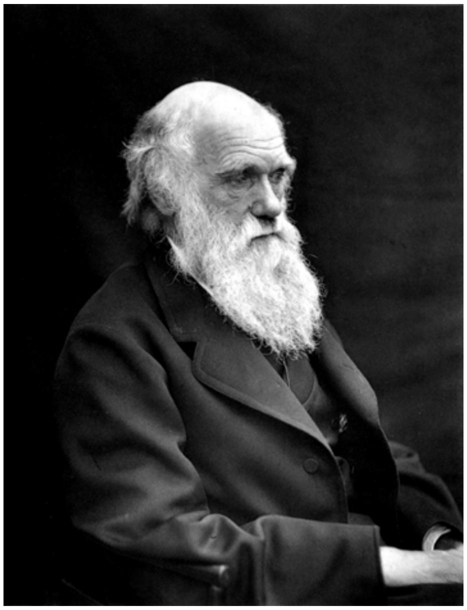


Figure 3 Charles Darwin's theory of evolution was a departure from the traditional view of Creation and attracted much public interest and criticism.

Figure 4 Darwin studied several species of finch on the Galapagos Islands.

Figure 5 On the Galapagos Islands, tortoises' shells vary in shape according to habitat.

distinct species. Importantly, most of these finches were found on different islands, highlighting the unique evolutionary paths taken by species in isolation (Figure 4).

In his journal, Darwin noted that these birds were strikingly similar to those found on the mainland of South America. This led him to question why the different populations looked so similar, if new and distinct beings had been placed on the islands at the time of Creation.

The arid, volcanic Galapagos Islands archipelago is also home to different species of tortoise, each adapted to their specific environments. Darwin observed that the different types of tortoise had different-shaped shells (Figure 5). Tortoises that lived on dry islands, such as Hood Island, had shells that were raised at the front so they could reach up for vegetation. In contrast, tortoises that lived on islands with dense vegetation had low-domed shells to help them push through the shrubbery.

When he returned to England, Darwin became aware that humans had 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 1798 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 6). Darwin concluded from this that, under changing circumstances, favourable variations would tend to be preserved and unfavourable ones would be destroyed.

At last, Darwin had a hypothesis to test, but it would take another 20 years of painstaking hard work 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.

Figure 6 Was the plague simply nature's way of keeping the human population in check?

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, now known as Malaysia and Indonesia.

Wallace collected thousands of specimens, including insects, shells and bird skins, as well as mammal and reptile samples, many of which were new species to science at the time. Two of his best-known discoveries are Wallace's standardwing bird-of-paradise (*Semioptera wallacei*), renowned for its striking plumage (Figure 7A), and Wallace's flying frog (*Rhacophorus nigropalmatus*), noted for its large, webbed feet and ability to glide between trees (Figure 7B).

During his time in the Malay Archipelago, Wallace independently proposed the theory of natural selection as the mechanism for evolution. In 1858, he corresponded with Darwin, outlining his ideas in a series of letters.

Concerned about the implications of their similar theories, Darwin and his friends debated how best to share credit for the groundbreaking work of both men, given both theories 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 7 (A) Wallace's standardwing bird-of-paradise (*Semioptera wallacei*); (B) Wallace's flying frog (*Rhacophorus nigropalmatus*)

Understanding the importance of the origins of species

Biodiversity and conservation

Knowing how species evolve can help us appreciate the diversity of life on the Earth. This understanding is essential for conservation efforts, as it informs strategies to protect endangered species and their habitats, recognising the interdependence of ecosystems.

Evolutionary biology

The study of species' origins provides insights into the mechanisms of evolution, such as natural selection, mutation and **genetic drift**. This foundational knowledge is critical for the field of evolutionary biology and helps scientists understand how life adapts over time.

genetic drift a random evolutionary mechanism that causes changes in allele frequencies within a population's gene pool over time

Medical and agricultural advances

Understanding species' origins can lead to breakthroughs in medical research and agriculture. For example, studying the evolution of pathogens can help in developing vaccines and treatments, while knowledge of plant and animal evolution can improve crop yields and livestock breeding.

Ecological balance

Recognising how species interact within ecosystems helps us understand ecological balance. This knowledge is vital for managing natural resources and addressing environmental challenges such as climate change, habitat destruction and invasive species.

Cultural and philosophical perspectives

Understanding the origins of species also has implications for philosophy and ethics, influencing our views on humanity's place in nature, our responsibilities towards other living beings and the moral considerations of biodiversity loss.

Test your skills and capabilities

Test your skills and capabilities 9.11

Refining science theories

Although Charles Darwin is credited with the theory of evolution, he built on 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 doing the following.
- **a** Compare (the similarities and differences between) Lamarck's theory and Darwin's theory.
- **b** Discuss the importance of August Weismann's experiment.
- **c** Compare the different approaches of Darwin and Wallace.
- **d** Decide which scientists made significant contributions to the theory of evolution.

Skills builder: Communicating

2 This section presented several evolutionary theories. Construct a timeline to present this information succinctly. (THINK: What are the key events? Where do I need to include these?)

Lesson 9.12
Review: Evolutionary change

Summary

Lesson 9.1 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 whereby selection pressures (environmental factors affecting an organism's survival) choose a trait or characteristic (or do not choose it) so that a species becomes better suited to its environment. The concept of "survival of the fittest" drives natural selection.
- All scientists make observations of the world around them; they then use these observations and reasoning to draw conclusions (inferences).

Lesson 9.3 Convergent and divergent evolution

- 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 9.5 Fossils provide evidence of evolution

- Fossils are the 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 9.7 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 9.8 DNA and proteins provide chemical evidence for evolution

- The basic structure of DNA and proteins is identical for all species on the 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 9.10 Aboriginal and Torres Strait Islander Peoples' artwork provides evidence of ecosystem change

- Aboriginal and Torres Strait Islander Peoples have inhabited Australia for at least 65,000 years.
- Rock paintings dated to over 10,000 years old show evidence that megafauna coexisted with Aboriginal and Torres Strait Islander Peoples.

Review questions 9.12

Review questions Module 9

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

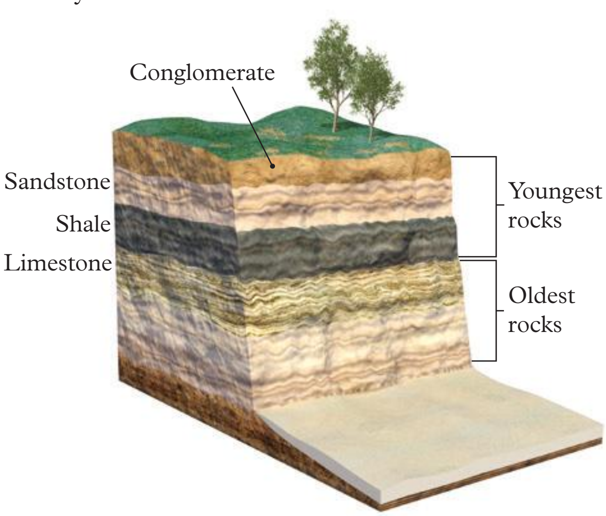


Figure 1 Layers of rock

4 Define the term "natural selection" and identify the four essential factors for this process.

5 Define the terms "gene pool" and "genetic drift".

6 Distinguish between convergent and divergent evolution.
  a *Archaeopteryx* had features of both birds and lizards. Identify the term that is applied to fossils that show the evolutionary progression between two very different forms.

Comprehend

7 Explain the difference between incorrectly suggesting an organism has evolved and correctly suggesting that a population of organisms has evolved.

8 Describe Gondwana.

9 The layering of sedimentary rocks is useful in relative dating. Explain the basic principle of comparative dating.

10 Explain precisely how fossils provide evidence for evolution.

11 Explain why a vestigial structure, once it has been reduced to a certain size, may not disappear altogether.

12 Explain how the study of DNA sequences helps in our understanding of evolution.

13 Use examples to illustrate the two critical deductions that Darwin made: the struggle for existence and the survival of the fittest.

Analyse

14 Contrast a hypothesis and a theory.

15 Contrast "transitional fossil" and "living fossil".

16 Compare the terms "allopatric speciation" and "gene flow".

17 Compare the terms "diversity" and "evolution".

Apply

18 *Callistemon* (bottlebrushes) are unusual because their stems (branches) do not terminate in flowers

Figure 2 *Callistemon* flowers

Figure 3 Tortoises on different Galapagos Islands have unique features.

(Figure 2). 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.

19 The tortoises of the Galapagos Islands (Figure 3) 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.

20 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.

21 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), *Diprotodon* 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

22 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

23 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.

24 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 them.

25 Evaluate the strengths and weaknesses of the various forms of evidence that support evolution.

Research

26 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.

Darwin and the Galapagos Islands

Much of Darwin's theory developed while he was visiting the Galapagos Islands.

- Identify which new species Darwin found there.
- Describe what was so unique about these species.
- Describe how Darwin's findings helped him to develop his ideas.
- Explain what was unique about the Galapagos Islands that helped Darwin develop his theories.

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 the governmental policies and societal attitudes.

Figure 4 The White Australia Policy was one of several inhumane and profoundly hurtful policies based on a misconception of heredity and evolution.

Modern-day evidence for evolution

There is evidence of current populations evolving by natural selection all around us. Investigate one of the following topics and see whether you can find evidence of evolution by natural selection occurring today.

- Explain how controlled breeding can modify organisms.
- Explain how the number of predators can affect the evolution of bright colouration.
- Explain how natural selection leads to pesticide resistance.

Figure 5 *Myzus persicae* (green peach aphid) is resistant to multiple pesticides and is a problem for Australian farmers.

Climate change and natural selection

Climate scientists predict that the average temperature of the Earth will increase by 2°C over the next 100 years.

- Explain how this climate change will affect species on the 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.
- Describe how a new species may evolve as a result of climate change.

Figure 6 Increased incidence of bushfires in Australia is one of the devastating effects of increasing global temperatures.

Real-time evolution

Significant advances in our understanding of evolution by natural selection have been vital to the study of diseases and pests. Antibiotic resistance in bacteria and the tolerance to herbicides in crops and pesticides in agriculture are monitored closely.

- Explain why these examples are important.
- Explain why they need close monitoring.
- Explain why these organisms demonstrate evolution at such a fast rate.

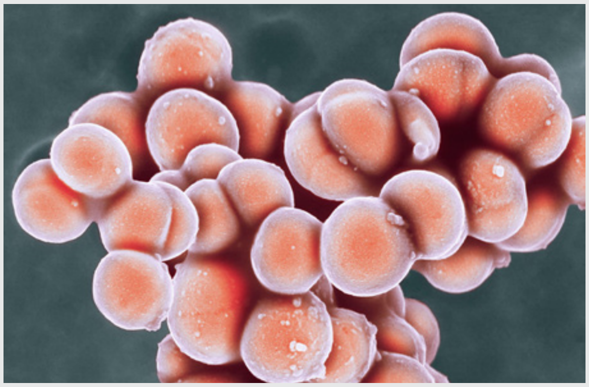
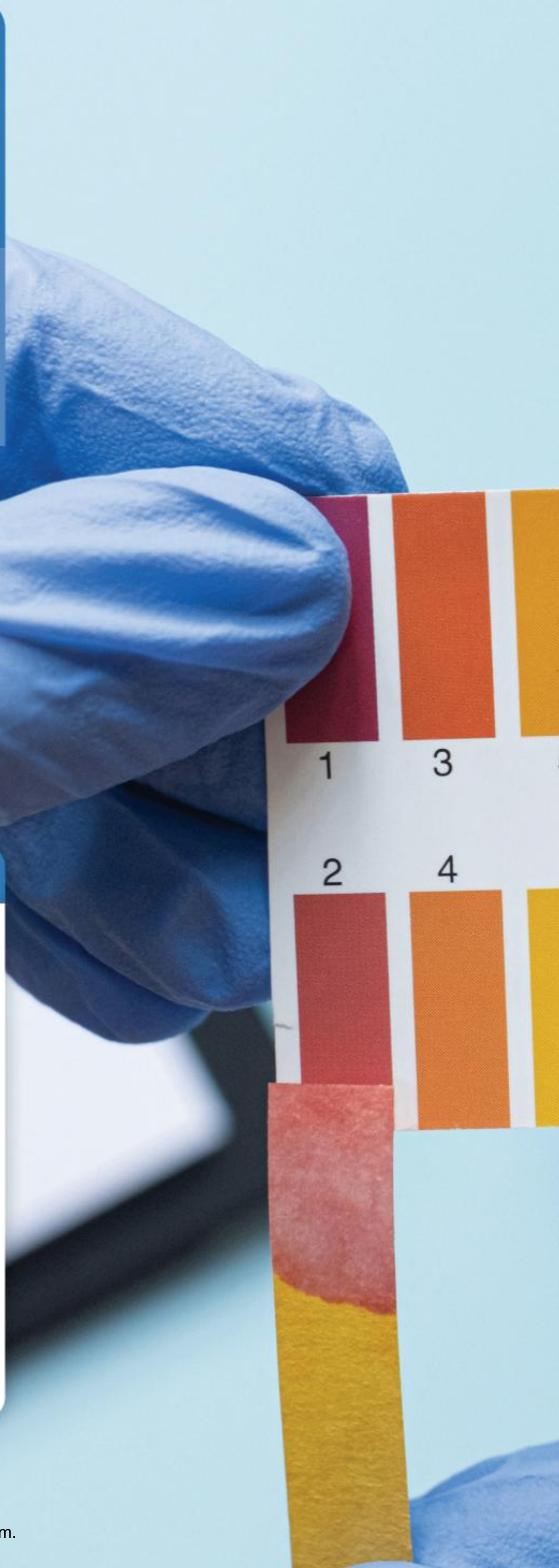


Figure 7 Scanning electron micrograph of methicillin-resistant *Staphylococcus aureus* (MRSA)

Module 10

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 helps us understand what's happening during the reaction.

In the chemical industry, controlling the rate of a reaction is vital. Various factors are used to increase the rate of a reaction, including the surface area, the concentration of a solution and the temperature of the substances. Stirring and using a catalyst can also increase the rate of a reaction.

Lessons in this module

Lesson 10.1
Mass is conserved in a chemical reaction

Learning intentions and success criteria

Key ideas

→ In the word equations for chemical reactions, the starting chemical reactants are on the left-hand side of the arrow, and the final chemical products are on the right-hand side of the arrow.

→ The law of conservation of mass states that the total mass of the reactants is equal to the total mass of the products.

Representing chemicals

reactant a substance used at the beginning of a chemical reaction; written on the left side of a chemical equation

product a substance obtained at the end of a chemical reaction; written on the right side of a chemical equation

When examining chemical reactions, we can represent the substances in different ways. The substances that are present at the start of a chemical reaction are called the **reactants**. The substances formed by the chemical reaction are called the **products**. We can write this using a simple word equation. Consider the reaction between the acid in vinegar and sodium bicarbonate. This reaction produces water, carbon dioxide gas and a substance called sodium acetate, and it can be represented as:

acetic acid (in vinegar) + sodium bicarbonate → sodium acetate + carbon dioxide + water

The acetic acid and sodium bicarbonate are the starting chemicals (reactants) for this reaction. The products are the chemicals formed by the reaction. In this reaction, the products are sodium acetate, carbon dioxide and water.

The law of conservation of mass

Sometimes a reaction only has one reactant. For example, when mercury oxide is heated (one reactant) it can produce two products: mercury metal and oxygen gas.

Like all gases, oxygen has a mass. This means it can be weighed in grams on the Earth. In an open system where there is no closed container or room, the oxygen gas could escape. This means the reactant (mercury oxide) would weigh more before it was heated than the weight of the mercury after heating because the oxygen would have escaped. This is different to a closed system, where the oxygen would not be allowed to escape. In a closed system, the reactant (mercury oxide) would weigh the same as the products (mercury metal and oxygen gas). This is an important observation. It shows that the total mass of the chemicals is not changed in a chemical reaction.

When a chemical reaction takes place, the chemicals interact, causing the bonds between the atoms to break apart and make new, different molecules. No atoms are produced in the process and no atoms are destroyed (Figure 1). This is one of the most important laws in science: the law of conservation of mass.

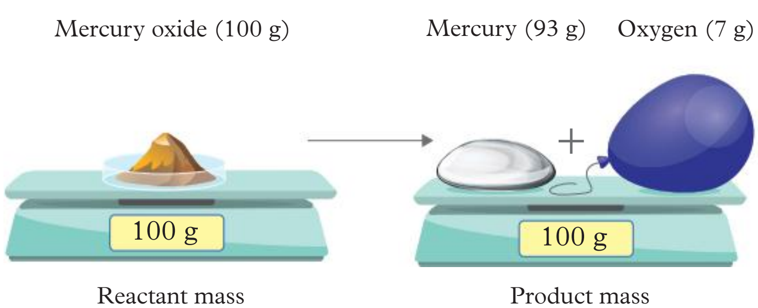


Figure 1 When mercury oxide (HgO) is heated, its atoms rearrange to form mercury liquid (Hg) and oxygen gas (O_2). The overall mass of reactants and products is the same — no atoms are destroyed, and no new atoms are created.

Example of a chemical reaction

Methane gas (CH_4) is the main gas present in natural gas, which is used for cooking in the home and for heating. It has one carbon atom and four hydrogen atoms. When it burns, it combines with oxygen (O_2) in the air to form carbon dioxide (CO_2) and water (H_2O).

Figure 2 shows what happens to the atoms during this reaction. Different atoms are represented by different colours. Table 1 shows the different representations of the reactants and products.

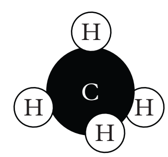
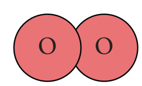
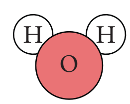
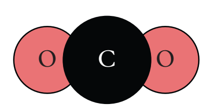
1 Count the number of each type of atom in the reactants (left-hand side of the arrow) and count the number of each type of atom in the products (right-hand side of the arrow). What do you notice?

2 Describe what has happened to the hydrogen atoms during the chemical reaction.

3 Describe what has happened to the oxygen atoms. Make sure you use the correct names of the chemicals in your description.

4 Write the chemical reaction as a word equation in which the reactants are on the left-hand side and the products are on the right-hand side (Figure 2).

Table 1 Representations of four chemicals

Chemical name	Formula/symbol	Diagram
Methane	CH_4	
Oxygen	O_2	
Water	H_2O	
Carbon dioxide	CO_2	

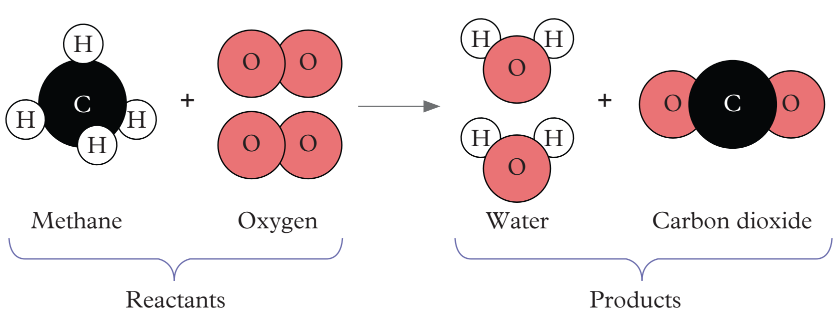


Figure 2 Atoms are rearranged during a chemical reaction.

Check your learning 10.1

Check your learning 10.1

Retrieve

1 Define the term "mass".

Comprehend

2 If no mass is lost or gained in a chemical reaction, explain what this tells you about the individual atoms involved in the reaction.

3 Explain why the products have very different properties from those of the reactants, even though the total mass remains the same.

4 Represent the following reaction as a word equation (by identifying the reactants and products):

Magnesium ribbon was burnt in the presence of oxygen to produce magnesium oxide.

Analyse

5 Use Table 1 to identify:

a an element composed of molecules

b a compound composed of molecules.

6 Early alchemists repeatedly tried to turn lead into gold. Infer, using the law of conservation of mass, why this would be impossible.

Apply

7 Evaluate each of the following equations to determine if they obey the law of conservation of mass (by comparing the number and types of atoms in the reactants to the number and type of atoms in the products, and deciding if the atoms are conserved).

a $C + O_2 \rightarrow CO_2$

b $H_2 + O_2 \rightarrow H_2O$

Skills builder: Processing and analysing data and information

8 Presenting information and data in the most appropriate way will help you interpret and analyse the data. Consider the following reactions and write them as word equations. This can help you understand the reaction.

a A piece of magnesium reacts with oxygen in the air to form magnesium oxide. (THINK: What is the product? What is the reactant?)

b When a piece of copper is added to a solution of silver nitrate, it creates a solution of copper nitrate and solid silver. (THINK: What is the product? What is the reactant?)

Lesson 10.2

Investigation: Comparing mass before and after a chemical reaction

Purpose

To determine if mass is conserved in a chemical reaction

Materials

- Sodium bicarbonate
- Vinegar
- Balloon
- Balance
- Measuring cylinder
- 2 conical flasks
- Watch glass
- Spatula

Part A

Procedure

1 Copy Table 1 to record your results.
2 Weigh out 2.0 g of sodium bicarbonate onto a watch glass.
3 Add 20 mL of vinegar to a flask.
4 Ensure the balance is reading zero. Weigh the vinegar and flask. Record this mass (M_1).
5 Predict whether the mass of the flask and vinegar after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.
6 Add 2 g of sodium bicarbonate (M_2) to the flask containing the vinegar and swirl until the bubbling stops (Figure 1).
7 Weigh the flask after the reaction has stopped. Record the final mass (M_3).

Figure 1 Sodium bicarbonate is added to the flask containing the vinegar.

Results

Table 1 Results table for Part A

Mass of flask and vinegar (M_1)	Mass of sodium bicarbonate (M_2)	Total mass before reaction ($M_1 + M_2$)	Mass after reaction (M_3)

Part B

Procedure

1 Copy Table 2 to record your results.
2 Weigh out 2.0 g of sodium bicarbonate onto a watch glass.
3 Add 20 mL of vinegar to a flask.
4 Ensure the balance is reading zero. Weigh the vinegar, flask and a balloon. Record this mass (M_1).
5 Predict whether the mass of the flask, vinegar and balloon after the reaction with the sodium bicarbonate will be more, the same or less than the initial mass.
6 Add 2 g of sodium bicarbonate (M_2) to the balloon and carefully stretch the opening of the balloon over the neck of the flask so that the sodium bicarbonate does not spill.
7 Hold the end of the balloon directly over the top of the flask so that the sodium bicarbonate spills into the vinegar (keeping the contents sealed; Figure 2).
8 Weigh the flask, with the balloon still attached, after the reaction has stopped. Record the final mass (M_3).

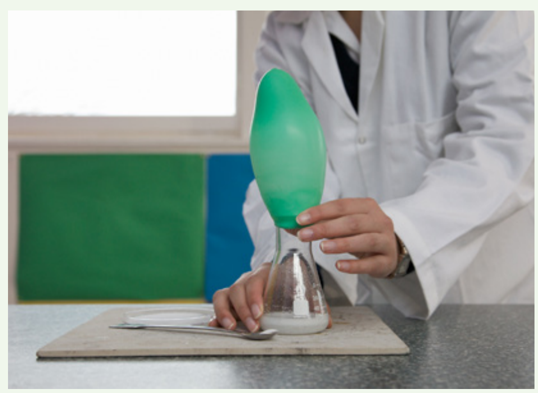


Figure 2 Hold the end of the balloon directly over the top of the flask.

Results

Table 2 Results table for Part B

Mass of flask, vinegar and balloon (M_1)	Mass of sodium bicarbonate (M_2)	Total mass before reaction ($M_1 + M_2$)	Mass after reaction (M_3)

Discussion

1 Compare the initial and final masses for each part of the experiment.
2 Compare the results with your prediction.
3 Identify the gas that was produced.
4 Describe the purpose of sealing the flask with the balloon.
5 Describe the purpose of the control for this experiment.
6 Identify a possible error for this experiment. Describe how this error could be minimised.

Conclusion

Compare the results of this reaction to the law of conservation of mass.

Lesson 10.3

Balanced chemical equations show the rearrangement of atoms

Learning intentions and success criteria

Key ideas

→ Chemical reactions can be described through observations, word equations or symbols.

→ The law of conservation of mass is used to write a balanced chemical equation.

→ A balanced chemical equation has equal numbers of each type of atom on both sides of the equation.

Describing chemical reactions

Perhaps you have seen sodium metal reacting with water at school or on the internet (Figure 1). This is a chemical reaction between the sodium metal and the water.

There are different ways to describe this reaction.

Figure 1 Sodium metal reacts violently with water, undergoing a chemical change.

- Describing observed changes: the sodium metal dissolves in the water, heat is produced and fizzing is caused by the production of hydrogen gas. If there is enough heat, the hydrogen gas catches fire above the sodium metal.
- Using a word equation: the reactants are sodium and water and they interact to form the products, which are sodium hydroxide and hydrogen gas. A word equation summarises the changes:

  sodium + water → sodium hydroxide + hydrogen
- Using a chemical equation: this includes the formulas of all the substances involved and the ratios in which they react:

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

In this example, two sodium atoms react with two water molecules to form the products: two molecules of sodium hydroxide and one molecule of hydrogen.

Each representation tells us something different about the changes occurring in the chemical reaction. In each of these representations, we can identify the state of the reactants and the products using letters and brackets, as seen in Table 1.

Table 1 States and their symbols

State	Symbol
Gas	(g)
Liquid	(l)
Solid	(s)
Aqueous (dissolved in water)	(aq)

Reacting hydrogen and oxygen

When hydrogen gas burns in oxygen, large amounts of heat energy are produced. If this reaction happens in uncontrolled conditions, it is very dangerous (Figure 2). When used safely in a carefully controlled way, hydrogen can be an excellent renewable fuel that doesn't emit carbon dioxide. Car manufacturers are already developing hydrogen-fuelled cars. An advantage of using hydrogen as a fuel is that the only substance emitted in the exhaust is water vapour: there are no carbon dioxide emissions. Also, unlike fully electric cars, hydrogen cars do not need enormous, heavy batteries.

When hydrogen combusts with oxygen in the air, the oxygen atoms and hydrogen atoms split up from one another and join together to form water (H_2O). The atoms have not been created or destroyed. You can show what is happening by using a diagram or a chemical equation.

Balancing chemical equations requires a systematic approach, where each atom is counted on both sides of the equation. Changing the number of one group of molecules (by changing the larger coefficients and not the subscripts) may affect a number of other atoms. It is important to continue to check and change the coefficients until all atoms are conserved. Worked example 10.3A illustrates how to write balanced chemical equations.

Figure 2 The reaction of hydrogen with oxygen caused the *Hindenburg* explosion.

Worked example 10.3A Balancing equations

Write the chemical equation for the reaction below:

Hydrogen combines with oxygen to produce water.

Solution

Steps	What to do	Working out
a.	Write out the word equation for the reaction.	hydrogen + oxygen → water
b.	Write a simplified chemical equation using the formulas of each molecule involved.	$H_2 + O_2 \rightarrow H_2O$
c.	Work out the numbers of each type of atom in the reactants (left-hand side) and in the products (right-hand side).	(see table c)
d.	Compare the number of each type of atom in the reactants with the number in the products. As the law of conservation of mass isn't met, 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 (see table). We cannot change the subscripts (from H_2O to H_2O_2) because this would change water into hydrogen peroxide.	$H_2 + O_2 \rightarrow 2H_2O$ (see table d)
e.	The unbalanced hydrogen atoms can be balanced by doubling the number of hydrogen molecules (see table). The equation is said to be balanced.	$2H_2 + O_2 \rightarrow 2H_2O$ (see table e)
f.	Add the state (solid, liquid, gas or aqueous) of each molecule (Table 1).	$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$

Table c:

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2	2		2	1

Table d:

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	2	2		4	2

Table e:

	Reactants		→	Products	
Type of atom	H	O	→	H	O
Number of atoms	4	2		4	2

Check your learning 10.3

Check your learning 10.3

Retrieve

1 Recall what the "(s)", "(l)", "(g)" and "(aq)" symbols represent in the chemical equation for the reaction of sodium metal with water.

Comprehend

2 Explain why chemical equations that are not "balanced" are always incorrect.

Analyse

3 Balance the following equations by adding numbers as required.

a ___ Na + ___ H_2O → ___ NaOH + ___ H_2

b ___ H_2 + ___ O_2 → ___ H_2O

c ___ CH_4 + O_2 → ___ CO_2 + ___ H_2O

d ___ Mg + ___ HCl → ___ H_2 + ___ $MgCl_2$

Apply

4 Identify which representation of a chemical reaction tells us most about the chemicals. Justify your answer.

5 Imagine one of your classmates missed this lesson and asked for your help to understand how to balance chemical equations. Consider how you would explain it to them. Create a set of instructions using the medium you think would be most useful (e.g. a written list, an illustrated poster, a presentation).

Skills builder: Communicating

6 Balancing equations is a clear way of communicating to other scientists the chemical change in an experiment. Answer the following questions about when sodium reacts with chlorine gas to form sodium chloride.

a Write the word equation for this reaction. (THINK: What was present at the start? What is present at the end?)

b Write the word equation as a chemical equation using the formulas of the substances involved. (THINK: What is the original formula for each substance?)

Lesson 10.4

Challenge: Modelling chemical equations

Aim

To model the rearrangement of atoms in a chemical reaction

What you need:

- Paper bags
- Model atom kit (or laminated squares labelled oxygen [O = blue] atom, carbon [C = black] atom, hydrogen [H = white] atom)
- Felt-tipped pen

Part A

What to do:

1 Each paper bag represents a molecule. Create a molecule of oxygen (O_2) by placing two oxygen "atoms" in a paper bag. Write "O_2" on the bag.

2 Use two paper bags and four model hydrogen atoms to create two molecules of hydrogen (H_2). You have now created the reactants in the chemical reaction:

3 $2H_2 + O_2 \rightarrow 2H_2O$

4 Label the two remaining paper bags "H_2O". Take the model atoms out of the reactant bags and place them in the product H_2O bags. Are there enough atoms to fill the H_2O bags?

Questions

1 Explain why there needed to be more molecules/bags of hydrogen than oxygen.

2 Describe what would happen if one more molecule of oxygen was added to the reaction.

3 Compare this model reaction to the law of conservation of mass.

Part B

What to do:

1 Use new bags and the model atoms to create two molecules of methane (CH_4).

2 Identify the number of oxygen molecules (O_2) that you would need to turn these methane molecules into carbon dioxide (CO_2) and water

(H_2O). Use the bags and model atoms to check your prediction.

Questions

1 Identify the number of oxygen molecules you needed to balance this equation.

2 Identify the number of carbon dioxide and water molecules you were able to create with two methane molecules.

3 Write the word equation for this reaction.

4 Write the balanced chemical equation for this reaction.

Lesson 10.5
Different types of reactions have different features

Learning intentions and success criteria

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 which group it belongs to.

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 reactions, among others.

Synthesis reactions

Synthesis is the building up of compounds by combining simpler substances, normally elements:

A + B → AB

This is a general equation that helps you determine what will be produced in a synthesis reaction. In synthesis reactions, the two reactants combine to form a new product. For example:

sodium + chlorine → sodium chloride

synthesis a reaction that involves building up compounds by combining simpler substances, usually elements

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 10.3A (page 460).

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–Bosch 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.

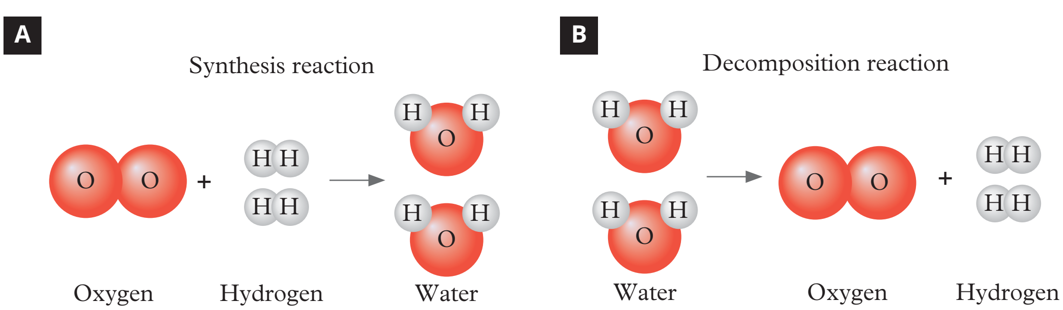


Figure 1 (A) Synthesis reactions combine the reactants to make a more complex product. (B) Decomposition reactions break the chemical bonds in the reactants to form simpler substances.

Decomposition reactions

decomposition a reaction that involves the breakdown of a compound into simpler substances

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:

$2Al_2O_3 \rightarrow 4Al + 3O_2$

Quicklime, or calcium oxide (CaO), is an important industrial product. It is used in agriculture as a fertiliser and to neutralise acidic soils. It is also a key component in building materials, such as mortar. Calcium oxide is produced by the thermal decomposition of calcium carbonate ($CaCO_3$):

calcium carbonate → calcium oxide + carbon dioxide

$CaCO_3 \rightarrow CaO + CO_2$

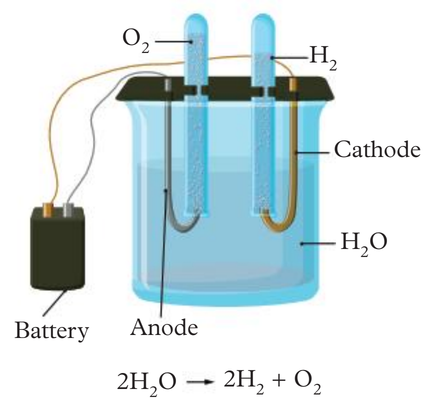


Figure 2 Electrolysis equipment. At the anode, water is being broken down into oxygen gas and hydrogen ions. At the cathode, hydrogen gas is being produced from hydrogen ions and electrons.

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.

Displacement reactions

displacement reaction a reaction resulting in the displacement of an atom or group of atoms

single displacement reaction a reaction in which a more reactive element displaces a less reactive element on a molecule

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 (K) with sodium chloride (NaCl). 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.

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 10.5A Writing balanced chemical equations

Write the chemical equation for the following reaction.

Magnesium reacts with hydrochloric acid to produce hydrogen gas and magnesium chloride.

Solution

<table>
<tr><th>Steps</th><th>What to do</th><th>Working out</th></tr>
<tr><td>a.</td><td>Identify the reactants and products.</td><td>Reactants: magnesium and hydrochloric acid
Products: hydrogen gas and magnesium chloride</td></tr>
<tr><td>b.</td><td>Write out the word equation for the reaction.</td><td>magnesium + hydrochloric acid → hydrogen + magnesium chloride</td></tr>
<tr><td>c.</td><td>Identify the formula for the reactants and products.
For example, hydrogen (H_2) exists as a pair of atoms and is represented as subscripts.
Magnesium and the chlorine atom bond ionically (check their charge).</td><td>Magnesium: Mg
Hydrochloric acid: HCl
Hydrogen gas: H_2
Magnesium chloride: $MgCl_2$</td></tr>
<tr><td>d.</td><td>Write out the chemical equation.</td><td>$Mg + HCl \rightarrow H_2 + MgCl_2$</td></tr>
<tr><td>e.</td><td>Work out the number of each type of atom in the reactants and in the products.</td><td><table>
<tr><th></th><th colspan="3">Reactants</th><th>→</th><th colspan="3">Products</th></tr>
<tr><td>Type of atom</td><td>Mg</td><td>H</td><td>Cl</td><td>→</td><td>Mg</td><td>H</td><td>Cl</td></tr>
<tr><td>Number of atoms</td><td>1</td><td>1</td><td>1</td><td></td><td>1</td><td>2</td><td>2</td></tr>
</table></td></tr>
<tr><td>f.</td><td>Compare the number of each type of atom in the reactants with the number in the products. As the law of conservation of mass isn't met, we need to add a whole hydrochloric molecule by including numbers (called coefficients) before the formula of the substances. This balances the number of hydrogen and chlorine atoms (see table).</td><td>$Mg + 2HCl \rightarrow H_2 + MgCl_2$<table>
<tr><th></th><th colspan="3">Reactants</th><th>→</th><th colspan="3">Products</th></tr>
<tr><td>Type of atom</td><td>Mg</td><td>H</td><td>Cl</td><td>→</td><td>Mg</td><td>H</td><td>Cl</td></tr>
<tr><td>Number of atoms</td><td>1</td><td>2</td><td>2</td><td></td><td>1</td><td>2</td><td>2</td></tr>
</table></td></tr>
<tr><td>g.</td><td>Add the state (solid, liquid, gas or aqueous) of each molecule.</td><td>$Mg(s) + 2HCl(aq) \rightarrow H_2(g) + MgCl_2(aq)$</td></tr>
</table>

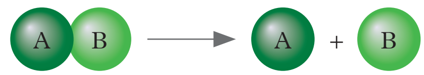
double displacement reaction an exchange of ions from the two reactants to form two new products

Double displacement reactions

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.

A summary of each different type of reaction covered in this topic is shown in Table 1.

Table 1 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.	
Decomposition	A compound reacts and breaks down into two or more products.	
Single displacement	A more reactive element replaces another less reactive element on a molecule.	
Double displacement	Two reactants exchange ions to form two new products.	

Check your learning 10.5

Check your learning 10.5

Retrieve

1 Define the term “synthesis reaction”.

Comprehend

2 Identify the following reactions as synthesis, decomposition, single displacement and double replacement.

a $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

b $CaF_2(s) + Br_2(l) \rightarrow CaBr_2(s) + F_2(g)$

c $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

d $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

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 10.6

Investigation: Direct synthesis with a "pop"

Caution

- Wear protective clothing and safety glasses throughout this experiment.
- Avoid contact with hydrochloric acid.

Purpose

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

Procedure

1 For this reaction, you require a test tube containing hydrogen gas. The easiest way to produce this is to place three 1 cm lengths of magnesium ribbon in a test tube and add 10 mL dilute hydrochloric acid (Figure 1).

Figure 1 Magnesium ribbon is reacted with 10 mL of HCl.

2 Place the other test tube (make sure it is dry) upside down over the top of the first test tube so that any hydrogen gas produced enters the second test tube (Figure 2).

Figure 2 A second test tube is used to trap the hydrogen gas.

3 After 15 seconds, place a rubber stopper over the end of the second test tube to trap the hydrogen gas; you now have a test tube of hydrogen gas.

4 Place the sealed test tube containing the hydrogen gas into the test-tube rack.

5 Light the wooden splint. Remove the rubber stopper and carefully hold the burning splint close to the top of the test tube.

6 Observe the reaction that occurs and examine the inside of the test tube closely.

Results

Record your observations in an appropriate format.

Discussion

1 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 10.7

Investigation: Decomposing a carbonate

Caution

- Wear safety glasses, lab coat and gloves when working with chemicals.
- Ensure the open end of the test tube is facing in a safe direction while heating.

Purpose

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

Procedure

1 Describe the appearance of copper(II) carbonate.
2 Carefully place one spatula of copper(II) carbonate into the test tube.
3 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).
4 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.

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.

Figure 2 Copper carbonate is a green powder before it is heated.

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 10.8
Investigation: Neutralisation reactions

Caution

- Wear protective gloves, 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.

Purpose

To investigate neutralisation reactions

Materials

- 1 M hydrochloric acid
- 1 M sodium hydroxide solution
- Universal indicator
- Solution
- Dropping pipettes
- 10 mL measuring cylinder
- 100 mL beaker
- Petri dish
- Colour chart

Procedure

1 Using the measuring cylinder, transfer 5.0 mL of hydrochloric acid into the beaker and then rinse out the measuring cylinder with water.

2 Add two drops of universal indicator solution to the acid.
3 Pour 10 mL of the sodium hydroxide solution into the measuring cylinder.
4 Using a dropping pipette, add the sodium hydroxide from the measuring cylinder to the acid in the beaker.
5 Stop adding the sodium hydroxide when the acid has been neutralised. (The indicator will turn green at this point.)
6 Record how much sodium hydroxide you needed to add.
7 Carefully empty and rinse out your glassware. Repeat the whole investigation. Instead of adding universal indicator, use the same amount of sodium hydroxide as recorded in step 6.
8 Pour the solution into a Petri dish and leave open in a safe place in the laboratory for a few hours. As the solution evaporates, record your observations.

Results

Present your results in a table.

Discussion

1 Write a word equation for the neutralisation reaction.
2 Write a balanced chemical equation (including states) for the neutralisation reaction.
3 Explain if a neutralisation is a type of displacement reaction.
4 Why was it essential to rinse the measuring cylinder with water after it was used?
5 Why was the investigation repeated without the indicator?
6 How could you produce the solid salt more quickly in the last step of the method?
7 What do you notice about the shape of the salt crystals produced? What can you infer from this about the arrangement of the particles inside the salt crystals?

Conclusion

What have you observed about neutralisation reactions?

Lesson 10.9
Acids have a low pH, bases have a high pH

Learning intentions and success criteria

Key ideas

→ Acids taste sour and contain at least one hydrogen ion; bases taste bitter and feel soapy to the touch.

→ Acids have a pH less than 7 and bases have a pH greater than 7.

→ 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

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 (wear down) 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.

Figure 1 Many cleaning products are alkaline solutions.

acid a hydrogen-containing substance that has the ability to donate a proton

Bases

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.

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.

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

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, $CaCO_3$

Figure 2 Some vegetables, such as red cabbage, can be used to make pH indicators.

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 (Figure 2).

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

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

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

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.

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.

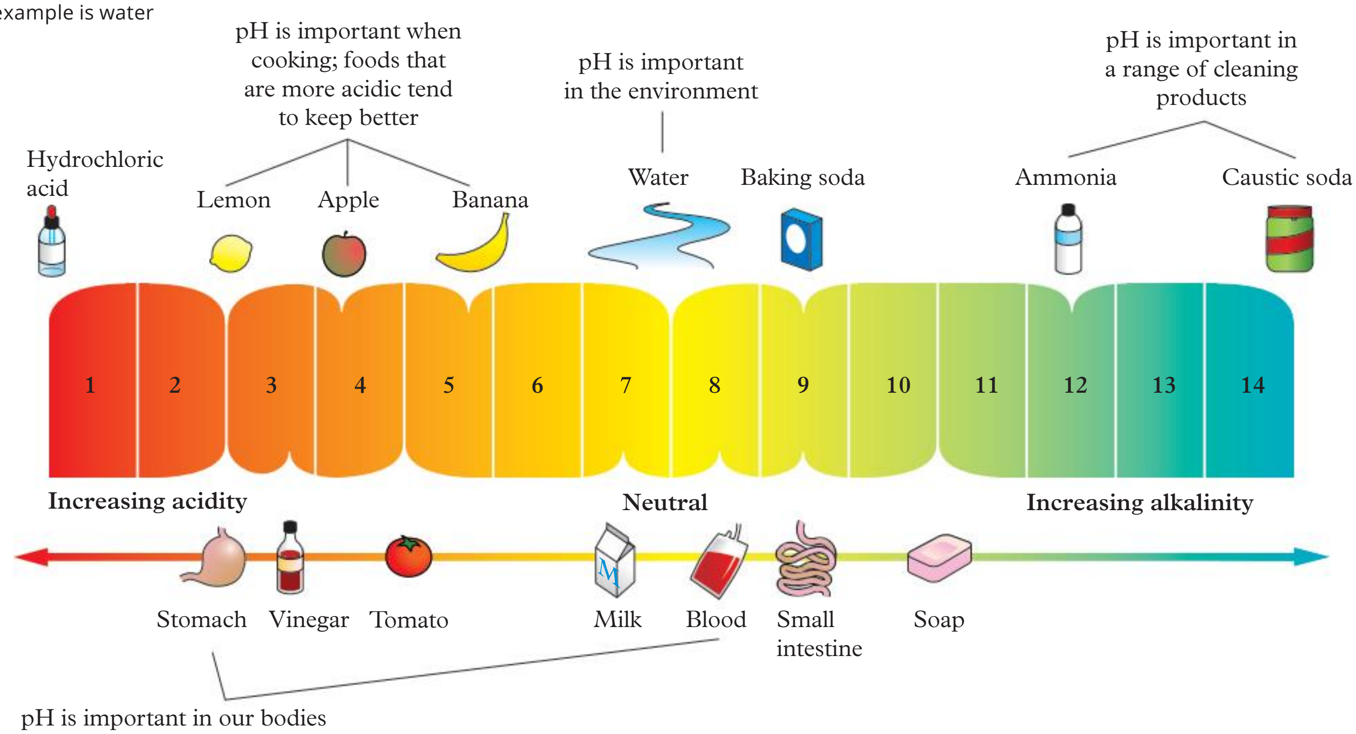


Figure 3 The pH scale

Check your learning 10.9

Check your learning 10.9

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 is being measured?)
  c Propose one variable that would need to be controlled. (THINK: What are the drinks being tested in? What else could impact acid and base levels?)

Lesson 10.10
Challenge: Testing with pH paper

Aim

To test the pH levels of a variety of substances

What you need:

- pH paper and pH colour chart or universal indicator
- White tile
- Variety of laboratory acids and bases
- Vinegar
- Milk
- Toothpaste
- Lemon juice

What to do:

1 Tear off approximately 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.

Questions

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.

Figure 1 pH paper and colour chart

Lesson 10.11

Investigation: What if plants were used to create an indicator?

Introduction

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.

Purpose

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)

Procedure

1 Make the indicator as follows.
   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 Test the indicator as follows.
   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).

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.

Lesson 10.12
Investigation: Acid titrations

Caution

Wear safety glasses, lab coat and gloves when working with chemicals.

Purpose

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
- Four test tubes
- Test-tube rack
- Pipette
- Matches
- Bench mat

Procedure

Part A

1. Draw up a table to record each test and the results for each acid.
2. 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.
3. Repeat step 2 with 0.1 M ethanoic acid, using a fresh test tube.
4. 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).
5. Repeat step 4 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 5 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:

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) + \text{energy}$

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 strength and concentration of acids.

Lesson 10.13
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.

→ We can speed up the reaction rate by increasing the surface area, concentration or temperature, or by stirring the reactants.

Learning intentions and success criteria

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 a reaction proceeds

Collision theory

collision theory in order for a reaction to occur, the reacting particles must collide with enough energy and at the correct angle

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 **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.

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 between the hydrogen ions. This intermediate substance is unstable and only exists for a short time before it breaks apart.

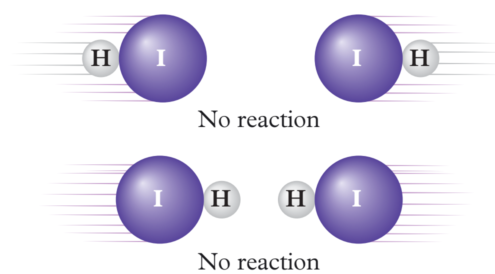


Figure 1 If collisions between HI molecules are unsuccessful, the HI molecules do not react with each other.

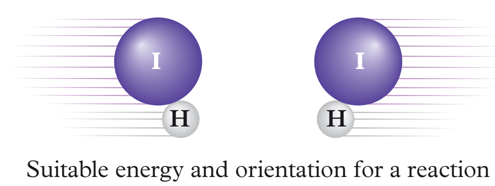
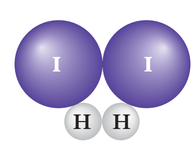


Figure 2 When the collisions between particles have enough energy, and the particles are aligned correctly, a reaction may occur.



H_2I_2 is an intermediate complex.

Figure 3 During the intermediate stage, H_2I_2 is formed. This molecule is unstable and short-lived.

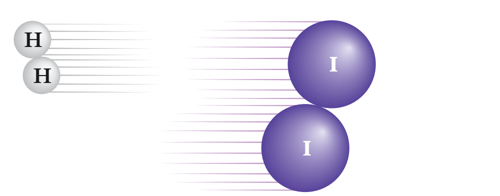


Figure 4 The final products are formed and move apart (partly due to electrostatic repulsion).

Increasing the rate of collisions

To increase the rate of a reaction, we 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.

Increasing 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. The reaction occurs on the surface of the magnesium, so 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).

Increasing 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).

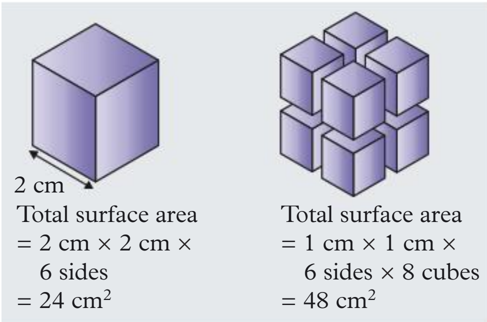


Figure 5 The total surface area of many small particles is larger than that of a single large particle of the same volume.

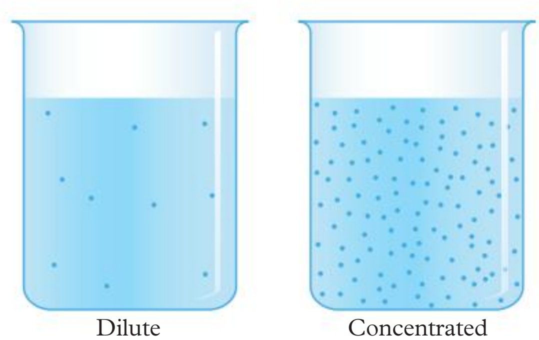


Figure 6 A concentrated solution contains more dissolved particles than a dilute solution.

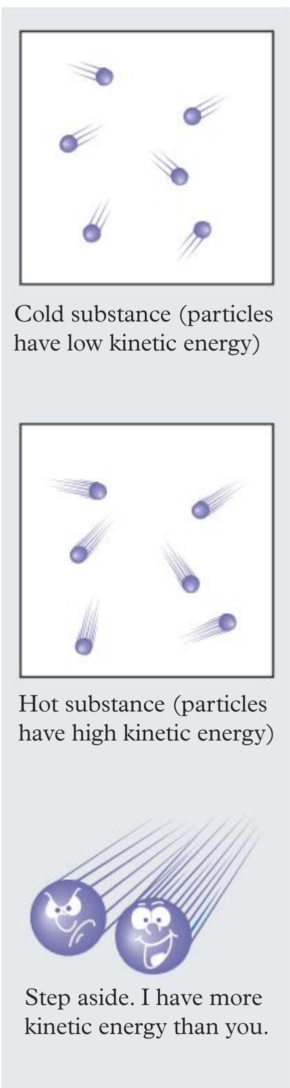


Figure 7 At higher temperatures, the average energy of the particles is increased and the particles vibrate faster.

In the reaction between magnesium and hydrogen ions, the reaction will occur faster if there are more hydrogen ions in a given volume. So, using a hydrochloric acid solution with a higher concentration (i.e. more hydrogen ions in a given volume) will speed up the reaction. When there are more particles, there are more collisions and, therefore, a higher reaction rate.

Increasing 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).

kinetic energy the energy an object or particle has due to its motion

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 catalysts are an exception.

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

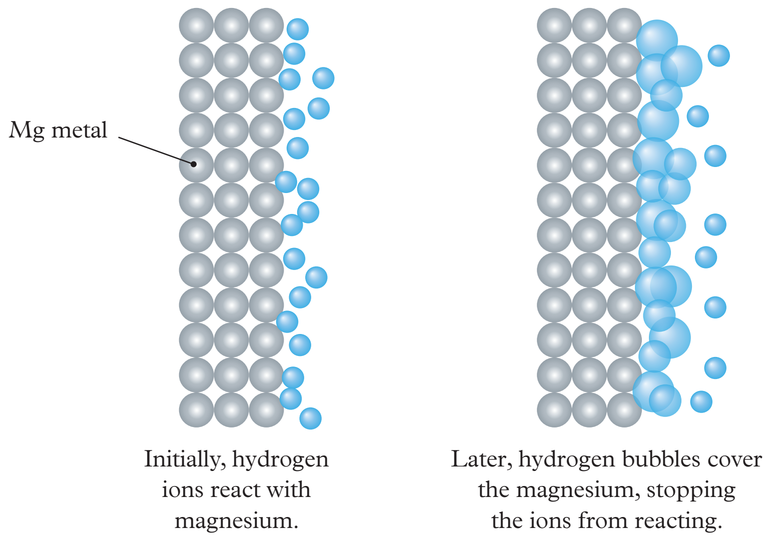


Figure 8 Sometimes the presence of the product can slow down a chemical reaction.

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.

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 are 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 people 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 people of this region 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 10.13

Check your learning 10.13

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 learned in this lesson 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.

Skills builder: Conducting investigations

8 Your teacher wants you to investigate the effect of concentration on reaction rate.

a Explain why it is important to tare the balance of your conical flask on the electronic balance. (THINK: What impact would this have on your results? Would they be accurate?)

b Assess why using a conical flask is more appropriate than a beaker. (THINK: What would the difference in reaction be?)

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.

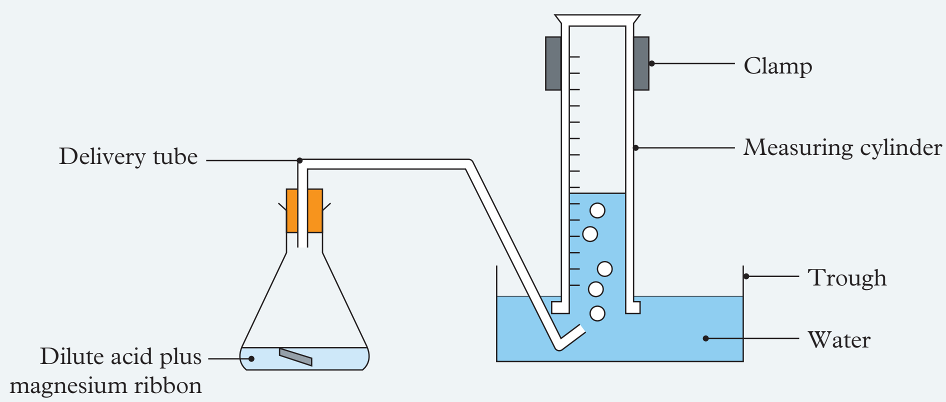


Figure 10 The scientist's experimental set-up

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

Lesson 10.14

Catalysts increase the rate of a reaction

Learning intentions and success criteria

Key ideas

→ Catalysts increase the rate of a chemical reaction without being permanently changed.

Introduction

catalyst a substance that increases the rate of a chemical reaction without undergoing any permanent chemical change

A **catalyst** is a substance that speeds up a chemical reaction but is not used up in the reaction. Catalysts work in many ways.

Solid catalysts provide a surface on which the reaction can occur. The particles of reactants get adsorbed (stuck onto) the surface, where they react to form the products. The products are then released from the surface of the catalyst. This frees up the catalyst to be used again by other reactant molecules.

Figure 1 Catalytic converters are used to reduce harmful pollution from exhaust gases.

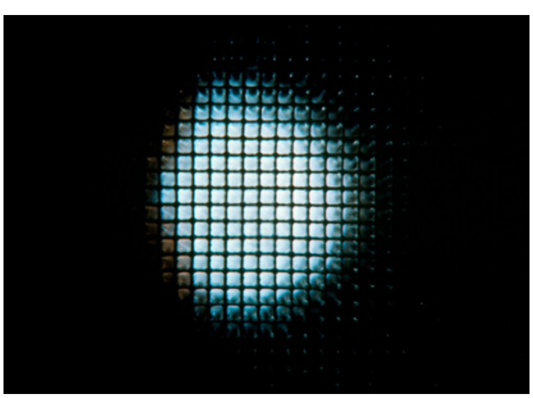


Figure 2 Catalysts are often in the form of a grid to maximise the surface area.

Pollution control in cars

Solid catalysts are used in the catalytic converters of car exhaust pipes (Figure 1). 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 metals adsorb (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.

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 10 km and 50 km high, with the greatest concentration at an altitude of 30 km. 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 inhalers, as well as in foam insulation for furniture, bedding, coffee cups and hamburger containers. They were also used as a refrigerant gas in refrigerators and air conditioners. Today, manufacturers use alternative gases where possible to avoid damaging the ozone layer.

Figure 3 Chlorofluorocarbons (CFCs) were used to pressurise the gas in aerosol cans before it was proved that CFCs damage the ozone layer.

CFCs such as trichlorofluoromethane or freon-11 (CCl_3F) 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.

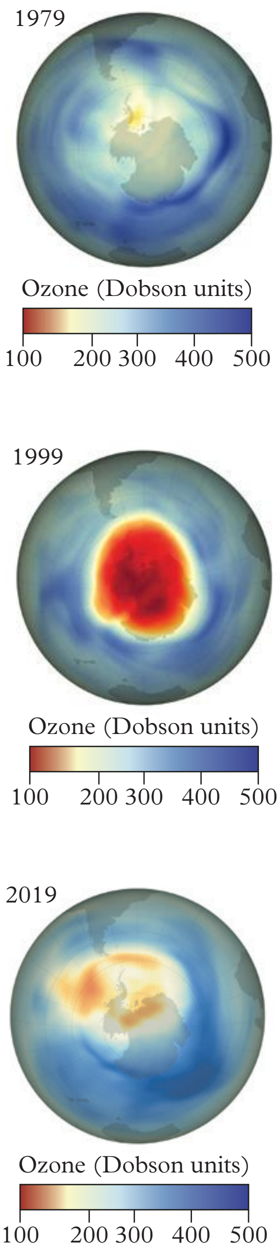


Figure 4 The darker colours show the growth of the "hole" in the ozone layer between 1979 and 1999, and its decrease after CFCs were banned.

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.

substrate a molecule that reacts with an enzyme

active site the region of an enzyme to which substrates can bind

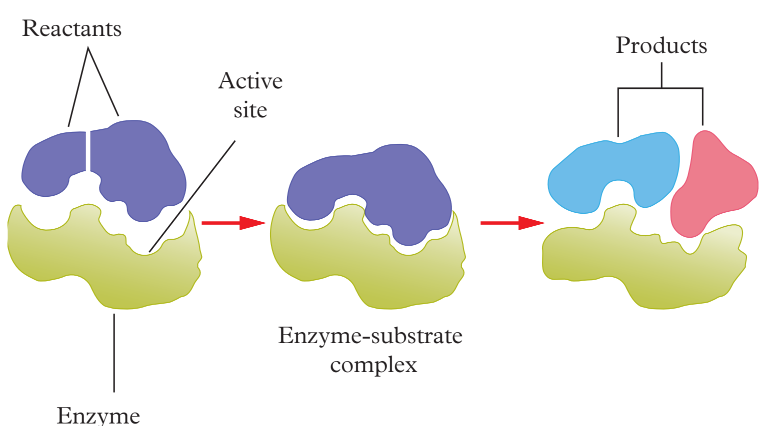


Figure 5 Enzymes only work with specific reactants that can bind to their active site.

Check your learning 10.14

Check your learning 10.14

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: Communicating

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 10.15
Investigation: Using a catalyst

Introduction

The reaction used in this experiment is the decomposition of hydrogen peroxide:

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

Purpose

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
- Two test tubes
- Test-tube rack
- Spatula (small)
- 10 mL measuring cylinder

Procedure

1 Using a measuring cylinder, measure 5 mL of hydrogen peroxide solution into two separate test tubes.
2 Allow one of the tubes to stand; add a small amount of manganese dioxide to the other test tube using a spatula.
3 Observe and describe the changes that occur in the two test tubes.

Results

Record your observations in an appropriate format.

Discussion

1 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.

Conclusion

Describe how a catalyst affects the rate of a reaction.

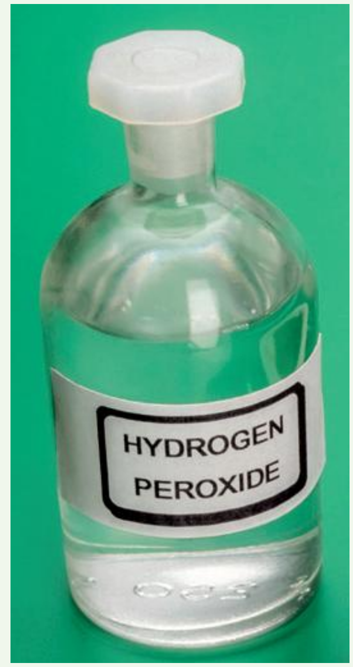


Figure 1 Hydrogen peroxide

Lesson 10.16

Investigation: Factors affecting reaction rate

Caution

- Wear protective gloves, 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.

Purpose

To investigate the factors that affect the rate of a reaction between hydrochloric acid and calcium carbonate

Materials

- 40 g small marble chips (calcium carbonate) of similar size
- 20 mL of 0.5 M hydrochloric acid (HCl)
- 60 mL of 1.0 M HCl
- 20 mL of 2.0 M HCl
- 10 g large marble chips (calcium carbonate)
- 10 g powdered calcium carbonate
- Electronic balance
- Stopwatch
- Thermometer
- 25 mL measuring cylinder

- Eight 100 mL conical flasks
- 500 mL beaker
- Ice cubes
- Kettle

Procedure

Write a hypothesis for this experiment (If … then … because …)

Concentration

1 Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of small marble chips into the flask.

2 Using a measuring cylinder, add 20 mL of 0.5 M HCl to the conical flask still sitting on the electronic balance. Immediately tare the balance once, so that it returns to zero briefly, and start the stopwatch. The numbers on the balance will move into negative readings from zero as gas is given off.

3 Record in your results table (Table 1) the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

4 Repeat steps 1 to 3 using 1.0 M HCl, then 2.0 M HCl.

Temperature

Cold

1 Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of small marble chips into the flask.

2 To cool the hydrochloric acid, create an ice bath by placing some water and ice cubes in the 500 mL beaker.

3 Using a measuring cylinder, add 20 mL of 1.5 M HCl to another conical flask and place it carefully in the ice bath (make sure water does not enter the flask)

4 Use the thermometer to monitor the temperature of the hydrochloric acid (aim for approximately 10 to 15°C).

5 Once the hydrochloric acid has reached the desired temperature, place the flask with the marble chips onto the electronic balance. Carefully add the cold hydrochloric acid, then 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.

6 Record in your results table (Table 1) the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

Room temperature

1 Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of small marble chips into the flask.

2 Using a measuring cylinder, add 20 mL of 1.0 M HCl at room temperature 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.

3 Record in your results table (Table 1) the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

Warm

1 Place a conical flask on the electronic balance and tare the balance so it reads zero. Weigh approximately 10 g of small marble chips into the flask.

2 To warm the hydrochloric acid, create a hot bath by placing some hot water in the 500 mL beaker.

3 Using a measuring cylinder, add 20 mL of 1.0 M HCl to another conical flask and place it carefully in the hot bath (make sure water does not enter the flask)

4 Use the thermometer to monitor the temperature of the hydrochloric acid (aim for approximately 40°C).

5 Once the hydrochloric acid has reached the desired temperature, place the flask with the marble chips onto the electronic balance. Carefully add the warm hydrochloric acid, then immediately tare the balance once, so that it returns to zero briefly, and start the stopwatch.

6 Record in your results table (Table 1) the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.

Surface area

1 Place a conical flask on the electronic balance and tare the balance so it reads zero.
2 Weigh approximately 10 g of large marble chips (low surface area) into the flask.
3 Using a measuring cylinder, add 20 mL of 1.0 M HCl to the conical flask still sitting on the balance. Immediately tare the balance once, so that it returns to zero briefly, and start the stopwatch.
4 Record in your results table (Table 2) the mass loss in grams at 30 seconds, 1 minute and then every minute until 8 minutes.
5 Repeat steps 1 to 4 using 10 g of powdered calcium carbonate (high surface area) instead of marble chips.
6 Compare the rate of mass loss between the large marble chips and the powdered calcium carbonate to assess the effect of surface area on reaction rate.

Results

1 Copy and complete Table 1 and Table 2.
2 On one graph, plot the mass loss by minutes for the variations of hydrochloric acid used.

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 with the results you obtained.

Table 1 Results from the temperature and concentration experiments

Experiment	30 s	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min
0.5 M HCl									
1.0 M HCl									
2.0 M HCl									
Cold 1.0 M HCl									
Room temperature 1.0 M HCl									
Warm 1.0M HCl									

Table 2 Results from the surface area experiment

		Time (s)									
Large chips		0	30	60	120	180	240	300	360	420	480
Trial 1	Mass (g)										
Trial 2											
Powder											
Trial 1	Mass (g)										
Trial 2											

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 Discuss how changes in concentration, temperature and surface area affect the rate of reaction, using evidence from your results.

6 Explain the particle model theory to account for the trends you observed in reaction rates across all three variables tested.

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).

Conclusion

Write a conclusion for your experiment that includes a general statement summarising the evidence that supports your hypothesis.

Lesson 10.17

Science in context: Chemical reactions can produce important products

Introduction

Ammonia (NH_3) is one of the most important chemicals used in industry. It plays a crucial role in agriculture, as a key ingredient in fertilisers, and is also used in cleaning products and industrial processes.

The process used to manufacture ammonia is called the **Haber–Bosch process**, named after Fritz Haber and Carl Bosch, who developed the process in the early twentieth century.

Haber–Bosch process the method for the production of ammonia

The Haber–Bosch process

The Haber–Bosch process combines nitrogen gas (N_2) from the air with hydrogen gas (H_2) to form ammonia. This reaction occurs under specific conditions to maximise efficiency:

$$\text{nitrogen} + \text{hydrogen} \rightarrow \text{ammonia}$$
$$N_2 + 3H_2 \rightarrow 2NH_3$$

This is a reversible reaction, meaning ammonia can decompose back into nitrogen and hydrogen. To produce ammonia efficiently, certain conditions are carefully controlled.

- High pressure: Around 200 atmospheres (200 times normal atmospheric pressure) is required. High pressure forces the gas molecules closer together, increasing the likelihood of collisions and reactions.
- High temperature: About 400 to 500 °C is used. While high temperatures speed up the reaction, they also favour the decomposition of ammonia because the reaction is exothermic (releases heat). Therefore, a balance must be struck.
- Catalyst: Iron is used as a catalyst to speed up the reaction without being consumed.

Raw materials

- Nitrogen (N_2): This is extracted from the air, which is 78 per cent nitrogen.
- Hydrogen (H_2): This is obtained from natural gas (methane, CH_4) through a process called steam reforming.

Importance of ammonia production

Fertilisers

Ammonia is primarily used to create nitrogen-based fertilisers, such as ammonium nitrate and urea. These fertilisers are essential for growing crops to feed the world's population. Without ammonia production, modern agriculture could not sustain the global demand for food.

Other uses

The following are some other common uses of ammonia.

- Cleaning products: Ammonia is a common ingredient in household cleaners (Figure 1).
- Refrigerants: Ammonia is used in industrial refrigeration systems.
- Chemical manufacturing: Ammonia serves as a precursor for producing other chemicals, such as nitric acid.

Figure 1 Many of our cleaning products include ammonia as the major chemical.

Figure 2 Algal blooms are an environmental concern when fertilisers run into water ways. This can harm aquatic life and disrupt ecosystems.

Challenges and environmental impact

Energy-intensive process

The Haber–Bosch process requires significant amounts of energy, primarily because of the high pressure and temperature conditions used. This energy often comes from fossil fuels, contributing to greenhouse gas emissions.

Environmental concerns

Excess use of fertilisers can lead to problems such as water pollution. Run-off from fields can carry nitrates into rivers and lakes, causing algal blooms that harm aquatic life (Figure 2).

Innovations

Scientists are working on making the process more sustainable by:

- using renewable energy sources
- developing catalysts that work at lower temperatures and pressures
- recycling waste gases from the process.

Test your skills and capabilities

Test your skills and capabilities 10.17

Writing a speech

An important role of scientists is to evaluate the sustainability of processes used to synthesise materials. This includes considering where the energy and materials required to carry out processes are sourced from, as well as the impact that synthesised products could have on the environment. Scientists often identify and communicate issues, as well as offer sustainable alternatives at conferences or in scientific journal articles. This can inspire other scientists and manufacturers to consider greener options that are better for the health of our planet.

Imagine you are presenting an evaluation of the Haber–Bosch process at a scientific conference. Write a speech that addresses the following points.

1. What is the Haber–Bosch process? What product does it create and why is it important?
2. Why does the Haber–Bosch process require a large energy input?
3. Where is this energy usually sourced from and what impact does using this source of energy have on our planet?
4. What cleaner energy sources could be used to fuel the Haber–Bosch process?
5. How does the product generated from the Haber–Bosch process impact the environment?
6. What changes can industries make or what alternatives to the product can be used to reduce negative impacts on the environment?
7. Is there a sustainable alternative to the Haber–Bosch process?
8. If so, what are its strengths and weaknesses against the Haber–Bosch process?

Lesson 10.18

Review: Chemical reactions

Summary

Lesson 10.1 Mass is conserved in a chemical reaction

- In the word equations for chemical reactions, the starting chemical reactants are on the left-hand side of the arrow, and the final chemical products are on the right-hand side of the arrow.
- The law of conservation of mass states that the total mass of the reactants is equal to the total mass of the products.

Lesson 10.3 Balanced chemical equations show the rearrangement of atoms

- Chemical reactions can be described through observations, word equations or symbols.
- The law of conservation of mass is used to write a balanced chemical equation.
- A balanced chemical equation has equal numbers of each type of atom on both sides of the equation.

Lesson 10.5 Different types of reactions have different features

- 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 10.9 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 the touch.
- Acids have a pH less than 7 and bases have a pH greater than 7.
- 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.

Lesson 10.13 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.
- We can speed up the reaction rate by increasing the surface area, concentration or temperature, or by stirring the reactants.

Lesson 10.14 Catalysts increase the rate of a reaction

- Catalysts increase the rate of a chemical reaction without being permanently changed.

Review questions 10.18

Review questions Module 10

Retrieve

1 Explain what the law of conservation of mass is.
2 Identify the pH value of pure water.
3 List three common indicators used to measure pH.
4 List the different types of chemical reactions.
5 Identify the factors that affect the rate of reaction.
6 Identify which of the following is a balanced chemical equation.
  A $CH_4 + O_2 \rightarrow CO_2 + 2H_2O$
  B $CH_4 + 2O_2 \rightarrow CO_2 + H_2O$
  C $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  D $CH_4 + O_2 \rightarrow 2CO_2 + 2H_2O$

Comprehend

7 Describe how atoms are rearranged in a chemical reaction.
8 Explain why mass is conserved during a chemical reaction.
9 Explain what pH measures and how it relates to acidity and alkalinity.

10 Explain the role of a catalyst in affecting the rate of a chemical reaction.

Analyse

11 A student conducted three different chemical reactions: a synthesis reaction, a decomposition reaction and a neutralisation reaction. The student measured the mass of reactants and products for each reaction and confirmed that mass was conserved. The student also plotted a graph showing the relationship between time (x-axis) and the mass of products formed (y-axis) for each reaction. Describe the process of writing a balanced chemical equation, including states, for each of the following reactions.

a The synthesis of magnesium oxide from magnesium and oxygen

b The decomposition of hydrogen peroxide into water and oxygen gas

c The neutralisation of hydrochloric acid with sodium hydroxide.

12 Explain how Figure 1 supports the law of conservation of mass.

Apply

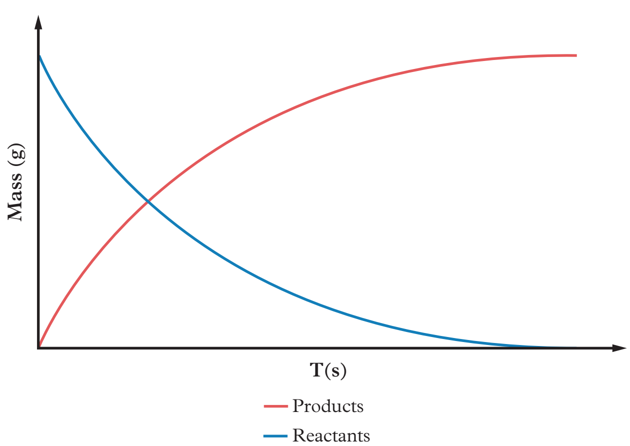


Figure 1 A graph of a chemical reaction

13 Describe the process of writing a balanced chemical equation, including states. Provide an example of each of the following:

- a synthesis reaction
- a decomposition reaction
- a neutralisation reaction.

14 Predict the products of a reaction between hydrochloric acid and sodium hydroxide, and write a balanced chemical equation with states.

15 Apply particle collision theory to explain why temperature changes affect reaction rate.

16 Zinc reacts with hydrochloric acid to produce zinc chloride and hydrogen gas according to the following word equation:

zinc + hydrochloric acid → zinc chloride + hydrogen gas

You have the following data from the reaction.

- Mass of zinc used = 32.7 g
- Mass of hydrochloric acid used = 73.0 g
- Mass of zinc chloride produced = 100.0 g
- Mass of hydrogen gas produced = 5.7 g

Demonstrate the law of conservation of mass by calculating the total mass of reactants and products for this reaction. In your response:

» show your working for the total mass of the reactants and total mass of the products

» confirm whether mass is conserved

» explain how the conservation of mass is shown in this chemical reaction.

Critical and creative thinking

17 Discuss the limitations of using simple laboratory models to represent real-world chemical reactions.

18 Create a poster that visually explains the factors affecting reaction rates (temperature, concentration, surface area and catalysts) with real-world examples.

19 Evaluate the effectiveness of different methods (indicators versus pH meters) in accurately measuring pH changes during a reaction.

Social and ethical thinking

20 Discuss the social and ethical implications of using neutralisation reactions to manage industrial waste or environmental pollution. In your response:

- explain how neutralisation reactions are used to reduce the harmful effects of acidic or basic waste products
- evaluate the benefits of neutralisation in protecting ecosystems and water quality
- discuss any potential ethical concerns related to waste disposal, resource use or the long-term effects on the environment and local communities.

Research

21 Research and report on how pH monitoring is used in an industry (e.g. agriculture, water treatment or food production).

22 Investigate how industries use catalysts to speed up chemical reactions and discuss the environmental and economic benefits.

23 Choose one of the following topics for a research project.

Phosphoric acid

Phosphoric acid has a wide variety of uses, including as a fertiliser, rust remover and food additive. It is even an ingredient of cola drinks. Describe how it is produced and explain why it has many uses.

Figure 2 Phosphoric acid is used to produce many products, such as fertiliser.

Explosives

The history of the development of explosives is fascinating.

- Describe when explosives were first used and how they work.
- Identify the main chemicals used in explosives and the different types of these chemicals.
- Explain the part Alfred Nobel played in the development of explosives.

Figure 3 Explosive device being tested in an isolated area

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.

- Identify where these metals are found in Australia.
- Identify the chemical name of the mineral in which these metals are found.
- Describe the chemical processes that are used to extract the pure metal.

Figure 4 Niobium is a rare metal used in microelectronic devices, which are crucial in modern electronic circuits.

Carbon footprints

By making small changes to our lifestyle, we can reduce our carbon footprint and lessen our impact on the environment.

- Describe what is meant by the phrase "carbon footprint".
- Identify the chemical reactions that contribute to an increase in carbon dioxide in the atmosphere.
- Identify the other gases that contribute to the enhanced greenhouse effect.
- Describe how carbon footprints are measured.
- Describe what is meant by the phrase "carbon offset".

Figure 5 Our actions have an effect on the environment.

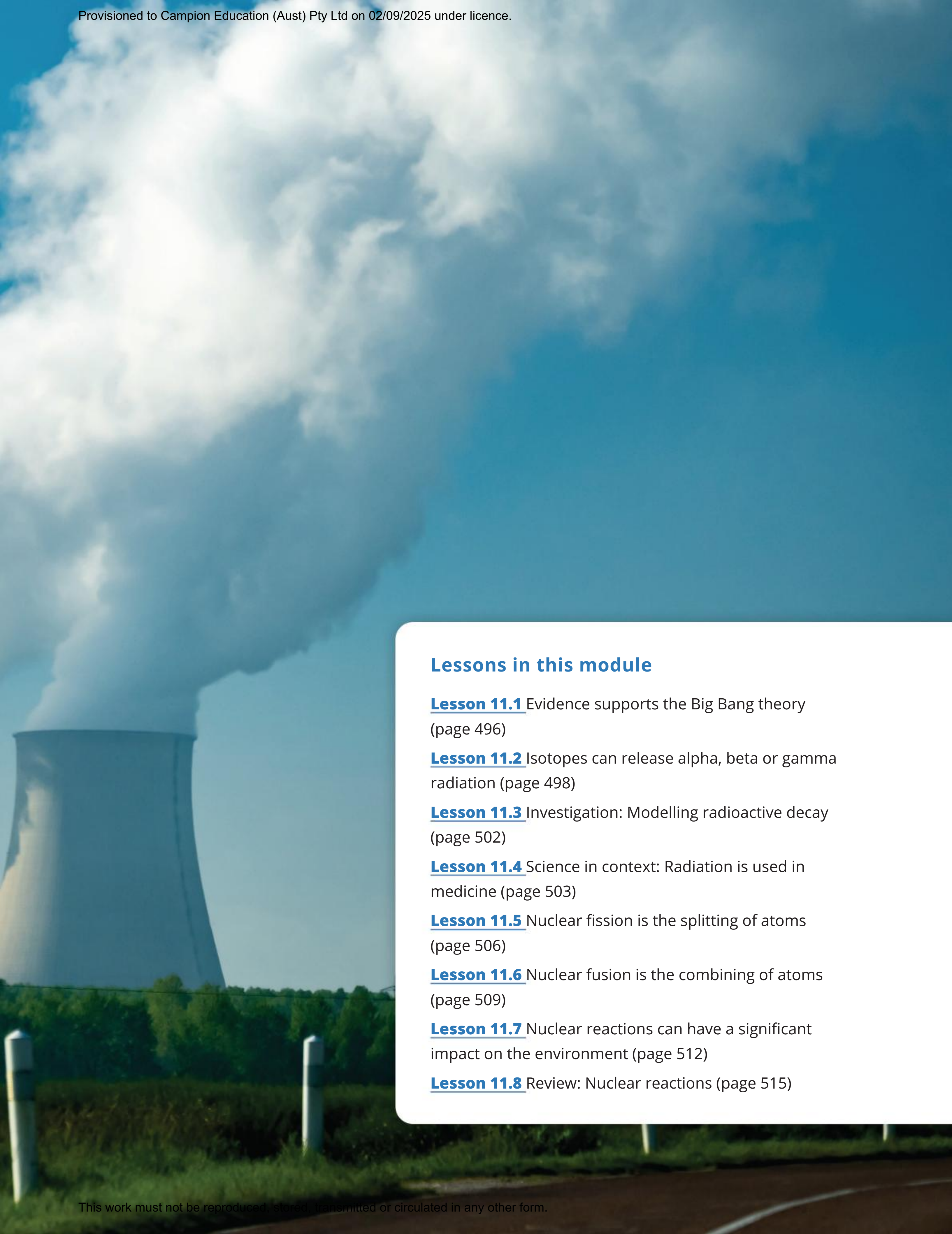
Module 11

Nuclear reactions

Overview

Nuclear reactions release a significant amount of energy. Nuclear fission is a process in which a large, unstable atomic nucleus splits into two smaller, more stable nuclei, whereas nuclear fusion is a process in which two small atomic nuclei combine to form a larger nucleus. Nuclear fission is widely used in nuclear power plants to generate electricity, with the heat produced used to create steam that drives turbines.

Using nuclear fission to generate energy is controversial, with some benefits as well as significant challenges. Unlike with fossil fuels, carbon dioxide is not released in the process of making energy in nuclear power plants, although the environmental impact of the extraction of the required resources must be considered, as well as the management of nuclear waste, which remains hazardous for thousands of years.



Lessons in this module

Lesson 11.1
Evidence supports the Big Bang theory

Learning intentions and success criteria

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.

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 then. In 1929, the US astronomer Edwin Hubble discovered that the spectra of light from galaxies implied that they were moving away from the Earth. Hubble also found one of the most significant results in the history of the origin of the Universe; that the further away galaxies were from the Earth, the faster they were moving.

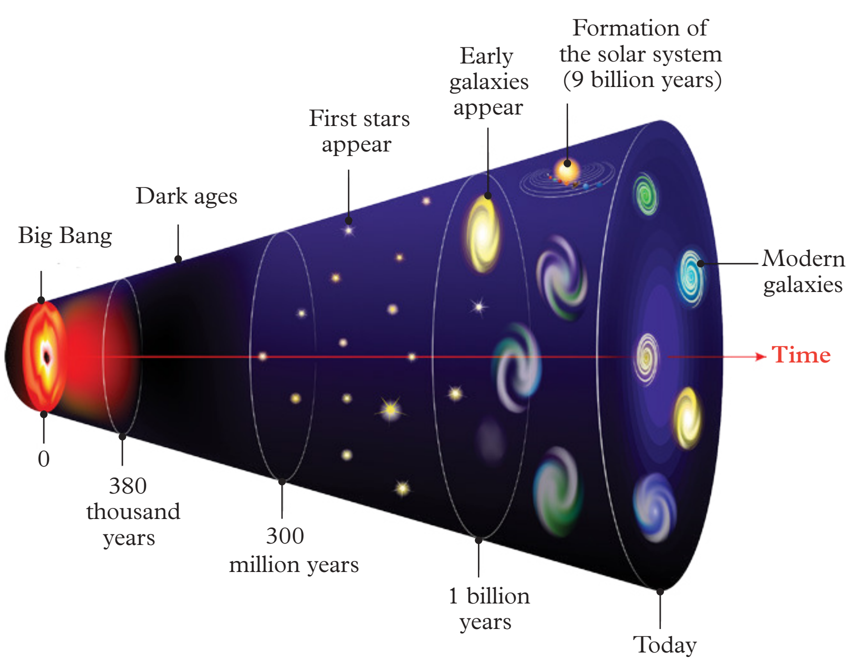


Figure 1 According to the Big Bang theory, the Universe began from a rapid expansion from a hot, dense state.

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 starts 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.

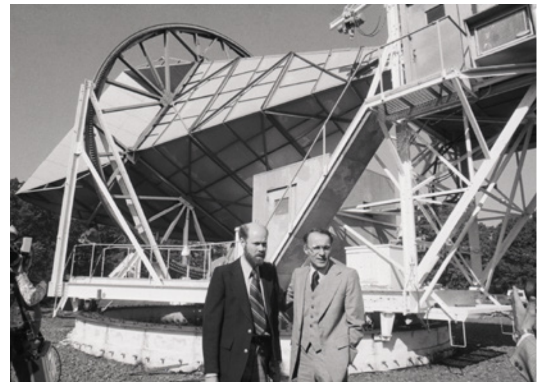


Figure 2 Arno Penzias (left) and Robert Wilson (right) in front of their horn antenna, with which they discovered cosmic microwave background radiation

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 American scientists, Arno Penzias and Robert Wilson (Figure 2), found evidence that the leftover energy existed as background radiation.

While testing a new, sensitive, horn-shaped radio telescope antenna, Penzias and Wilson found a strong background noise that was interfering with transmission. They weren't trying to find it, they just happened to notice it. 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).

cosmic microwave background radiation remnant electromagnetic radiation left from early stages of the Universe

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.

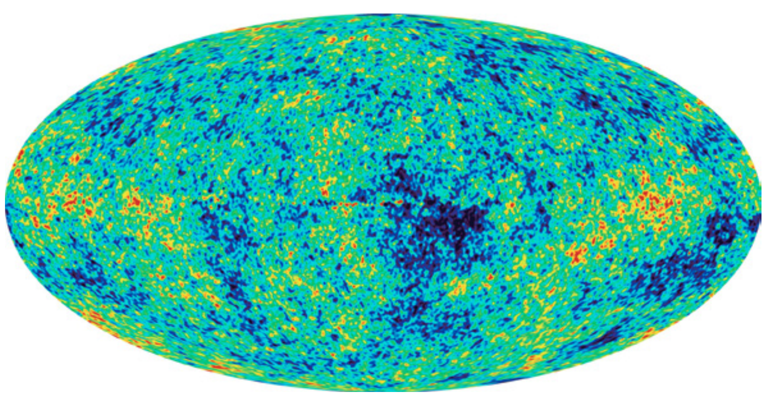


Figure 3 Fluctuations in the cosmic microwave background radiation are shown as temperature fluctuations over the sky. These fluctuations correlate with the formation of nearby matter. In this image, blue represents cooler temperatures and red represents warmer temperatures.

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,

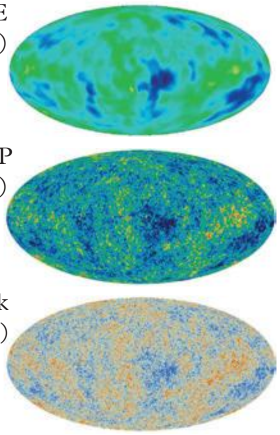


Figure 4 Images from the COBE, Wilkinson Microwave Anisotropy Probe (WMAP) and Planck satellites

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 (Figure 4).

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 11.1

Check your learning 11.1

Comprehend

1 Explain why the Big Bang was not a bang at all.

2 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.

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.

Lesson 11.2

Isotopes can release alpha, beta or gamma radiation

Learning intentions and success criteria

Key ideas

→ Some isotopes are unstable and may decay.

→ Radioactive decay produces alpha, beta and gamma radiation.

→ The half-life of an isotope is the time it takes for half the remaining unstable isotopes to decay.

Isotopes and radioactive decay

Atoms of the same element always have the same number of protons, but sometimes they can have different numbers of neutrons. When this happens, we call them **isotopes**.

Isotopes are different versions of the same element. They behave in the same way chemically because they have the same number of protons and electrons, but their masses are slightly different because of the extra or missing neutrons.

For example, carbon has two common isotopes: carbon-12 and carbon-14. Both are carbon because they have six protons, but carbon-12 has six neutrons, while carbon-14 has eight neutrons.

To show an isotope in notation form, we write the element's symbol with two numbers. The mass number (protons + neutrons) goes at the top left, and the atomic number (protons) goes at the bottom left.

For example, carbon-14 is written as ${}^{14}_{6}C$, where 14 is the mass number and 6 is the atomic number. This tells us it is a carbon atom with six protons and eight neutrons (since $14 - 6 = 8$).

While the number of neutrons can vary, having too many or too few neutrons results in an unstable nucleus that decays radioactively. In the first 20 elements, stable nuclei have a similar number of neutrons and protons.

This process of decay causes the emission of energy in the form of radiation and is known as **radioactive decay**. Hydrogen-1 and hydrogen-2 are stable, but hydrogen-3 is unstable and breaks down. Therefore, hydrogen-3 is a radioactive isotope and is called a **radionuclide**. Radionuclides occur naturally, but they can also be manufactured in a nuclear reactor. All radionuclides release energy when they break down and form a more stable atom. This energy can be calculated using Einstein's famous equation:

$$E = mc^2$$

where E is energy, m is the change in the mass when the radionuclide converts to its stable form and c is the speed of light.

isotopes different forms of the same element that have a different atomic weight due to a different number of neutrons, but the same number of protons

radioactive decay the conversion of a radioactive isotope into its stable form, releasing energy in the form of radiation

radionuclide a radioactive isotope

alpha particle a radioactive particle containing two protons and two neutrons; can be stopped by a piece of paper

beta particle a radioactive particle (high-speed electron or positron) with little mass; can be stopped by aluminium or tin foil

Types of nuclear radiation

Alpha (α), beta (β) and gamma (γ) radiation all originate from an unstable nucleus. An **alpha particle** is identical to a helium nucleus. It contains two protons and two neutrons. Americium-241, which is commonly used in smoke detectors, is an example of an alpha particle emitter. Its nucleus decays to neptunium-237, which is a more stable atom.

The decay of americium-241 to neptunium-237 can be shown in a nuclear equation:

$${}^{241}_{95}Am \rightarrow {}^{237}_{93}Np + \frac{4}{2}\alpha$$

In a nuclear equation, the mass numbers on each side of the arrow add to the same value. In this case, they both add to 241. This demonstrates that the total mass of the particles before and after the decay is the same.

Beta particles are produced when a neutron in the nucleus decays into a proton and an electron. The electron is the beta particle that leaves the atom. An example of beta decay is the decay of iodine-131 to xenon-131:

$${}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + \beta$$

The beta particle has very little mass, so the mass of the new nucleus formed is very similar to the original iodine-131 nucleus. As the beta particle is released, a neutron in

Figure 1 Smoke detectors contain a radioactive source, usually americium-241.

gamma ray a high-energy electromagnetic ray released as a part of radioactive decay; can be stopped by lead

effect becomes a proton, so the atomic number of the resulting nucleus increases by one.

Gamma rays are high-energy electromagnetic rays, similar to X-rays, which are emitted after alpha particle or beta particle emission when the nucleus is still excited.

An example is when cobalt-60 decays to form nickel-60:

$$^{60}_{27}\text{Co} \rightarrow ^{60}_{28}\text{N} + \beta + \gamma$$

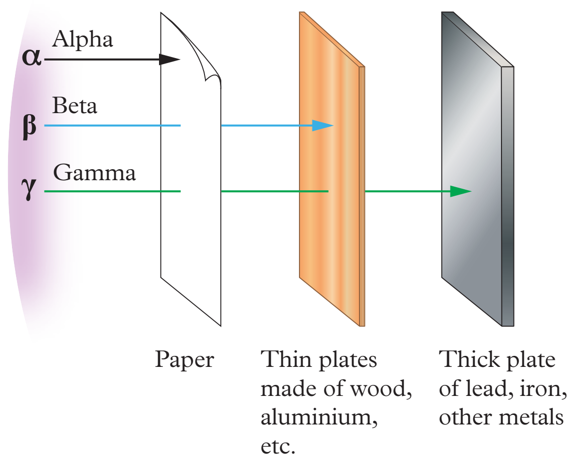


Figure 2 The relative penetrative power of alpha, beta and gamma radiation. Alpha particles are stopped by paper. Beta particles are stopped by aluminium foil. Gamma rays can only be stopped by lead.

Cobalt-60 is an artificially produced **radioisotope** that is used in medical radiotherapy, sterilisation of medical equipment and irradiation of food. Because gamma radiation is an electromagnetic wave (rather than a particle, such as alpha and beta radiation), it is highly penetrating and can cause cell damage deep within the body if exposure levels are high.

Radioactive half-life

Radioactive decay is a random process, so we cannot predict which radioactive nuclei in a sample will decay. The rate of radioactive decay, however, follows a pattern. As a radioactive sample decays, less and less of the original radioactive atoms are left and more of the alternative stable atoms are formed. This means the radioactivity level drops. The half-life of a radioactive material is the time taken for half the radioactive nuclei in a sample to decay into the stable atoms (see examples in Table 1). This is also equivalent to the time taken for the radioactivity to drop to half of its original value.

When the radioactivity reaches one-half of its original level, one half-life has passed. When it reaches one-quarter of its original level, two half-lives have passed, and so the pattern continues. A graph of radioactive decay against time gives a characteristic shape called an exponential decay curve (Figure 3). Worked example 11.2A shows how to calculate the half-life of a radioactive element.

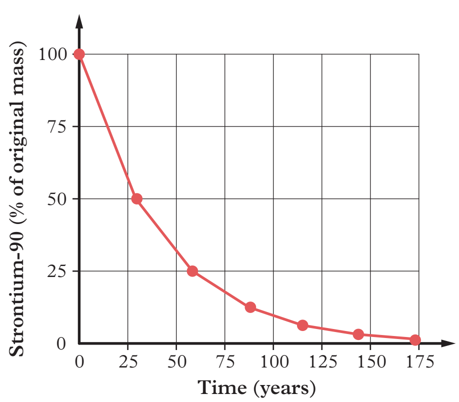


Figure 3 A radioactive decay curve for strontium-90, which has a half-life of 28.8 years

radioisotope an isotope (different versions of the same element due to differing atomic mass) that emits radiation due to an unstable nucleus

Table 1 Half-lives of important medical radionuclides

Radionuclide	Half-life
Bismuth-213	46 minutes
Technetium-99m	6 hours
Lutetium-177	6.7 days
Iodine-131	8 days
Chromium-51	28 days
Strontium-89	50 days

Worked example 11.2A Calculating half-life

Strontium-90 is a radioactive element that has a half-life of 28.8 years. For 1,000 g of strontium-90, calculate:

a the amount of strontium-90 left after one half-life

b the number of years it would take for strontium-90 to decay to 125 g.

Solution

Steps	What to do	Working out
a.	For part **a**, after one half-life, half of the 1,000 g would have decayed.	Remaining strontium-90 = $\frac{1}{2}$ × 1,000 g = 500 g
b.	For part **b**, to calculate the number of years it would take 1,000 g to decay to 125 g, the number of half-lives needs to be determined.	Starting strontium-90 mass (0 years) = 1,000 g 1 half-life (28.8 years) = 500 g 2 half-lives (57.6 years) = 250 g 3 half-lives (86.4 years) = 125 g Therefore, the time for 1,000 g of strontium-90 to decay to 125 g = 86.4 years.

Check your learning 11.2

Check your learning 11.2

Retrieve

1 Define each of the following terms.

a Radioactive decay

b Radionuclide

c Half-life

Comprehend

2 Represent an isotope for each of the following in the form AZX. You may need to use the periodic table to determine the atomic number of the elements.

a Iodine-131

b Cobalt-60

c Technetium-99

d Fluorine-18

3 A number of the elements have radioactive isotopes. In each case, it is the nucleus of the atom that is unstable. Describe how you could protect yourself from each of the following types of radiation.

a Alpha

b Beta

c Gamma

Analyse

4 At 3:00 pm, 80,000 atoms of a radionuclide were sitting on the bench. At 3:10 pm, after 10 minutes of radioactive decay, there were only 5,000 of the original atoms left. (The others had decayed into a more stable isotope.)

a Calculate the half-life.

b Explain the relationship between the half-life of the radionuclide and the number of atoms it has.

Apply

5 Investigate one radioactive isotope that is used in medicine. State the symbol for the isotope and its uses.

Skills builder: Processing and analysing data and information

6 Look at Figure 3, which shows the radioactive decay curve for strontium-90.

a Identify the level of strontium-90 at 25 years. (THINK: Which axis in the graph represents time?)

b How many years did it take for the levels of strontium-90 to change from 75 to less than 10? (THINK: What scale does the graph use?)

Lesson 11.3
Investigation: Modelling radioactive decay

Introduction

This investigation illustrates the idea of exponential decay and half-life. Counters represent the nuclei.

Purpose

To model the half-life of a radioactive compound

Materials

- Counters (at least 30) to represent nuclei
- A4 paper
- Disposable plastic cup
- Permanent marker

Procedure

1. Draw a results table, as shown in Table 1 in the Results section.
2. Write “M” on one side of each counter.
3. Count the total number of counters that you have, record this number, and place them in the plastic cup.
4. Shake the cup and tip all the counters onto the paper.
5. Those that have the “M” facing upwards represent atoms that have decayed. Move these to a “discard” pile.
6. Count the remaining “nuclei” and record this number.
7. Place the remaining nuclei back into the cup, shake them and tip them out again.
8. Move the decayed nuclei to the discard pile and count those remaining. Record the number.
9. Continue until you have three or fewer nuclei.
10. Repeat the whole process two more times.

Results

1. Record the results from the experiment in Table 1.

Table 1 Results from the experiment

Number of shakes	Number of undecayed “atoms”		
	Trial 1	**Trial 2**	**Trial 3**
0 (start)			
1			
2			
…			

2. Draw a set of axes with the number of atoms remaining (vertical axis) and the number of shakes (horizontal axis). Plot points and draw a line of best fit through the points for each of the three trials.

Discussion

1. The atomic nuclei were represented by counters. Describe how the half-life of the decay process was represented.
2. Contrast the shapes of the curves drawn for each trial.
3. Explain how the overall shape of the curves would or would not change if you started with more atomic nuclei.
4. In this experiment, you would eventually end up with no “undecayed” counters. Evaluate whether this would be the case with a real radionuclide (by describing how atoms randomly decay in real life, comparing this to the counter demonstration and deciding whether every atom of a real radionuclide would become stable).

Lesson 11.4

Science in context: Radiation is used in medicine

Introduction

The radiation produced by isotopes can damage the cells in our body, or it can be used to identify and cure diseases. Nuclear medicine is a diagnostic imaging method often used in X-ray departments in hospitals and medical clinics.

Effects of radiation

The main reason that radiation is harmful is that it can cause atoms in other substances to become ions. The emitted alpha and beta particles have enough mass and/or energy to remove electrons from the outside of atoms, which changes the properties of the atoms. This process also causes the release of reactive particles, called free radicals. If this occurs in our bodies, these free radicals can go on to damage other important molecules in the body. If DNA is damaged, this can have serious effects, because DNA is the molecule that contains instructions for other biochemical processes. It is also a molecule that can reproduce itself, so the effect of one damaged DNA molecule can be multiplied thousands or even millions of times because copies of the affected DNA are created. Many cancers linked to radiation start in this way.

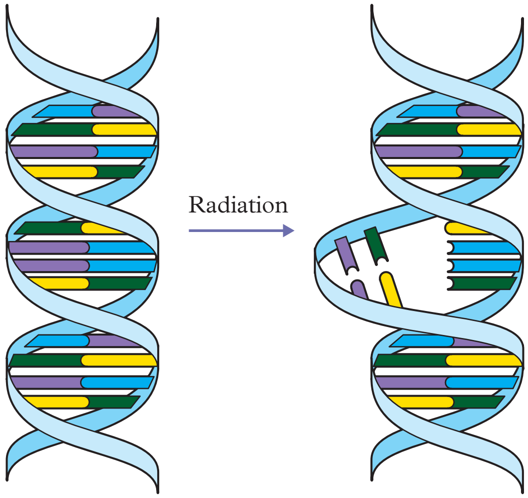


Figure 1 Radiation can damage the structure of DNA molecules.

Radiation and medicine

Despite the damage that can be caused by radiation, it has many uses in medicine. The most common medical application is the use of X-rays to identify damaged or broken bones. Less common is the injection of a radioactive isotope into a patient. The radiation accumulates at the site of a cancer or other damaged tissue and is detected by special monitors.

Radiation therapy uses the ability of radioactive isotopes to kill off cancer cells. A gamma knife is a version of this, where thin beams of radiation are targeted directly at the site of the cancer growth. Cancer cells are normal cells that have had their DNA slightly changed. This change is not enough to kill the cancer cell. Instead, it allows the cancer cell to grow very quickly. Radiotherapy uses radioactive isotopes to cause more damage to the cancer cells. Most commonly, the radioactive particles released by the isotope are directed at the site of the cancer. Eventually, when the cancer cells are damaged enough, they die (a process called apoptosis).

Figure 2 X-rays use radiation to make images of the bones in the body.

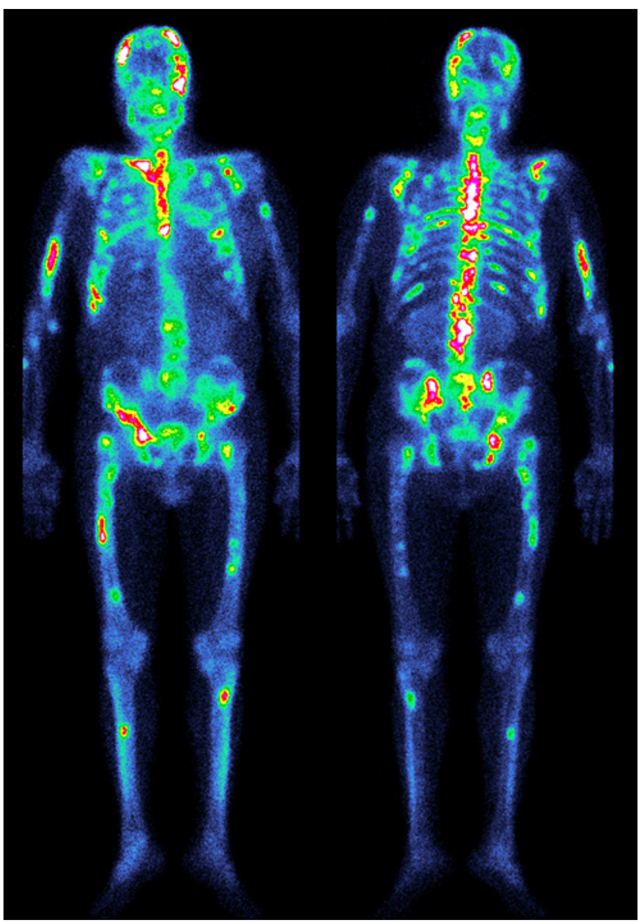


Figure 3 A technetium-99m bisphosphonate bone scan shows up abnormalities within bones.

Careers in radiation

A nuclear medicine technologist uses medical imaging to help radiologists diagnose illnesses. Before the first patient arrives, the technologist must measure the amount of radioactivity delivered to the department. The isotope, in liquid form, is drawn up into the required amounts and added to "cold" kits so that the day's scans can be performed.

A cold kit is a vial containing a particular chemical agent that, once introduced into the human body, will travel to a particular organ. Each test uses a particular compound, which travels to a known organ of the body based on its chemical composition and the way it is introduced into the body.

Most people referred to nuclear medicine departments require bone scans. These may be performed to diagnose cancer, investigate the extent of arthritis, screen for fractures that do not show on a plain X-ray or look at infection of bone.

In other cases, the blood is of interest. The blood of a patient can be "labelled"; that is, mixed with a small amount of radionuclide. This is used to locate the site of internal bleeding. Once the internal bleeding has been located, surgeons can operate, knowing exactly where to begin finding the haemorrhaging (bleeding) vessel so that it may be sealed to prevent further blood loss.

The nuclear medicine technologist typically performs a number of these tests each day, looking at a variety of pathologies. Nuclear medicine technologists must be familiar with many organs in the body so they know whether the images obtained appear normal or abnormal. There is also the opportunity to learn about the various treatments for different conditions patients can have. Although a nuclear medicine technologist may learn to interpret images and determine what pathology a person has, they are not qualified to make a formal diagnosis. They must present the images to the radiologist, who makes the diagnosis. Nuclear medicine technologists have a close working relationship with radiologists, surgeons and nurses.

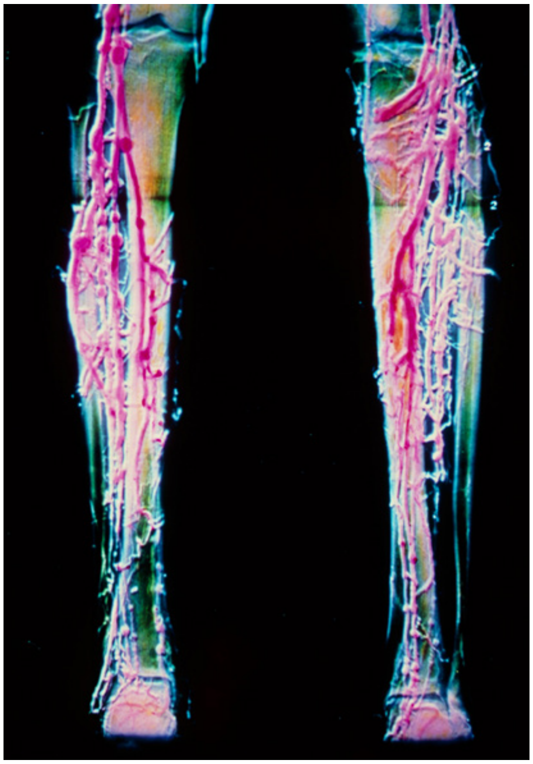


Figure 4 Radioactive dye injected into the blood shows blood flow in the blood vessels.

Test your skills and capabilities

Test your skills and capabilities 11.4

Asking questions

In critical thinking, you are encouraged to ask many questions; however, it can be difficult to think of the right questions to ask. The best questions will have the following characteristics.

- Asking yourself specific questions is useful and can help identify assumptions that you or someone else may be making. For example: "How do I know this?", "What is the evidence that supports this?", "Who wrote this?" and "Why did they write this?"
- Open questions are best when they are directed at someone else. An open question does not have a yes or no answer. Instead, it encourages the person to explain their response. For example: "How do you feel about …?", "Where do you think this idea came from?" and "What makes you say that?"

1 Write three questions that you could ask yourself or someone else about the radiation discussed in this lesson. They could be questions that identify any assumptions or biases that are held about radiation or cancer treatment.

2 Write three open questions that you could ask a nuclear medicine technologist about radiation or cancer treatment.

If you have access to a nuclear medicine technologist, ask them the questions you wrote in question **2**. Alternatively, ask someone in your class to answer the questions you wrote in question **1**. A good question will make them think critically before they provide an answer.

Skills builder: Planning investigations

3 Stella has been told she has to receive an X-ray to see if her ribs are broken. Sometimes, X-rays to the ribs need to be repeated to get a clear image. Stella is concerned about the amount of radiation this may involve, so she is conducting a risk assessment.

   a Identify the risk of high radiation to Stella. (THINK: Is the X-ray likely to deliver high levels of radiation?)

   b Identify measures that could be taken to prevent unnecessary radiation exposure. (THINK: Is there PPE that Stella and the radiologist could wear?)

Lesson 11.5
Nuclear fission is the splitting of atoms

Learning intentions and success criteria

Key ideas

- → Nuclear fission is the splitting of an atom into two smaller, stable nuclei.
- → Large amounts of energy are released when nuclear fission occurs.
- → Uranium and plutonium are two elements that can undergo nuclear fission.
- → Nuclear power plants can generate energy from nuclear fission due to a chain reaction.

Introduction

nuclear fission when the nucleus of an atom splits into two or more smaller nuclei, with the release of energy

Nuclear fission is the process in which a large, unstable atomic nucleus, such as uranium-235 or plutonium-239, splits into two smaller, more stable nuclei, releasing a significant amount of energy (Figure 1).

Nuclear fission is widely used in nuclear power plants to generate electricity, where the heat produced from fission is used to create steam that drives turbines.

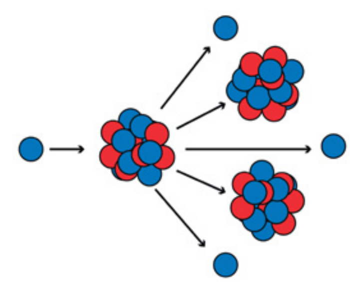


Figure 1 How an atom can be split into smaller nuclei

Uranium-235

Uranium-235 is a radioactive isotope of the element uranium. Of the uranium that is found naturally, only 0.72 per cent is made of uranium-235. It has a half-life of about 700 million years. Uranium-235 is commonly used in nuclear reactors because its nucleus can split easily when hit by a neutron. When it splits, it forms barium-144 and krypton-89, along with three neutrons that can trigger more nuclear fission reactions.

Nuclear fission releases a lot of energy which can be used as nuclear energy in nuclear reactors. It can also heat water into steam, which can be used to spin a turbine to produce carbon-free electricity.

The process of nuclear fission

Nuclear fission is the process in which the centre of a large atom, called the nucleus, splits into two smaller parts.

This reaction is usually triggered by bombarding the unstable nucleus with a slow-moving neutron, causing it to become even more unstable and break apart. Along with energy, additional neutrons are also released, which can go on to trigger further fission reactions in a chain reaction.

An example of nuclear fission is seen when uranium-235 absorbs a tiny particle called a neutron. This makes the atom unstable, causing it to split into two smaller atoms. When this happens, it also releases more neutrons and a lot of energy. Some of the atom's mass is turned into energy, following Einstein's famous equation $E = mc^2$.

An example of this process is shown by the following equation and in Figure 1:

$$^{235}_{92}U + n \rightarrow {}^{236}_{92}U \rightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n + \text{energy}$$

Chain reactions

The neutrons released during a fission reaction can hit other atoms, causing them to split too. This creates a chain reaction, where one fission reaction leads to many more. In nuclear power plants, this reaction is carefully controlled to produce electricity safely (Figure 2). In nuclear weapons, the reaction is uncontrolled, causing a powerful explosion.

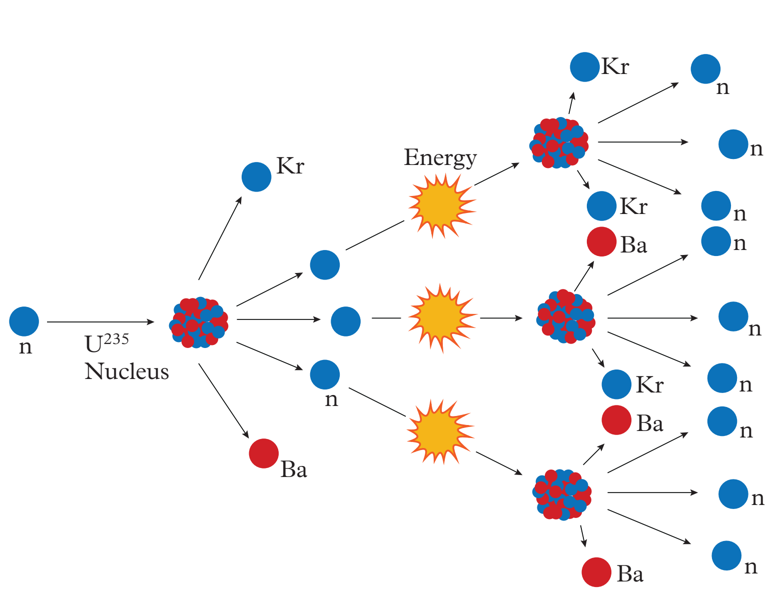


Figure 2 An example of a neutron being absorbed by a uranium-235 nucleus and splitting into krypton-92 and barium-141, and releasing neutrons and a large amount of energy, forming a chain reaction

Benefits of nuclear fission

Nuclear fission has many advantages.

- Clean energy: The greenhouse gas, carbon dioxide, is not released.
- Production: One million times more energy per kilogram is released than burning coal, oil or gas.
- Climate change: Nuclear fission can help combat climate change by reducing the reliance on fossil fuels.
- Safety: The design of modern reactors makes them reliable and safe to run.

Challenges of nuclear fission

Nuclear fission has many challenges in being the source of energy production, including the following.

- Safety: People do not feel comfortable living near nuclear power plants.
- Environment: The mining of nuclear material causes damage to habitats and water sources, and greenhouse gases are also released in this process.
- Infrastructure: It costs lots of money to build a nuclear power plant, as well as to decommission one.
- Waste: Radioactive waste must be stored safely for thousands of years (which is expensive), with potential leaks polluting underground water and the soil.
- Incidents: People are wary of incidents in Europe and Japan (Figure 3) that have caused economic and health issues, as well as damage to the environment and the power plant itself.

Figure 3 The Fukushima nuclear power plant was severely damaged by the tsunami that followed the 2011 earthquake, which disabled the power supply and cooling systems.

Applications of nuclear fission

Nuclear fission is used in power plants to generate electricity (Figure 4). It also powers submarines and ships. There are challenges with its use, however, such as dealing with dangerous radioactive waste and preventing nuclear accidents.

Table 1 details a number of radioactive isotopes that undergo nuclear fission, as well as their common uses.

Table 1 Some examples of radioactive isotopes that undergo nuclear fission and their uses

Isotope	Common use
Uranium-235 (^{235}U)	Primary fuel in most nuclear reactors and nuclear weapons
Uranium-233 (^{233}U)	Used in some advanced nuclear reactors (thorium fuel cycle)
Plutonium-239 (^{239}Pu)	Used in nuclear reactors and as a key material in nuclear weapons
Plutonium-241 (^{241}Pu)	Contributes to fission in nuclear reactors, especially in mixed oxide (MOX) fuel

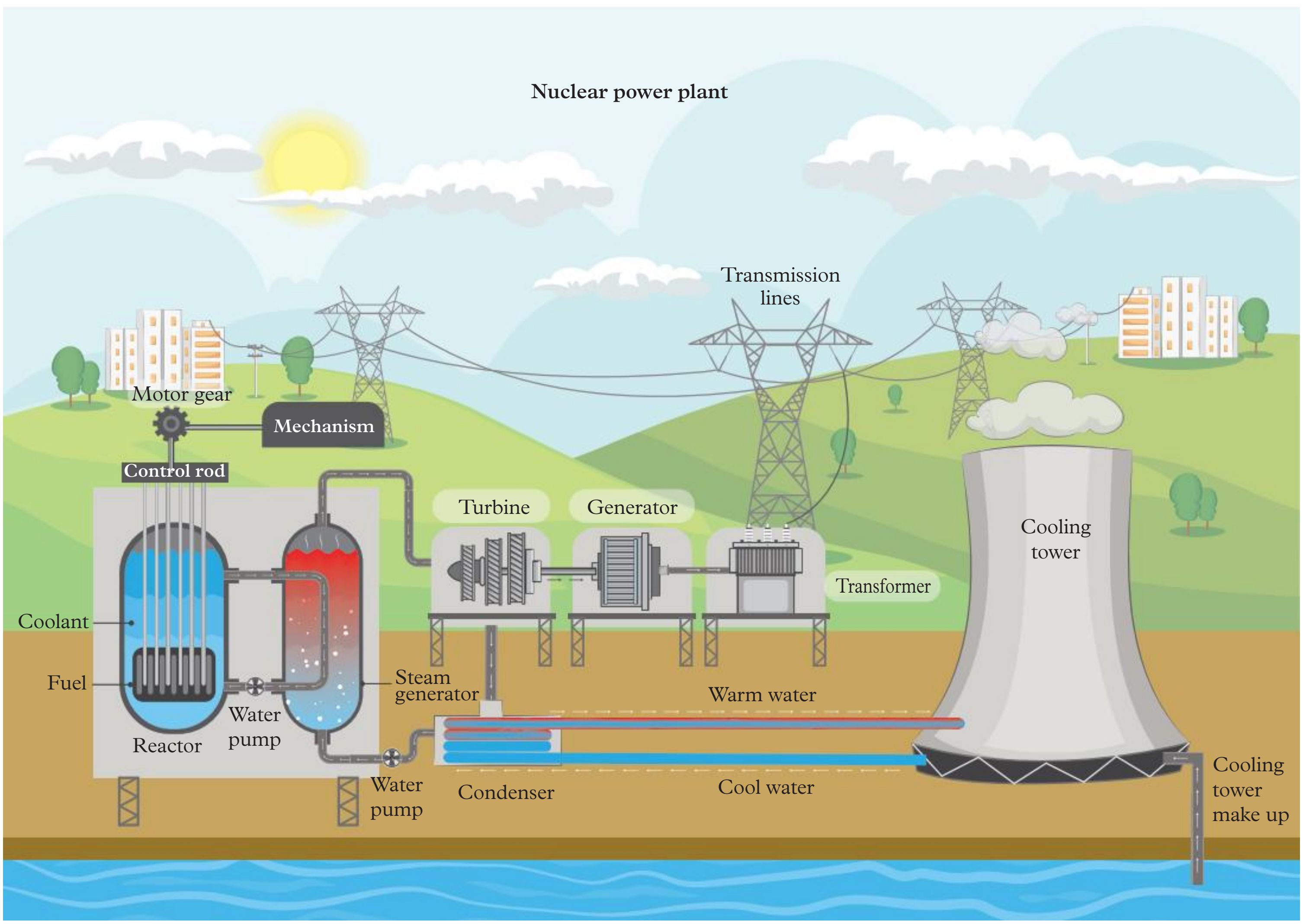


Figure 4 A nuclear power plant generates electricity by using nuclear fission to produce heat, which converts water into steam, driving turbines that generate power.

Check your learning 11.5

Check your learning 11.5

Retrieve

1 Explain nuclear fission.
2 Name two elements commonly used in nuclear fission.

Comprehend

3 Explain how a chain reaction occurs in nuclear fission.
4 Describe what happens to the nucleus of an atom during nuclear fission.
5 Explain why nuclear fission releases energy.

Analyse

6 Discuss the advantages and disadvantages of using nuclear fission as an energy source.

Lesson 11.6

Nuclear fusion is the combining of atoms

Key ideas

→ Nuclear fusion occurs when two small atomic nuclei, such as those in hydrogen atoms, combine to form a larger nucleus.

→ Nuclear fusion releases large amounts of energy.

→ Our Sun undergoes nuclear fusion.

→ Common fuels for nuclear fusion are deuterium and tritium.

→ Nuclear fusion has various benefits; it is safe, it creates low waste, it doesn't produce greenhouse gases,k and hydrogen is readily available.

→ The challenge of nuclear fusion is creating controlled reactions on the Earth.

Learning intentions and success criteria

Introduction

Nuclear fusion is a process in which two small atomic nuclei combine to form a larger nucleus, releasing a huge amount of energy. This is the same process that powers the Sun and other stars (Figure 1). Understanding nuclear fusion helps explain how stars shine. Scientists are trying to use this process to create cleaner energy on the Earth.

nuclear fusion the process in which smaller nuclei come together and form a larger nucleus

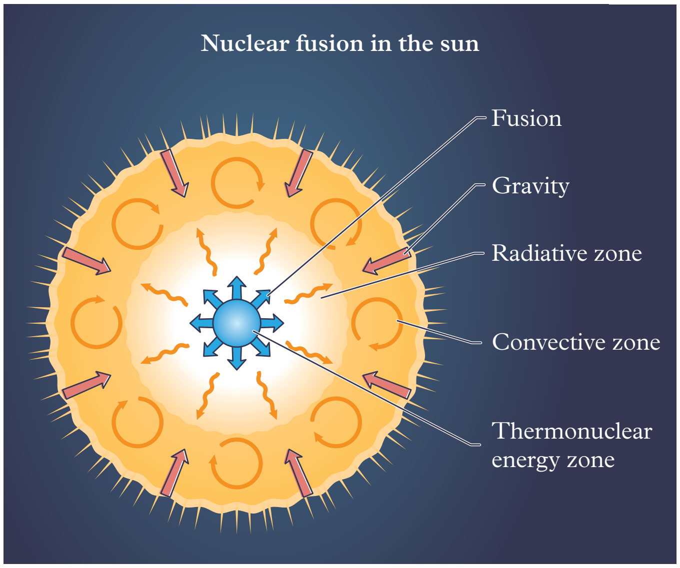


Figure 1 The process of nuclear fusion powers the Sun and other stars.

The process of nuclear fusion

Nuclear fusion occurs when two light atoms, such as hydrogen, are forced together under extreme heat and pressure. When they collide with enough energy, they combine to form a larger atom, such as helium, while releasing energy.

An example of a fusion reaction is shown by the following equation and in Figure 2.

$$^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + \text{energy}$$

Nuclear fusion commonly uses two types of hydrogen, called deuterium and tritium, as fuel (Figure 3). Deuterium is found in very small amounts in natural hydrogen (only about 0.0153 per cent) and can be taken easily from seawater. Tritium can be made from lithium, which is common in nature.

Even though deuterium is rare, just 1 L of water has enough of it to produce as much energy as burning 300 L of oil. This means that there is enough deuterium in the oceans to provide energy for humans for millions of years.

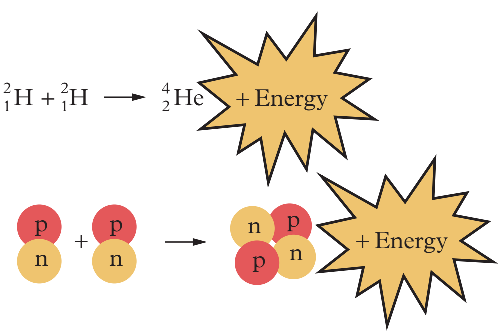


Figure 2 In the reaction shown, two hydrogen atoms fuse to form a helium atom, releasing enormous energy as light and heat.

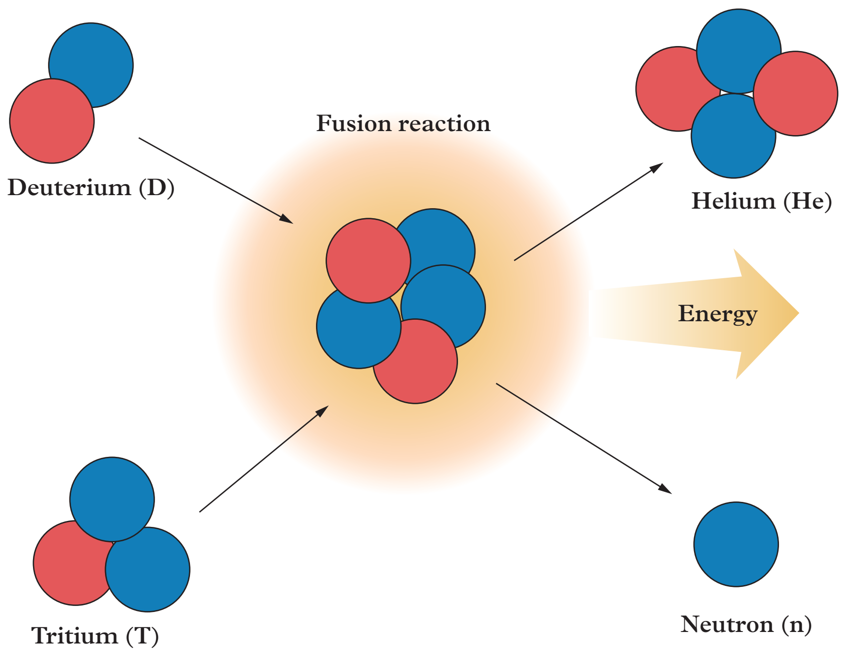


Figure 3 A nuclear fusion energy diagram using models of deuterium, tritium, helium and a neutron

Conditions for nuclear fusion

Nuclear fusion requires incredibly high temperatures (millions of degrees) and immense pressure to overcome the natural repulsion between the positively charged nuclei. These conditions exist naturally in stars but are difficult to create on the Earth. Scientists are working on building fusion reactors to replicate these extreme conditions safely.

Benefits of nuclear fusion

Nuclear fusion has many potential advantages.

- Clean energy: Fusion produces no greenhouse gases.
- Abundant fuel: Hydrogen, used in fusion, is plentiful in water.
- Safe: Fusion reactors have no risk of a meltdown like fission reactors do.
- Low waste: Fusion creates far less radioactive waste than nuclear fission.

Challenges of nuclear fusion

Despite its potential, creating controlled nuclear fusion on the Earth is extremely difficult because of the high temperatures and pressures needed. Current experimental reactors like the International Thermonuclear Experimental Reactor (ITER, which also means "the way" in Latin) are still in development, with hopes of making fusion a viable energy source in the future (Figure 4).

Table 1 details a number of isotopes that participate in nuclear fusion, as well as whether these isotopes are stable or radioactive.

Figure 4 Aerial view of the nuclear reactor site ITER in Cadarache, France

Table 1 Examples of isotopes that participate in nuclear fusion

Element/isotope	Stable/radioactive	Fusion context
Deuterium (^2H)	Stable	Common fusion fuel
Tritium (^3H)	Radioactive	Common fusion fuel
Helium-3 (^3He)	Stable	Occurs in stars and research
Helium-4 (^4He)	Stable	Formed in **stellar fusion**

stellar fusion is the process where light atomic nuclei fuse under extreme heat and pressure in stars, releasing energy

Check your learning 11.6

Check your learning 11.6

Retrieve

1 Name two elements commonly used in nuclear fusion.

Comprehend

2 Explain how nuclear fusion occurs.
3 Describe the conditions that are necessary for nuclear fusion to occur.
4 Explain why nuclear fusion releases energy.
5 Discuss how nuclear fusion is different from nuclear fission.

Analyse

6 Discuss the advantages of using nuclear fusion as an energy source.
7 Explain why it is difficult to achieve nuclear fusion on the Earth.

Lesson 11.7

Nuclear reactions can have a significant impact on the environment

Learning intentions and success criteria

Key ideas

→ Extracting nuclear material requires the creation of mines, which can lead to habitat destruction.

→ Thermal pollution can affect aquatic ecosystems.

→ Radioactive waste products remain hazardous for a very long time, so long-term disposal methods must be well considered.

→ Environmental impacts must be considered before Australia utilises nuclear energy.

Nuclear reactions and environmental impact

Nuclear reactions, including fission and fusion, have the potential to provide large amounts of energy; however, they come with significant environmental considerations. In Australia, while there are no nuclear power plants, uranium mining is a prominent industry. Understanding the environmental impacts of nuclear reactions is essential, especially as global energy demands grow and climate change prompts discussions about low-carbon energy alternatives.

Raw material extraction and environmental impact

Nuclear fission relies on uranium, a material mined in regions like South Australia's Olympic Dam and the Northern Territory's uranium mine, Jabiluka. Uranium mining can lead to habitat destruction, particularly in biodiverse areas such as the Kakadu region, as well as water pollution due to run-off from mining operations.

Fusion, a less mature technology, requires hydrogen isotopes like deuterium, found in seawater, and tritium, which is produced from lithium. With Australia's significant lithium reserves, mining for fusion materials could have similar environmental impacts, including land degradation and water usage.

Figure 1 Jabiluka, a uranium mine in Kakadu National Park

Energy production and local ecosystems

Before uranium is used in the process of nuclear fission, it needs to be enriched so that it contains a higher concentration of the U^{235} isotope that is required to sustain a nuclear chain reaction. The process of **enriching** uranium and using it in reactors requires vast amounts of water for cooling, potentially placing a strain on water resources in arid regions like South Australia. Cooling systems can also affect aquatic ecosystems through thermal pollution. Fusion energy – although generating less radioactive waste – requires extremely high temperatures and advanced technology to maintain reactions, consuming significant resources during development. While fusion avoids some of fission's environmental drawbacks, its infrastructure demands remain a concern.

enriching increasing the proportion of a specific component in a mixture

Nuclear waste management

The waste produced by nuclear reactions creates one of the most significant challenges for the environmental. Fission generates long-lived radioactive waste such as spent fuel rods which remain hazardous for thousands of years.

The Australian Nuclear Science and Technology Organisation (ANSTO) in Lucas Heights, NSW, conducts research on nuclear technology and isotopes. While ANSTO does not produce energy, it generates low-level radioactive waste that requires careful management and storage. Currently, some low and intermediate-level radioactive waste is stored at ANSTO, while high-level waste is sent overseas.

Case study ANSTO's Synroc® System

Video: Safely Managing Nuclear Waste

ANSTO is developing Synroc®, a new way to deal safely with radioactive waste. This technology is used to treat waste from nuclear medicine such as Mo-99, which is used in hospitals for diagnosing illnesses.

The Synroc® system is designed to turn dangerous liquid waste into a solid, compact and safe form that can be stored or disposed of easily.

The process has several steps, but it focuses on making the waste safer to handle and easier to store long term. What makes Synroc® special is that it is a world-first technology created in Australia, and is also used to help other countries deal with their radioactive waste. This means that Australia is leading the way in making radioactive waste treatment safer and more sustainable.

Considerations for Australia's energy future

As Australia evaluates its energy options, the environmental impacts of nuclear reactions must be carefully considered. While nuclear energy offers a low-carbon alternative to fossil fuels, its life cycle impacts – from mining to waste management – pose challenges that need addressing. Future discussions about nuclear energy should include robust strategies to minimise environmental harm, prioritise community consultation and explore sustainable technologies.

Figure 2 Abandoned mine sites are an environmental hazard due to the destruction of habitats and water pollution.

Check your learning 11.7

Check your learning 11.7

Retrieve

1 Identify a key reason why nuclear energy can be considered as an alternative to fossil fuels.

Comprehend

2 Describe the role of uranium mining in Australia's nuclear industry.

3 Explain how uranium mining can impact ecosystems such as the Kakadu region.

4 Explain how nuclear fission reactors can affect water resources in arid regions like South Australia.

Analyse

5 Compare the environmental impacts of nuclear fission and nuclear fusion energy production.

6 Discuss why nuclear waste is considered a major environmental challenge for fission power.

7 Discuss why Synroc® is significant both in Australia and internationally.

8 Explain why community consultation is important when considering Australia's future use of nuclear energy.

Lesson 11.8
Review: Nuclear reactions

Summary

Lesson 11.1 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 11.2 Isotopes can release alpha, beta or gamma radiation

- Some isotopes are unstable and may decay.
- Radioactive decay produces alpha, beta and/or gamma radiation.
- The half-life of an isotope is the time it takes for half the remaining unstable isotopes to decay.

Lesson 11.5 Nuclear fission is the splitting of atoms

- Nuclear fission is the splitting of an atom into two smaller, stable nuclei.
- Large amounts of energy are released when nuclear fission occurs.
- Uranium and plutonium are two elements that can undergo nuclear fission.
- Nuclear power plants can generate energy from nuclear fission due to a chain reaction.

Lesson 11.6 Nuclear fusion is the combining of atoms

- Nuclear fusion occurs when two small atomic nuclei, such as those in hydrogen atoms, combine to form a larger nucleus.
- Nuclear fusion releases large amounts of energy.
- Our Sun undergoes nuclear fusion.
- Common fuels for nuclear fusion are deuterium and tritium.
- Nuclear fusion has various benefits; it is safe, it creates low waste, it doesn't produce greenhouse gases,k and hydrogen is readily available.
- The challenge of nuclear fusion is creating controlled reactions on the Earth.

Lesson 11.7 Nuclear reactions can have a significant impact on the environment

- Extracting nuclear material requires the creation of mines, which can lead to habitat destruction.
- Thermal pollution can affect aquatic ecosystems.
- Radioactive waste products remain hazardous for a very long time, so long-term disposal methods must be well considered.
- Environmental impacts must be considered before Australia utilises nuclear energy.

Review questions 11.8

Review questions Module 11

Retrieve

1 State the definition of half-life.
2 State one example of a radioactive isotope and its use.
3 Outline how the first elements formed after the Big Bang.
4 Identify one use of radioisotopes in medicine.
5 Identify symbols commonly used for alpha and beta particles in nuclear equations.
6 Identify two common types of radiation emitted by unstable nuclei.
7 Describe the conditions that make a nucleus unstable.
8 Describe the process of nuclear fission.
9 Describe the process of nuclear fusion.

Comprehend

10 Explain why hydrogen and helium were the most common elements formed after the Big Bang.

11 An isotope of uranium, uranium-238 (^{238}U), undergoes alpha decay. Represent this decay as a balanced nuclear equation.

12 An isotope of carbon, carbon-14 (^{14}C), undergoes beta decay to become nitrogen-14. Represent this decay as a balanced nuclear equation.

13 Describe what happens to the atomic number and mass number during alpha decay.

14 Describe how beta decay changes the identity of an element.

15 Describe how half-life data can be used to estimate the age of archaeological samples.

16 Describe how radioisotopes are used in environmental monitoring.

17 Explain why isotopes with long half-lives are used for dating geological formations.

18 Describe the environmental impacts of mining uranium for nuclear fission.

Analyse

19 Compare the energy output and waste products of fission and fusion.

20 Discuss why heavier elements could not form immediately after the Big Bang.

21 Discuss the risks and ethical considerations of using radioisotopes in society.

Apply

22 Apply your understanding of alpha decay to write a nuclear equation for the decay of radon-222 (^{222}Rn).

23 Use your knowledge of beta decay to predict the daughter nucleus when potassium-40 (^{40}K) undergoes beta-minus decay.

24 Apply the concept of half-life to estimate how much of a 200 g sample of cobalt-60 (half-life = 5.3 years) remains after 10.6 years.

25 Calculate the missing atomic number and mass number in an alpha decay reaction for uranium-238
$^{238}U \rightarrow ? + \alpha$ particle.

26 Calculate the missing atomic number and element symbol in a beta decay reaction for carbon-14.
$^{14}C \rightarrow ? + \beta$ particle.

27 Calculate how many neutrons are present in a nucleus of uranium-235.

28 Calculate how many protons and neutrons are present in a helium-4 nucleus.

29 Evaluate the potential risks of opening a new uranium mine in an ecologically sensitive area.

30 Evaluate the societal benefits of using radioisotopes in medical imaging and treatment.

Social and ethical thinking

31 Radiation can be used to kill cancerous cells. This treatment, however, can also damage cells in other parts of the body, causing side effects such as nausea, hair loss and fatigue. Discuss what is meant by the expression: "The end justifies the means" in relation to radiation treatment.

Critical and creative thinking

32 A community group is protesting the construction of a nuclear power plant near their town, arguing that the risks outweigh the benefits. Develop three critical thinking questions the group might ask the government or energy company to challenge the decision to build the plant.

33 Design an infographic that compares nuclear fission and nuclear fusion. Your infographic should include:

- diagrams of both processes
- a comparison of energy outputs, waste products and environmental impacts
- examples of where each process is used or being researched
- a creative element, such as a slogan or symbol that communicates your overall message.

Research

34 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.

Targeted alpha therapy

A cancer cell is a normal cell in the body that is growing in an uncontrolled way. This growth often means that cancer cells have different markers on their surface, which makes them easier to identify. Targeted alpha therapy (TAT) uses special molecules that carry alpha radioactive particles to stick to the markers on a cancer cell.

- Describe how this form of therapy works.
- Describe the types of cancer that are treated by this method.
- Describe how widespread its use is.
- Identify the risks associated with this form of radiotherapy and how they are reduced.

Aboriginal and Torres Strait Islander Peoples' perspectives

Research how Aboriginal and Torres Strait Islander Peoples view Country not just as land but as a living system that includes spiritual, cultural and ecological connections.

- Explain how this perspective might influence views on uranium mining and environmental protection.
- Describe how the concept of Caring for Country could guide more sustainable management of nuclear-related industries.
- Reflect on how including Aboriginal and Torres Strait Islander Peoples' voices in environmental decision-making benefits both communities and ecosystems.
- Suggest ways that science and Aboriginal and Torres Strait Islander Peoples' knowledge can work together to reduce the environmental impacts of mining and nuclear waste storage.

Uranium mining

Research the process and environmental impacts of uranium mining in Australia.

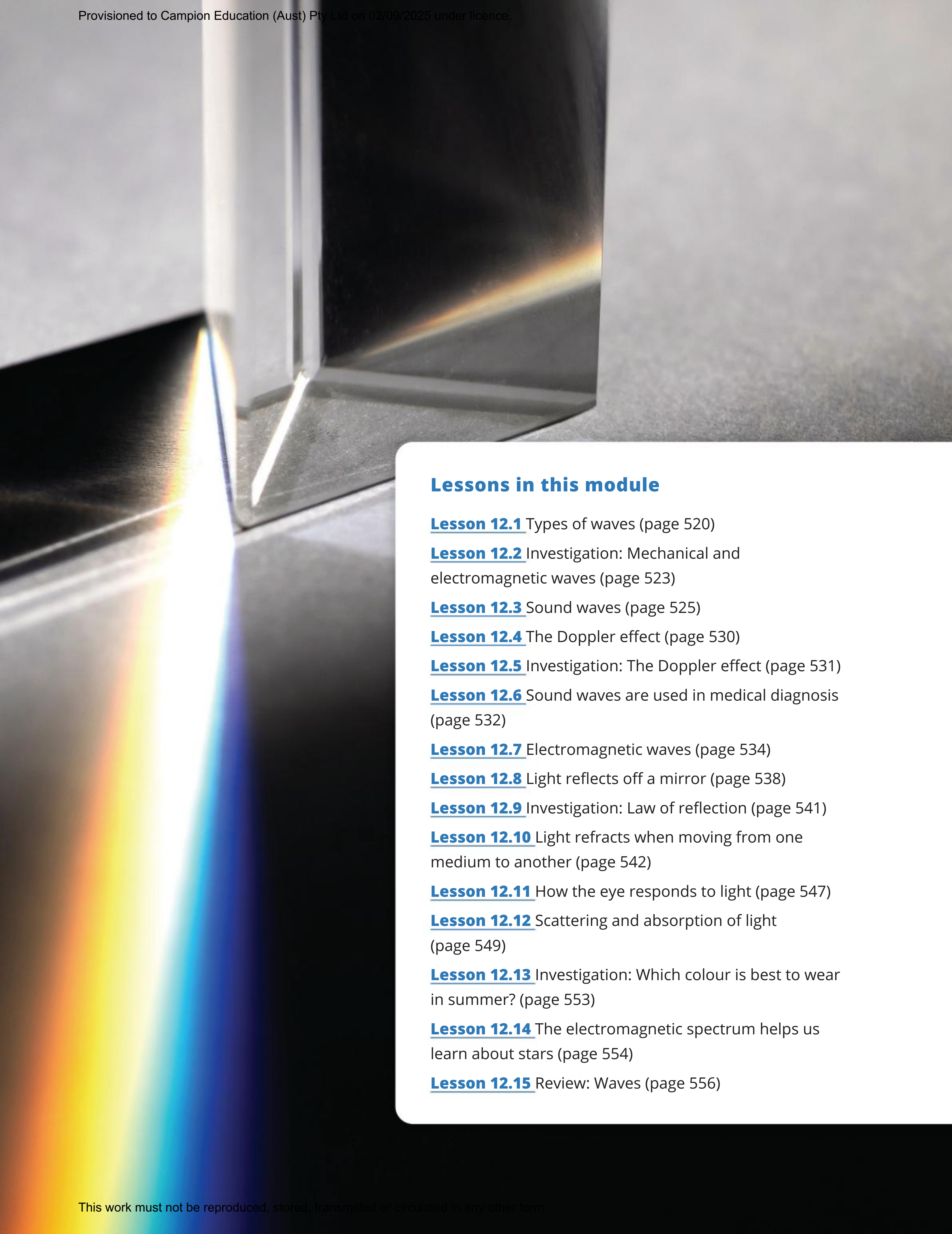
- Identify key uranium mining sites in Australia (e.g. Olympic Dam, Jabiluka).
- Describe the process of extracting and processing uranium.
- Explain the short-term and long-term environmental impacts of uranium mining on local ecosystems and water sources.
- Discuss how mining companies and governments attempt to reduce these environmental impacts.

Module 12

Waves

Overview

A wave is a disturbance that transfers energy without transferring matter. All waves have the properties of amplitude, wavelength, frequency and speed. Sound is a mechanical wave that is caused by the vibration of particles. The speed of sound varies according to the temperature and material it travels through, and the volume and pitch are linked to the amplitude and frequency of the wave. Light is an electromagnetic wave, and our eyes can only see a small amount of the electromagnetic spectrum, which we call visible light. Light reflects off mirrors and refracts when moving from one medium to another. Radio waves, microwaves and X-rays are other examples of electromagnetic waves.



Lessons in this module

Lesson 12.1
Types of waves

Learning intentions and success criteria

Key ideas

→ A wave is a disturbance that transfers energy without transferring matter.

→ Mechanical waves need a medium to transfer energy.

→ Electromagnetic waves can transfer energy in space (vacuum).

→ Frequency and period have a reciprocal relationship.

→ The speed of a wave can be calculated by multiplying its wavelength and frequency.

→ Light moves in an electromagnetic transverse wavelike motion.

Introduction

Waves play an important role in our everyday life, and it's important to understand the types of waves and their features and how they allow us to see, hear and communicate.

Types of waves

A **wave** is a disturbance that transfers energy through a medium or space. A **medium** is the matter that waves travel through.

wave a disturbance that transfers energy through a medium or space without the transfer of matter

medium the matter that waves travel through

Mechanical and electromagnetic waves

Water waves, sound waves and seismic waves are examples of **mechanical waves** (Figure 1). Mechanical waves need a medium to propagate (transfer energy). They transfer energy by the oscillation (vibration) of the particles of the medium. The particles vibrate in their position. They go back and forth or up and down about their original position so they have no net movement. It means the energy of the wave is transferred without any net movement of particles of the medium.

mechanical waves waves that need a medium to propagate (transfer energy)

Light is an **electromagnetic wave**. Electromagnetic waves transfer energy through space without any need for a medium.

electromagnetic wave a transverse wave that transfers energy through space without any need for a medium

Figure 1 A water wave is a mechanical wave.

Transverse waves

Energy is transferred in **transverse waves** if particles of the medium vibrate at right angles to the direction that the wave travels (Figure 2). The highest points of transverse waves are called crests and the lowest points are called troughs. Light is a transverse wave.

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

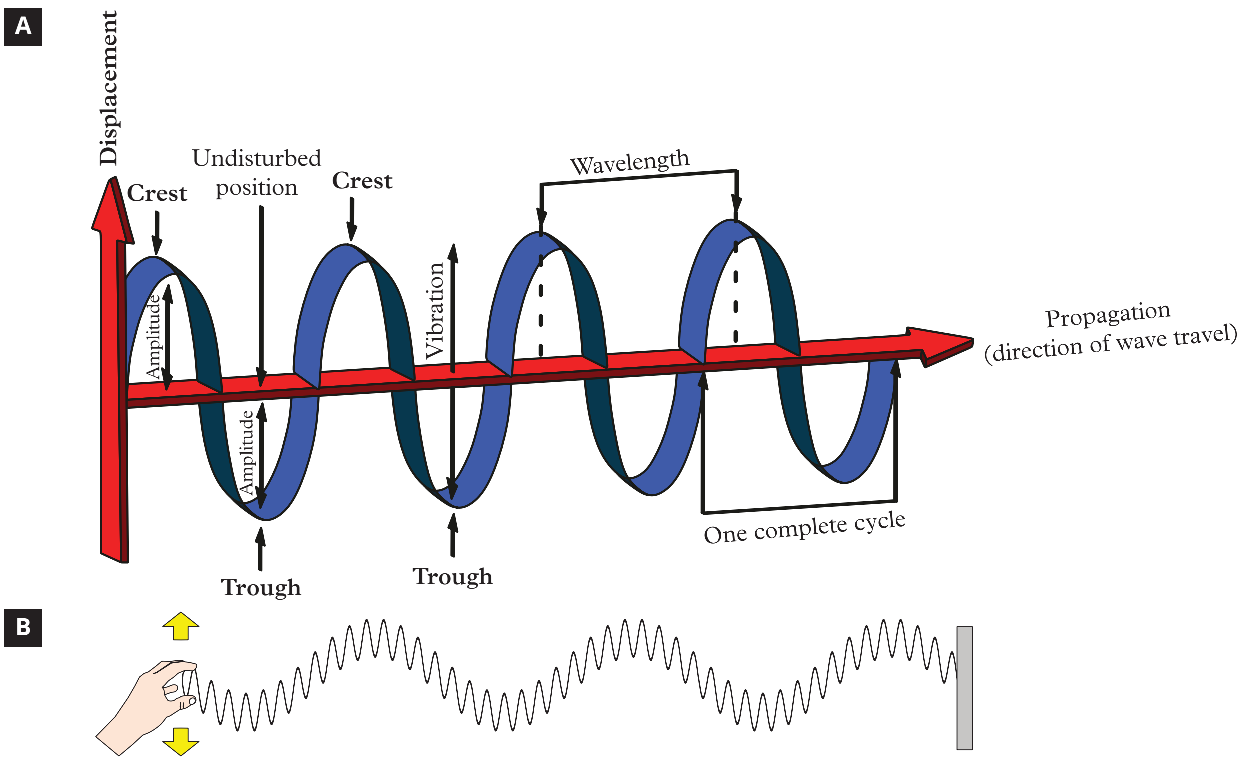


Figure 2 (A) Transverse wave and its features; (B) Transverse waves, showing the direction of the vibration of particles is at right angles to the direction of energy transfer.

Longitudinal waves

Energy is transferred in **longitudinal waves** (compression waves) if particles of the medium vibrate in the same direction that the wave travels (Figure 3). As the disturbance travels through the particles of the medium, it pushes them closer to each other. Then it pulls them further apart. The areas where particles are closer to each other are called compressions, and areas where particles are further apart are called rarefactions. Sound waves are longitudinal waves.

longitudinal wave a type of (sound) wave where the particles move in the direction of travel of the wave; also known as a compression wave

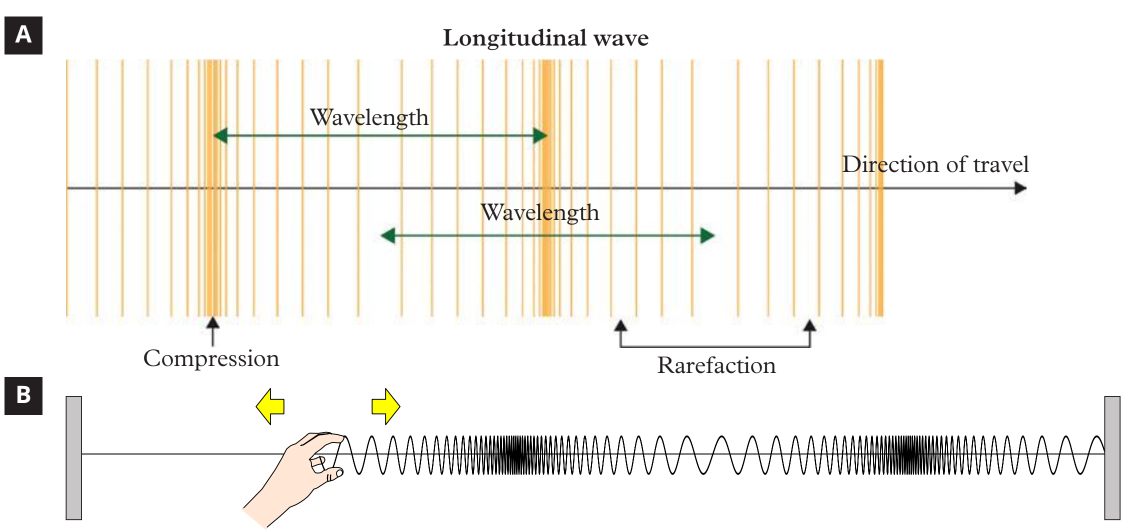


Figure 3 (A) Compressions and rarefactions in a longitudinal wave; (B) Longitudinal waves showing that the direction of the vibration of particles is parallel to the direction of energy transfer.

Features of waves

You can describe all waves using the following features.

- The wavelength (λ, pronounced lambda) is the distance between two successive crests (compressions) or successive troughs (rarefactions). Its unit of measurement is metre (m).
- The amplitude (*A*) is the maximum distance that a particle of the medium moves from its rest position. Its unit of measurement is also a metre. The more energy a wave has, the bigger its amplitude.
- The period (*T*) is the time taken for a complete wave to pass a point. Its unit of measurement is second (s).
- Frequency (*f*) is the number of waves passing a point in one second. This is measured in the unit hertz (symbol Hz), 1 Hz = 1 s^{-1}.

Period and frequency have a reciprocal relationship. This means that if frequency increases, the period decreases, and if frequency decreases, the period increases.

$$f = \frac{1}{T}$$

Energy transfer can happen more rapidly if the wave has a higher amplitude or a higher frequency. The medium through which the waves travel will also determine how efficiently energy is transferred.

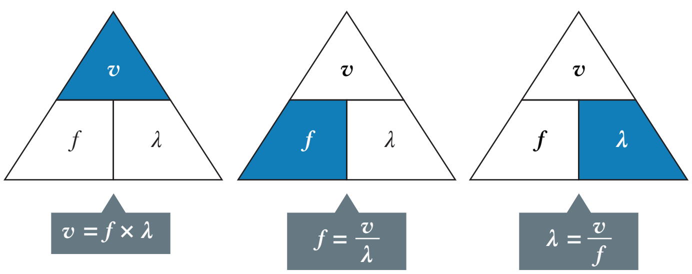


Figure 4 The relationship between a wave's speed, frequency and wavelength

Calculating the speed of a wave

The speed of a wave can be calculated using the wave equation, which shows the relationship between a wave's speed (*v*), frequency (*f*) and wavelength (λ) (Figure 4).

Its unit of measurement is metres per second (m/s or ms^{-1}).

Check your learning 12.1

Check your learning 12.1

Retrieve

1 Explain the difference between mechanical waves and electromagnetic waves.

2 Compare a transverse wave and a longitudinal wave using diagrams.

3 Define the following terms:

- **a** wavelength
- **b** amplitude
- **c** frequency.

Comprehend

4 The frequency of a wave is measured in units called hertz (Hz). Describe the relationship between a hertz and the unit of time, the second (s).

Apply

5 Calculate the frequency of a wave if the time taken for its complete oscillation is 0.5 s.

6 Use the equations in Figure 4 to complete Table 1.

Table 1 Wave properties

Speed (m/s)	Wavelength (m)	Frequency (Hz)
50	2.0	
50		100
	1.5	50

7 A group of students moves a string up and down 10 times per second to create a wave. The wavelength of the wave is measured to be 1 m. Calculate the speed of the wave.

8 The relationship between wavelength and frequency is described as an inverse or reciprocal relationship. Discuss what is meant by "inverse or reciprocal" as used in this statement.

Analyse

9 Energy is transferred by a wave without transferring particles. Account for this statement.

Lesson 12.2

Investigation: Mechanical and electromagnetic waves

Purpose

To investigate how a mechanical wave requires a medium to travel through, but an electromagnetic wave does not

Materials

- Bell jar
- Cork
- Electronic bellVacuum pump
- Power supply
- Connecting wires
- Small light source to fit inside the bell jar

Procedure

1 Set up the apparatus as shown in Figure 1.
2 Place a small light source inside the bell jar.
3 Switch on the light source to turn on the light.
4 Ring the bell inside the jar.
5 Can you hear the sound of the bell? Record your observation.
6 Can you see the light from the light source? Record your observation.
7 Slowly pump out the air to reduce the air pressure inside the jar.
8 What happens to the intensity of the sound as the air pressure decreases? Record your observation.
9 What happens to the intensity of the light as the air pressure decreases? Record your observation.

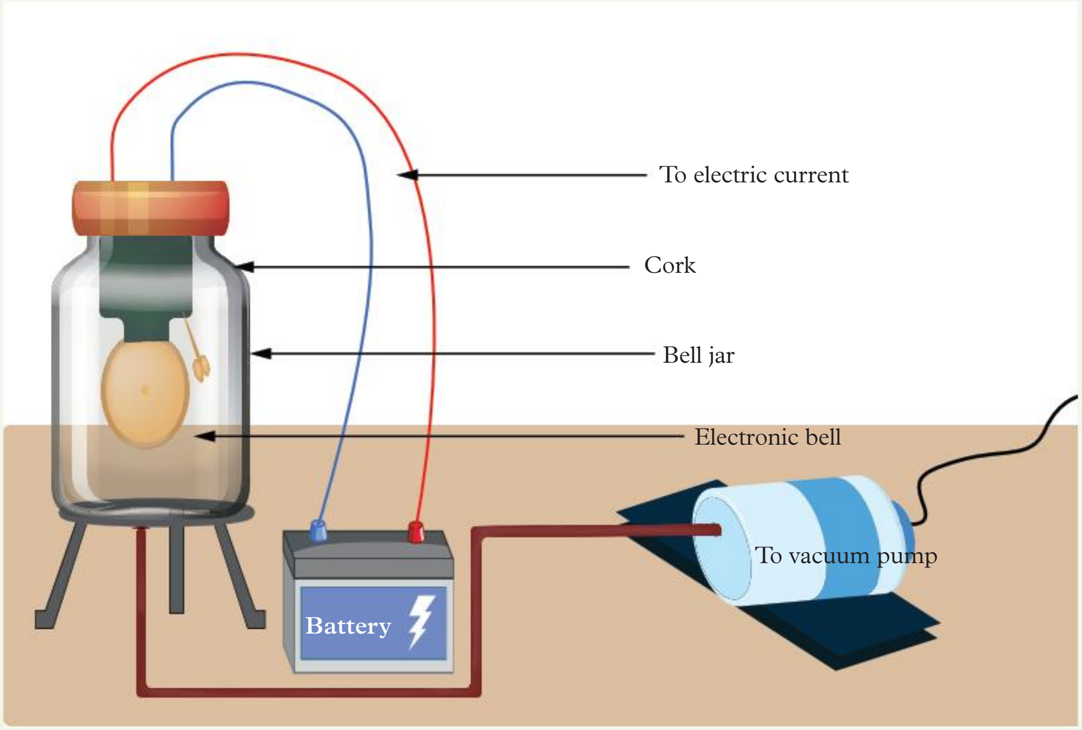


Figure 1 The experiment's set-up

Results

Copy and complete Table 1.

Table 1 Changes to the light and sound intensity as air pressure is changed

Pump run time (seconds)	Light intensity	Sound intensity

Discussion

1 Describe the key differences between mechanical and electromagnetic waves.
2 Explain why mechanical waves need a medium to travel through, but electromagnetic waves do not, using your observations to support your answer.
3 Describe the pattern you observed between wave type and speed, the medium or energy transfer.

Conclusion

Write a conclusion for this experiment that relates the findings to the aim.

Lesson 12.3
Sound waves

Key ideas

→ Sound is caused by the vibration of particles moving in a longitudinal wave.

→ One wavelength is the distance between one compression of air particles and the next.

→ The distance the air particle moves from its normal position is called the amplitude.

→ The number of waves passing a point each second is the frequency of the wave.

→ The speed of sound varies according to the temperature and material through which it travels.

→ Sound travels faster at higher temperatures because the particles can compress more easily.

Learning intentions and success criteria

Introduction

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

Modelling sound waves

We know that sound energy travels because we can often hear it a long way from its source.

Consider the example of a drum being played. The drum skin vibrates (moves up and down) when it is hit. The kinetic energy of the vibrations is transferred to the surrounding air particles, pushing them closer together in one place and forcing them further apart in another. In this way, the air around the drum is made to vibrate too. This causes the particles further away to vibrate, and so on, until the air close to your ears eventually vibrates and causes your eardrum to vibrate too. And that's when you hear the sound.

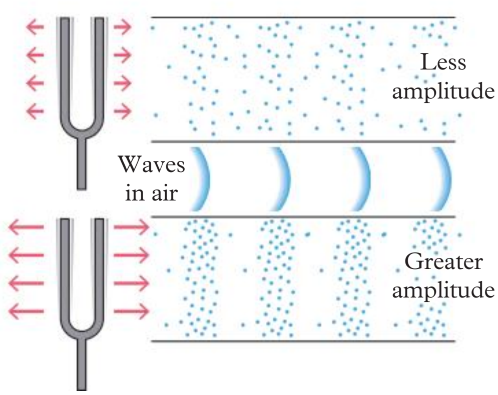


Figure 1 Red arrows indicate how far a particle in a sound wave moves from its normal position.

This means the air particles do not travel to your ear. Instead, they move back and forth parallel to the wave as the vibration passes through the air. The distance a particle of air moves from its normal position is called the amplitude of the wave (Figure 1).

A sound wave moves out in all directions from the place where the vibration began (Figure 2).

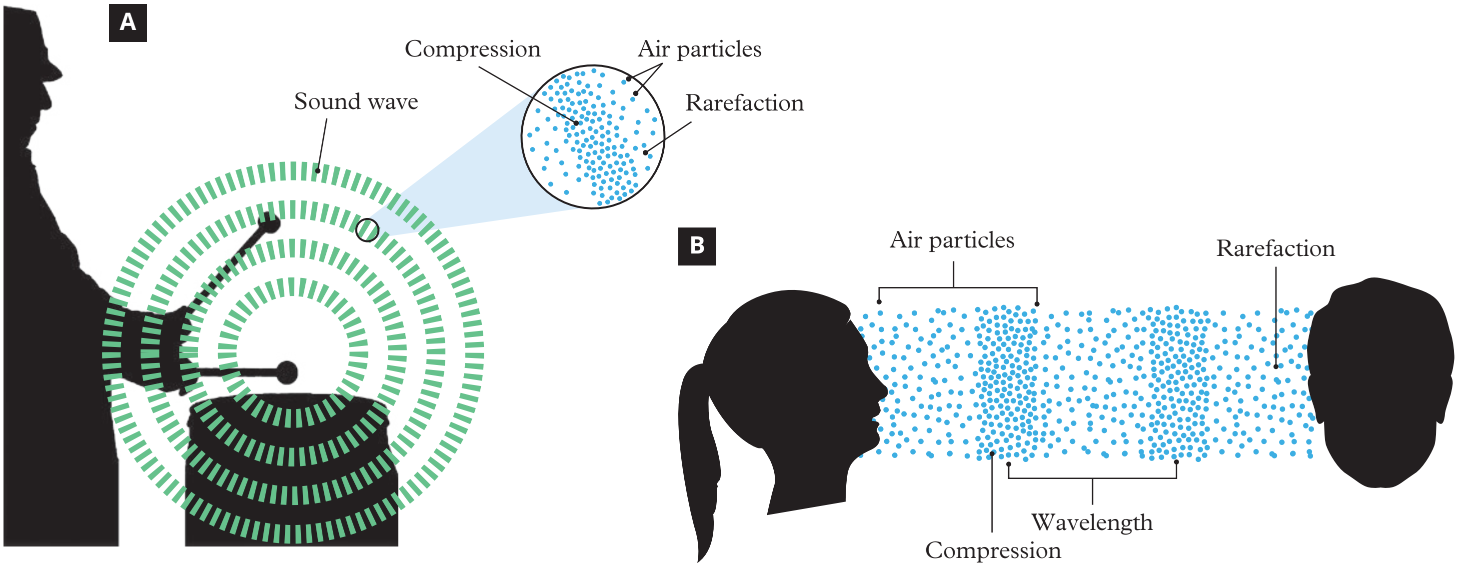


Figure 2 (A) When a drummer hits a drum skin and (B) when a person speaks, a sound wave is produced.

How do we hear?

The external ear captures the sound waves in the environment. The waves then travel through the ear canal to the eardrum. The eardrum vibrates and sends the vibrations to the three small bones in the middle ear. These bones amplify (increase) the vibrations and

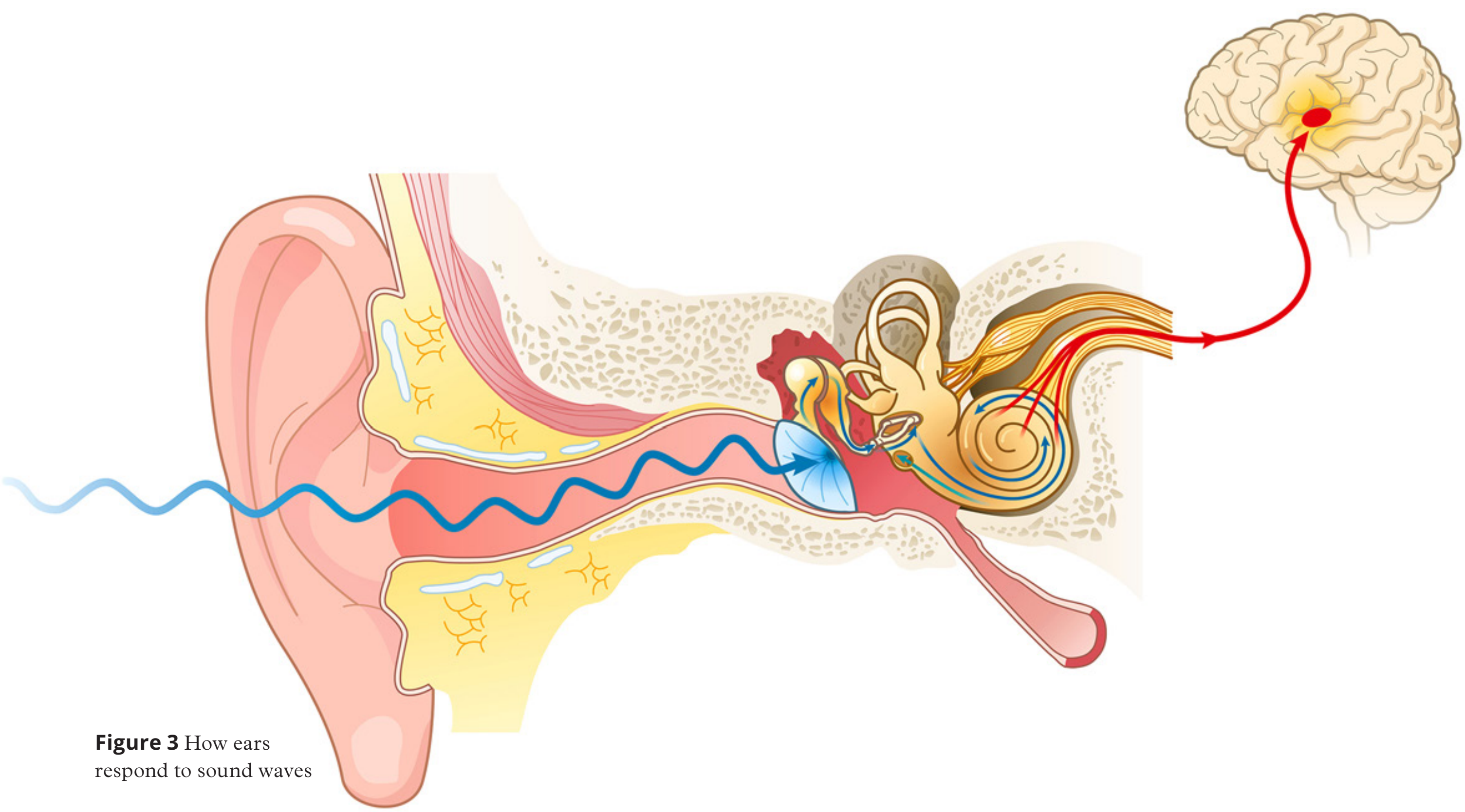


Figure 3 How ears respond to sound waves

send them to the inner ear. The inner ear is a snail-shaped structure filled with fluid. The fluid vibrates and sends the signal to the brain, and that is when you hear the sound.

Speed of sound

In outer space, you could see an explosion without hearing a thing. This is because sound needs a substance (medium) to travel through. The medium could be a solid, a liquid or a gas. The **speed of sound** is affected by the closeness of the particles in a medium and how far they can move. For example, the particles in water are much closer together than in air, so they collide more easily and thus transfer energy more quickly. This means a sound wave can travel faster through water. The particles in a solid are packed even closer together. Therefore, at a constant temperature, sound waves travel the fastest through solids and the slowest through gases (Table 1).

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

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

Medium	State	Temperature (°C)	Speed (m/s)
Air	Gas	0	331
Air	Gas	20	343
Water	Liquid	20	1,482
Lead	Solid	20	1,960
Glass	Solid	20	5,640
Steel	Solid	20	5,960

Describing sound

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

Volume

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

When setting the volume of the music you're listening to or the show you're watching, it should be **audible**. If the volume is set too high, this can damage your hearing over time.

Humans can typically hear in the range of 20 to 20,000 Hz. Anything outside of this range is unable to be heard. **Infrasound**, while not heard by humans, can be felt, such as low frequency earthquakes.

audible able to be heard

infrasound sounds that cannot be heard by humans, with frequencies usually below 20 Hz

Pitch

We hear different frequencies as different pitches. For example, a soprano singer sings the high notes in an opera. These notes are high pitched. The sound waves for these notes have very short wavelengths and therefore high frequency. A deep bass singer is able to sing very low-pitched notes. These notes have long wavelengths and few of them can pass a point each second. Therefore, they have a low frequency.

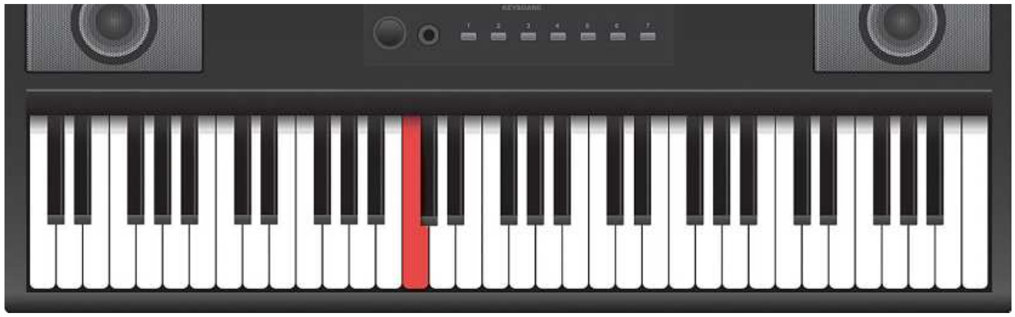


Figure 4 Middle C (shown in red) played on a piano has a wavelength of 1.33 m and creates vibrations at a frequency of 256 vibrations every second, or 256 Hz.

As the waves move further away from their source, they lose energy and eventually fade out. As neighbours will confirm, the closer you live to a drummer, the louder they seem!

Materials used by Aboriginal and Torres Strait Islander Peoples to make musical instruments

Using the properties of materials to make musical instruments has a long history. Music started by copying animal sounds but adding meaningful words to tell stories. To add rhythm to these songs, humans began making musical instruments. One of the earliest instruments was wooden sticks like clapsticks made by Aboriginal and Torres Strait Islander Peoples (Figure 5). They are made of durable hardwood such as mulga or wattle wood, which can make sharp sounds. When the clapsticks are struck, they transfer kinetic energy from the movement of the hands to the sticks. The energy is then transferred to the air through sound waves. The wood's density and hardness contribute to the sharpness and loudness of the sound, making it ideal for communication over long distances.

Figure 5 An example of clapsticks made by Aboriginal and Torres Strait Islander Peoples

Figure 6 A didgeridoo is a wind instrument made by Aboriginal and Torres Strait Islander Peoples

Wind instruments such as didgeridoos (Figure 6) made by Aboriginal and Torres Strait Islander Peoples can make loud, steady sounds when blown. This instrument is made by first finding the required wood of the eucalyptus tree, which is hollowed out by natural termites. This is then cut down to the required length. The hollow is important because blowing in the hollowed wood makes the particles of air vibrate. The energy is transferred through the vibrating air particles. The hollow structure also allows for the resonance of the sound waves.

Check your learning 12.3

Check your learning 12.3

Retrieve

1 State how the particles in air are arranged in a:
  a compression
  b rarefaction.

2 Identify which of the following materials will allow sound to travel the fastest: water, lead, air or glass.

Comprehend

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

4 Explain how the air moves when an opera singer sings a note.

5 Explain why sound travels faster in warmer air.

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

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

Analyse

8 Of the two springs shown in Figure 7, identify which demonstrates a:
  a lower frequency
  b shorter wavelength.

9 Imagine you have three tuning forks of frequencies 250, 500 and 1,000 Hz. Identify the frequency that would have the:
  a lowest pitch
  b highest pitch.

10 Contrast the frequency and the pitch of sound.

Apply

11 Investigate how the speed of sound in air changes in different temperatures (HINT: Hot air has faster moving particles).

Skills builder: Planning investigations

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

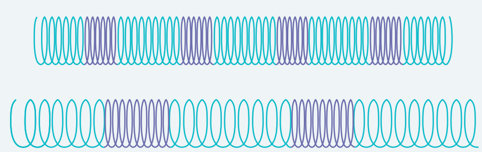


Figure 7 Springs

Lesson 12.4
The Doppler effect

Learning intentions and success criteria

Key ideas

→ The Doppler effect is an apparent change in pitch (frequency) of a wave.

→ The cause of the Doppler effect is the relative motion between the source of the wave and the observer.

The Doppler effect

the Doppler effect the apparent change in the frequency of a wave when there is a relative motion between the source of the wave and the observer

If an ambulance passes you with its siren blaring, you will notice an apparent change in pitch (frequency) of the sound. It seems to increase as the ambulance moves towards you and drops as it moves away from you. This apparent change in frequency is called **the Doppler effect**, and it is a property of all waves (such as sound waves or light waves). The cause of the Doppler effect is the relative motion between the source of the wave and the observer. It is important to note that there is no change in the actual frequency of the source; it is simply a change in how it appears to the observer.

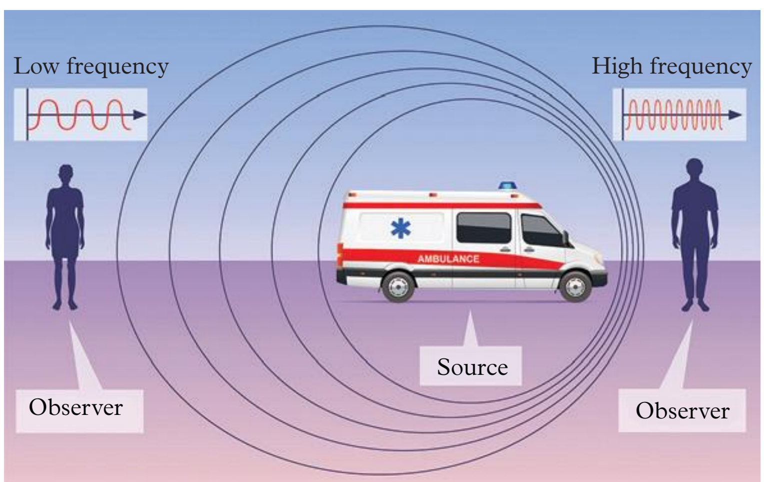


Figure 1 The Doppler effect in sound waves. The ambulance moves away from the observer on the left and towards the observer on the right. The sound wave seems higher frequency to the observer on the right and lower frequency to the observer on the left.

Check your learning 12.4

Check your learning 12.4

Retrieve

1 Describe the Doppler effect.

2 Describe how the pitch of a sound changes as the source of sound moves away from you.

Apply

3 Research if the Doppler effect applies to water waves and give an example if applicable.

Lesson 12.5
Investigation: The Doppler effect

Purpose

To investigate the Doppler effect in sound waves

Hypothesis

Read the procedure to understand the experiment and then write a hypothesis for this investigation by filling in the blanks.

If the ball ____________________, then ____________________ will ____________________ because ____________________.

Materials

- Tennis ball
- 9 V buzzer
- 9 V battery
- Three connecting wires
- Scraps of paper
- Tape
- Heavy-duty rubber bands
- Strong string
- Knife
- String

Procedure

1 Connect one terminal of the battery to one terminal of the buzzer using connecting wires. Ensure that you connect the buzzer terminal to the matching battery terminal: positive to positive or negative to negative.

2 Connect a wire to the other terminal of the battery.

3 Connect a wire to the other terminal of the buzzer.

4 Cut a small slit in the tennis ball to fit the buzzer and the battery inside it.

5 Leave the loose ends of the wires (from steps 2 and 3) outside the ball.

6 Secure the buzzer and the battery inside the ball using tape.

7 Pack the ball with scrap paper to ensure the components stay in place.

8 Use tape or heavy-duty rubber bands to secure the opening of the ball.

9 Attach the ball securely to a string.

10 Connect the loose ends of the wires to complete the circuit, making the buzzer start buzzing.

11 Twirl the ball around your head, or throw it back and forth with a partner, either outside or in a safe indoor environment.

12 Observe how the pitch of the buzzer changes as it moves towards or away from you.

13 Record your observations.

Results

Table 1 Observations about pitch

Buzzer	Observations about pitch
Moving away from you	
Coming towards you	

Discussion

1 Describe what the Doppler effect is and explain how your observations from the investigation demonstrated it.

2 Explain the patterns you observed in the pitch or frequency of the sound as the source moved.

3 Describe any sources of error that might have affected your results and determine how you could improve the investigation.

Conclusion

Write a conclusion for the experiment.

Lesson 12.6
Sound waves are used in medical diagnosis

Learning intentions and success criteria

Key ideas

→ Sonar uses sound waves underwater to determine how far away an object is.

→ Ultrasounds are used to look at internal organs.

→ The clarity of an ultrasound image depends on the frequency of the sound waves used. Ultrasound uses high-frequency, short-wavelength sound waves, which produce clearer and more detailed images than lower-frequency, longer-wavelength sound waves (like normal sound).

Introduction

One of the properties of waves, including sound waves, is reflection. This occurs when a wave reaches the boundary between two media. The wave reflects off the boundary and returns to the original medium. If a sound wave reflects repeatedly, an echo occurs.

High-frequency sound waves are used by sonic rangers and for medical diagnosis.

Sonar

ultrasound a high-frequency sound, with a frequency above the range humans can hear

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

Sound waves with very high frequencies are called **ultrasound**. Their frequency is more than 20,000 Hz, which is higher than the frequency that humans can hear. The higher the frequency of a wave, the more energy it has and the shorter its wavelength.

In all wars since World War I, reflected waves have been used to detect enemy submarines under water. In a similar way to radar (which sends out radio waves), **sonar** sends out sound waves and records how long the sound takes to reflect or echo back after striking an object. The longer the sound takes to return, the further away the object is. An exact location can be calculated by knowing how fast sound travels in water. This information, along with the time taken for the sound to return, allows the exact location of a submarine to be determined. Sonar is used widely today and can help map the ocean floor (Figure 1), check the depth of water and locate schools of fish.

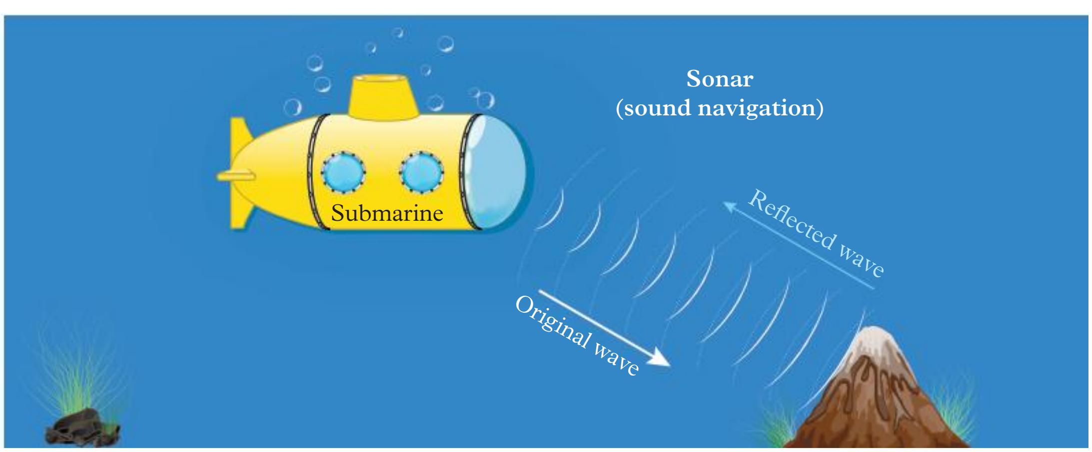


Figure 1 Sound echo is used to map the ocean floor.

Ultrasound and medical diagnosis

Ultrasound is used to see the structure of internal body organs (Figure 2 and Figure 3). The sound waves are sent into the body and reflect off the part of the body being analysed. These reflected waves are then received by a detector and analysed. Ultrasound is considered a safe method for observing internal organs.

To create a clear image, the wavelength of the sound waves should be smaller than the part of the body being observed. The higher the frequency (which corresponds to a shorter wavelength), the more detailed the image produced. Therefore, ultrasounds with high frequencies and short wavelengths are used for internal imaging instead of normal sound waves with lower frequencies and longer wavelengths.

As the frequency of sound waves increases, their absorption by body tissues also increases. Therefore, the frequency used should be appropriate for the body part being analysed. For example, very high frequencies (around 50 MHz or 50,000,000 Hz) are used for body parts near the surface, such as the eyes, while lower frequencies (around 3–5 MHz or 3,000,000–5,000,000 Hz) are used for deeper body parts, such as the heart.

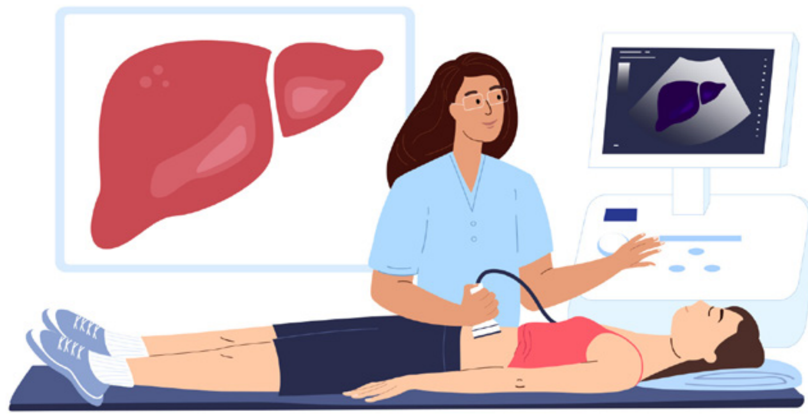


Figure 2 Ultrasounds are used for medical diagnosis.

Figure 3 An ultrasound image of a foetus

Check your learning 12.6

Check your learning 12.6

Retrieve

1 Describe ultrasound.

2 Describe how sonar works.

3 Explain why eyes can be analysed using much higher frequency sound waves than the frequency used for analysing the heart.

Apply

4 Bats navigate by echolocation. Compare echolocation to sonar.

Lesson 12.7
Electromagnetic waves

Learning intentions and success criteria

Key ideas

→ The electromagnetic spectrum is a way of describing all the different forms of light, including the light we see.

→ All forms of light travel at the same speed through a vacuum and are transverse waves.

→ The electromagnetic spectrum is a range of electromagnetic waves with different wavelengths and energies.

→ All electromagnetic waves travel at the same speed through a vacuum.

→ Light also behaves like a particle called a photon.

→ Electromagnetic waves from the highest to the lowest wavelength (and the lowest to the highest energy) are radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

Introduction

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

Electromagnetic spectrum

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

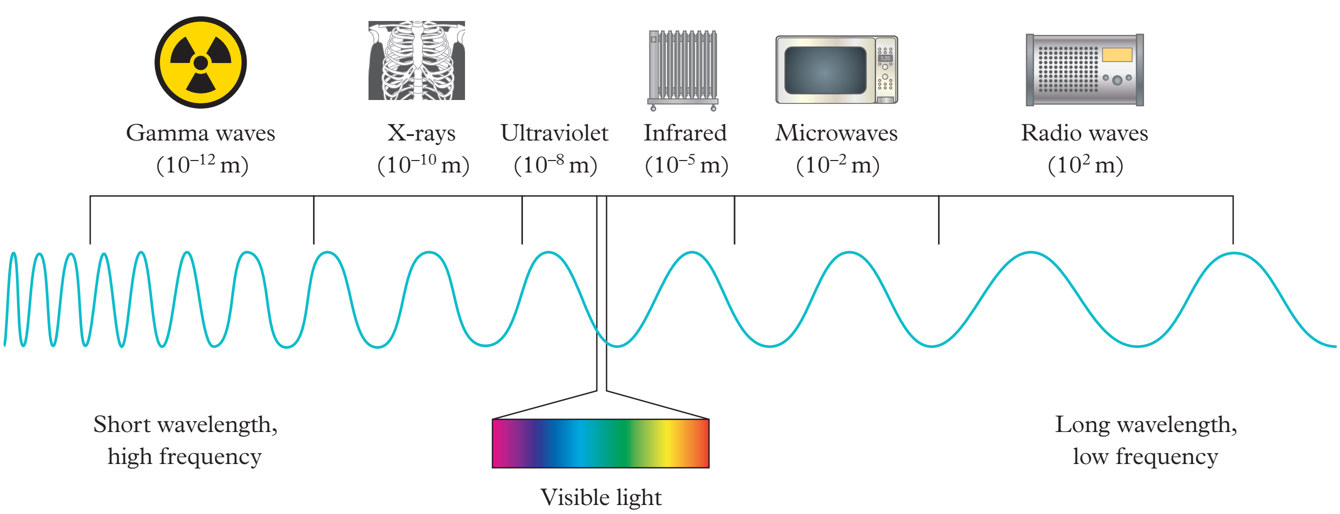


Figure 1 The electromagnetic spectrum

Our eyes can only see a small amount of these electromagnetic waves; called visible light. The different types of light (electromagnetic waves) have common features. They all travel at the same speed in a vacuum – the speed of light – however, they have an obvious difference. They have different wavelengths and, therefore, different frequencies and energy.

As you have already learned, sound waves need a medium in which to travel, but electromagnetic waves do not need a medium to travel in. They can travel from the Sun to our Earth through a vacuum. In addition, as electromagnetic waves can travel through a vacuum (which has no particles), there is no loss of energy due to the friction between particles. Thus, they travel a longer distance compared with sound waves.

The electromagnetic spectrum has many uses

Radio waves

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

Microwaves

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

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

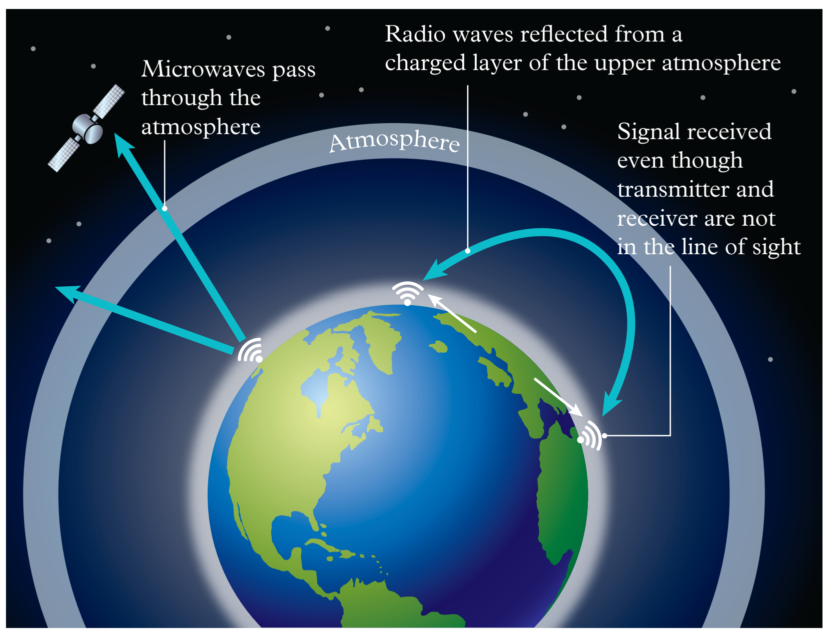


Figure 2 Electromagnetic waves with different wavelengths behave differently in the Earth's atmosphere.

Infrared rays

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

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

Visible light

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

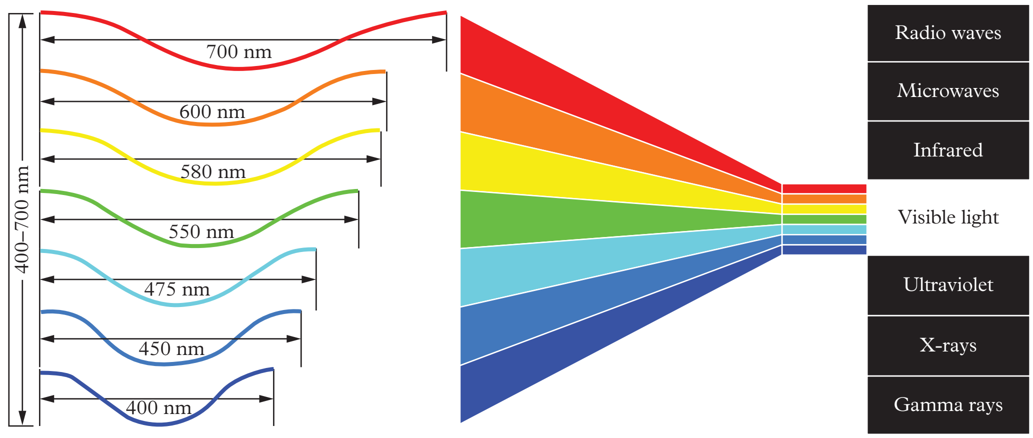


Figure 3 Different colours of visible light have different energy. Violet with the shortest wavelength has the highest energy, and red with the longest wavelength has the lowest energy.

Because light waves have different wavelengths, they also have different frequencies. The frequency of a light wave is a measure of the number of waves that pass a point each second (unit Hz). As the frequency becomes higher, more waves (with short wavelengths) pass a point each second. This means high frequencies have shorter wavelengths.

Is light a particle or a wave?

Experiments by early scientists provided two forms of evidence about how light behaves. In some experiments, light behaved as if it was a wave. Other experiments indicated that light was a particle.

photon an elementary particle of electromagnetic radiation that acts as both a particle and a wave

Scientists now agree that light consists of a particle called a **photon**, which can move in a wavelike fashion. Just like a wave of water, it can bounce or reflect off surfaces and slow down if it travels through a thicker, denser material. Just like a separate particle, it can move by itself through space. This is how the light from the Sun can reach the Earth.

Speed of light

Light waves travel extremely fast: 300,000 km/s in a vacuum. This value is known as the speed of light. The speed of light is much faster than sound, which is why you will always see the light from lightning before you hear the sound of the thunder. Light waves can travel through other media such as air, water and glass, where they slow down slightly. Unlike sound waves, light waves don't need a medium (solid, liquid or gas) in which to travel, due to their electromagnetic nature. They don't pass their energy from atom to atom like sound waves do. This means the different forms of light can travel through space to reach us on the Earth.

Ultraviolet radiation

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

X-rays

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

Gamma rays

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

Check your learning 12.7

Check your learning 12.7

Retrieve

1 Classify electromagnetic waves from highest energy to lowest energy.

2 Explain how a microwave oven works.

Comprehend

3 Explain why you see lightning before you hear thunder.

Analyse

4 Explain why long exposure to UV radiation is dangerous, but we are not worried about our exposure to visible light.

5 Recall the order of the colours of visible light in order of increasing energy.

6 Sound is a wave, but sound cannot travel through a vacuum (empty space). Light can travel in a vacuum. Contrast sound and light to explain these two statements.

Apply

7 Investigate why the amount of water in food is important when cooking in a microwave and explain how this relates to the electromagnetic spectrum.

8 Investigate more uses for electromagnetic waves.

9 A hospital is deciding between using ultraviolet (UV) light and X-rays for different medical purposes. Their data is in Table 1.

a Analyse the data to explain why UV light is used for sterilising surfaces, while X-rays are used for imaging bones.

b Discuss how the penetration ability and energy level of each wave influence its medical application.

c A new piece of medical technology uses EM waves with very short wavelengths and very high energy.

i Predict which part of the EM spectrum this technology is using.

ii Suggest one possible use for this technology and justify your answer based on the wave's properties.

Table 1 A hospital's data

Property	Ultraviolet (UV)	X-rays
Wavelength	~10^{-8} m	~10^{-10} m
Energy	Moderate	High
Penetration	Low	High
Use	Surface sterilisation	Imaging bones

Skills builder: Questioning and predicting

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

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

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

Lesson 12.8
Light reflects off a mirror

Learning intentions and success criteria

Key ideas

→ Light can travel through transparent objects and is blocked by opaque objects.

→ Translucent objects allow some light energy through.

→ When light is reflected off a mirror, the angle of incidence is equal to the angle of reflection (law of reflection).

→ The image in the mirror is called a virtual image.

transparent a material or object that you can see through; allows light to pass through

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

opaque a substance that does not allow light to pass through

image what is formed when light from an object is reflected by a mirror

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

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

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

law of reflection when light is reflected off a surface, the angle of incidence will equal the angle of reflection

Introduction

Light can reflect off a glass window, but most of the light is transmitted and passes through. This is because the glass in the window is **transparent**. Some types of frosted glass prevent us from seeing through them clearly. They are **translucent** because they let some light through, but objects cannot be seen clearly. If an **opaque** material is shiny enough or has a shiny coating, it will reflect the light and allow us to see the clear **image**. The best example of this is a mirror.

Law of reflection

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

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

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

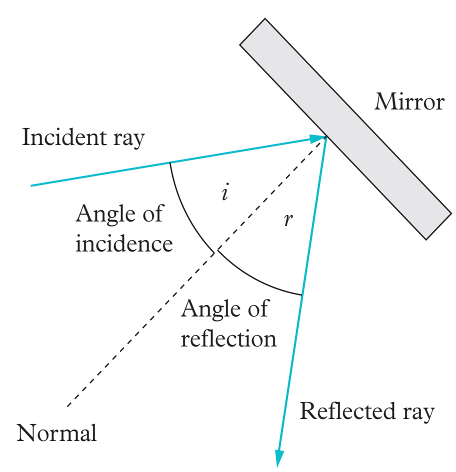


Figure 1 The angle of incidence (i) and the angle of reflection (r) are the same when light reflects off a mirror.

Virtual image

When we look in a plane mirror (a flat mirror), we see a picture or image of ourselves. In the case of a plane mirror, the image is always a **virtual image**. This means it cannot be captured on a piece of paper or on a screen as a movie projector does.

The image always forms where the reflected light rays or their extensions cross. The image we see in a plane mirror is laterally inverted, or flipped sideways (Figure 2 and Figure 3).

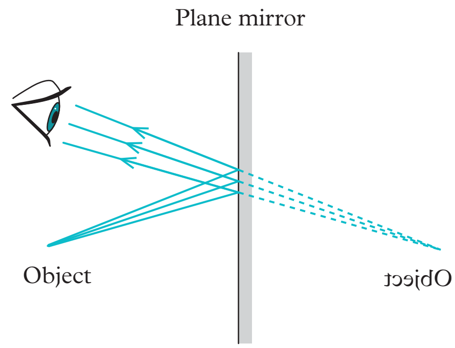


Figure 2 The image in a plane mirror is virtual, laterally inverted, the same size as the object and the same distance from the mirror.

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

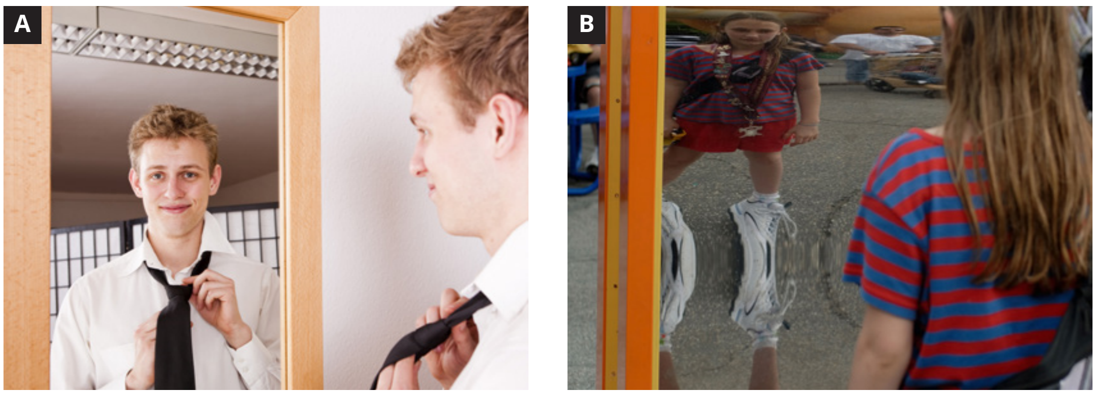


Figure 3 (A) Mirrors show the lateral inversion of what we look like. (B) Curved mirrors can distort the virtual image.

Convex and concave mirrors

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

Curved mirrors are not as predictable as plane mirrors. They can change the size and nature of the object's image.

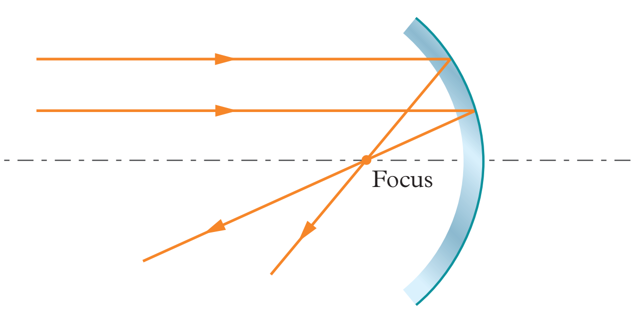


Figure 4 A concave mirror. The orange lines show the path of the light. The incident rays are coming into the mirror, and the mirror reflects them through a point where they converge. This point on a concave mirror is called the focus.

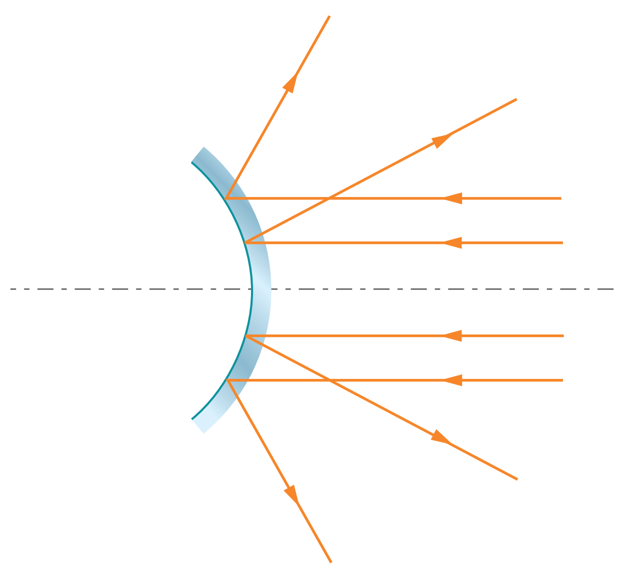


Figure 5 A convex mirror. The orange lines show the path of the light, with the incident rays coming towards the mirror, while the reflected rays leave the surface of the mirror.

convex refers to a lens or mirror that is thicker in the centre than at the ends

concave refers to a lens or mirror that is thinner in the centre than at the ends

Curved mirrors can be **convex**, where the centre sticks out, or **concave**, where the centre goes in, like a cave.

Concave mirrors cause the reflected light to bend towards a central point (Figure 4). They are used in reflecting telescopes. Convex mirrors scatter the light of an object (Figure 5). They are typically used in passenger side mirrors.

Check your learning 12.8

Check your learning 12.8

Retrieve

1 Define the terms "transparent", "translucent" and "opaque" and identify one example of each.

2 Recall one use each of convex and concave mirrors.

Comprehend

3 Explain why light fittings are often translucent.

4 Define the following terms using a diagram to illustrate your definitions:

  a normal

  b incident ray

  c angle of incidence

  d reflected ray

  e angle of reflection.

5 Describe a virtual image and provide an example of where you would see one.

Figure 6 Virtual or real?

Analyse

6 Compare concave and convex mirrors.

7 Compare plane mirrors and convex mirrors.

Apply

8 View the image in Figure 7. If the incident ray is ray **a**, identify which one of the rays (**b** or **c**) is the reflected ray.

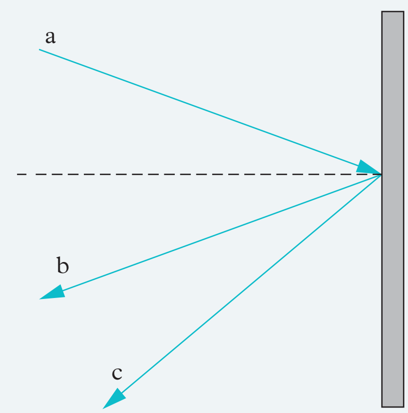


Figure 7 Reflection of an incident ray

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

10 Investigate some uses of concave and convex mirrors.

Lesson 12.9
Investigation: Law of reflection

Purpose

To learn how to use a Hodson light box

Materials

- Hodson light box
- Sheet of white A4 paper
- Pencil
- Ruler
- Protractor

Procedure

1 Place the light box on the paper.

Figure 1 Placing the light box on the paper

2 Plug the light box into the DC sockets of a power supply. The higher the voltage set, the brighter the light globe will be.

Figure 2 Plugging the light box into a power supply

3 Slide a slot former into the opposite end of the light box to where the mirror flaps are located. Usually a single-slot or a three-slot former is used.

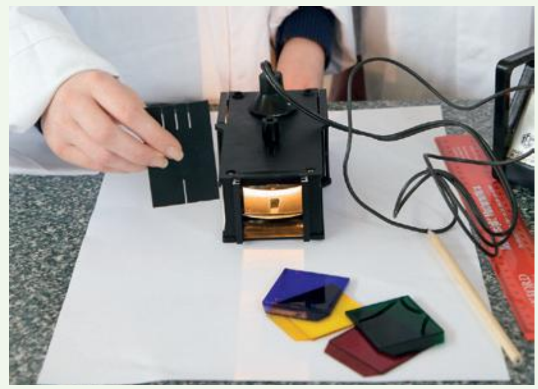


Figure 3 Sliding a slot former into the light box

4 Aim the light ray at the target, in this case a plane mirror.

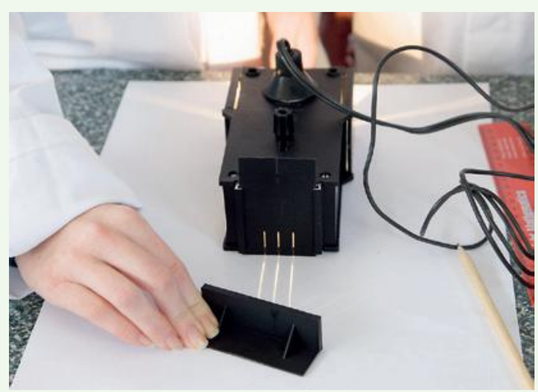


Figure 4 Aiming the light ray at the target

Figure 5 Marking the incident and reflected rays

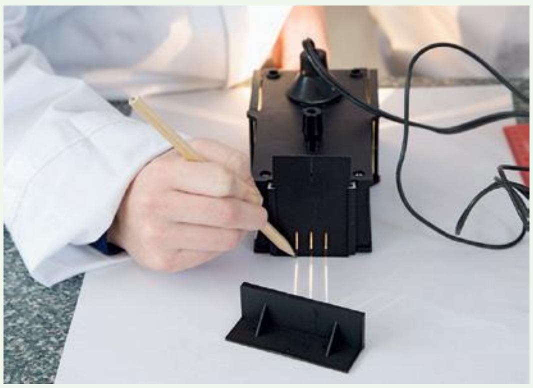


Figure 6 Joining the dots with a pencil and ruler

5 Use a sharp pencil to mark the incident and reflected rays with dots (Figure 5).
6 Remove the light box and join the dots with thin, straight pencil lines, using a ruler (Figure 6).
7 Use a protractor to measure the angle of incidence and the angle of reflection.

Discussion

1 Compare your angle of incidence to your angle of reflection.
2 Do your results confirm the law of reflection?
3 Discuss any errors that may have occurred during this investigation and the impact this would have on your results.

Lesson 12.10
Light refracts when moving from one medium to another

Learning intentions and success criteria

Key ideas

→ Refraction is the bending of light as it enters from one medium and travels to another.

→ Reflection occurs from shiny surfaces, but when light strikes a transparent material, it enters the material and may change direction (towards or away from the normal).

→ Convex lenses cause light rays to converge, while concave lenses cause light rays to diverge.

→ For total internal reflection to occur, two conditions must be met: light must travel from a more-dense medium into a less-dense medium; and the angle must be greater than the critical angle.

→ Due to total internal reflection in optic fibres, signals are able to travel quickly (speed of light) with minimal signal loss.

Refraction

Have you ever wondered why a spoon in a glass looks broken? **Refraction** is the bending of light as it passes from one transparent medium (substance or material) into another. Often, when light is refracted, our view is distorted. You might be familiar with this effect when looking through water (Figure 1).

Figure 1 Water refracts light and distorts images.

The amount of bending depends on the optical density or **refractive index** of the material and has the symbol *n*. The bent ray is called the **refracted ray** and its angle with the normal is the **angle of refraction** (symbol *r*). The higher the optical density, the slower the light travels through it.

When a light ray enters a denser medium, such as from air into water, it slows down and consequently bends closer to the normal. When the light ray leaves the denser medium and moves into a less dense medium, it is able to speed up. When this happens, the light ray bends away from the normal (Figure 2).

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

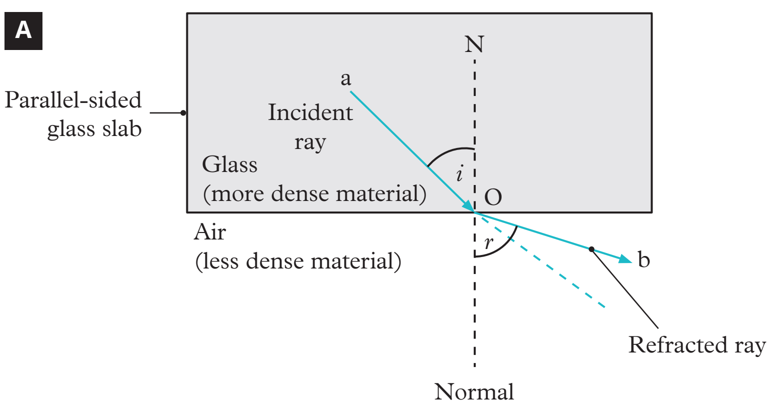
The only time that light does not refract is when it enters a new medium along the normal (90° to the surface). It still changes speed, but there is no bending of the light.

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

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

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

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



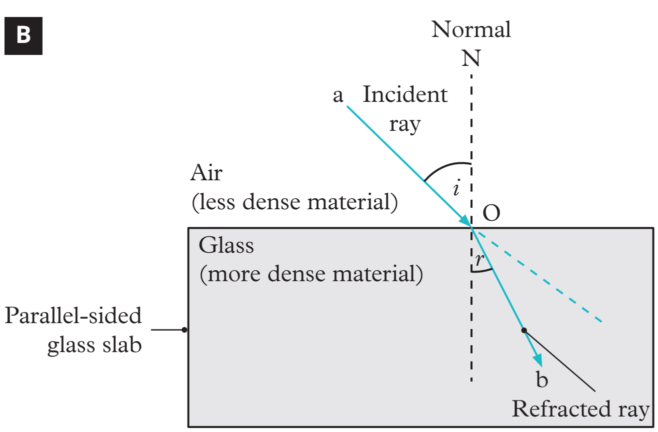


Figure 2 (A) Light entering a less dense medium bends away from the normal. (B) Light entering a denser medium bends towards the normal.

Refraction in everyday life

Refraction explains a lot of everyday phenomena (see Figure 3, Figure 4 and Figure 5). Refraction also explains how lenses work.

Figure 3 Swimming pools and the ocean look shallower than they really are. The depth we see is the apparent depth. This person looks shorter in the water because the apparent depth is less.

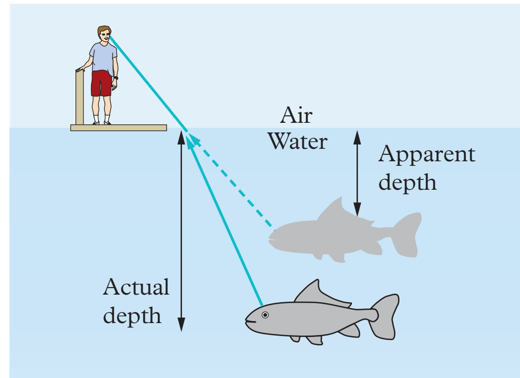


Figure 4 Refraction makes underwater objects appear closer to the surface than they really are. The fish looks closer than it really is because the light has left a denser medium.

Figure 5 Refraction makes straight objects appear disconnected. This pencil looks bent because its apparent position is different from its real position.

Lenses

lens a curved piece of transparent material

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

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

converge when rays of light move towards a single point

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

diverge when rays of light move away from each other

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

Convex lenses cause light rays to **converge** (or focus). The focus (or focal point) is the point where the rays cross, and the **focal length** is the distance from the focus to the middle of the lens (Figure 6).

Concave lenses cause light rays to **diverge** (or spread out) (Figure 7). The focus is on the other side of the lens, and to find it, the diverging rays are extended back until they cross at the apparent source. The focus can therefore be described as a **virtual focus** because the light rays do not really come from this point.

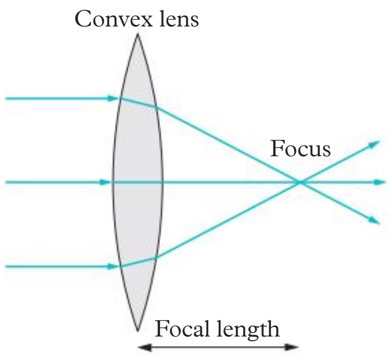


Figure 6 Parallel rays converge to a focal point with convex lenses.

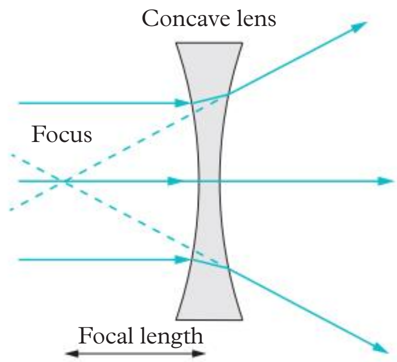


Figure 7 Parallel rays diverge from a focus with concave lenses.

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

Total internal reflection

Optic fibres have revolutionised communication systems (Figure 8). Instead of always relying on copper wires to carry electrical signals, we now use bundles of optic fibres to carry light signals for landline telephone calls, the internet and networking of computers. They work on the basis of total internal reflection (Figure 9, Figure 10 and Figure 11).

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

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

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

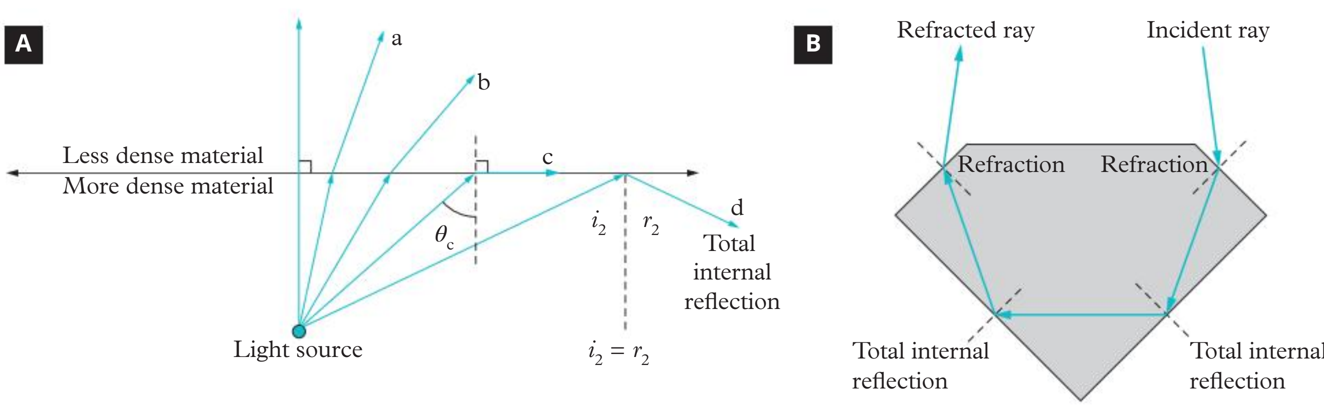


Figure 9 (A) Rays **a** and **b** are refracted because the angle of incidence is less than the critical angle. Ray **c** occurs when the critical angle is reached. Ray **d** is reflected when the angle of incidence is greater than the critical angle. (B) Total internal reflection.

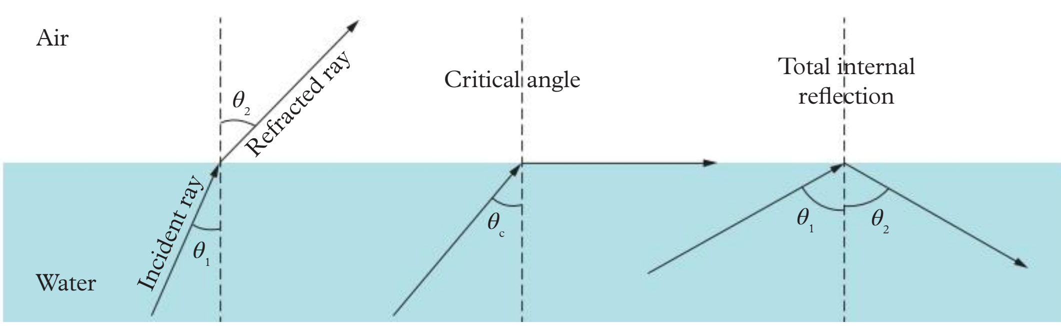


Figure 10 When light refracts, the refraction angle depends on the angle between the incident light and the boundary. At the critical angle, light bends to a point that it can be seen parallel to the boundary between the two materials.

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

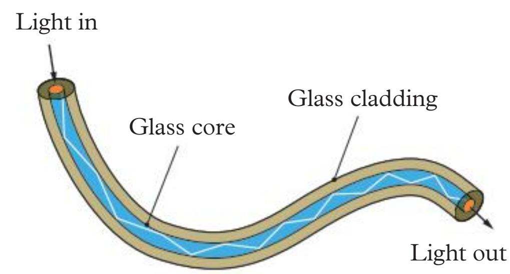


Figure 11 Light zigzags along inside an optic fibre at the boundary of the core and the cladding.

only occurs when light attempts to travel from a more dense medium into a less dense medium and only for angles greater than the critical angle.

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

Check your learning 12.10

Check your learning 12.10

Retrieve

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

2 Identify three everyday examples where refraction takes place.

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

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

5 Recall the principle behind optic fibres.

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

Analyse

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

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

9 Distinguish between convex and concave lenses.

10 Choose one everyday application of refraction (e.g. rainbows, mirages, camera lenses, etc.) and answer the following questions.

- **a** Research how refraction is involved in your chosen everyday application.
- **b** Using the concept of refractive index, explain the science of how light bends in your application.
- **c** Analyse how the properties of the materials involved, e.g. air, glass, water, plastic, etc., affect the behaviour of light. Include a diagram to support your analysis.
- **d** Evaluate the importance of refraction in your application and explain what would happen if refraction did not occur.

Apply

11 Investigate some uses of convex and concave lenses.

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

Skills builder: Conducting investigations

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

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

Lesson 12.11
How the eye responds to light

Key ideas

→ Your eyes can form images of objects through the refraction of light.

→ The refraction of light in the eyes occurs by the cornea and the lens.

→ Light-sensitive cells in the retina convert light signals to electrical signals.

→ Electrical signals are sent to the brain through the optic nerve.

Learning intentions and success criteria

cornea a thin, transparent material that protects the eye and refracts light

pupil the black, circular opening that controls the amount of light entering the eye

dilation widening of the pupil to allow more light to enter the eye

iris the coloured part of the eye that controls the dilation and shrinking of the pupil

Introduction

Your eyes can see a small part of electromagnetic waves called visible light. Visible light consists of wavelengths in the range of 380 to 700 nm. Eyes are like cameras; they refract light to form an image.

The eye

The refraction of light in the eye occurs through the **cornea** and the lens. The cornea is a thin, transparent membrane that has two purposes: protecting the eye and refracting the light.

After light passes through the cornea, it enters your eyes through a small opening called the **pupil**. The size of the pupil can change depending on the intensity of light. This change in size happens through the **dilation** of the pupil. The **iris** is the coloured part of your eye (Figure 1).

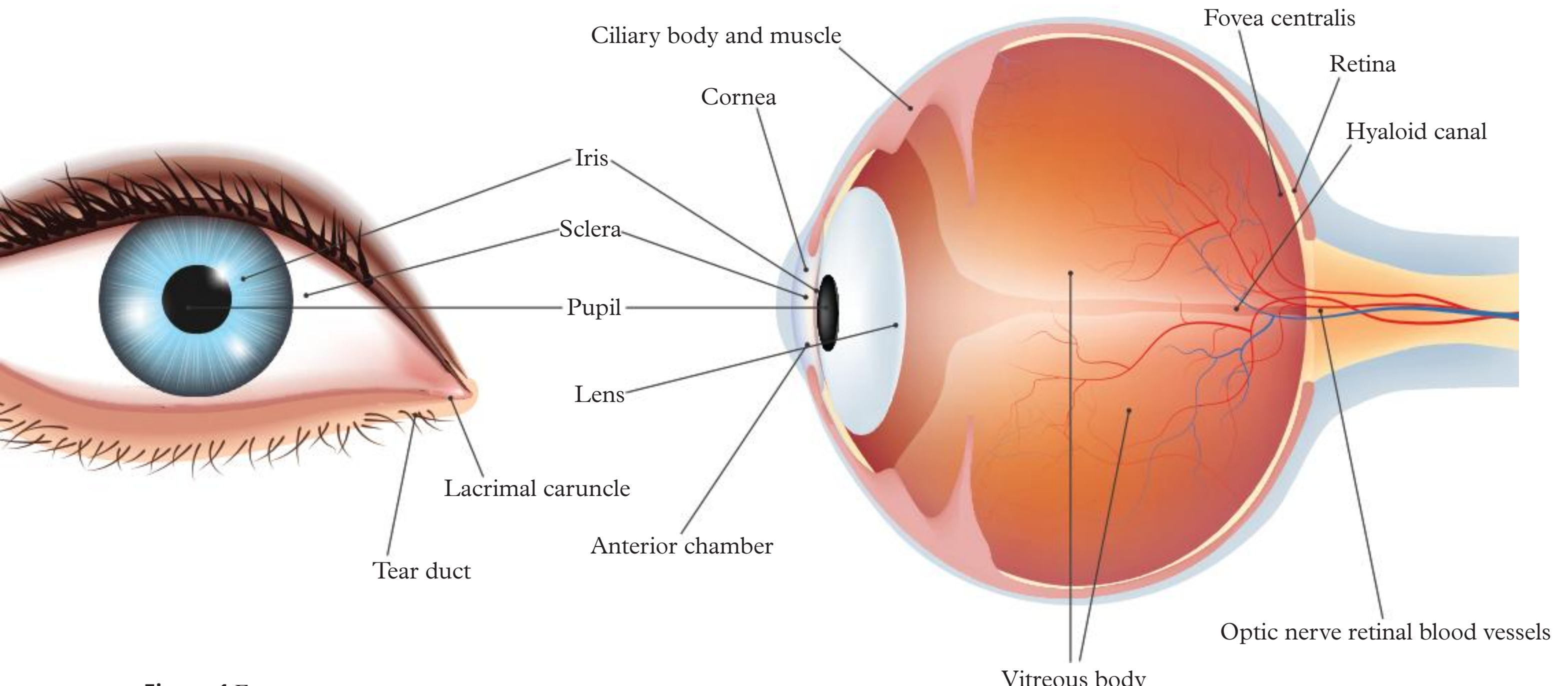


Figure 1 Eye anatomy

retina light-sensitive cells that convert light into electrical signals

accommodation the process where the shape of the eye's lens changes to focus images of objects at different distances

optic nerve the connection that sends the electrical signal to the brain to create the image; creates a blind spot where it meets with the retina due to the lack of light-sensitive cells

When light enters the eye, it strikes the convex lens, which further refracts the light. The lens is adjustable, and its shape changes to focus images of objects at different distances onto the **retina**. This process of changing the shape of the lens is called **accommodation**. Accommodation occurs by contracting and relaxing of the ciliary muscles attached to the lens. To see closer objects, the lens becomes thicker and more converging. When observing distant objects, the eye is more relaxed.

The cornea and lens work together to focus light onto the retina, where an inverted, real image is formed. The retina contains light-sensitive cells that convert light signals to electrical signals. There are two types of light-sensitive cells in the retina: rods and cones. Rods are sensitive to the intensity of light and cones are sensitive to different wavelengths of light and help us to see colours.

The electrical signals travel from the retina to the brain through the **optic nerve**. The area of the retina over the optic nerve is called the blind spot. It lacks light-sensitive cells, which is why we cannot see images in that area. Finally, the brain processes these electrical signals to create the upright image that we see (Figure 2).

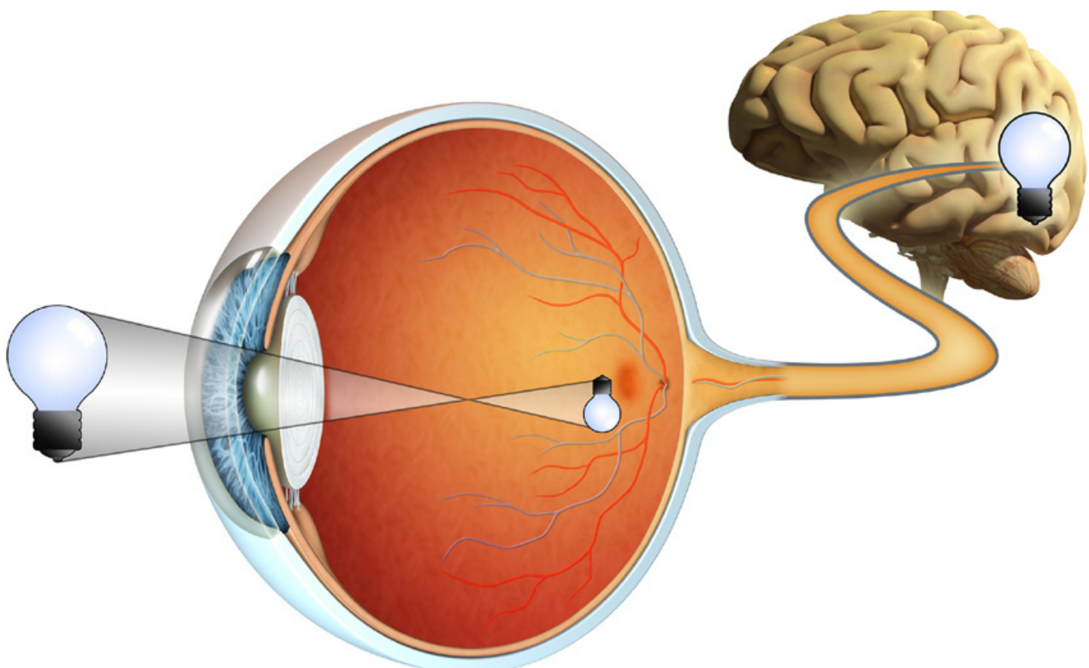


Figure 2 How your eyes and brain process images

Check your learning 12.11

Check your learning 12.11

Retrieve

1 Identify the type of lens in the eye.
2 Describe the blind spot in the eye.
3 Explain how accommodation happens in the eye.

Apply

4 Investigate how a camera works and compare it with the eye.
5 Investigate how short-sightedness occurs and how it can be corrected.

Lesson 12.12
Scattering and absorption of light

Key ideas

- → Scattering of light is the cause of phenomena such as the Tyndall effect, the blue sky and the reddish sky during sunrises and sunsets.
- → The colour of an object is the colour of light reflected or transmitted by the object to your eyes.

Learning intentions and success criteria

Introduction

If light with a specific frequency strikes an object, it may be absorbed, reflected, transmitted or scattered.

Scattering of light

Have you ever wondered why the sky is blue or why it looks red during sunrise and sunset? The cause of these phenomena is the **scattering of light**.

Scattering occurs when light waves strike particles such as dust, gases or water droplets, causing them to deflect from their original path in different directions.

scattering of light when light waves strike particles such as dust, gases or water droplets, causing them to deflect from their original path in different directions

Tyndall effect

The Tyndall effect refers to the scattering of light by **colloidal particles** (Figure 1 and Figure 2). Colloidal particles are small enough to remain evenly distributed in a mixture but larger than the particles in a solution. This scattering makes the path of a light beam visible. You have observed the Tyndall effect when a beam of light enters a dark room through a small opening. The light is scattered by dust particles in the room.

colloidal particles particles small enough to remain evenly distributed in a mixture but larger than the particles in a solution

Figure 1 The Tyndall effect in a forest occurs when light is scattered by tiny water droplets.

Figure 2 The Tyndall effect of light when light enters a dark room through a window involves dust particles in the air scattering the light.

Blue sky

The visible part of sunlight contains different colours. Red light has a lower frequency and longer wavelength, while blue light has a higher frequency and shorter wavelength. There are particles in the air that are smaller than the wavelengths of visible light. These particles scatter blue light more than red light, making the sky appear blue.

Red sunset and sunrise

At the time of sunrise and sunset, the Sun is lower in the sky, near the horizon. The light travels a longer distance through the Earth's atmosphere. Most of the blue light with shorter wavelengths is scattered by the particles in the air. The light that reaches your eyes is the longer wavelengths of red and orange. This makes the sky appear red or orange (Figure 3).

Figure 3 The Tyndall effect is the cause of the reddish sky during the sunset.

Absorption of light

White light, which contains a range of frequencies (or colours) will be selectively absorbed, reflected or transmitted by an object. How an object interacts with light depends on the nature of its atoms and the frequency of light.

Everything is made up of atoms, and atoms contain electrons. Electrons tend to vibrate at specific frequencies. If the frequency of light matches the natural vibrational frequency of electrons in the atoms of the object, the object will absorb that frequency of light. As the electrons absorb this energy, they begin to vibrate and the light energy is transformed into heat energy. If the frequency of the light does not match the vibrational frequency of the electrons, the light is either reflected or transmitted by the object.

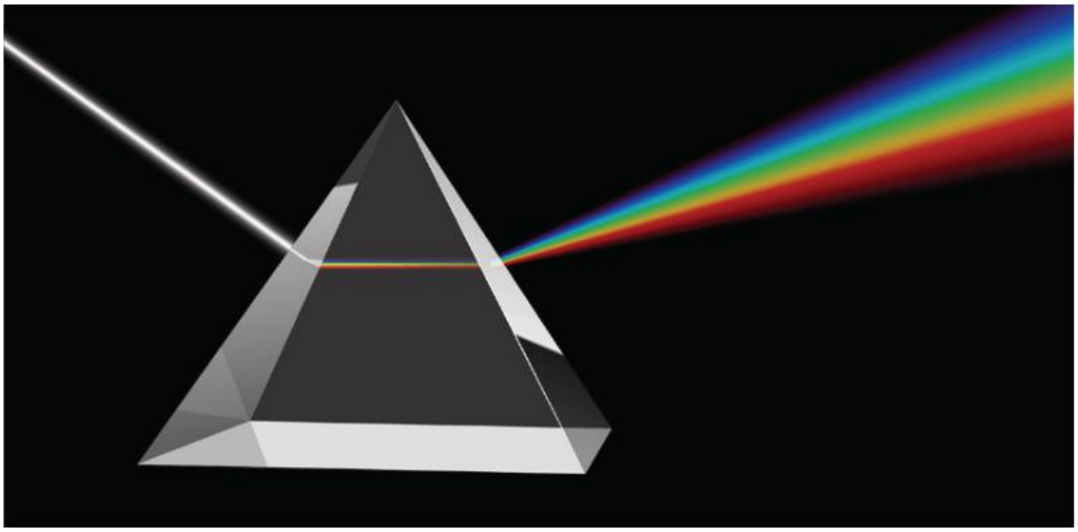


Figure 4 Dispersion in action

Visible light

White light can be separated into a range of different colours and shades, but there are generally considered to be seven basic colours: red, orange, yellow, green, blue, indigo and violet. This range of colours is called the **visible spectrum**. The process used to produce these colours is called dispersion (Figure 4).

Each colour of the visible spectrum has a different wavelength (i.e. the length of one complete cycle of a wave) and is refracted by a different amount. This produces the separation of colours. A rainbow is an example of dispersion (and total internal reflection) caused by the refraction of light through water droplets. Three of the seven basic colours are called **primary colours of light**. These are red, green and blue. This is because these three alone can be mixed to produce white light (Figure 5). When two of the primary colours are mixed, they form **secondary colours of light**. For example, red light and blue light make a red–blue light called magenta. These rules are different for paints, so if you are an art student, you will need to think differently when considering mixtures of light compared to mixtures of paint!

Colour of objects

Objects do not inherently have colour. The colour you see is the result of the mix of

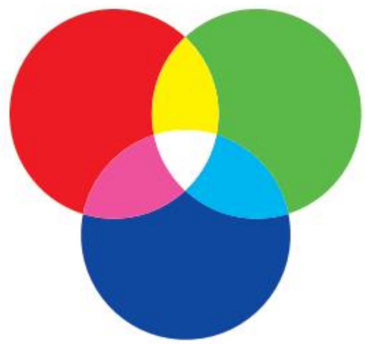


Figure 5 Where the red, green and blue lights overlap, white light is produced. The secondary colours are formed by the overlap of two of the primary colours.

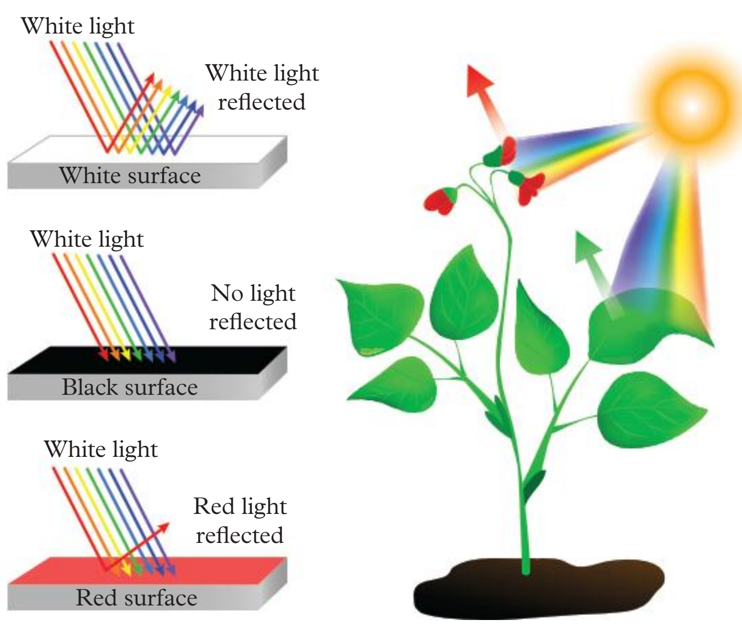


Figure 6 The colour you see an object is the colour of light reflected by the object to your eyes

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

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

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

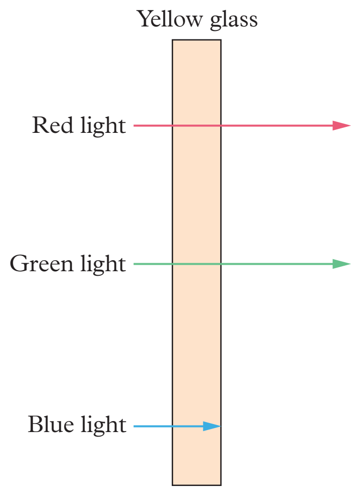


Figure 7 A filter that transmits red and green light and absorbs blue light will appear yellow.

frequencies of light that are reflected or transmitted by the object to your eyes (Figure 6 and Figure 7). It means the frequencies that do not match the vibrational frequencies of the electrons of the object and are not absorbed by it. For example, if an object absorbs all frequencies of white light, no light is reflected or transmitted to your eyes, and you see the object as black. On the other hand, if an object does not absorb any frequencies, all the colours of white light are reflected or transmitted to your eyes and you see the object as white.

Check your learning 12.12

Check your learning 12.12

Retrieve

1 Identify the result when green and red lights are mixed.

2 Identify what a green surface appears like under red light. Explain why it appears this way.

3 Identify what you would see if you looked at a white light through a yellow filter. Explain your answer.

4 Describe why the sky appears blue.

Analyse

5 Distinguish between primary and secondary colours of light.

6 If white light is a mixture of all the primary colours of light, deduce what black light is.

7 A white light is shone over an object. The blue light is reflected from it and the rest of the light is absorbed. Identify the colour of the object.

8 Explain why it is better to wear darker colours in winter and lighter colours in summer.

Apply

9 Predict what would happen if red and blue lights were mixed, then write a hypothesis that would test this. Identify the independent variable and dependent variable in your hypothesis and propose any variables you would need to control.

Skills builder: Communicating

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

- **a** Investigate the formation of rainbows. (THINK: What key words should I use? Is the source of information credible?)
- **b** Write a paragraph using scientific language to explain how rainbows are formed. (THINK: Is my language too descriptive? Am I explaining the scientific concept or describing a rainbow?)

Lesson 12.13

Investigation: Which colour is best to wear in summer?

Caution

If completing the investigation outside, wear a hat, use sunscreen and wait under the shade in between taking measurements.

Purpose

To determine which colour is best to wear to keep cool in summer

Materials

- Infrared thermometer
- Stopwatch
- Different coloured t-shirts of the same size and brand
- Direct sunlight or lamp

Procedure

1. Set up a table to record your data.
2. Work in pairs. In a shaded area, have your partner hold the t-shirt while you record the initial temperature of the t-shirt using the infrared thermometer. Do this for each t-shirt.
3. Lay the t-shirts out, ensuring they are the same distance from the light source, and start the stopwatch.
4. Measure and record the surface temperature of each t-shirt, using the infrared thermometer, every 2 minutes for 20 minutes.

Discussion

1. Explain which t-shirt colour absorbed the most heat. Justify your answer.
2. Explain which t-shirt colour reflected the most light. Justify your answer.
3. Determine which colour people should wear in summer versus winter.
4. Discuss how fabric type or thickness could affect the results of this investigation.
5. Design a solution for your school or home that uses knowledge of light reflection or absorption to solve a heat-related problem, reduce energy use or improve comfort.

Lesson 12.14

The electromagnetic spectrum helps us learn about stars

Learning intentions and success criteria

Key ideas

→ The Doppler effect can be used in astronomy to determine if objects are moving away or towards an observer.

→ Blue shift occurs when a light source and an observer move towards each other.

→ Red shift occurs when a light source and an observer are moving away from each other.

→ Stars emit light across a wide range of wavelengths in the electromagnetic spectrum, producing what is known as a continuous spectrum.

→ An absorption spectrum is produced when certain wavelengths are absorbed by the atoms in the cool gas. This creates a spectrum with dark lines where specific wavelengths are missing, showing which elements are present.

The Doppler effect in astronomy

Visible light consists of the colours red, orange, yellow, green, blue, indigo and violet, in order of increasing frequency. According to the Doppler effect, if a source of light and an observer move towards each other, the frequency of light appears higher to the observer. In other words, the frequency of the light shifts towards the blue (higher frequency). This is referred to as a **blue shift**. If the source of light and the observer move away from each other, the light appears to have a lower frequency. In this case, the frequency shifts towards the red and is referred to as a **red shift**.

The Doppler effect in light waves has helped astronomers gather evidence about the expanding Universe. They observe the light coming from stars to determine whether a star is moving towards or away from us. Light coming from stars moving away from us appears red-shifted, while light from stars moving towards us appears blue-shifted. Light from distant galaxies shows a red shift, meaning they are moving away from us. This provides evidence of the expanding Universe.

blue shift the shift in the frequency of light towards higher frequencies, or the blue end of the spectrum, as the source of light and the observer move towards each other

red shift the shift in the frequency of light towards lower frequencies, or the red end of the spectrum, as the source of light and the observer move away from each other

Continuous spectra

In the core of stars, nuclei (plural of nucleus) of atoms fuse (come together) to form a larger nucleus. This process is called nuclear fusion. During nuclear fusion, an enormous amount of energy is released. For example, the Sun's energy comes from the fusion of hydrogen atoms into helium, and because of this fusion reaction, the cores of stars are extremely hot. Stars emit radiation, similar to the tungsten filament in an incandescent light bulb.

Stars emit a full range of frequencies, including visible light from the electromagnetic spectrum, which is called a **continuous spectrum**. A **spectrum** is a chart or graph that shows the intensity of emitted light across different wavelengths. A rainbow is a natural spectrum. Raindrops spread out the sunlight when it travels through them. Astronomers use a device called a **spectroscope** to spread out the light into its different wavelengths (Figure 1).

continuous spectrum a spectrum that contains all wavelengths of light

spectrum a chart or graph that shows the intensity of emitted light across different wavelengths

The intensity of light emitted by a star varies across different wavelengths. The wavelength with the highest intensity is called the peak wavelength. The higher the temperature of a star, the shorter the peak wavelength, meaning it has a higher frequency and more energy. Therefore, the colour of stars depends on their surface temperatures. For example, a red star is cooler than a blue star as the wavelength of blue light is less than that of red light. Since there is a relationship between a star's temperature and its peak wavelength, astronomers use the peak wavelength to calculate the star's surface temperature.

Absorption spectra

The atmosphere of a star is cooler than its core and contains gaseous atoms and ions, which absorb some of the wavelengths of light emitted by the star. The core of the star is hot and produces a continuous spectrum, so astronomers can learn about the star's atmosphere by examining the wavelengths that are absorbed and missing from the continuous spectrum.

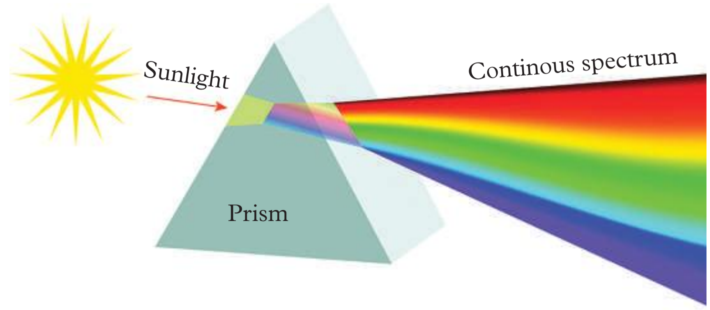


Figure 1 The continuous spectrum of the sunlight produced by a prism (spectroscope)

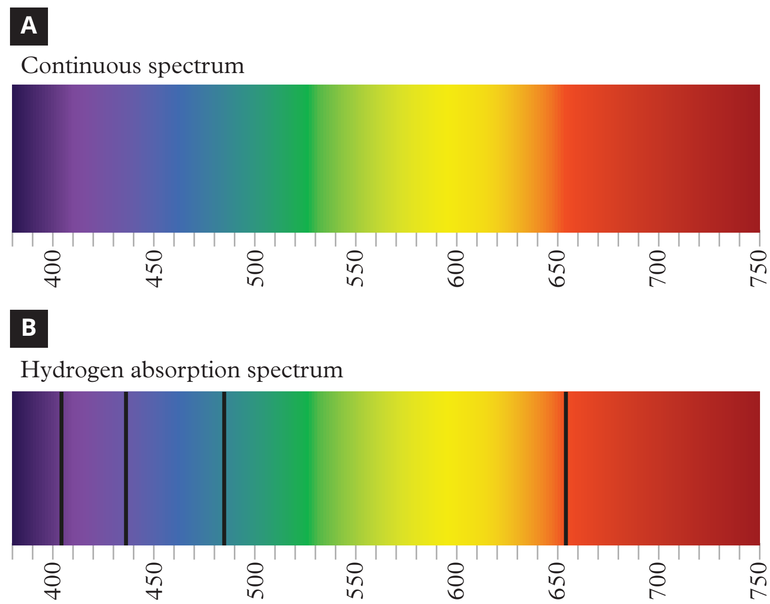


Figure 2 (A) Visible continuous spectrum; (B) Visible absorption spectrum. The absorbed wavelengths appeared as dark lines.

Check your learning 12.14

Check your learning 12.14

Retrieve

1 Describe how astronomers use the Doppler effect to study the motion of stars and galaxies.
2 Explain how astronomers can use spectra of stars to determine their surface temperatures.
3 Explain how the absorption spectrum of a star provides information on the chemical composition of the star.

Analyse

4 Compare continuous spectra and absorption spectra.
5 Identify whether a red star has a higher surface temperature than a yellow star. Explain your answer.

Lesson 12.15
Review: Waves

Summary

Lesson 12.1 Types of waves

- A wave is a disturbance that transfers energy without transferring matter.
- Mechanical waves need a medium to transfer energy.
- Electromagnetic waves can transfer energy in space (vacuum).
- Frequency and period have a reciprocal relationship.
- The speed of a wave can be calculated by multiplying its wavelength and frequency.
- Light moves in an electromagnetic transverse wavelike motion.

Lesson 12.3 Sound waves

- Sound is caused by the vibration of particles moving in a longitudinal wave.
- One wavelength is the distance between one compression of air particles and the next.
- The distance the air particle moves from its normal position is called the amplitude.
- The number of waves passing a point each second is the frequency of the wave.
- The speed of sound varies according to the temperature and material through which it travels.
- Sound travels faster at higher temperatures because the particles can compress more easily.

Lesson 12.4 The Doppler effect

- The Doppler effect is an apparent change in pitch (frequency) of a wave.
- The cause of the Doppler effect is the relative motion between the source of the wave and the observer.

Lesson 12.6 Sound waves are used in medical diagnosis

- Sonar uses sound waves underwater to determine how far away an object is.
- Ultrasounds are used to look at internal organs.
- The clarity of an ultrasound image depends on the frequency of the sound waves used. Ultrasound uses high-frequency, short-wavelength sound waves, which produce clearer and more detailed images than lower-frequency, longer-wavelength sound waves (like normal sound).

Lesson 12.7 Electromagnetic waves

- The electromagnetic spectrum is a way of describing all the different forms of light, including the light we see.
- All forms of light travel at the same speed through a vacuum and are transverse waves.
- The electromagnetic spectrum is a range of electromagnetic waves with different wavelengths and energies.
- All electromagnetic waves travel at the same speed through a vacuum.
- Light also behaves like a particle called a photon.
- Electromagnetic waves from the highest to the lowest wavelength (and the lowest to the highest energy) are radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

Lesson 12.8 Light reflects off a mirror

- Light can travel through transparent objects and is blocked by opaque objects.
- Translucent objects allow some light energy through.
- When light is reflected off a mirror, the angle of incidence is equal to the angle of reflection (law of reflection).
- The image in the mirror is called a virtual image.

Lesson 12.10 Light refracts when moving from one medium to another

- Refraction is the bending of light as it enters from one medium and travels to another.
- Reflection occurs from shiny surfaces, but when light strikes a transparent material, it enters the material and may change direction (towards or away from the normal).
- Convex lenses cause light rays to converge, while concave lenses cause light rays to diverge.

- For total internal reflection to occur, two conditions must be met: light must travel from a more-dense medium into a less-dense medium; and the angle must be greater than the critical angle.
- Due to total internal reflection in optic fibres, signals are able to travel quickly (speed of light) with minimal signal loss.

Lesson 12.11 How the eye responds to light

- Your eyes can form images of objects through the refraction of light.
- The refraction of light in the eyes occurs by the cornea and the lens.
- Light-sensitive cells in the retina convert light signals to electrical signals.
- Electrical signals are sent to the brain through the optic nerve.

Lesson 12.12 Scattering and absorption of light

- Scattering of light is the cause of phenomena such as the Tyndall effect, the blue sky and the reddish sky during sunrises and sunsets.
- The colour of an object is the colour of light reflected or transmitted by the object to your eyes.

Lesson 12.14 The electromagnetic spectrum helps us learn about stars

- The Doppler effect can be used in astronomy to determine if objects are moving away or towards an observer.
- Blue shift occurs when a light source and an observer move towards each other.
- Red shift occurs when a light source and an observer are moving away from each other.
- Stars emit light across a wide range of wavelengths in the electromagnetic spectrum, producing what is known as a continuous spectrum.
- An absorption spectrum is produced when certain wavelengths are absorbed by the atoms in the cool gas. This creates a spectrum with dark lines where specific wavelengths are missing, showing which elements are present.

Review questions 12.15

Review questions Module 12

Retrieve

1 Identify which of the following terms can be used to describe sound waves.
 A Transverse waves
 B Electromagnetic waves
 C Microwaves
 D Longitudinal waves

2 Identify which of the following is correct.
 A Sound waves travel faster than light waves.
 B Sound travels faster in air than in water.
 C Light travels faster than sound.
 D Sound can travel through space.

3 Define the term "frequency" of sound. Identify its unit of measurement.

4 Complete this paragraph by identifying the missing words. The first letter of each missing word is given.
 Sound is created by v________. The v________ create c________ and r________ due to the movement of the particles as the sound w________ passes through. The w________ travels through the substance and is known as a l________ wave. The greater the vibration, the higher the v________ of the sound, which means it sounds l________. Sound waves must have a m________ to pass through.

5 Describe the relationship between the Doppler effect and light waves.

6 Discuss the importance of spectrum lines in understanding what stars are made of.

Comprehend

7 Explain why astronauts could shout at each other with their helmets touching if the radio communication broke down on the Moon.

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

9 Explain why sound travels faster in solids than in air.

10 Describe the difference between the primary colours of light and the primary colours of paint.

11 Explain how pitch and frequency of sound are related.

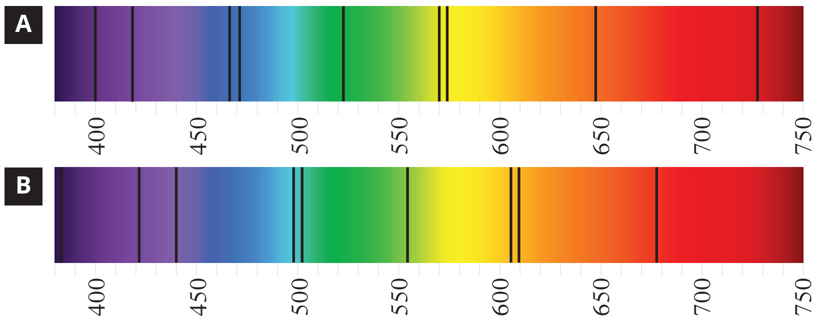


Figure 1 The absorption spectrum of (A) a galaxy while at rest and (B) the galaxy moving

12 Describe the conditions that can slow the speed of light.

13 Describe how light moves in an optic fibre.

14 Describe the appearance of the Australian flag when viewed in:

a blue light

b red light

c green light.

Analyse

15 Explain how energy is transferred in transverse waves and longitudinal waves.

16 Compare the reflection of light and the refraction of light.

Apply

17 A student claimed that black is not a colour. Evaluate their claim (by explaining how an object can appear black, defining what is a colour of light and deciding if the student is correct).

18 Aboriginal and Torres Strait Islander Peoples use the didgeridoo for many important ceremonies. Long didgeridoos produce sounds that are lower in pitch and frequency than short didgeridoos. Describe what this information tells you about the sound wave that is produced. (HINT: Consider the length of the sound waves produced by each didgeridoo.)

19 Provide an example of the Doppler effect that occurs in the real world. Explain how this impacts what we hear or observe.

20 A wave travels at a speed of 250 m/s and has a wavelength of 2 m. What is its frequency?

21 A sound wave has a frequency of 380 Hz and travels through air at a speed of 340 m/s. What is its wavelength?

22 The first image in Figure 1 shows the absorption spectrum of a galaxy while at rest. The second image shows the galaxy moving. Determine if red shift or blue shift is occurring and justify your response.

Critical and creative thinking

23 Table 1 shows the speed of sound at different temperatures.

a Using graph paper, create a graph of the speed of sound (vertical axis) at various air temperatures (horizontal axis).

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

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

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

Table 1 The speed of sound at different temperatures

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

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

a Use this information to compare how light and sound travel.

b Determine what this tells us about the ability of light energy to travel through outer space.

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

Research

26 Choose one of the following topics for a research project. A few guiding questions have been provided, but you should add more questions that you wish to investigate. Present your report in a format of your own choosing.

Supersonic planes

Identify what "supersonic sound" means.

- Contrast a supersonic jet and a normal jet aircraft.
- Describe one of the problems with supersonic planes.
- Describe why the Concorde was removed from air travel service.

Figure 2 The Concorde has been removed from air travel service.

Night vision goggles

Night vision goggles allow soldiers to see at night and spot the enemy before they are spotted themselves. They give an army a tactical advantage.

- Describe how the goggles work.
- Identify the limitations of these goggles (i.e. Will they work in a totally dark environment? Do they have any disadvantages for the soldiers operating them?)

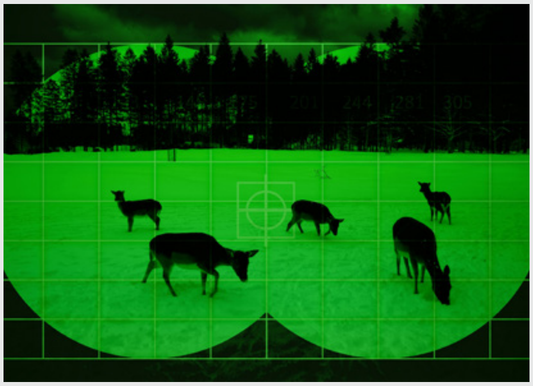


Figure 3 View of deer in a forest through night vision goggles

Noise-cancelling headphones

The first commercial noise-cancelling headphones hit the market in 1989 and are now a must-have when travelling, such as on a train or an aeroplane.

- Describe the main difference between noise-cancelling headphones and regular headphones.
- Explain how noise-cancelling headphones work.
- Discuss any similarities and differences in the technologies for over-ear noise-cancelling headphones and in-ear noise-cancelling headphones.

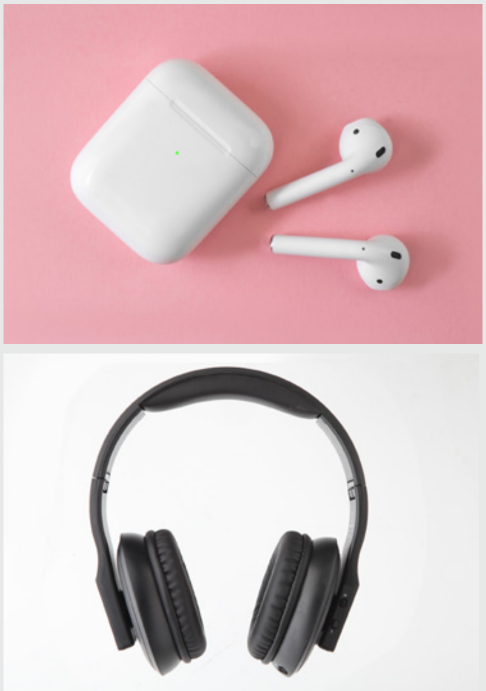


Figure 4 Headphones have come a long way over the last 40 years.

Module 13 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 should brake or change speed. Understanding Newton's laws helps explain everyday motion and how to stay safe during movement.

Lessons in this module

Lesson 13.1
Distance and displacement

Learning intentions and success criteria

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

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. At the end of the day, however, 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 how far an object has travelled in a set time

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

scalar quantity quantity that has magnitude (size)

magnitude the size or extent of something

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

Distance 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, east–west or up–down. Time is always

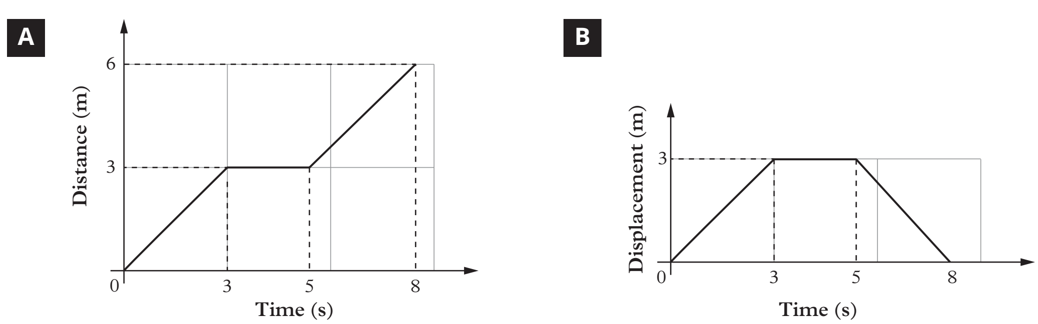


Figure 1 These two graphs show the same journey. (A) The distance–time graph shows a person travelling 3 m for the first 3 seconds, resting for 2 seconds, before travelling 3 m in the final 3 seconds. (B) The displacement–time graph shows us the same journey described in (A) and also tells us that the person travelled back to their starting point.

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.

The displacement–time graph (Figure 1B) shows the position of a person walking north from the origin (0 m) for 6 seconds and moving to a new position 4 m away from the origin, stopping for 2 seconds and then walking south for 4 seconds. They pass the origin after 2 seconds and end up at 4 m south of the origin.

Worked example 13.1A shows how to calculate distance and displacement over time.

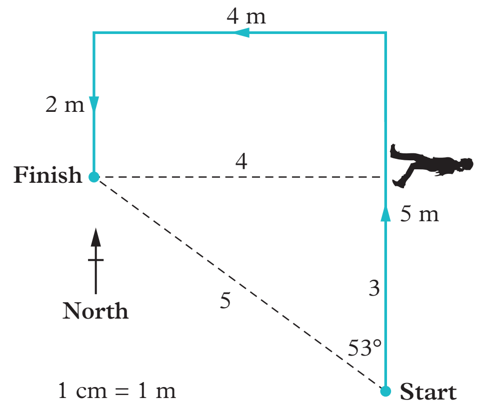


Figure 2 This person walks a total of 11 m. The displacement can be calculated by drawing a right-angle triangle and using Pythagoras' theorem. The final position of the person is 5 m north, 53° west or 5 m on a bearing of 307°.

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. This, however, is not their displacement. Their displacement only compares where they finish to where they started.

Worked example 13.1B shows how to calculate distance and displacement using direction.

Worked example 13.1A Calculating distance and displacement over time

The displacement–time graph shown in Figure 1 shows the movements of a person over 8 seconds.

Solution

Steps	What to do	Working out
a.	To determine the total distance travelled, use the graph to determine where the person stopped.	After 8 seconds, the person had travelled a total distance of 6 m.
b.	The total displacement is the distance and direction from the starting point.	Displacement = 3 m + 0 m − 3 m = 0 m

Worked example 13.1B Calculating distance and displacement using direction

A person walks 5 m north, 4 m west and then 2 m south (Figure 2).

a Calculate the distance travelled by the person.

b Calculate the displacement of the person from their starting point.

Solution

Steps	What to do	Working out
a.	For part **a**, the total distance travelled by the person can be calculated by adding all the distances together.	distance = 5 m + 4 m + 2 m = 11 m
b.	For part **b**, the displacement of the person is the straight line distance between the starting and finishing point. The displacement can be determine by using Pythagoras' theorem, where c is the (long) hypotenuse, and a and b are the sides on each side of the right angle.	$a = 3\,\text{m}, b = 4\,\text{m}, c = ?$ $c^2 = a^2 + b^2$ $c^2 = 32 + 4^2$ $= 9 + 16$ $= 25\,\text{m}$ $c = \sqrt{25}$ $= 5\,\text{m}$

Steps	What to do	Working out
c.	To determine the direction of the displacement for part **b**, the angle must be calculated using sine, cosine or tangent.	$\cos\theta = \frac{\text{adjacent length}}{\text{hypotenuse length}}$ $\cos\theta = \frac{3}{5}$ $\theta = 53°$
d.	Use true or compass bearing to describe the displacement.	5 m on a bearing of 307° (true bearing) OR 5 m N53°W (compass bearing)

Check your learning 13.1

Check your learning 13.1

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 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.

Skills builder: Processing and analysing data and information

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

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

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

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

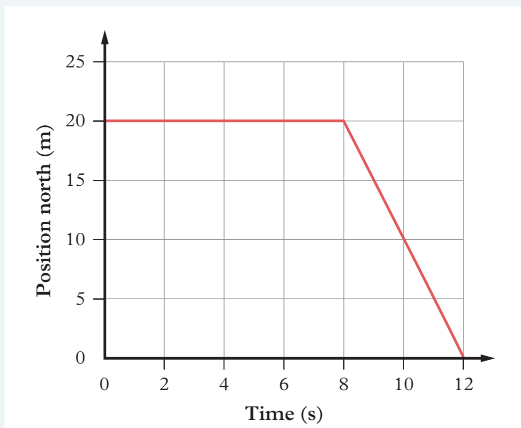


Figure 3 A position–time graph

Lesson 13.2
Speed and velocity

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.

Learning intentions and success criteria

Speed

Speed is a measure of how fast a 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.

speed the distance travelled per unit of time

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:

average speed the total distance travelled divided by the total time taken

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

This rule, or formula, can also be expressed in a triangle, as shown in Figure 3. The triangle is a good memory tool to help you work out three formulas from the one diagram. Worked example 13.2A shows an example calculation.

Average speed can also be determined by the gradient (or slope) of a distance–time graph (Figure 2), where Δ is the Greek letter delta and means "change in".

$$\text{gradient} = \frac{\text{rise}}{\text{run}} = \frac{\Delta d}{\Delta t} = \frac{5.5 - 1}{3.5 - 0} = 1.3 \text{ m/s}$$

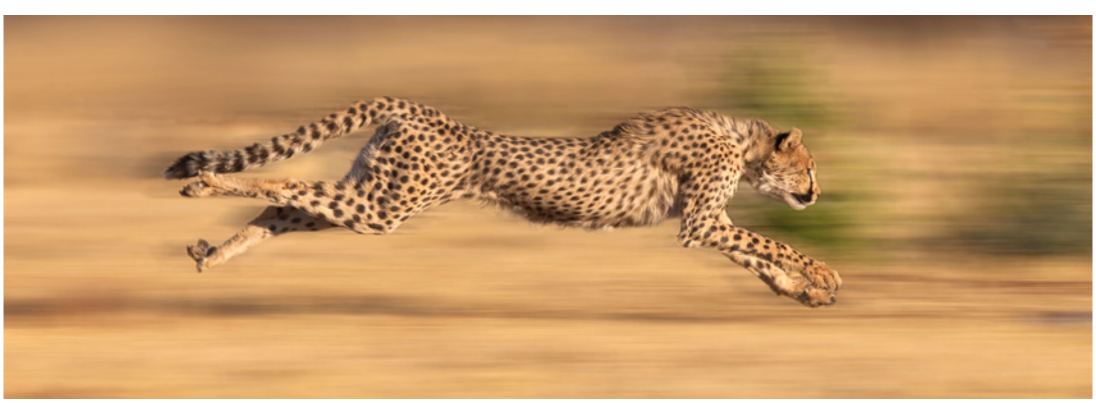


Figure 1 The cheetah is the fastest land animal. It can reach speeds of up to 112 km/h.

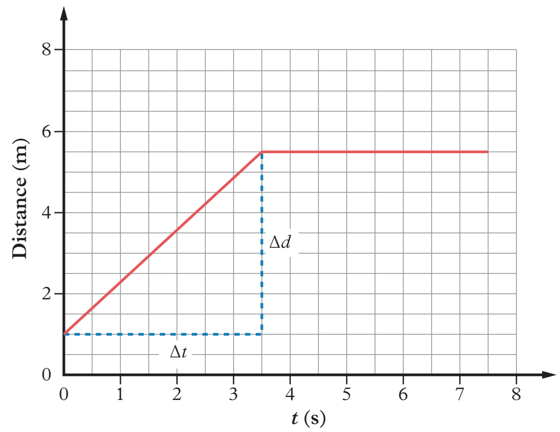
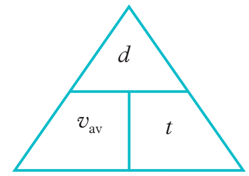


Figure 2 The speed of the object in this distance–time graph can be calculated by determining the gradient of the graph.



$$v_{av} = \frac{d}{t}$$

$$t = \frac{d}{v_{av}}$$

$$d = v_{av} \times t$$

Figure 3 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.

Worked example 13.2A Calculating distance using average speed

Calculate the distance travelled by an object moving at an average speed of 5 m/s for 1.5 seconds.

Solution

Steps	What to do	Working out
a.	Use the triangle in Figure 3 to determine the formula for distance travelled.	d = $v_{av} \times t$
b.	Substitute in the values for average speed and time.	d = 5 × 1.5
c.	Calculate the value of d, including units.	d = 7.5 m

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 approach 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.

Velocity

velocity the vector quantity that measures speed in a particular direction

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 italic "*v*" to show that it also has direction. The average velocity of an object (v_{av}) is calculated in a similar way to average speed, but displacement (symbol *s*) is used instead of distance (Figure 4).

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

$$v_{(av)} = \frac{s}{t}$$

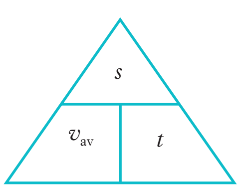


Figure 4 The average velocity triangle. Cover the quantity you want to calculate, and the other two quantities will form the formula.

The direction of the average velocity is the same as the direction of the displacement. Average velocity can be determined from the gradient of a displacement–time graph. The nature of the gradient indicates the direction. For example, in Figure 5, between 0 and 6 seconds, the gradient is positive (going up) on the displacement–time graph, indicating that the velocity is constant or unchanging and in the positive direction. Between 6 and 8 seconds, the gradient is zero (or horizontal), meaning the object is not moving and the velocity is zero. Between 8 and 12 seconds, the gradient slopes downwards, indicating that the velocity is constant and moving in the negative direction.

Worked example 13.2B shows how to calculate the velocity of the object using the gradient of the displacement–time graph.

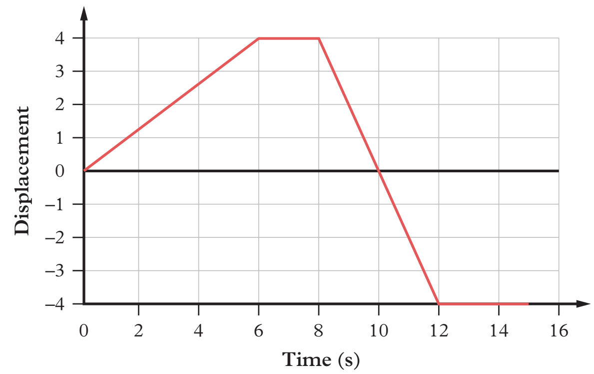


Figure 5 The velocity of the object in this displacement–time graph can be calculated by determining the gradient of the graph.

Worked example 13.2B Calculating velocity

Calculate the average velocity of the object in Figure 5 between:

a 0 to 6 seconds **b** 6 to 8 seconds **c** 8 to 12 seconds.

Solution

Steps	What to do	Working out
a.	Identify the formula required. The average velocity is equal to the gradient of the displacement–time graph.	$v_{av} = \text{gradient} = \frac{\text{displacement}}{\text{time}}$
b.	In part **a**, the displacement is 4 m over the 6 seconds. Direction must be included.	$v_{av} = \frac{4-0}{6} = 0.7$ m/s north
c.	In part **b**, the gradient of the graph is zero, so the average velocity will equal zero.	gradient = 0 $v_{av} = 0$ m/s
d.	In part **c**, the total displacement is −8 (moving in the opposite direction) over the 4 seconds. Direction must be included.	$v_{av} = \frac{-8}{4} = -2$ $v_{av} = -2$ m/s = 2 m/s south

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 speed is decreasing (slowing down) until it reaches 0 m/s.

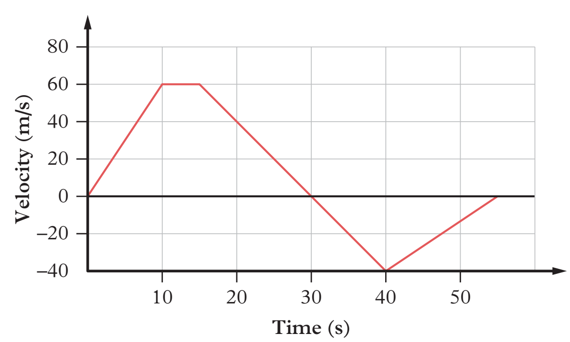


Figure 6 This velocity–time graph shows an object with changing velocity.

In velocity–time graphs, if the graph slopes below the *x*-axis, then the object is speeding up in the opposite direction. The velocity–time graph in Figure 6 shows an object with changing velocity. The object increases its velocity from 0 m/s to 60 m/s in the first 10 seconds. It then travels at a constant 60 m/s for 5 seconds before slowing down. At 30 seconds, it has stopped, and then it starts travelling in the opposite (negative) direction before eventually slowing to a stop.

The area under the graph determines the displacement in that time. Worked example 13.2C shows how to calculate the displacement and distance travelled of the object.

Worked example 13.2C Calculating displacement

Calculate the total displacement and distance travelled of the object in Figure 6.

Solution

You can calculate the total distance travelled and the displacement of the object using the area under the graph.

The graph needs to be broken into different sections so that the area under the graph can be calculated.

Steps	What to do	Working out
a.	Calculate the distance travelled from 0 to 10 seconds. The object increased speed or accelerated.	area (0–10 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 10 \times 60$ $= 300$ m
b.	Calculate the distance travelled from 10 to 15 seconds. The object kept the same speed.	area (10–15 s) = base $\times$ height $= 5 \times 60$ $= 300$ m
c.	Calculate the distance travelled from 15 to 30 seconds. The object slowed to a stop.	area (15–30 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 15 \times 60$ $= 450$ m
d.	Calculate the distance travelled from 30 to 40 seconds. The object increased speed in the negative (south) direction.	area (30–40 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 10 \times -40$ $= -200$ m
e.	Calculate the distance travelled from 40 to 55 seconds. The object decreased speed in the negative (south) direction.	area (40–55 s) $= \frac{1}{2} \times$ base $\times$ height $= 0.5 \times 15 \times -40$ $= -300$ m
f.	Calculate the total displacement by adding all the values, including direction.	displacment $= 300 + 300 + 450 - 200 - 300$ $= 550$ m north
g.	Distance is a scalar quantity and does not have a direction.	distance $= 300 + 300 + 450 + 200 + 300$ $= 1,550$ m

Unit conversion

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

The 3.6 arises because there are 60 seconds in a minute and 60 minutes in an hour, giving 60 × 60 = 3,600 seconds in an hour. Also, there are 1,000 m in a kilometre, so 3,600 ÷ 1,000 = 3.6.

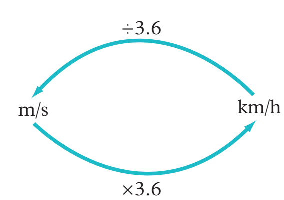


Figure 7 Follow the arrows to convert from one unit to the other.

Check your learning 13.2

Check your learning 13.2

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 Answer these questions.

  a Create a story that describes the motion of a person moving according to the graph in Figure 8.

  b Calculate the total distance travelled from the point of origin.

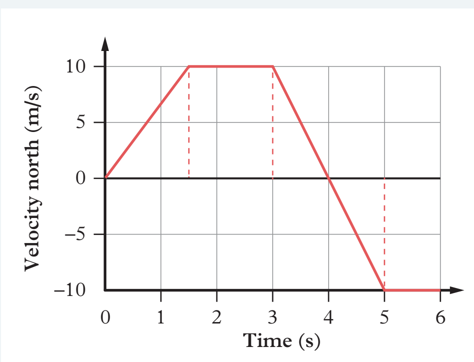


Figure 8 A velocity–time graph

Evaluate and create

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

  a Construct a distance–time graph.

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

  c Calculate the average speed of the person using the gradient of the graph.

Table 1 The position of a person at different times

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

Skills builder: Conducting investigations

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

  a Identify units that are used to measure speed.

  b (THINK: Do different speeds have different measurements? Does the distance affect the unit used?)

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

Lesson 13.3
Challenge: Bringing graphs to life

Introduction

Working in groups, act out the position–time graph in Figure 1.

What you need:

- Clear space (maybe outside)
- Tape measure
- Masking tape
- Marker pen
- Stopwatch

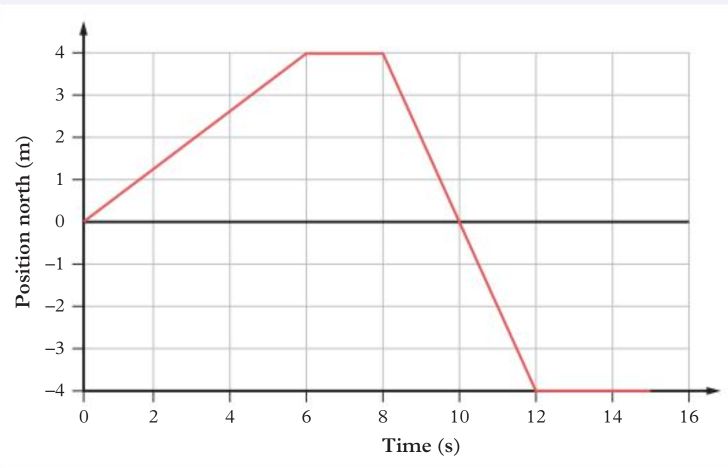


Figure 1 A position–time graph

What to do:

1. Form a group of two to four students.
2. Lay out a 4-m length of masking tape on the floor and mark it at intervals of 1 m.
3. Rehearse the motion shown in Figure 1 by discussing it with your group and even doing a walk-through rehearsal.
4. Start the stopwatch and try to match your motion to the graph. The person timing you will give you feedback on how you went.
5. Swap roles and repeat the activity until everyone in your group has had a turn.
6. Repeat the activity with another piece of masking tape on the floor, going 4 m in the opposite direction.

Questions

1. How did your group perform in this task?
2. What difficulties did you have in demonstrating the motion?
3. Draw your own position–time graph and try to act out the motion. How did you go this time?

Lesson 13.4
Investigation: The ticker timer

Purpose

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
- Two electrical wires

- Glue
- Ticker tape
- Carbon circles
- Ruler

Procedure

1 Connect the ticker timer to the AC terminals of the power supply using the two electrical wires (Figure 1). Set the power source at 6 V. Adjust as required.

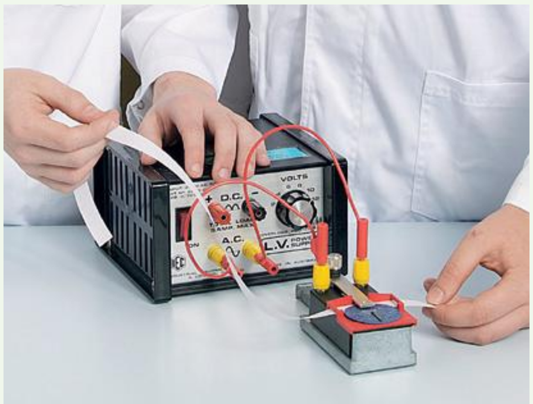


Figure 1 Connecting the ticker timer

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 (time on the x-axis and speed on the y-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 13.5
Investigation: Using a motion sensor

Purpose

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

Procedure

1 Connect the laptop to the motion sensor and open the appropriate software for your motion sensor.
2 Position the motion sensor several metres in front of the dynamics trolley and push the trolley towards the sensor. (You may need to attach a cardboard reflector to the front of the trolley to reflect the signal from the motion sensor back to the sensor.) Ensure the trolley does not contact the motion sensor.

Results

Analyse the data on the laptop to produce a 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 in Lesson 13.4 Investigation: The ticker timer (page 570) 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.

Figure 1 Motion sensors can be used to measure displacement, speed, velocity and acceleration.

Lesson 13.6
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.

Learning intentions and success criteria

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. Acceleration is how much an object changes its velocity every second. 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. As velocity can change when the direction changes, acceleration can also change when the direction changes. This means acceleration is also a vector quantity.

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. Other units for acceleration are possible, however, depending on the units of velocity and time.

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.

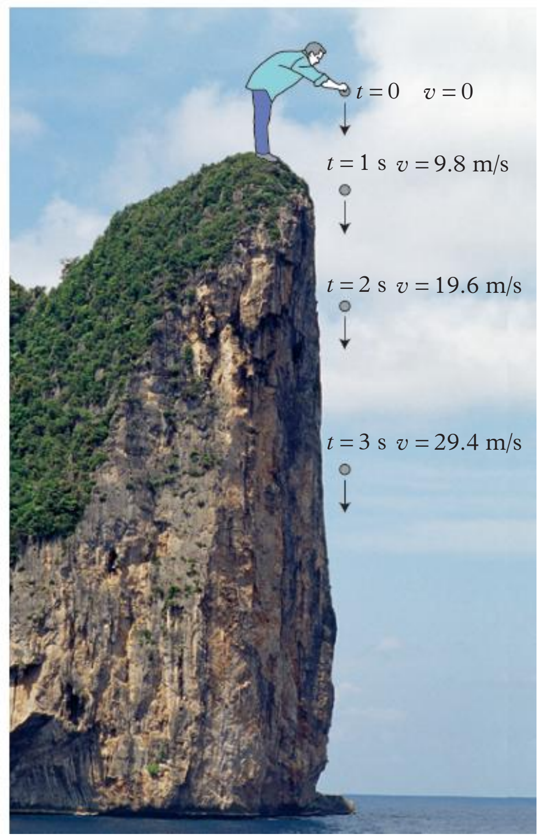


Figure 1 Each second, the speed of the falling rock increases by almost 9.8 m/s, ignoring air resistance. This means the acceleration is 9.8 m/s^2 downwards.

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.

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 sky dive, their movement follows the pattern of the rock. They speed up as they fall until they open their parachute and slow down to land.

acceleration the change of velocity over time

acceleration due to gravity the acceleration of an object due to a planet's gravitational field; on Earth, g = 9.8 or 10 m/s^2

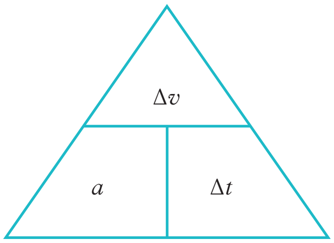


Figure 2 The acceleration triangle. Cover the quantity you want to calculate, and the other two quantities will form the formula.

Calculating acceleration

The formula for calculating acceleration (a) is:

$$\text{acceleration}(a) = \frac{\text{change in velocity}(\Delta v)}{\text{change in time}(\Delta t)}$$

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:

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

where v is the final velocity and 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 to Figure 5.

Worked example 13.6A describes the velocity and acceleration of an object, and Worked example 13.6B shows how to calculate the acceleration of the object.

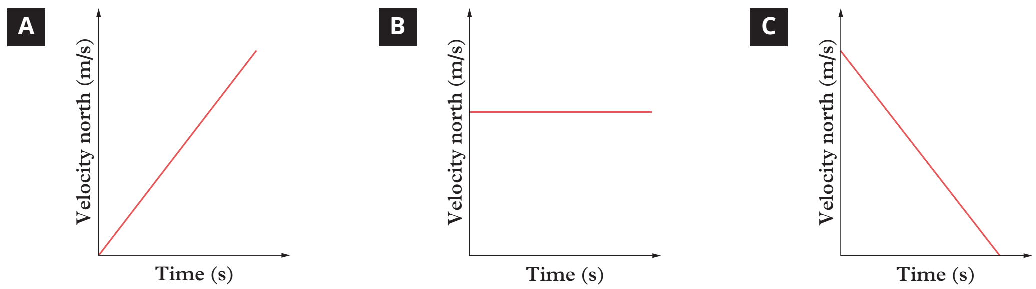


Figure 3 Velocity–time graphs (for an object moving in the positive direction) showing (A) constant positive acceleration (i.e. speeding up), (B) zero acceleration (i.e. constant velocity) and (C) negative acceleration (i.e. slowing down or decelerating)

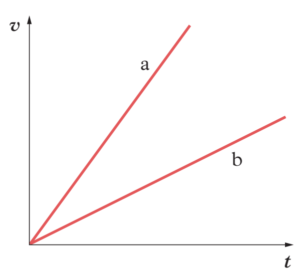


Figure 4 Velocity–time graphs showing a steep gradient, indicating high acceleration (a), and a gentle gradient, indicating lower acceleration (b)

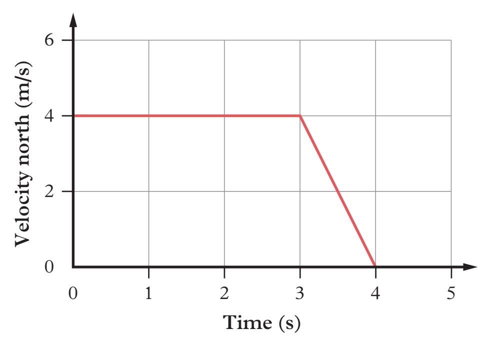


Figure 5 Acceleration can be determined by the gradient of a velocity–time graph.

Worked example 13.6A Describing velocity and acceleration

Describe the velocity and acceleration of the object in the first 3 seconds of Figure 5.

Solution

Steps	What to do	Working out
a.	To describe the velocity of the object, we need to look at the direction, velocity and time taken.	The object in the graph is travelling at a constant velocity of 4 m/s in the positive direction (north) for the first 3 seconds.
b.	To determine the acceleration of the object in the first 3 seconds, we need to calculate the gradient.	$\text{acceleration} = \frac{0}{3}$ $= 0\text{ m/s}$

Worked example 13.6B Calculating acceleration

Calculate the acceleration of the object in the last second of Figure 5.

Solution

Steps	What to do	Working out
a.	Using the graph, list the known values needed for the formula.	Initial velocity = 4 m/s, final velocity = 0 m/s Initial time = 3 seconds, final time = 4 seconds
b.	Substitute the values into the formula.	$\text{acceleration} = \frac{\text{change in velocity}}{\text{change in time}}$ $= \frac{\text{final velocity} - \text{starting velocity}}{\text{final time} - \text{starting time}}$ $= \frac{0 - 4\text{ m/s}}{4 - 3\text{ s}}$ $= \frac{-4\text{ m/s1}}{1\text{ s}}$ $= -4\,\text{m/s}^2$ Since the velocity is positive, the negative number indicates the object has decelerated.

Check your learning 13.6

Check your learning 13.6

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.

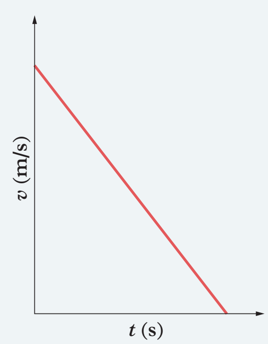


Figure 6
A speed–time graph

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 m/s². 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.

Evaluate and create

8 The data in Table 1 shows the change in the velocity of a car started from rest. Use the data to answer the following questions.
   a Construct the velocity–time graph of this object.
   b Calculate the acceleration of the object by using the gradient of the graph.

Table 1 The velocity of an object at different times

Time (s)	Velocity (m/s) north
0	0
5	5
10	9
15	15
20	22
25	25

Skills builder: Questioning and predicting

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

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

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

Lesson 13.7

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: $h = at^2$
(HINT: Rearrange the formula to make a (acceleration) the subject and substitute your values for h and t.)

2 The resulting value for 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 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 13.8

An object keeps the same velocity until a net unbalanced force acts on it

Key ideas

→ Forces act in pairs between two objects.

→ Newton's first law states: "An object remains at rest or in constant velocity unless acted on by a net unbalanced force".

Learning intentions and success criteria

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 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.

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 may be fictional, Newton himself is responsible for its creation.

Newton's laws

English scientist Isaac Newton (1642–1727) is often pictured as sitting under a tree until an apple falls on his head. 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).

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

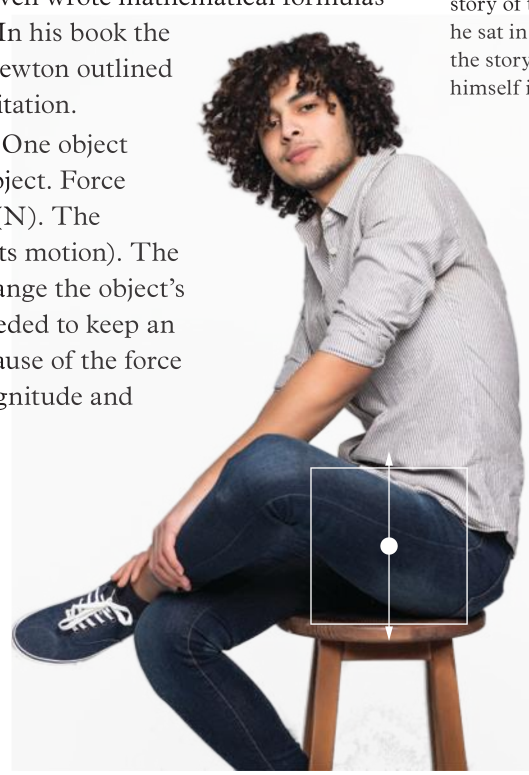


Figure 2 Zero net force is shown by two equal-length arrows pointing in opposite directions. This person will not move until a new force acts on them.

force a push or pull that, if unbalanced, can cause a change in an object's motion or shape

newton the unit used to measure force, symbol N

Newton's first law an object remains at rest or in constant velocity unless acted on by a net unbalanced force; also known as the law of inertia

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

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

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

Figure 3 Inertia is responsible for vehicles tilting as they turn. Without friction from tyres gripping the road, turning would be nearly impossible.

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.


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.

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 4). 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 from moving at 60 to 100 km/h. If you are not wearing your seatbelt, Newton's first law says that you will keep moving at the same speed (60 to 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 forward 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 a larger mass are described as having more inertia.

Check your learning 13.8

Check your learning 13.8

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 moves up.

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

Lesson 13.9

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 the car, bus or train and observe the position of the cotton and paperclip when the vehicle:

- – starts moving
- – slows its movement
- – travels at constant speed in a straight line.

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 13.10
Newton's second law

Learning intentions and success criteria

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 $F_{net} = ma$.

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

Introduction

Newton's laws are used in many unexpected ways. **Newton's second law** states: "The acceleration of an object is directly related to the magnitude and the direction of the net force acting on the object, and inversely related to the mass of the object". 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).

Figure 1 Pedalling provides the thrust force when riding a bike.

Force affects acceleration

If an object experiences an unbalanced net force, the object will change its velocity in the direction of the net 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.

Figure 2 Braking provides a drag force.

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).

Force, mass and acceleration

Would you need more push force to start moving a car or to 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:

net force = mass × acceleration

$F_{net} = m \times a$

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/s^2), 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 (Figure 4).

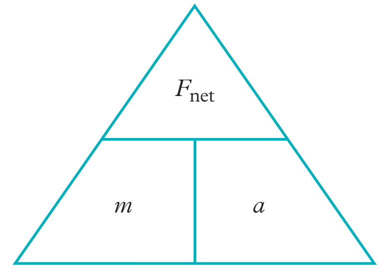


Figure 3 The net force equation can be written as a triangle. Cover the quantity you want to calculate, and the other two quantities will form the formula.

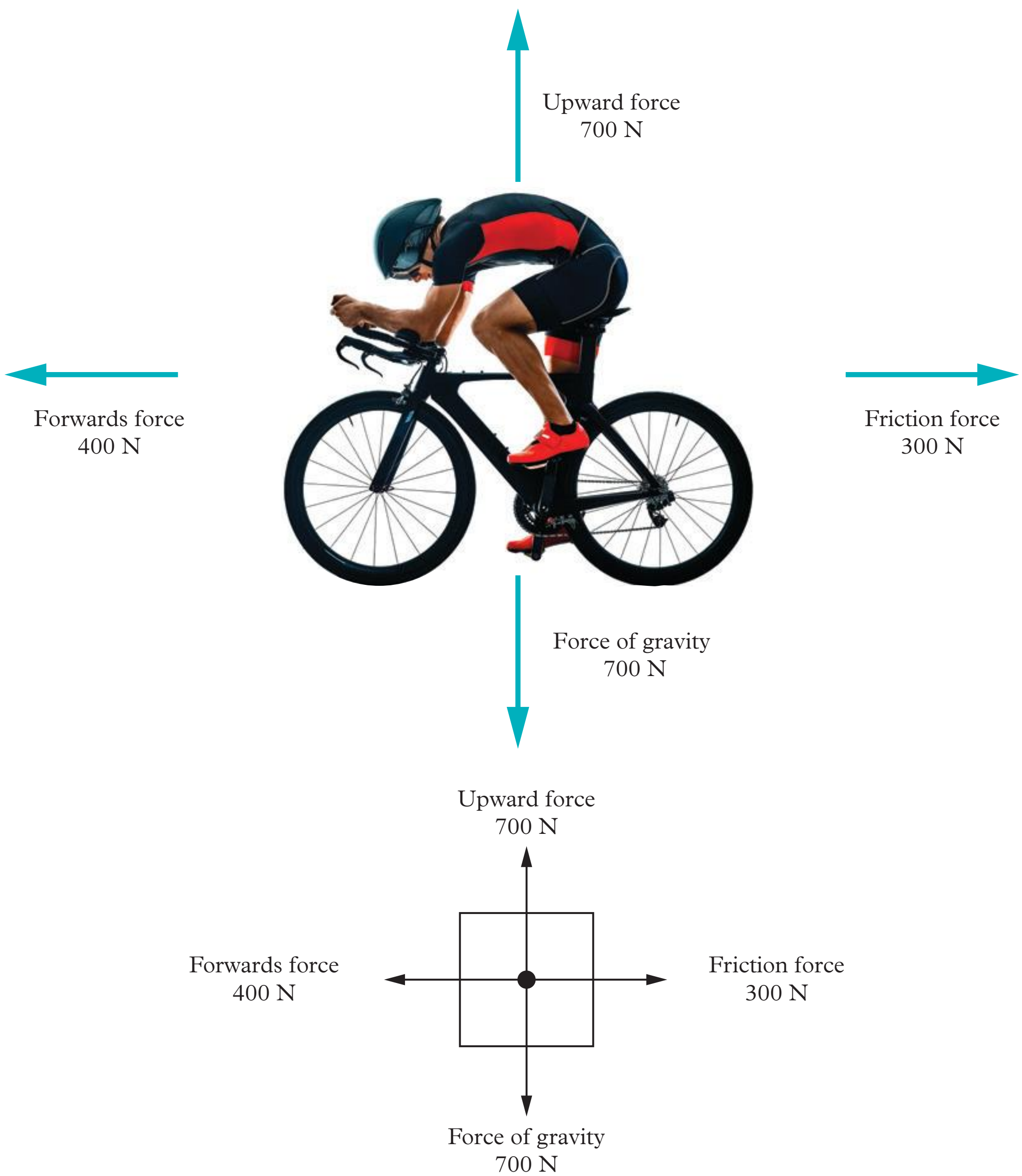


Figure 4 Various forces act on a cyclist.

Worked example 13.10A shows how to calculate acceleration using net force and mass.

Worked example 13.10A Calculating acceleration using net force and mass

Consider the cyclist and bike with a mass of 90 kg shown in Figure 4. The forwards-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

Steps	What to do	Working out
a.	To calculate the cyclist's acceleration, we first need to determine the net force. This is done by considering the forward force and the frictional force. The forces of gravity and the upward force are not included in this calculation as the cyclist is not moving vertically.	forward force = +400 N friction force = –300 N net force = 400 – 300 = 100 N forwards
b.	To calculate the cyclist's acceleration, we can use the formula, the net force and the cyclist's mass.	$\text{acceleration} = \frac{\text{net force}}{\text{mass}}$ $= \frac{100\text{ N forwards}}{90\text{ kg}}$ $= 1.11\text{ m/s}^2$ The cyclist would increase his velocity in the forward direction by 1.11 m/s every second.

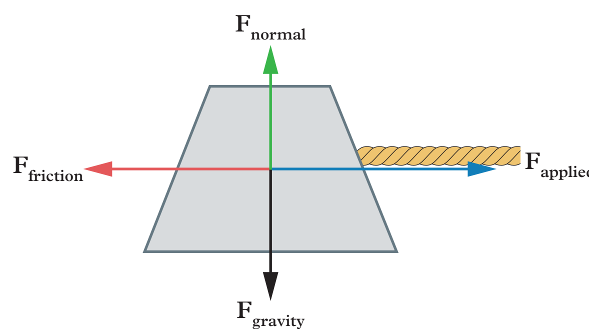


Figure 5 The arrows in the diagram show the forces acting on the object.

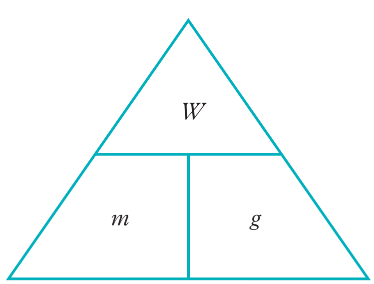


Figure 6 Weight is the force of gravity acting on an object's mass. Weight (force) = mass × acceleration due to gravity (symbol g).

Net force

The net force is the vector sum of all forces acting on an object. This means you must consider the direction of each force when adding them. You choose one direction as positive and the opposite direction as negative. Worked example 13.10B shows how to calculate the net force acting on an object.

Force diagrams show all the forces acting on an object. Arrows are used to show forces. The length of the arrow shows the size of the force. The direction of the arrow shows the direction of the force. All arrows should be drawn starting from the centre of the object (the centre of mass). Figure 5 shows all forces acting on an object.

Worked example 13.10B Calculating net force in one dimension

Calculate the net force acting on a car if the driving force is 2,000 N to the right and the total frictional force between the car's tyres and the road is 500 N to the left.

Solution

Steps	What to do	Working out
a.	We need to consider which direction is positive.	Moving to the right is positive.
b.	List the known values.	driving force = 2,000 N frictional force = −500 N
c.	Substitute these values into the formula to calculate net force.	F_{net} = 2,000 + (−500) = 2,000 − 500 = 1,500 N to the right

Mass or weight

We often use the term "weight" to indicate how much mass something has in kilograms; however, 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 m/s^2 and on the Earth is 9.8 m/s^2. This means an object on the Moon with a mass of 100 kg would have a weight of 160 N (100 kg × 1.6 m/s^2) and 980 N (100 kg × 9.8 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 6.

weight = mass × gravitational acceleration

$W = m \times g$

Figure 7 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.

Check your learning 13.10

Check your learning 13.10

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 is 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 a poster that explains why trucks need a greater stopping distance than cars.

Skills builder: Problem solving

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

Lesson 13.11
Investigation: Accelerating masses

Purpose

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

Procedure

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 in metres. 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 the impact of the weights hitting the floor.

5 Record the motion of the trolley as the masses fall by using a motion sensor, timing with a

Figure 3 Recording the motion of the trolley

stopwatch, or recording the motion on ticker tape (Figure 3).

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 (see Lesson 13.5 Investigation: Using a motion sensor, page 572) to determine the acceleration directly or from the gradient of a velocity–time graph.

b If you used a stopwatch, calculate the acceleration (2 × the distance travelled ÷ time squared).

c If you used a ticker timer, use the "every fifth dot method" (as per Lesson 13.4 Investigation: The ticker timer, page 570) to divide the tape into sections. Determine the speed of each section by dividing the distance covered by 0.1. 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 Describe how increasing the mass on the trolley affected the acceleration of the trolley.

4 Use Newton's second law of motion to explain the effect mass has on acceleration.

5 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 13.12
Each action has an equal and opposite reaction

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.

Learning intentions and success criteria

Newton's third law

Newton's third law of motion states that for every action, there is an equal and opposite reaction. For example, if you blow up a balloon and let it go, it flies around the room like a crazy rocket. As the air is forced backward out of the opening, the balloon is propelled forward 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

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

action force the force acted on one object by another object

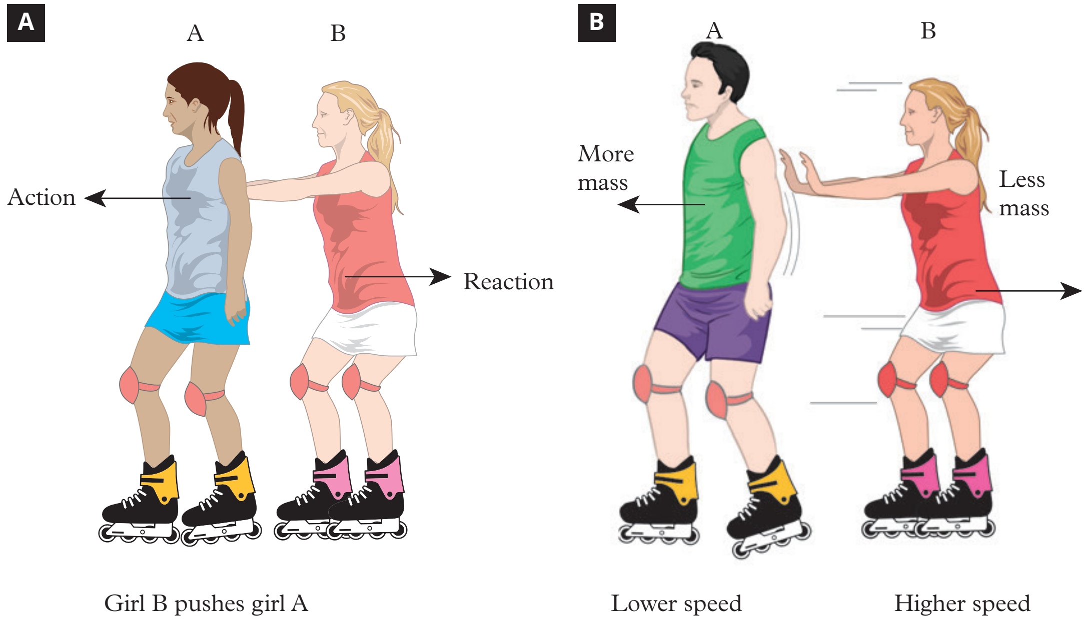


Figure 1 (A) Girls A and B have equal mass. Girl B pushes girl A (action), and girl A pushes girl B backwards (reaction). Girl A moves forwards and girl B moves backwards. (B) Boy A has more mass than girl B. Both the action and reaction forces are identical and opposite in direction. As boy A has more mass, his speed will be less than that of girl B.

reaction force the force acting in the opposite direction to an initial force

example is the rubber of the balloon contracting and pushing the air backward. The **reaction force** is the force of the air rushing out, pushing forward on the balloon.

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 an equal and opposite force back on you (you can feel it pushing against your hands). These two forces are an action–reaction pair, and they act on different objects (you and the wall), so they do not cancel each other out.

Figure 2 The rocket pushes exhaust gases back. As a result, the rocket is propelled upwards.

A net force is balanced or zero when all the forces acting on a single object are equal in size and opposite in direction. This is different from action–reaction pairs, which involve two different objects.

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.

The motion of a person on roller blades being pushed by another person (Figure 1) works in a similar manner. The two people experience an identical but opposite force. Newton's second law ($F_{net} = ma$) also tells us that smaller masses have higher accelerations for the same force. Therefore, if the two people in this situation have different masses (Figure 1B), the lighter person will have a higher acceleration and will reach a higher speed.

Figure 3 Sprinters use starting blocks to help them start a race with more power.

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. Rocket fuel, however, 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 upwards (Figure 2).

Check your learning 13.12

Check your learning 13.12

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 student of weight 500 N sits on a chair. Describe the direction and magnitude of the reaction force that acts on the student.

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 further.

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

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

Lesson 13.13

Investigation: What if forces were changed on Newton's rocket?

Purpose

To examine the action and reaction of a balloon rocket

Materials

- Balloon and balloon pump
- Drinking straw
- Sticky tape
- Fishing line
- Timer
- Measuring tape

Procedure

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. Measure the distance the balloon travels and the time it takes to come to a complete stop.
6. Re-inflate the balloon to the same diameter. Repeat step 5.
7. Repeat steps 5 and 6 five more times.
8. Determine the average speed of the balloon.

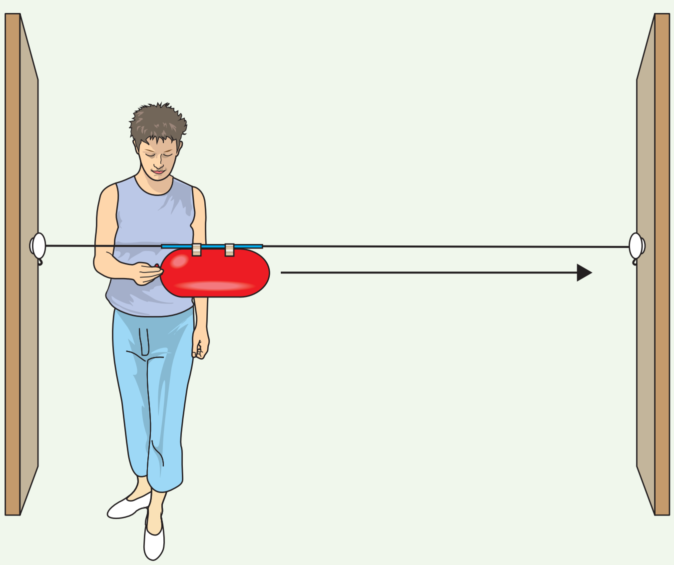


Figure 1 Experimental set-up

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 Draw a picture of the balloon rocket with all the forces that are acting on it.
3 Describe the action and reaction that occurs in the balloon rocket.
4 Explain how you would expect the average speed to change if the balloon was inflated less.

Conclusion

Describe how Newton's third law applies to your balloon rocket.

Lesson 13.14

Science in context: Understanding motion has allowed us to travel to space

Introduction

Satellites are used for different purposes, such as the global positioning system (GPS), communications and geographical mapping. A **satellite** is any object that orbits a planet or a star. How can a satellite be placed in an orbit around the Earth?

satellite any object that orbits a planet or a star

Rockets

Rockets are used to put satellites in space (Figure 1). The satellite is mounted on a rocket and the rocket is launched into space. When the rocket reaches the desired orbit, it releases the satellite.

According to Newton's first law, an unbalanced net force is required for a stationary object to start moving. A car burns fuel in its engine to provide energy to initiate motion. The car's engine uses the oxygen in the air to burn the fuel. A rocket also needs fuel and oxygen, but since there is no air in space, rockets must carry both fuel and oxygen. This mixture is called propellent.

Figure 1 A satellite orbiting the Earth

When the fuel in the rocket's engine burns, the rocket releases a mixture of gases and smoke (exhaust), backwards (action force). According to Newton's third law, the exhaust then pushes the rocket forwards (reaction force). This exerts an upward force called thrust on the rocket. As gravity pulls the rocket down, it needs a forward net force to move upwards. This means the thrust force must be larger than gravity. The rocket needs enough propellent to create a large enough thrust force.

To put the satellites at a specific distance from the Earth, the rocket needs to reach a specific speed. Applying Newton's second law helps scientists to calculate the amount of force required, and as a result, the amount of fuel. The knowledge of motion allows scientists to calculate how much thrust a rocket needs and how much fuel it requires overall (Figure 2).

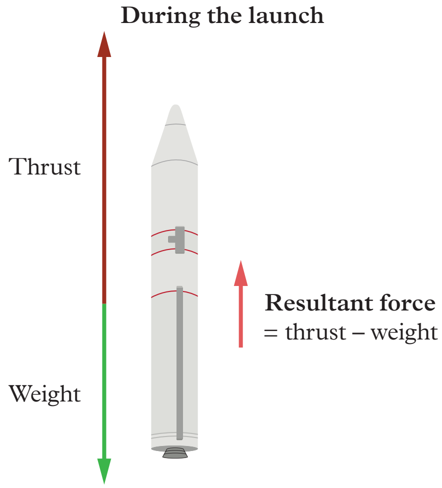


Figure 2 The forces acting on a rocket. The upward net force pushes the rocket to move upward.

Test your skills and capabilities

Test your skills and capabilities 13.14

Creating an infographic

Infographics are visual tools that present information using a combination of images and text. Infographics draw focus towards visual elements to explain concepts and limit text to only what is essential, presenting ideas in a concise way. Create an infographic to present some of the key ideas from this lesson. In your infographic, include:

1. a short description of what a satellite is
2. some of the major uses of satellites
3. an explanation of how satellites are placed in space by rockets (relating to Newton's second and third laws)
4. a force diagram showing how forces act on a rocket.

Lesson 13.15
Review: Motion

Summary

Lesson 13.1 Distance and displacement

- 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 13.2 Speed and velocity

- 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 13.6 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 13.8 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 unless acted on by a net unbalanced force".

Lesson 13.10 Newton's second law

- Newton's second law states: "The acceleration of an object is directly related to the magnitude and direction of the net force acting on the object, and inversely related to the mass of the object".
- The equation for Newton's second law can be expressed as $F_{net} = ma$.

Lesson 13.12 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.

Review questions 13.15

Review questions Module 13

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.

3 Recall the formula that is used to calculate average speed.
  A $\text{Average speed} = \frac{\text{total time taken}}{\text{total distance travelled}}$
  B $\text{Average speed} = \frac{\text{total displacement}}{\text{total time taken}}$
  C $\text{Average speed} = \frac{\text{total acceleration}}{\text{total displacement}}$
  D $\text{Average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$

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

4 Identify each of the following quantities (and their units) as scalar or vector.
- **a** Force
- **b** Distance
- **c** Velocity
- **d** Speed
- **e** Displacement
- **f** 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 A student 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 to 5 seconds

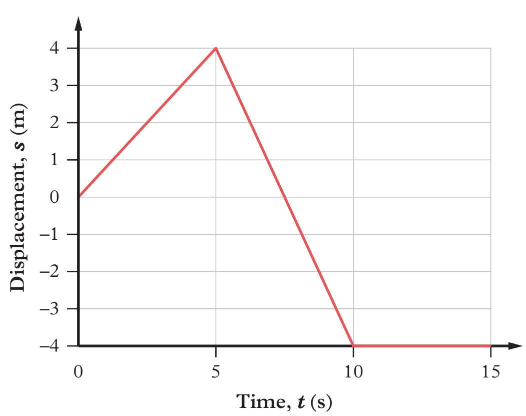


Figure 1 A displacement–time graph

- **b** 5 to 10 seconds
- **c** 10 to 15 seconds

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 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 9.8 m/s^2.

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-angle triangle with these values and using Pythagoras' theorem).

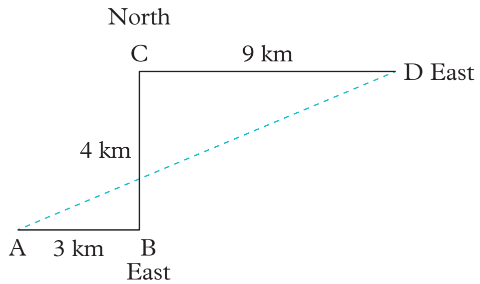


Figure 2 The displacement of a person

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.

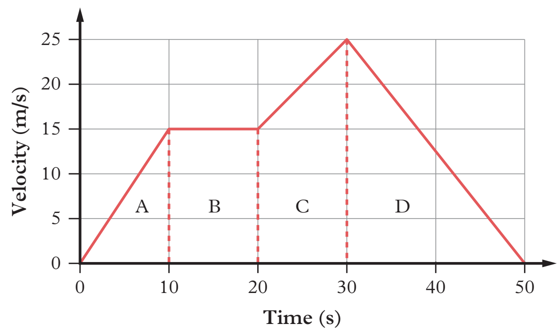


Figure 3 The velocity–time graph of a bike rider

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 A person walked 1 km to the supermarket from their house, then 3 km to the florist and then 3 km back home again. Calculate their total displacement and identify the correct answer from the list below.

a 7 km

b 0 km

c 21 km

d 14 km

22 On a wet Monday morning, a school bus that has to travel 24 km leaves its starting place at 7:35 am and only manages an average speed of 36 km/h on its trip to school. There is a clear section on the highway when the bus has a speed of 74 km/h. The bus then does various runs during the day and arrives back at the school in time to depart at 3:45 pm. It arrived back exactly at its starting place at 4:25 pm.

a Calculate the displacement of the bus between 7:35 am and 4:25 pm.

b 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".

23 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.

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

Apply

25 A person decided to go for a walk. They started by walking 5 km north, which took them 30 minutes. Then they walked 3 km south, a journey that took them 20 minutes. After that, they sat on a bench for 10 minutes before continuing their walk south for another 2 km, which took them 10 minutes.

a Draw a displacement–time graph for the journey.

b Calculate the total distance they travelled.

c Calculate the total displacement of the trip.

d Calculate their average speed.

e Calculate their average velocity.

Social and ethical thinking

26 Investigate two safety features used in cars and explain how they work. Discuss how the socioeconomic status of a person can determine the safety of the car they drive.

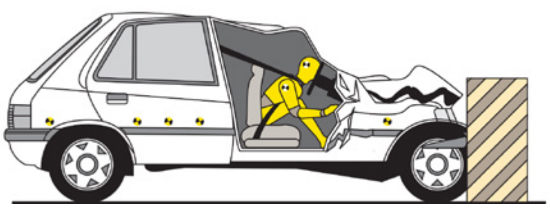


Figure 4 A crash-test car

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 impact the way the dummy would be affected in a crash.
- Research the development of female crash-test dummies.
- Describe the differences in the size, mass and shape between the male and female dummies.

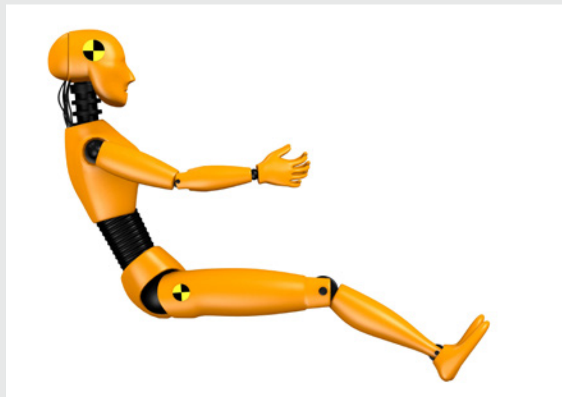


Figure 5 A female crash-test dummy

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 one kilometre 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.

How Aboriginal and Torres Strait Islander Peoples' use forces

For thousands of years, Aboriginal and Torres Strait Islander Peoples have experimented with forces when designing weaponry, such as spear throwers and bows for hunting. Research and describe how variables, including force, mass and acceleration, have been used to increase the speed and impact force of spear throwers and bows.

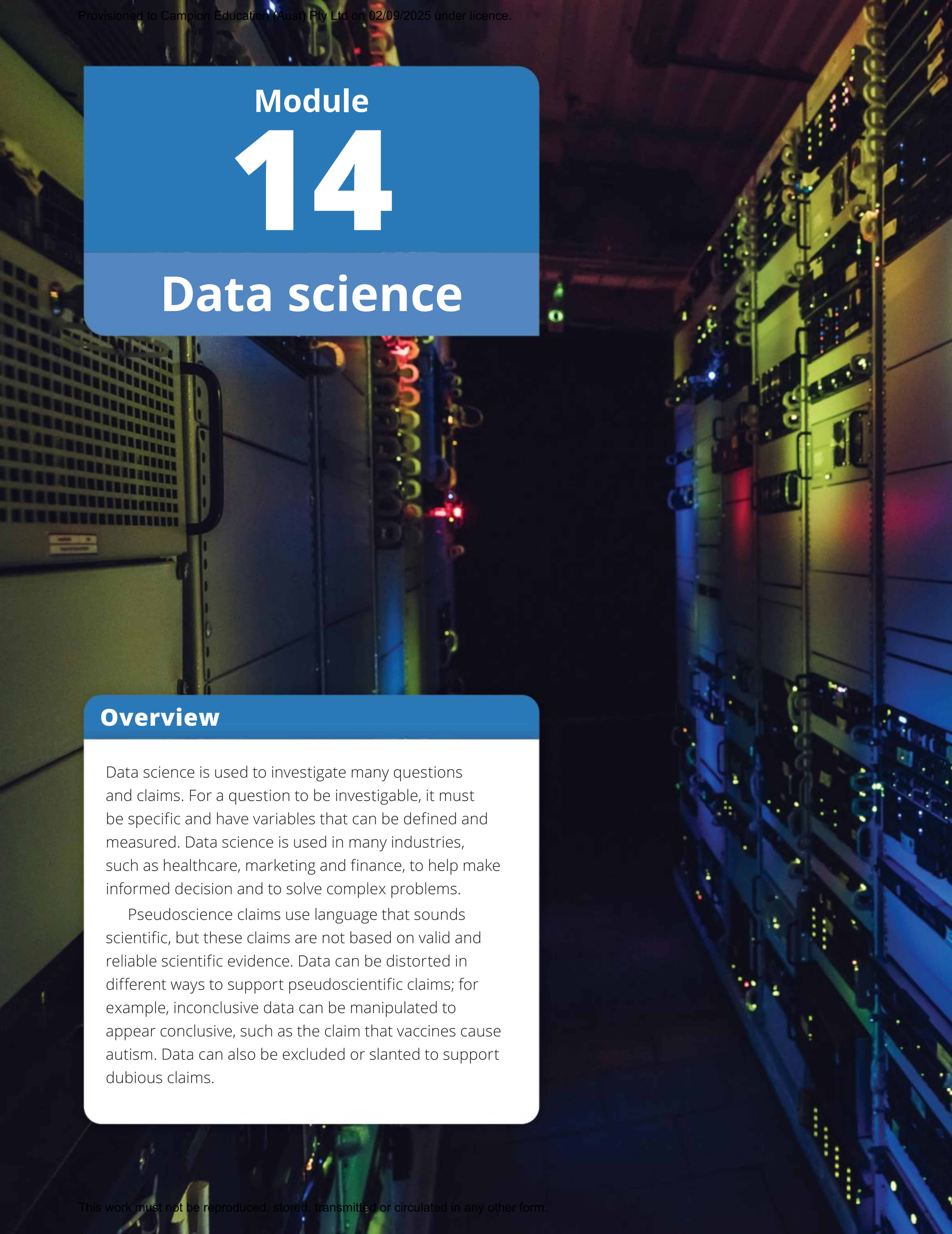
Figure 6 Stone spear points used by Aboriginal and Torres Strait Islander Peoples in Australia

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 7 Aircraft use a combination of forces, such as lift, weight, thrust and drag, in different balances for different movements.



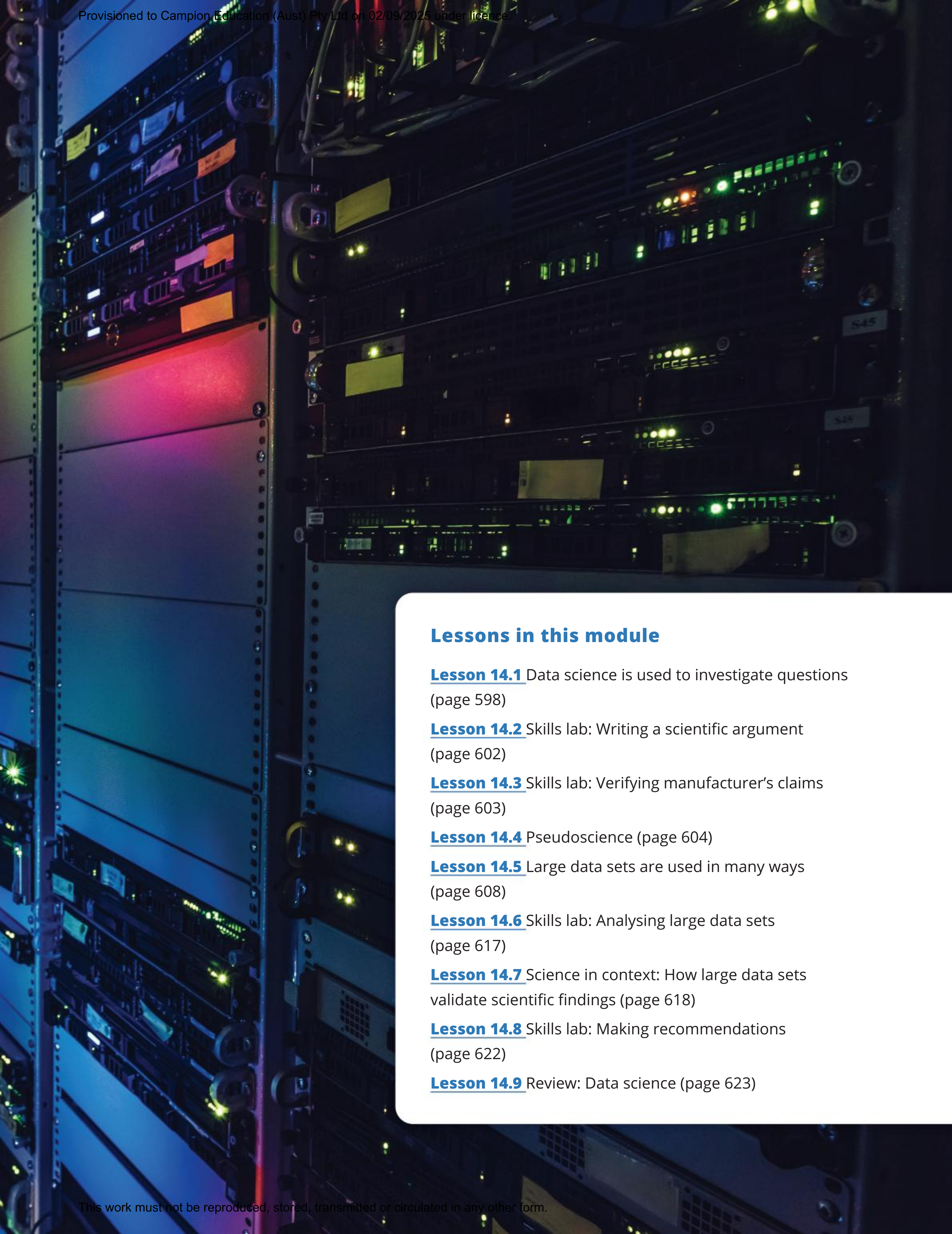
Module 14

Data science

Overview

Data science is used to investigate many questions and claims. For a question to be investigable, it must be specific and have variables that can be defined and measured. Data science is used in many industries, such as healthcare, marketing and finance, to help make informed decision and to solve complex problems.

Pseudoscience claims use language that sounds scientific, but these claims are not based on valid and reliable scientific evidence. Data can be distorted in different ways to support pseudoscientific claims; for example, inconclusive data can be manipulated to appear conclusive, such as the claim that vaccines cause autism. Data can also be excluded or slanted to support dubious claims.



Lessons in this module

Lesson 14.1
Data science is used to investigate questions

Learning intentions and success criteria

Key ideas

→ Investigative questions require specific and measurable data to answer them.

→ Science uses the scientific method to ensure data is reliable and valid.

→ Scientists need to consider the availability and cost of resources before they undertake an investigation.

→ Scientists should always verify the reliability of the sources of information that they use for research.

Investigable and non-investigable questions

investigative able to be investigated through measurement and observation

non-investigable cannot be investigated through measurement and observation

An **investigative** question is an inquiry question that is answered through observation, experimental investigation or secondary research. Questions that cannot be answered using these methods are **non-investigable**.

Non-investigable questions

Non-investigable questions:

- require an opinion or have a variety of answers
- are close-ended (e.g. yes/no questions)
- generate a factual response that can be looked up
- are not specific
- do not define variables
- are not measurable through observation and investigation.

An example of a non-investigable question is "What are the best conditions for plant growth?" This is a non-investigable question because it is not specific and does not define variables, which means it is not measurable through investigation.

Investigable questions

Investigable questions:

- require some data collection to answer them
- are specific
- define the variables and the effect of changing the variables
- are measurable through observation and investigation.

An example of an investigable question is "What is the effect of sunlight on the growth of pea plants?" This is an investigable question because it is specific and it defines variables that can be measured.

Considerations for scientific investigation

A scientific investigation requires planning and needs consideration of the resources available to complete the research effectively. Some questions cannot be tested if there is no access to data or information. For example, it would be impossible to investigate supernatural phenomenon that may involve aliens. An investigation involving extinct animals (e.g. the woolly mammoth) may be difficult.

The cost and availability of technology and resources also needs to be considered when undertaking an investigation. For example, if an investigation required access to the James Webb telescope (Figure 1), this could only be carried out by people who had specialised roles and funding to do so.

The complexity of the investigation also needs to be accounted for. Some investigations with many variables may be too challenging to complete in a single investigation and could take several investigations over a period of years to draw a conclusion. Gregor Mendel developed the idea that traits are passed from one generation to the next by conducting hundreds of experiments with pea plants over many years.

Figure 1 The James Webb telescope is a specialised piece of equipment and is not something you would have access to if you wanted to complete an investigation related to faraway planets and stars.

Verifying and refining scientific knowledge

Scientific research using the scientific method is a formal process that is specific to scientific investigations. The scientific method is accepted by the scientific community as a way of conducting research in science. Investigations that are conducted using the scientific method need to be controlled, measurable, reproducible and based on scientific concepts.

The hypothesis is the basis of the scientific method. Scientific investigations are designed and conducted to collect data that either supports or does not support the hypothesis.

Scientists will develop a testable hypothesis based on research in order to develop and plan the investigation.

A controlled experiment means that variables are explicitly identified, and the investigation tests the effect of changing only one variable (the independent variable) on the dependent variable. In this way, the conclusion formulated is specific to the changes that were made to the independent variable.

A logical method that clearly outlines how the data will be collected makes the investigation reproducible. Scientists should expect to obtain the same results if they conduct an investigation in the exact same way as the original investigation.

credible information that is reliable, trustworthy and based on evidence

Repeating an experiment helps to confirm that the results are consistent and that the variables have been controlled. If the results are inconsistent, the scientist can identify any errors that may have been made and modify the method to obtain more accurate and reliable results.

If the scientific method is used correctly for scientific investigation, this presents evidence that is observable and not subjective. This allows researchers to be confident in conclusions obtained from scientific evidence, which further develops scientific knowledge. When the evidence is credible, hypotheses can be supported or rejected based on the strength of the investigation. Without hypothesis testing, scientific evidence could be subjective and unreliable.

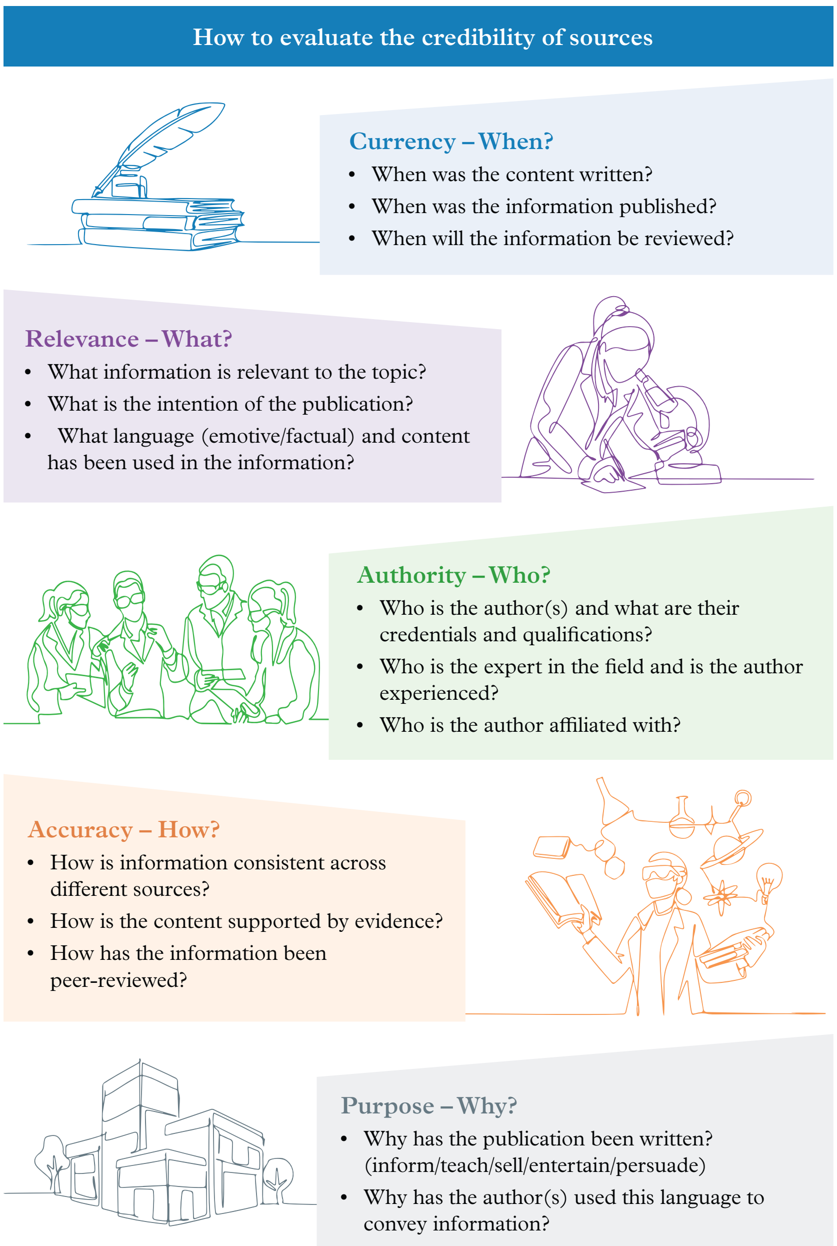


Figure 2 The CRAAP test used to help evaluate sources of information.

Developing evaluation criteria

Evaluating secondary sources

In order for scientific information to be **credible**, research should be conducted using valid and reliable sources. It is important for scientists to evaluate the resources they use and reference in their research.

Reliability and validity are about how well a method measures something. When conducting a practical investigation, reliability is a measure of how consistent the data is. Validity of a method is a measure of the accuracy of the data collection. The same measures apply when considering the reliability and validity of online content. Reliability of secondary

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sources measures the consistency of information across sources. Is the information accurate across different sources? Validity is a measure of the appropriateness of the information. Who are the authors? Is there potential for bias in the publication? Is the information current?

In order for sources to be both reliable and valid, it is important the information comes from credible sources. These sources include peer-reviewed articles in scientific journals, books or professional publications.

The CRAAP test is a method that can be used to evaluate sources online (Figure 2). CRAAP stands for Currency, Relevance, Authority, Accuracy and Purpose. Once sources have been evaluated for reliability and validity, the scientist needs to decide if the sources are suitable to be included in the research.

Identifying claims that can be tested

In today's society, there is an abundance of information from many sources. It is important to apply critical thinking to assess the information and verify claims that appear to be scientific. When people are more discerning about claims made in the news or social media, the spread of false or sensationalised information is prevented.

Check your learning 14.1

Check your learning 14.1

Comprehend

1 Damar Hamlin is a National Football League (NFL) player who collapsed during a game. Some conspiracy theories have emerged about what caused his collapse – one theory claims that the Pfizer COVID-19 vaccine was responsible. Search for blog posts online that discuss these theories. Choose one blog post and answer the following questions.
   - **a** Outline the main claim being made in your chosen blog post.
   - **b** Describe your initial reactions to the post.
   - **c** Describe the language that is used in the post.
   - **d** Describe the intentions of this post.
   - **e** Discuss if there is evidence to back up this claim.
   - **f** Discuss if this would be a credible post.

Apply

2 Find five articles that provide a reason for Damar Hamlin's collapse.
   - **a** Identify the search terms used to find the information.
   - **b** Write a reference list for the sources using a widely used citation style, such as APA or Harvard.
   - **c** Outline the reasons given for Damar Hamlin's collapse.
   - **d** Develop criteria to evaluate if the sources are credible. Summarise your findings in a table with appropriate headings.

3 Go to the BioInteractive website; the link is provided.

Weblink: BioInteractive

   - **a** Use the search term "scientific claims" or browse the website for a claim that can be investigated.
   - **b** Before reading the article, write the source in the citation style you chose in question **2b**.
   - **c** Discuss the validity and reliability of the article.
   - **d** Investigate five credible secondary sources to see if the claim can be verified.

Lesson 14.2
Skills lab: Writing a scientific argument

Introduction

Science needs to be objective. A good scientist is an objective scientist who can apply critical thinking to interpret data and evaluate claims. Scientists can have confidence in their ideas when they are peer reviewed by the scientific community. The process of peer review helps to ensure that research is valid and reliable by critically evaluating the research methods, results and conclusions made by the scientists.

Aim

To identify valid scientific arguments

Writing a scientific argument

A scientific argument is an explanation or claim that is supported by evidence and justified by reasoning. Scientific arguments do not use belief or opinion to support an argument. A scientific argument requires scientists to support their claims with data that has been gathered through research and then use scientific knowledge and logic to justify how the data supports the claim. The data must be valid and reliable so it can be reproduced and verified by the scientific community.

There are three main components of a scientific argument.

1 A claim: a statement that answers a scientific question or explains a cause-and-effect relationship.
   – What is the scientific claim being made?
2 Evidence: trends or patterns in data that can be observed in multiple trials or repeats of an investigation.
   – What is the data that supports the claim?
3 Scientific reasoning: the scientific explanation for why the evidence supports the claim.
   – What is the scientific knowledge that explains the connection between the claim and the evidence?

Questions

1 Read the claims below and rank them in order from strongest to weakest. Justify your response.
   a Everybody has a brain, therefore it should be easy to remember information.
   b People need to study to remember information.
   c Rest breaks help people remember information because the brain is processing during the rest time.
   d Remembering information is not important.
2 Read the evidence below and rank it from strongest to weakest. Justify your response.
   a When I nap, I remember things better.
   b In tests involving several people learning a number sequence and observing the activity of the hippocampus (learning centre of the brain), it was concluded that 94 per cent of learning occurred in rest breaks.
   c Humans have been remembering information for thousands of years.
   d A study has been conducted to show that people need rest breaks to remember information.
3 Read the scientific reasoning statements below and rank them in order from strongest to weakest. Justify your response.
   a When you rest, it allows your brain to process information instead of learning it, and this helps you remember information more accurately.
   b People who have frequent rests are not as stressed and this helps to relax the brain, which makes remembering information easier.

c Prolonged cognitive tasks use working memory; this leads to fatigue. Rest breaks help reset the brain to recover from mental exhaustion, which reduces cognitive load and improves memory recall.

4 Watch the video; the link is provided below.

Video: A Scientific Argument for Short Breaks and Naps

a Outline the claim made in the video.
b Describe the evidence for the claim.
c Provide a statement from the video that uses qualitative observations as evidence.
d Provide a statement from the video that uses quantitative observations as evidence.

5 Research one of the following claims.
- Artificial sweeteners have no adverse health effects.
- Video games improve cognitive function.
- Self-driving cars are safer than human drivers.
- Genetically modified foods are unsafe for human consumption.
- Lead consumption is linked to high crime rates.

a Write a scientific argument for or against the chosen claim. Use a range of evidence to support your argument.
b Share your argument with one of your peers. Discuss the following.
  i Does the argument contain all the components of a scientific argument?
  ii Is the argument logical?
  iii Is the argument supported by evidence?
  iv Can the argument be improved?
  v Are you persuaded by the argument presented by the members of your group?
c Scientists use many ways to communicate ideas, including popular media. Choose a media platform to present the claim and the supporting evidence. You need to use scientific language appropriately while considering your audience.

Lesson 14.3
Skills lab: Verifying manufacturer's claims

Aim

To determine if a manufacturer's claims about their product are accurate

Method

1 Choose one of the following claims about a product (or choose one of your own).
- Honey has antibacterial properties.
- Moisturisers prevent water loss of the skin.
- Nanotechnology sunscreens are more effective than normal sunscreens.
- One serving of orange juice contains 100 per cent of the recommended daily vitamin C intake.
- Shampoos and conditioners are pH neutral.
- Energy-efficient light bulbs consume 80 per cent less energy than traditional light bulbs.
- Thermal cups keep beverages hot or cold for 12 hours.
- Superglue can support weights up to 50 kg.

2 Design and conduct a valid and reliable experiment to verify the claim made by the manufacturer.

Questions

1 Use your data as evidence to present your conclusions to the class.

2 Ask your peers to evaluate the reliability of your data and the validity of your method to verify your investigation.

Lesson 14.4
Pseudoscience

Learning intentions and success criteria

Key ideas

→ Data can be misused or distorted to create pseudoscientific claims.

→ Data can be distorted in different ways by presenting inconclusive results or extrapolating, excluding or slanting information.

→ Claims should be investigated with scepticism to determine if they are pseudoscience or scientific facts.

→ Pseudoscience frequently uses scientific-sounding words and anecdotal evidence, and is often inconsistent with existing scientific knowledge.

What is pseudoscience?

pseudoscience incorrect beliefs that are mistakenly thought to be scientific

"Pseudo" comes from the Greek word for "false". **Pseudoscience** is false science. Pseudoscientific claims may use language that sounds scientific, but these claims are not based on valid and reliable scientific evidence, and they are often inconsistent with well-established scientific knowledge.

An example of pseudoscience is astrology. Astrologers suggest that information about people can be determined by the position of celestial objects. Data is gathered using charts and tables. Statements in horoscopes are vague, which allows them to be misinterpreted as "true". Astrological claims, however, cannot be investigated using the scientific method and are not reproducible; therefore, they cannot be verified. Astrology is a social construct that can be linked to spiritual beliefs and is not a scientific discipline.

In contrast, astronomy is a recognised discipline in the scientific field. Astronomy is the study of celestial bodies using the principles of physics and chemistry. It is studied using data from telescopes, satellites and other scientific instruments. The movements of the planets are predictable based on historical data. These predictions can be tested and verified by other experts, and this allows for evidence-based knowledge.

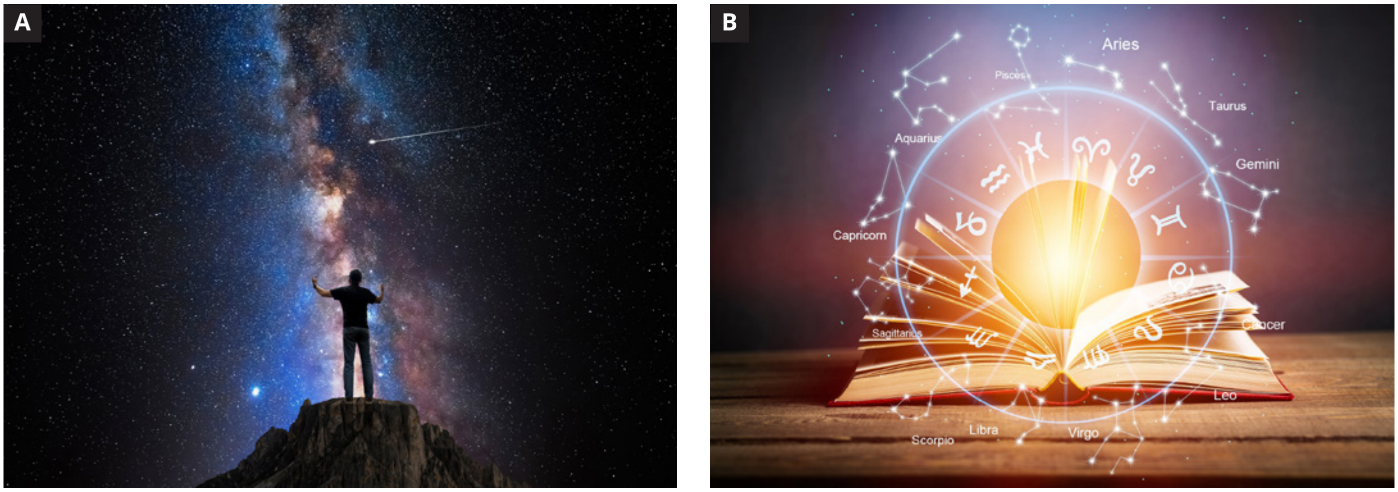


Figure 1 Astronomy (A) is a scientific discipline that uses measurement and observation to study celestial objects, whereas astrology (B) is the belief system that claims that the position of the celestial objects influences human behaviours and events on the Earth.

How can data be distorted?

There are different ways that data can be misused or misinterpreted, which can alter the conclusions drawn from it. In this way, pseudoscience can have dangerous consequences. The manipulation of data that leads to false conclusions can be a threat to people's welfare and safety. In the medical field, false information leads to fear and mistrust in science and doctors, and this can ultimately cost people their lives. When pseudoscience becomes mainstream, it can delay policy and action, as is the case with the climate change debate.

Inconclusive data

Inconclusive data can be thought to be conclusive by mistake or can be manipulated to appear conclusive. An example of this is the claim by Andrew Wakefield that vaccines cause autism. The study was undertaken using only 12 children who were specifically selected for the study. The study suggested that the onset of autism symptoms occurred shortly after vaccination. This was presented as evidence, disregarding the fact that autism symptoms often occur at the same age as children are vaccinated. Wakefield also fabricated the data and had altered the medical histories of the children in the study. Some of the children had no symptoms of autism. Studies conducted on a larger sample, which was a more accurate representation of the population, concluded that there was no link between vaccines and autism.

inconclusive not leading to a definite conclusion or result

Extrapolating data

Data can be extrapolated to predict future trends based on unsupported assumptions. For example, in the 1968 book *The Population Bomb*, Paul R. Ehrlich predicted that the global population growth would exceed the availability of food, and this would lead to mass starvation and social collapse by the 1970s and 1980s. The rapid population growth seen in the 1920s was used to make this prediction, with the assumption that this trend would continue indefinitely. The prediction failed to account for advances in technology and the development of agricultural practices.

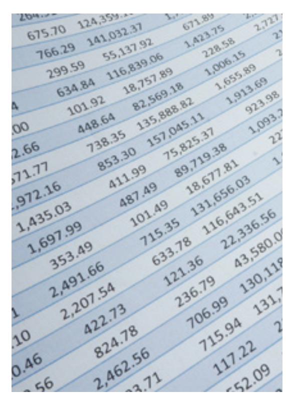


Figure 2 Data can be distorted in a number of ways, including being excluded, extrapolated or inconclusive.

Excluding data

Data can be removed or ignored when it does not fit a particular conclusion. For example, data exclusion has been used in the climate change debate. There is a focus on temperature data from specific time periods or regions that have slower warming rates.

Slanting data

Slanting data involves focusing on select trends while ignoring other trends. For example, studies have shown the benefits of vitamin C for immune health, however, an over-consumption of vitamin C can lead to negative outcomes such as nerve damage. This information is omitted in marketing materials or labelled as "rare" without supporting evidence.

How to tell if a claim is pseudoscience

scientific scepticism questioning the scientific basis of claims, theories or beliefs

It can be challenging to distinguish between science and pseudoscience, especially if the language used sounds scientific. It is important to approach all claims objectively but also apply **scientific scepticism**. In science, scepticism involves applying critical thinking and examining claims to determine if the information is credible.

Some of the indicators of a pseudoscientific claim can be easily identified prior to further research into the claim.

Misuse of scientific language

Often pseudoscientific claims use words that sound scientific, but the words are used incorrectly or even made up. For example, quantum healing claims that you can heal your body using "quantum energy fields" or "quantum consciousness". A quantum energy field is a term used in physics that refers to the behaviour of particles at a subatomic level. Its use in quantum healing has not been defined, has been misused in this context and has no basis in quantum physics.

Anecdotal evidence

anecdotal based on personal accounts rather than facts or research

Use of **anecdotal** evidence or stories can be an indicator of pseudoscience. Anecdotal evidence is difficult to verify and cannot be proven or disproven. For example, detox diets claim to "cleanse" the body of toxins after a restrictive diet. Advertisements for these diets promise improved health and often involve testimonials from people saying how good they feel after these diets. There is no scientific support for the claims made by the company or by the people sharing their stories.

Claims that cannot be verified using the scientific method

Pseudoscience claims can be outrageous and they often cannot be verified using the scientific method. For example, mental telepathy is the ability to communicate from mind to mind without using any physical means of communication. The claim that people can read minds or communicate over long distances is an extraordinary one that, if true, would change our understanding of chemistry, physics and biology. Claims of telepathy are not supported by evidence and cannot be verified through reproducible experiments.

Claims that are inconsistent with scientific knowledge

Pseudoscientific claims are inconsistent with existing scientific knowledge. Information that is not peer reviewed or connected to other research may be considered pseudoscience if there is not enough evidence to support the claims or there is strong scientific evidence that contradicts the claims. For example, the flat Earth movement claims that the Earth is a flat, stationary disc (Figure 3). Despite centuries of evidence supporting the Earth's spherical shape and rotation on its axis and around the Sun, there are still groups of people that advocate for the flat Earth concept.

Figure 3 The Earth has been proven to be spherical, yet there are people who still believe the Earth is flat.

Check your learning 14.4

Check your learning 14.4

Apply

Pseudoscience in popular media

1 Read each of the claims below.

a Decide if each claim is pseudoscientific or scientific. Describe the factors that allowed you to differentiate if the claim is pseudoscientific or scientific.

b Conduct an investigation of secondary sources to verify if any of the claims are true.

c Describe how the data has been manipulated to support the claims made.

Claim 1: "Introducing ClearGlow™ – the revolutionary acne-healing crystal elixir!"

"Say goodbye to acne for good with ClearGlow™, a one-of-a-kind acne treatment that works to harmonise your skin's energy field, balance your body's natural frequencies and remove impurities from within.

"Simply apply a few drops twice daily, and within weeks you'll experience clearer, smoother and more radiant skin without harsh chemicals or side effects.

"Thousands of people have already experienced miraculous results, and now it's your turn to unlock your skin's true potential. Start your ClearGlow™ journey today and let the power of crystals transform your skin naturally!"

Claim 2: "BoostMax™ – The ultimate superfood blend for teenagers!"

"Unlock your full potential with BoostMax™, the world's most powerful superfood blend specifically designed for the unique nutritional needs of teenagers. Packed with rare, nutrient-dense ingredients like pure blue spirulina, ancient Himalayan Goji berries and supercharged cacao powder, BoostMax™ gives you a natural energy boost that lasts all day long, without the crash of sugary energy drinks!

"This potent blend works to balance your hormones and optimise your metabolism, helping you to improve your energy levels and enhance athletic performance. BoostMax™ is scientifically formulated to detoxify your body, fight off muscle fatigue and give you the physical stamina you need to succeed.

"Just one scoop in your smoothie or water and you'll start feeling the difference within days. Clinical studies have shown an 89 per cent increase in energy levels and overall improvement in physical health over a 7-day period. Try it today and feel the natural power of superfoods working for you!"

Claim 3: "QuantumBoost™ – Harness the power of quantum energy for enhanced mental performance!"

"Unlock your brain's full potential with QuantumBoost™, the revolutionary supplement designed to amplify your cognitive abilities using the latest breakthroughs in quantum science. Our formula harnesses the energy frequencies of quantum particles to stimulate neural pathways, improve memory retention and enhance your mental clarity and focus – just like quantum particles that exist in multiple states at once!

"QuantumBoost™ works by aligning the brain's energy field with quantum-level vibrations, enhancing neuroplasticity and boosting brain function at a cellular level. With regular use, you'll experience improved concentration, faster problem-solving skills and an overall sharper mind.

"Backed by cutting-edge quantum technology, QuantumBoost™ is scientifically formulated to optimise brain function and unlock mental performance that you didn't even know was possible. Just take one capsule daily and experience the future of cognitive enhancement today!"

Claim 4: "GlowSkin™ – Harness the power of microcurrent technology to revitalise your skin"

"GlowSkin™ uses cutting-edge microcurrent technology to stimulate the deep layers of your skin, encouraging collagen production and improving skin tone. This non-invasive process mimics the body's natural electrical currents, leading to smoother, firmer skin with just 10 minutes of use each day. The gentle pulses boost cellular activity and increase blood flow, giving you radiant, youthful skin without the need for harsh chemicals or invasive treatments."

Lesson 14.5
Large data sets are used in many ways

Learning intentions and success criteria

Key ideas

→ Big data refers to sets of data generated from large studies that can be used to enhance scientific understanding and allow scientists to make predictions.

→ Data can be analysed using descriptive statistics, including mean, median and mode.

→ Data can be analysed to determine if there is a correlation between the data.

→ A causal relationship can only be determined if the independent variable occurs first and a change in the independent variable causes a change in the dependent variable.

→ Large data sets have been used to verify scientific findings.

Features of large data sets

Large data sets, also known as "big data", are sets of data that are collected from large surveys or multiple studies. Big data has revolutionised the way scientists gather and analyse information. Big data is characterised by the 5 Vs: volume, velocity, variety, veracity and value. Large data sets are generated from a variety of sources at an exponential rate and volume. They can be used to investigate complex questions.

The availability and nature of the data sets can limit research topics. They can also broaden scientific research, however, as more data is made available and as the technology to store, process and analyse data improves.

Large data sets are very complex and cannot be analysed thoroughly using regular software or personal computers. Supercomputers that have massive processing power are used to perform complex calculations and simulations on large data sets (Figure 1).

Conducting scientific research using big data requires following the same steps as any scientific investigation. For example, the Australian Bureau of Statistics (ABS) collects data from approximately 25 million Australians during the Census every 5 years. Census data was used to conduct an investigation to determine if there was a correlation between the likelihood of students undertaking tertiary studies and both parents completing tertiary education. The researcher needed to search for the relevant data and then decide which data was relevant for the analysis in order to conduct the investigation and draw a conclusion.

As another example, if a scientist is looking at COVID-19 data, they could use the Australian Centre for Disease Control (CDC) database and use the search terms “infectious diseases” and “COVID-19”. If they were specifically looking for COVID-19 vaccination data, they could narrow the search further by adding the search term “vaccination” or “vaccine”. If they wanted data specific to Australia, they could eliminate data from other countries.

Data can be gathered from various sources, including databases, data warehouses (which store current and historical data) and even social media platforms. Data from these sites is in the form of raw data. Not all the information is useful for a research study. The relevant data needs to be extracted from these sources.

Once the data is collected, it needs to be cleansed and prepared for analysis. Data cleansing is the process of fixing or removing incorrect, incomplete or duplicate data. If data is incorrect, the data analysis will be flawed. The refined data set would then need to be sorted to make it suitable for analysis.

Figure 1 Supercomputers can process more complex calculations or large data sets, but require large amounts of energy to keep them cool!

The application of large data sets

The use of big data in science has enhanced scientific understanding and allowed scientists to make predictions and conduct investigations that would normally be too vast to undertake using traditional methods.

Analysis of large data sets has been used in many industries, such as in the research and manufacture of pharmaceuticals, conservation biology and agricultural research. For example, genome sequencing technology has enabled improvements in diagnosis and treatment for cancer patients based on data obtained from existing cancer patients.

Data obtained from telescopes and satellites collect vast amounts of data on black holes, galaxies, stars and so on. Analysis of this data is used to identify new celestial objects and track space weather events that could impact the Earth.

Satellite-based weather stations gather data that tracks climate patterns, air quality, ocean temperatures and greenhouse gas emissions. This data is used to predict climate change and describe the impact on ecosystems. It can then be used to inform policies and mitigation strategies.

Statistical analysis techniques

descriptive statistics methods used to summarise and describe the main features of a data set

Descriptive statistics can be used to inform further statistical analysis or make predictions beyond the data. For example, the size of an animal is dependent on environment, diet and genetics. A scientist could use modelling to predict the size of offspring based on these variables. Descriptive statistics provide an analysis of quantitative data and summarise the data set. They represent data numerically and graphically and provide information about the shape of the distribution of the data.

Data collected for statistical analysis must be measurable and an accurate representation of the population. For example, if water quality testing of a lake is done with too few samples, then this may not be representative of the quality of the whole lake. Where the samples are taken from is also important. If samples are only taken at the edge of the lake, this will give different results to samples taken in the middle of the lake. This would also not be an accurate representation of the water quality in the lake.

Likewise, in population studies, the sample size should be large enough to represent the population, and participants should be chosen at random in order to avoid bias.

Descriptive statistics are an important part of scientific investigation because they provide a starting point for analysis of the data. This form of analysis can help identify errors or outliers in the data and inform the next steps of the investigation and data analysis. If there are errors in the data, scientists may need to derive an alternative method to obtain the data. Descriptive statistics can also inform further investigations and statistical analysis.

Univariate data

univariate data data about a single variable

Univariate data is data that is gathered around a single characteristic; that is, it has one variable. The variable can be either categorical or numerical. An example of univariate data could be counting the number of students who fall within a particular height range.

Measures of central tendency

There are three different methods to determine the middle or centre of the data: the mean, the median and the mode (Figure 2). These are called the measures of central tendency because they help us find the centre of the data.

The mean is a calculation of the average of the data. This is not useful in describing how the values are distributed. Values that are very small or very large can impact the mean. Sometimes these values can be considered as errors in the data, but if they are not, then the mean calculation may not be representative of the population. For example, if the mean was calculated for the average salary of a group of people and one person was earning

Measure of central tendencies

Mean (average)

$$\text{Mean} = \frac{\text{sum of numbers}}{\text{the number of values}}$$

E.g.
Mean of 4, 5, 2, 1, 5, 7

$$\text{Mean} = \frac{4+5+2+1+5+7}{6} = 4$$

Median

Arrange in ascending order.
Median = middle value

E.g.
Median of 1, 1, 2, 2, 4, 4, 5, 5, 5, 5, 7, 7

$$\text{Median} = \frac{(4+5)}{2} = 4.5$$

Mode

Most common value

E.g.
Mode of 4, 5, 2, 1, 5, 7

Mode = 5

Figure 2 An example of how to determine the mean, median and mode

$1,000,000, this would give a high average and not accurately represent the salary of the rest of the group.

The median is the middle item of the data. To find the median, the data is sorted from lowest to highest and the number in the middle identified. The median solves the problem of the extreme values when the mean is calculated.

The mode is a measure of the frequency of the data. In a room where 10 people earned the same salary of $50,000 and 10 different people earned varying salaries, the mode would be $50,000 as this is the salary with the highest frequency.

Measure of dispersion

The range of data provides the difference between the maximum and minimum values. This gives a measure of the spread or dispersion of data, but not the distribution of data.

The spread of data is determined by the **standard deviation**. The standard deviation is a measure of the average deviation (distance) from the mean (average). If the standard deviation of a data set is small, then most of the data is very close to the average. If the standard deviation is large, the data varies a lot from the average.

standard deviation measures how close the values in the data set are to the mean; a low standard deviation indicates data points are clustered tightly around the mean, while a high standard deviation means they are more dispersed

Shape

The shape of the distribution is important for determining the type of analysis that can be performed on the data. In a normal distribution, the data is in the shape of a bell curve and the mean and median are the same (Figure 3). If data patterns follow normal distribution, then 68 per cent of the data will fall +/– the standard deviation value off the average.

If the shape of the distribution curve is skewed, this means that the distribution could be negatively skewed (where the peak is shifted to the right) or positively skewed (where the peak is shifted to the left) (Figure 4). A skewed distribution curve means that the data can have extreme values. If the shape of the distribution curve is symmetric, it means the mean, median and mode are the same.

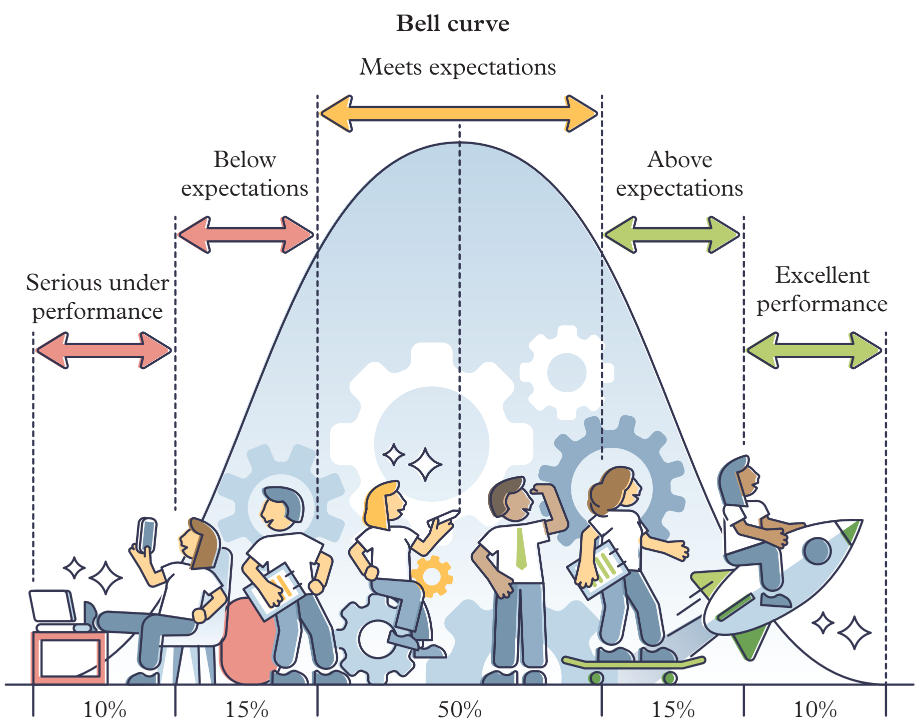


Figure 3 A normally distributed bell curve showing 68 per cent in the +/– range of the mean

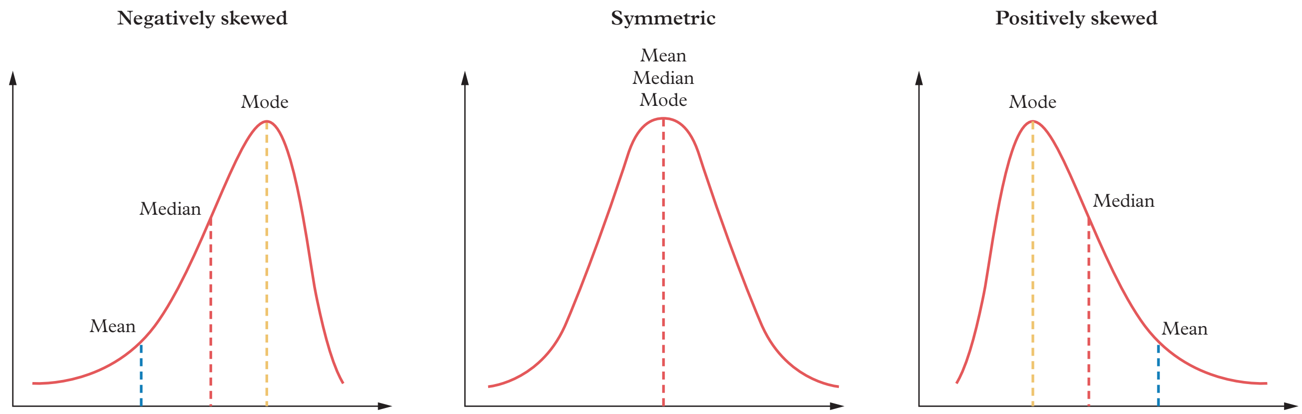


Figure 4 Comparison of mean, median and mode when data is normal (symmetric), skewed to the left or skewed to the right

kurtosis indicates how much data resides in the tails (outliers) compared to a normal distribution

Kurtosis is a measure of the flatness of the peak. A value of zero indicates a normal distribution. A positive value indicates the distribution is more peaked than a normal distribution, and a negative value indicates that it is flatter than a normal distribution. Negative kurtosis indicates a distribution with more extreme scores away from the median. Positive Kurtosis indicates a narrow range of scores closer to the median.

Worked example 14.5A Calculating standard deviation

Calculate the standard deviation for the following data set – 5, 7, 3, 7 and 10.

Solution

Steps	What to do	Working out
a.	Calculate the mean by adding all the data values, and dividing by the number of data values	mean $= \frac{5 + 7 + 3 + 7 + 10}{5}$ $= \frac{32}{5}$ $= 6.4$
b.	Find the square deviation from the mean by subtracting the mean from the data value, then squaring it.	See Table 1
c.	Add the squared deviations	$1.96 + 0.36 + 11.56 + 0.36 + 12.96 = 27.20$
d.	Calculate the variance by dividing the squared deviation by (n-1), where n is the number of data values.	Variance $= \frac{27.20}{5 - 1}$ $= 6.8$
e.	Calculate the standard deviation by taking the square root of the variance.	Standard deviation $= \sqrt{6.8}$ ≈ 2.61

Table 1 Deviations and squared deviations from the mean

Data value	Deviation from the mean	Squared deviation
5	$5 - 6.4 = -1.4$	$(-1.4)^2 = 1.96$
7	$7 - 6.4 = 0.6$	$(0.6)^2 = 0.36$
3	$3 - 6.4 = -3.4$	$(-3.4)^2 = 11.56$
7	$7 - 6.4 = 0.6$	$(0.6)^2 = 0.36$
10	$10 - 6.4 = 3.6$	$(3.6)^2 = 12.96$

Analysing univariate data

To analyse univariate data, the measures of central tendency are used (Figure 2) along with the measure of dispersion (the degree of spread) and its shape. Univariate data can be visualised and then analysed using histograms, box plots (also known as a box-and-whisker plots) (Figure 5) and bar charts.

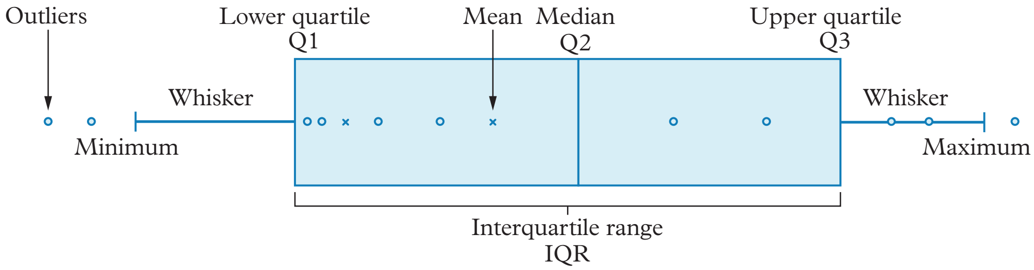


Figure 5 A box plot is a visual representation of univariate data that shows the range of the data, the mean and the median.

Analysing bivariate data

Bivariate data is the comparison of two sets of data. Descriptive statistics on bivariate data allow a comparison to determine if there is a relationship between the two variables. For example, an analysis would be conducted to determine if there was a relationship between height and weight.

bivariate data data that involves two variables and aims to explore the relationship between them

Bivariate data can be analysed by generating a scatter graph that plots point *x* and *y* for each observation; for example, plotting the height and weight for each student. The scatter graph provides a general pattern or trend in the data. The degree of the relationship between variables is given by the **correlation coefficient**. A positive value indicates a positive correlation (relationship) between the variables. A negative value indicates a negative correlation between the variables. The value of the correlation coefficient is a measure of the strength of the relationship. A value of 1 indicates a strong correlation.

correlation coefficient a number between −1 and 1 that quantifies the strength and direction of a linear relationship between two variables; often represented by "*r*"

A scatter graph is useful in identifying outliers or errors in the data if data points fall outside the general trend in the graph.

Causal and correlational relationships

When there is a strong **correlation** between data, it can be easy to conclude that the change in one variable causes the change in the other variable. For example, if there is a correlation between height and weight, we may conclude that height increase causes weight increase; however, a correlation between two variables does not always mean that one variable caused the change in the other.

correlation a relationship between two or more variables

When it is determined that one variable causes a change in another variable, this is known as a **causal relationship**. Causation indicates that one event is the result of the other event. A causal relationship cannot be established by a statistical analysis. A controlled experiment is required to determine the effect of one variable on another variable.

causal relationship a cause-and-effect relationship where one event or action directly leads to another

Correlation between variables indicates that there is a pattern in the data and a relationship between the variables (Figure 6). When variables show a strong correlation, it may be because they are linked by a variable that has caused both factors. Correlation is measured with a number from 1 to minus 1 and uses the symbol 'r', for example, in a strong positive correlation, r = 0.8, while r = −0.8 is a strong negative correlation.

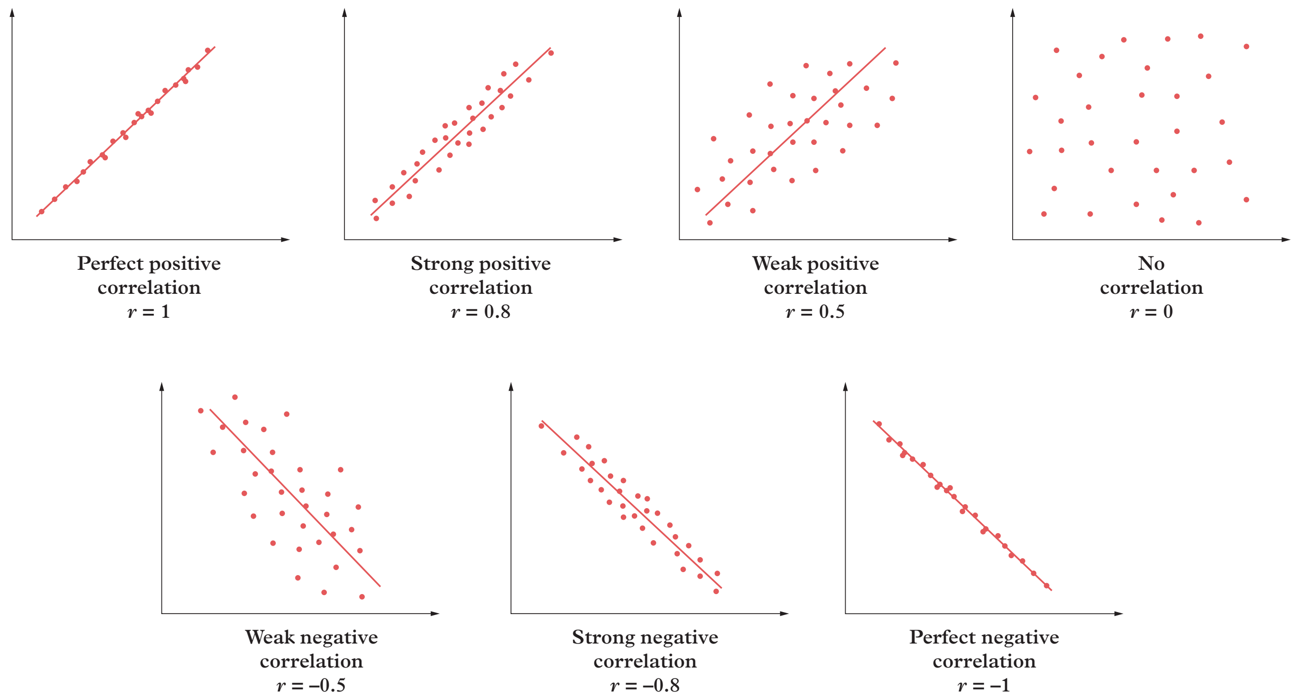


Figure 6 The different correlation relationships between data

For example, there may be a strong positive correlation between people who exercise and get skin cancer. Based on this correlation, some people could conclude that exercise causes skin cancer. The reality may be that the data set is from a population where there is a lot of sunlight which would encourage people to exercise more outdoors. The higher exposure to sunlight could cause the skin cancer in those people who exercise outdoors. Both the exercise and the cancer are caused by exposure to sunlight, but exercise and skin cancer are not causally related.

The first step in establishing if there is a causal relationship between variables is to establish if there is an association between the variables. A **regression analysis** can be used for this step.

regression analysis a statistical method used to predict how one variable (the dependent variable) changes when another variable (the independent variable) changes

temporal relationship the timing or order of events in relation to each other

Once a relationship has been established, a time order or **temporal relationship** for the variables needs to be established. In order for the change in the independent variable to cause a change in the dependent variable, the independent variable must occur first. This can be established through experimental design using a controlled study. In a controlled study, the sample or population is divided into two groups. The two groups receive different treatments under controlled conditions and the outcomes of each group would be measured and assessed. If an experiment cannot be conducted, then the use of existing research may be used to establish time order.

For example, a scientist might want to determine the effect of different liquids on plant growth. The control group will be treated as normal, watered with water only. The test group would be treated with different liquids. A controlled experiment compares an alternative treatment to what is normal or what has not been changed.

Once the time order has been verified, then alternative explanations for the observations must be ruled out. This is referred to as **non-spuriousness**, which means not false. A spurious or false relationship is when there appears to be a relationship between two variables, but the relationship is caused by a third variable, as seen in the example about outdoor exercise and skin cancer. In science, it can be difficult to establish causal relationships because there are so many variables that impact different phenomena.

non-spuriousness not false or fake

Smoking and lung cancer studies

In the mid 1900s, the incidence of lung cancer was rising significantly. Scientists suspected there was a link between smoking and lung cancer. Researchers needed to rule out other variables, such as radiation and air pollution that may cause lung cancer, in order to establish a causal relationship between smoking and lung cancer. Scientists conducted large-scale studies that tracked smoking habits and health outcomes of participants over several decades. The study found a strong correlation between smoking and lung cancer, with smokers being more likely to develop lung cancer.

The studies also showed that the probability of getting lung cancer increased with the number of cigarettes smoked per day. Scientists confirmed that smoking preceded the development of lung cancer in affected individuals. Scientists then conducted studies on animals to demonstrate that exposure to tobacco smoke, which contained known carcinogens, led to the formation of tumours. It is unethical to conduct similar experimentation on humans; however, further studies demonstrated that when individuals quit smoking, they reduced their risk of developing lung cancer. Based on this study, public health agencies concluded that smoking is the primary cause of lung cancer.

Figure 7 Studies have proven the link between smoking and lung cancer. Organisations like the Cancer Council share information to encourage people to stop smoking and the benefits of doing so.

Check your learning 14.5

Check your learning 14.5

Retrieve

1 Describe how large data sets are created and what that are used for.
2 Describe the features of large data sets.
3 Describe the steps taken that make data usable for scientists.

Comprehend

4 Describe the benefits of using descriptive statistic analysis to determine relationships.
5 Describe the limitations in using large data sets.

Analyse

6 Smoking has been linked to lung cancer as it directly damages the DNA of cells and causes them to grow uncontrollably. Figure 8 shows the rates of smoking in men and women from 1945–2000 as well as incidences of lung cancer.
   a Describe what the data is showing
   b Explain the trends in the graph.
   c Discuss if there is a correlation between smoking and lung cancer.
   d Discuss if the data shows that smoking causes lung cancer.
   e Describe what the data would need to show to demonstrate causation.

Apply

7 The data in Table 2 shows the air quality over a 24-hour period.
   a Copy the data into a spreadsheet.
   b Sort the data from lowest particulate matter to highest particulate matter.
   c Calculate the mean, median and mode for the data.
   d Identify the measure of central tendency that best represents the overall air quality for the day. Justify your response.
   e Describe what information the mode provides.

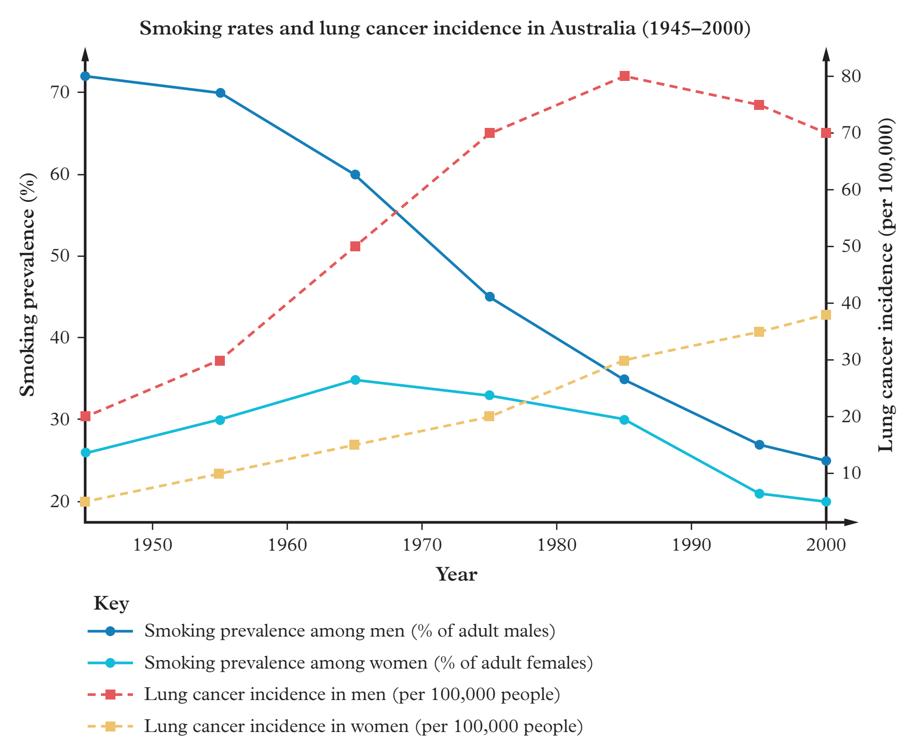
f Discuss if the data would change on a weekday (where there is high traffic and factories are operating) compared to a weekend.

g Describe which way the data would skew on a weekday compared to a weekend.

h Describe how this data may be useful to scientists.

Table 2 Air quality over a 24-hour period

Hour	Particulate matter (μg/m³)	Hour	Particulate matter (μg/m³)
1	12.5	13	23.3
2	15.3	14	25.5
3	14.2	15	28.4
4	16.8	16	26.7
5	17.1	17	29.8
6	16.4	18	30.2
7	18.9	19	29.5
8	19.3	20	27.8
9	21.1	21	24.6
10	20.5	22	23.4
11	19.7	23	22.1
12	22.2	24	21.0



1940s–1950s: Smoking was socially accepted and widely promoted.

1973: The Australian Government banned the advertising of cigarettes on TV and radio.

1985: State and territory health departments launched "Quit smoking" campaigns.

1990: The Australian Government and Department of Health introduced text health warnings on cigarette packs.

1992: The Australian Taxation Office increased cigarette prices by raising tobacco excise.

1996–2000: Health departments implemented indoor workplace smoking bans.

Figure 8 Smoking rates and lung cancer incidence in Australia (1945–2000); see timeline:

Lesson 14.6
Skills lab: Analysing large data sets

Aim

To analyse data sets and draw valid conclusions

Method

1 Access “Available datasets” in the weblink provided below.

Weblink: CSIRO

2 Choose one of the case studies to investigate.
3 Read the case study and summarise the information.
4 Download the data set and describe the data that has been collected.
5 In groups, identify and discuss some of the trends, patterns and relationships in the data.
6 Describe the implications of the relationships in the data.
7 Brainstorm inquiry questions that can be derived from the data set.
8 Choose one inquiry question to investigate. Refine the question so that it identifies variables and can be testable using the data.
9 Develop a hypothesis based on your reading in question **3**.
10 Describe how you will conduct the data analysis to answer the inquiry question.
11 Conduct the data analysis and draw a conclusion. Did the data support or not support the hypothesis? What is the answer to the inquiry question? Use evidence from your analysis to justify the conclusion.

Questions

Part A: Conducting a univariate analysis

Use your data set to complete the following.

1 Choose one of the variables to conduct a univariate analysis. Outline the criteria you used to select the data.
2 Examine the data set and determine if there is any missing data.
3 Describe how the data will be cleansed for analysis.
4 Create a histogram of the data. Describe the shape of the histogram.
5 Discuss if the data is normally distributed. Justify your response.
6 Identify any outliers in the data and, if any, determine if they are due to errors. If they are, exclude them from your analysis.
7 Calculate the mean, median and mode for the data. Which value best represents the measure of centre for the data?
8 Calculate the standard deviation of the data. How does the standard deviation help to interpret the data?
9 Outline the conclusions that can be made from the data analysis.

Part B: Conducting a bivariate analysis (causal and correlational relationships)

Use your data set to complete the following.

1 Identify two of the variables to conduct a bivariate analysis. Outline the criteria you used to select the variables.
2 Outline the relationship that you are investigating.
3 Create a scatter graph of the two sets of data using a spreadsheet such as Excel. Describe the graph.
4 Conduct a regression analysis to determine the correlation coefficient by right clicking on a data point on the graph and selecting “Add trendline”. Choose “Linear” and tick “Display equation on chart” and “Display R-squared value on chart”. Discuss the results.
5 Write a conclusion describing the relationship between the variables. Use data from your analysis to justify your conclusion.

Lesson 14.7
Science in context: How large data sets validate scientific findings

Introduction

Many scientific phenomena involve complex systems with numerous variables. Large data sets (big data) allow scientists to analyse these variables holistically (comprehensively) and investigate complex questions to validate scientific ideas. In traditional research, observations are made, a hypothesis is proposed, and data is collected and analysed to form a conclusion. When scientists look at large data sets, they can identify patterns and then develop a hypothesis that can be investigated. Large data sets enable scientists to easily identify trends that may not be apparent in smaller data sets. Using large data sets allows scientists to look at data over long periods of time. This is useful in determining causal relationships.

The availability of large data sets has also enabled scientists to validate hypotheses across multiple data sets. By combining data from diverse sources, scientists can verify the consistency of their findings. For example, combining genetic data with clinical studies has verified links between specific diseases and genes.

Scientists have become more collaborative in their research due to the availability of large data sets. This strengthens the scientific community as it draws on the expertise of many people across different countries and different fields, which improves the accuracy of scientific findings. This also leads to a more comprehensive understanding of scientific ideas.

Analysis of the data sets assists in identifying anomalies and errors. Large data sets reduce the impact of random errors on the analysis of the data. The size of the data improves its statistical reliability, which informs more valid conclusions. The data obtained is also more credible because it is collected from large populations for different reasons. The data is more likely to be unbiased and a better representation of the population.

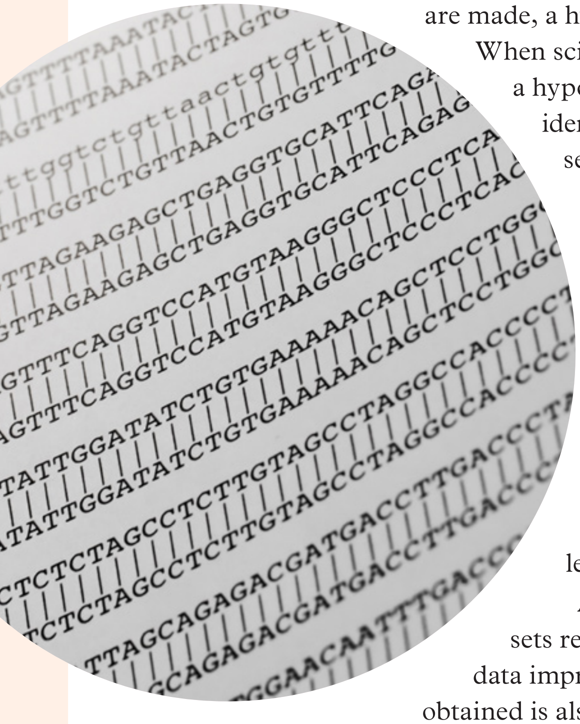


Figure 1 The entire human genome has been sequenced and contains 3 billion letters!

Using data sets

Scientists use large data sets to develop theoretical models against real-world observations. They can also use these models to improve the accuracy of predictions that are made, based on the data.

The use and analysis of large data sets has led to the validation of scientific ideas. Using large data sets to validate scientific ideas has had a profound impact, not only on the scientific community but also on society and the environment. The validation of scientific findings has resulted in more informed decision-making and better policies. It has led to enhanced public awareness and education, as well as economic growth, due to technological and scientific developments.

Table 1 provides examples of how large data sets have been used to validate scientific findings in different fields as well as the impact on society and the environment.

Table 1 How scientists have used data sets to verify scientific findings and the impact that this has had on society

Research area	Data set	Usage	Outcome	Impact
Climate change	Global temperature records, ice cores, CO_2 levels	Analysis of temperature trends, CO_2 levels and satellite data to track average global temperature	Validated the relationship between human activity and climate change	• Led to international climate change agreements like the Paris Agreement • Increased focus on renewable energy and strategies to reduce carbon emissions
Human genome project	Genome sequences from thousands of individuals	Mapping all human genes, studying genetic variations and confirming gene–disease relationships	Validated theories of genetic predispositions and evolutionary biology	• Improved diagnostics and treatments for genetic disorders like cystic fibrosis • Enabled gene-editing technologies like CRISPR
Plate tectonics	Earthquake data, ocean floor magnetic striping, satellite measurements	Tracked seismic activity, magnetic data and tectonic plate movement to confirm plate interactions	Validated the theory of plate tectonics, explaining continental drift, mountain formation and earthquakes	• Improved earthquake prediction models • Advanced mining and natural resource exploration • Informed hazard mitigation strategies
Evolutionary biology	Fossil records, genetic sequences, species distribution data	Tracked fossil changes over time, analysed genetic data and studied the adaptations of species	Supported Darwin's theory of evolution by natural selection and the concept of common ancestry	• Improved understanding of antibiotic resistance in bacteria • Provided evidence to support the conservation of endangered species by studying genetic diversity
Astronomy	Redshift and brightness data of galaxies	Measured galaxy redshifts and distances to confirm that galaxies are moving away from each other	Validated the Big Bang theory and led to the discovery of dark energy	• Advanced cosmological models • Improved space exploration technology • Inspired funding for telescopes like the James Webb Space Telescope
Epidemiology	Longitudinal health records, disease incidence data	Tracked health outcomes (e.g. Framingham Heart Study) and analysed disease spread (e.g. COVID-19 case patterns)	• Confirmed risk factors for diseases like heart disease • Validated public health measures like vaccination and social distancing	• Reduced global mortality from cardiovascular diseases • Guided pandemic responses, including vaccine distribution strategies
Protein folding	Protein structures from crystallography experiments	Trained AI models like AlphaFold on protein structure data to predict folding based on amino acid sequences	• Validated hypotheses about protein structure-function relationships • Accelerated biological research and drug development	• Enabled faster drug discovery, including treatments for diseases like cancer and Alzheimer's • Supported design for COVID-19 vaccines
Biodiversity	Global biodiversity records (Figure 2), satellite imagery	Tracked species distribution, extinction rates and habitat changes using remote sensing	Validated the impact of human activities on biodiversity and informed conservation efforts and sustainable development policies	• Strengthened policies like the Convention on Biological Diversity • Enhanced restoration projects for critical ecosystems like rainforests and coral reefs

Making evidence-based decisions

Evidence-based decision-making is a process that is based on research and experimental evidence to inform important decisions. These decisions have an impact on the world around us. A misinformed decision can have serious consequences, whereas a good decision can help make effective changes to the way we do things. No two people have the same view of the world. This is why it is important to gather reliable data and draw valid conclusions based on evidence. Scientists and policymakers need to be discerning about the evidence and conclusions that are used to make decisions.

Figure 2 Satellite imagery is used to assess the impact of natural events by providing a view of the damage to infrastructure and the environment, such as Woodburn before the floods in April 2021 (A) and five days after the floods in March 2022 (B).

Test your skills and capabilities

Test your skills and capabilities 14.7

Analysing data and information

Analysing data sets is integral in understanding global events, predicting outcomes and making decisions. These data sets can range from environmental data (carbon dioxide emissions, temperature and precipitation) to biological data (birth and death rates, diseases and obesity). Large data sets allow us to identify patterns and correlations that may not be immediately obvious in smaller samples. For example, we might observe trends in climate change by examining decades of atmospheric carbon dioxide and methane levels or uncover insights about the spread of diseases from analysing an epidemic curve. Drawing valid conclusions relies on accurate and reliable data sets and evidence-based reasoning.

There are several key factors to consider when analysing large data sets.

- What patterns or trends can be identified? Is there an increase or decrease over time?

- Are there any outliers or errors that need to be considered which can impact the reliability of the conclusion?
- Who collected the data and was their procedure reliable?

Skills builder: Analysing data

Many hunters and poachers kill rhinos and elephants for their tusks. The tusks are made of ivory, which has long been valued for its beauty and durability. For tens of thousands of years, humans have used ivory to craft everything from tools and piano keys to religious objects, art and luxury items. It is seen as a sign of wealth and status.

Not only is poaching harmful to the rhinos and elephants themselves, it is also detrimental to the ecosystems of which they are a part. Through eating plants and digesting their seeds as they travel, these animals are able to spread these seeds and promote biodiversity and growth of these plants. As heavier mammals, they also trample the ground, which destroys weeds and other undesired species that compete for resources with plant species that are needed for the ecosystem to flourish.

Use Table 2 to answer the following questions.

Table 2 Elephants killed illegally in North Luangwa Valley, eastern Zambia, 2007–2013 (Nyirenda et al., 2015)

Elephant type	Description of carcass	Number killed each year							Totals
		2007	2008	2009	2010	2011	2012	2013	
Tusks naturally present	Meat and tusks taken	3	2	2	4	6	6	4	27
	Meat and tusks not taken	0	0	0	2	1	0	5	8
	Meat intact but tusks taken	1	4	7	4	7	27	25	75
	Meat taken but tasks intact	0	0	2	2	3	0	8	15
Tusks naturally absent (tuskless)	Meat taken	0	0	1	0	2	0	1	4
	Meat intact	0	0	0	0	0	0	0	0
	Total number of elephants killed illegally	4	6	12	12	19	33	43	129

1 Table 2 shows the number of elephants that have been killed illegally, as well as what was taken from the animals in each of the kills.
- **a** Explain how this data confirms the claim that elephants have been killed for their tusks.
- **b** There are hundreds of records from 1968 to the present about the number of elephants and rhinos that have been killed illegally. This data includes the sex of the animals, the estimated age of the animals and the length of the tusks. Describe how this data might be useful to scientists.

2 There have been many solutions to try to prevent poachers from killing these animals for their tusks. One solution that has been proposed is to dye the tusks of rhinos and elephants (Figure 3).
- **a** Describe how this would prevent poachers from killing these animals
- **b** Evaluate if this would be an effective solution.

3 Research two of the methods currently used to prevent poachers.
- **a** Describe how the solutions work to prevent poaching.
- **b** Discuss the advantages and disadvantages of each of your chosen solutions proposed to prevent poaching.

Figure 3 Adding dye to the tusks or rhinos and elephants is one of the solutions being considered to prevent poaching.

c Assess the effectiveness of these solutions in preventing poaching. Is the proposed solution showing results that decrease the incidence of poaching? Use data to justify your response. Hint: Assess – make a judgement of the data's value, quality, outcomes, results or size.

Some other solutions that are currently being used to prevent poaching include:

» raising awareness
» supporting local communities in terms of generating income other than the ivory trade
» strengthening legislation and law enforcement
» promoting responsible tourism
» disrupting the supply chain.

Lesson 14.8
Skills lab: Making recommendations

Aim

To make a recommendation based on scientific evidence

Method

1 Choose one of the following statements (or one of your own) to investigate and make a recommendation based on experimental evidence.
- Make a recommendation for the cleanest water source based on water quality.
- Make a recommendation for the most energy-efficient light bulb.
- Make a recommendation about the most effective insulation materials.
- Make a recommendation about the most suitable fertiliser for plant growth.
- Make a recommendation about the effect of music on memory function.
- Make a recommendation for the most effective cleaning product.

Secondary sources

2 Use reputable secondary sources to research scientific evidence relevant to your chosen statement.

First-hand investigation

3 Design and conduct a reliable and valid first-hand investigation to gather data and inform your recommendations.

4 Conduct a descriptive analysis of your data.

5 Present your findings to the class, ensuring that your decision is based on evidence that you have collected in your research.

Questions

Secondary sources

Discuss the impacts of your investigation and recommendation.

Lesson 14.9
Review: Data science

Summary

Lesson 14.1 Data science is used to investigate questions

- Investigative questions require specific and measurable data to answer them.
- Science uses the scientific method to ensure data is reliable and valid.
- Scientists need to consider the availability and cost of resources before they undertake an investigation.
- Scientists should always verify the reliability of the sources of information that they use for research.

Lesson 14.4 Pseudoscience

- Data can be misused or distorted to create pseudoscientific claims.
- Data can be distorted in different ways by presenting inconclusive results or extrapolating, excluding or slanting information.
- Claims should be investigated with scepticism to determine if they are pseudoscience or scientific facts.
- Pseudoscience frequently uses scientific-sounding words and anecdotal evidence, and is often inconsistent with existing scientific knowledge.

Lesson 14.5 Large data sets are used in many ways

- Big data refers to sets of data generated from large studies that can be used to enhance scientific understanding and allow scientists to make predictions.
- Data can be analysed using descriptive statistics, including mean, median and mode.
- Data can be analysed to determine if there is a correlation between the data.
- A causal relationship can only be determined if the independent variable occurs first and a change in the independent variable causes a change in the dependent variable.
- Large data sets have been used to verify scientific findings.

Review questions 14.9

Review questions Module 14

Retrieve

1 Describe the difference between an investigative and non-investigative question.

2 Define pseudoscience and give an example.

3 Which statement is correct about peer review in science?

A Peer review is when friends check your work to make sure you have not made any mistakes.

B Peer review is when experts in the relevant field check scientific work to ensure that it is scientifically valid.

C Peer review is when the media checks scientific work to make sure that it is new and exciting research.

D Peer review is when general scientists check scientific work to make sure that it follows the scientific method.

4 The scientific method is used for scientific research. Describe how the scientific method can be:

a controlled

b measurable

c reproducible.

5 Describe the difference between validity and reliability of a secondary resource.

Comprehend

6 Explain why scientists need to consider the availability of resources before they conduct an investigation.

7 Explain how scientists' ideas can be developed through scientific research.

8 Discuss why it is important to evaluate online resources when conducting scientific research.

9 Explain how large data sets have been used to support scientific claims.

10 Describe how secondary sources can be evaluated for validity and reliability.

Analyse

11 Human design is a philosophy that encourages people to use their strengths and challenges as opportunities for growth. It can also give context to some of the patterns and frustrations that people face in their lives.

  a Research "human design philosophy". Find data to support the idea of human design philosophy. Discuss if the data has been misused or distorted in any way.

  b Discuss if human design philosophy is scientific fact or pseudoscience. Justify your response.

  c Explain why it is important to distinguish between pseudoscience and real scientific claims.

Apply

12 A claim is made that "Increased social media use is linked to poorer mental health among teenagers".

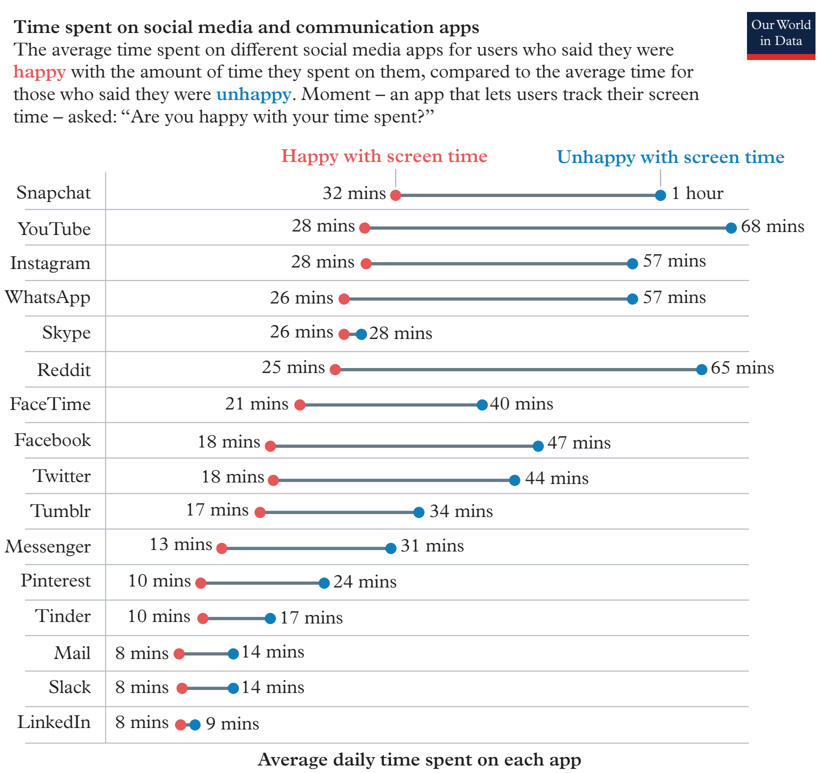


Figure 1 Data showing the time spent on different social media and communication apps.

a Use Figure 1 to answer the following questions.

  i Describe the relationship in the data.

  ii Describe the limitations in the data.

  iii Discuss if the data verifies the claim.

b Plot the data in Table 1 as a scatter graph and calculate the correlation coefficient.

  i Discuss if there is a correlation in the data.

  ii Discuss the limitations of the data.

  iii Discuss if the data verifies the claim.

  iv Discuss if the data shows causation. If it does, describe how; if it does not, explain what is needed to show causation.

Table 1 Data showing the average life satisfaction based on hours of social media per day.

Hours of social media use per day	Average life satisfaction score (1–7)
0–1	5.8
1–2	5.6
2–3	5.4
3–4	5.2
4–5	5.0
5–6	4.8

Social and ethical thinking

13 Describe the ethical considerations when using large data sets that include personal information.

14 Explain how the manipulation of data in the media may influence public opinion on scientific issues. Explain why this may be considered unethical.

15 Explain why it is important for scientists to communicate their findings clearly and honestly.

Critical and creative thinking

16 Design a public service announcement that educates people about the dangers of pseudoscientific claims.

Data analysis

17 Go to the weblink provided below.

Weblink: Best in Show, the Ultimate Dog Data

  a Describe what the data shows.

  b Click on the "See the Data" link near the bottom of the page to generate a spreadsheet with the data. Write an inquiry question that can be investigated using the data. For example, "Does the cost of breed relate to the intelligence of the dog?"

c Write a hypothesis that can be tested using the data.

d What variables would need to be investigated to answer your inquiry question?

e Plot a scatter graph of the data and conduct a regression analysis. Describe the relationship in the data.

f Draw a conclusion based on your data that answers the inquiry question and hypothesis.

g Describe how this data may be useful to scientists.

Research

18 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.

Nuclear energy

While Australia has historically relied on coal and natural gas, there is ongoing debate about whether nuclear energy could play a role in the country's energy future, given the impact of carbon emissions on climate change. Data science offers valuable insight into the economic, environmental and social implications of adopting nuclear power and informs discussions about the feasibility and impact of nuclear energy in Australia.

- Evaluate the type of data that would be collected and where it would come from, in order to assess the viability of nuclear power.
- How can data science help analyse Australia's energy consumption patterns and predict future energy needs?
- Determine the costs, risks and benefits of nuclear energy in Australia and how data can provide valuable insights.
- Some policymakers and citizens are reluctant to consider nuclear power for various reasons. Explain how data and modelling can be used to communicate the positives of nuclear energy, while also addressing any negatives.
- Identify ethical, social or safety considerations that should be addressed when exploring the use of nuclear energy in Australia.

Infectious diseases

Infectious diseases have disrupted societies throughout history. This includes the bubonic plague, the Spanish flu, smallpox and, most recently, COVID-19. Effective management to stop the spread and relieve the pressure on the medical system relies on timely access to accurate data. Data science allows for the collection and analysis of large data sets related to disease transmission, population demographics and healthcare resources. By applying modelling techniques, scientists and public health officials can track outbreaks, predict their spread and develop targeted responses.

- Explain what kind of data is important in tracking infectious diseases and how this data is collected.
- Communicate how data science can be used to identify and predict outbreaks of infectious diseases as well as be used for government and worldwide responses.
- Discuss the ethical considerations that arise when collecting and using personal health data for research purposes.
- Propose how data science can contribute to managing future outbreaks.

Transportation

In modern transportation, motion data plays a critical role in improving efficiency and ensuring safety. From monitoring vehicle speeds and breakdowns to analysing traffic flow patterns, data science provides valuable insights that can optimise transport systems. Advanced technologies, such as sensors and machine learning, are transforming the way we approach transportation challenges.

- Identify the types of data that are collected to monitor the motion of vehicles, and describe how they are analysed.
- Consider how data science can help predict and reduce traffic congestion.
- Investigate the role motion data has in the development of autonomous vehicles.
- Discuss how analysing trends and patterns in motion data can be used to improve road safety for other vehicles and pedestrians, and prevent and reduce accidents.
- Examine the limitations or ethical considerations when using motion or accident data in research.

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

acceleration
the change of velocity over time

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

accommodation
the process where the shape of the eye's lens changes to focus images of objects at different distances

accuracy
how carefully, correctly and consistently data has 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

action force
the force acted on one object by another object

active site
the region of an enzyme to which substrates can bind

adaptation
a characteristic or behaviour of a species that allows it to survive and reproduce more effectively

alkaline solution
a solution that consists of a base dissolved in water

alkali
a base that dissolves in water

alkane
an organic compound that only includes carbon and hydrogen atoms

allele
a version of a gene; a person inherits two alleles for each gene, one coming from each parent

allopatric speciation
a mode of speciation that occurs when a population is geographically separated into two or more isolated groups, preventing gene flow between them

alpha particle
a radioactive particle containing two protons and two neutrons; can be stopped by a piece of paper

amino acid
the building blocks of proteins, consisting of an amino group, a carboxyl group and a variable side chain

amyloplast
a specialised plant organelle packed with starch granules and used in geotropism

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

anecdotal
based on personal accounts rather than facts or research

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

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

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

anion
a negatively charged ion; an anion has more electrons than protons

anther
the end part of a stamen (male part of a flower); contains pollen

antibody
a molecule produced by B cells that binds to a specific pathogen

antidiuretic hormone (ADH)
a hormone that regulates the amount of water in the body

antigen
a substance that triggers an immune response, such as a molecule on the surface of a pathogen or an allergen

apoptosis
programmed cell death

artificial active immunity
the long-lasting immunity that develops after a vaccination when the immune system is exposed to a weakened version of a pathogen

artificial passive immunity
the temporary immunity that occurs when a person receives ready-made antibodies from an outside source

asbestosis
a lung disease caused by the inhalation of asbestos fibres

asexual reproduction
reproduction that involves a single organism producing offspring that are genetically identical to itself

atomic number
the number of an element in the periodic table, which equals the number of protons in that element

atom
the smallest particle of matter; cannot be created, destroyed or broken down (indivisible)

audible
able to be heard

autonomic nervous system
the part of the nervous system that controls involuntary actions such as heartbeat, breathing and digestion

autosomal dominant
an inheritance pattern in which only one copy of a gene (from either parent) carried on a non-sex chromosome is sufficient to cause the presence of a trait or disorder

autosomal recessive
an inheritance pattern in which two copies of a gene (one from each parent) carried on a non-sex chromosome are required for an individual to express the trait or disorder

autosome
a chromosome that does not determine the sex of an organism

auxin
a plant hormone that plays a crucial role in regulating growth and development

average speed
the total distance travelled divided by the total time taken

axon
a long projection of a neuron that carries electrical impulses away from the cell body to other neurons, muscles or glands

B

B cell
an immune cell that produces antibodies in response to pathogens

base
a substance that has the ability to accept a hydrogen proton

beta particle
a radioactive particle (high-speed electron or positron) with little mass; can be stopped by aluminium or tin foil

bias
leaning towards or against an idea by being prejudiced or unfair

binary fission
a form of asexual reproduction used by bacteria; the splitting of a parent cell into two equal daughter cells

bioaccumulation
the build-up of harmful substances in living organisms

biodegradable
a material that can be broken down naturally by living organisms, like bacteria, into harmless substances over time

biodiversity
the variety of life; the different plants, animals and microorganisms and the ecosystems they live in

biofuel
a renewable energy source derived from organic materials, including plants and animal waste

biomass
organic matter (material from organisms such as plants and animals); a renewable resource that can be used to generate energy

bioplastic
a type of plastic made from renewable biological sources, such as plants, rather than fossil fuels

biotechnology
the use of living organisms or their parts to develop products and technologies, often to improve human life or the environment

bivariate data
data that involves two variables and aims to explore the relationship between them

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

blue shift
the shift in the frequency of light towards higher frequencies, or the blue end of the spectrum, as the source of light and the observer move towards each other

Bohr model
the model of the atom developed by Niels Bohr in the 1910s, with electrons placed in shells centred on the nucleus

budding
asexual reproduction that involves a new organism developing from a bud on the parent and eventually detaching

bulb
a short, fleshy stem surrounded by layers of modified leaves; serves as a storage organ and a means of vegetative reproduction

C

carbon tax
a tax levied on the carbon content of fuels used by businesses or homes

carbon trading scheme
the process of allocating a set limit of carbon credits to businesses, which can then trade the credits

carcinogen
a substance that can cause cancer

carpel
the female reproductive structure of a flower, consisting of the stigma, style and ovary

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

cation
a positively charged ion; a cation has more protons than electrons

causal relationship
a cause-and-effect relationship where one event or action directly leads to another

cell body
the central part of a neuron that contains the nucleus and organelles

cell line
a cell culture developed from a single cell and therefore consisting of cells with a uniform genetic make-up

cell mutation
a change in a cell's DNA due to exposure to mutagens

central nervous system
the brain and spinal cord

centromere
the structure in a chromosome that holds two chromatids together

cerebrum
the largest part of the brain; divided into four lobes called the frontal lobe, the parietal lobe, the temporal lobe and the occipital lobe

cervix
the narrow neck connecting the uterus and the vagina

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 (histones) before replication

cilia
tiny hair-like structures on the surface of cells

circuit diagram
a diagrammatic way to represent an electric circuit

circular economy
a system that minimises or eliminates waste by reusing, recycling and regenerating materials

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
the change in global climate patterns, including temperature, over time

closed system
a system that does not allow matter to enter or leave but does allow energy to be transferred in or out

coal washing
the process of "cleaning" coal with water and chemicals to remove sulfur and other impurities before it is burned at a coal power plant

codon
a group of three nucleotides on mRNA

collision theory
in order for a reaction to occur, the reacting particles must collide with enough energy and at the correct angle

colloidal particles
particles small enough to remain evenly distributed in a mixture but larger than the particles in a solution

combustion
a reaction that involves oxygen and releases light and heat energy

competition
the struggle between individuals or groups for limited resources

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand; adenine pairs with thymine, and guanine pairs with cytosine

compostable
a material that can break down into rich soil (compost) under specific conditions, without leaving harmful residues

concave
refers to a lens or mirror that is thinner in the centre than at the ends

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

conductor
a material or substance that electrons can flow through; the flow of electrons through a conductor is electrical current

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

confounding variable
a variable that is not measured but may impact the results of an investigation

con
a disadvantage that is a risk or unfavourable outcome

consequentialism
an ethical framework focused on the outcome of an action or decision

continental drift
the continuous movement of the continents over time

continuous data
data that is measured and can be any value, such as height, mass, speed, temperature and distance

continuous spectrum
a spectrum that contains all wavelengths of light

control centre
the part of an organism, typically the brain or spinal cord in animals, that processes and responds to information received from receptors

control group
a group of organisms, chemical reactions or physical conditions that can be compared to the group that has had the independent variable changed

controlled variable
a variable that is kept constant and unchanged throughout an investigation

conventional current
the flow of positive charges in a circuit

converge
when rays of light move towards a single point

convergent evolution
the process whereby unrelated organisms evolve to have similar characteristics as a result of adapting to similar environments

convex
refers to a lens or mirror that is thicker in the centre than at the ends

Coriolis effect
the influence of Earth's rotation on the direction of movement of air or water

cornea
a thin, transparent material that protects the eye and refracts light

correlation
a relationship between two or more variables

correlation coefficient
a number between −1 and 1 that quantifies the strength and direction of a linear relationship between two variables; often represented by "*r*"

cosmic microwave background radiation
remnant electromagnetic radiation left from early stages of the Universe

covalent bond
a chemical bond involving the sharing of electrons between atoms; the sharing of electrons creates a stable electron configuration within the atoms

credible
information that is reliable, trustworthy and based on evidence

CRISPR-Cas9
a gene-editing tool that allows for easy and accurate modifications to DNA, enabling researchers to "cut" and "paste" genes in a way that can change how an organism functions

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

cross-linked polymer
a polymer consisting of multiple long polymer chains that have been linked together to form a three-dimensional structure

cross-pollination
the exchange of pollen and ova between different plants of the same species

crossing over
a process during meiosis where homologous chromosomes exchange segments of genetic material, leading to increased genetic variation in the resulting gametes

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

cultural protocol
the customs, values and guidelines that shape behaviour and interactions within a specific cultural group, ensuring respectful and appropriate interactions

cytokinesis
the splitting of a replicating cell into two cells

D

deciduous
a type of plant that loses its leaves during the cooler months to conserve energy when there is less sunlight; annual shedding of leaves

decomposition
a reaction that involves the breakdown of a compound into simpler substances

delocalised electrons
electrons that are not restricted to a single atom or covalent bond

dendrite
the part of a neuron (nerve cell) that receives a message and sends it to the cell body

deontology
an ethical framework focused on the intent of an action or decision

dependent variable
a variable in an investigation that may change as a result of changes to the independent variable

descriptive statistics
methods used to summarise and describe the main features of a data set

diatomic molecule
a molecule that is composed of two atoms of the same or different chemical elements

dilation
widening of the pupil to allow more light to enter the eye

diploid
containing two complete sets of chromosomes

discrete data
data where the numbers can be separated into different groups

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

displacement reaction
a reaction resulting in the displacement of an atom or group of atoms

distance
how far an object has travelled in a set time

diverge
when rays of light move away from each other

divergent evolution
the process whereby related species become more dissimilar over time due to different environmental pressures, resulting in distinct traits from a common ancestor

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

DNA replication
the process by which a cell makes an identical copy of its DNA

dominant allele
a gene variant that expresses its trait in an organism's phenotype even if only one copy is present

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

double displacement reaction
an exchange of ions from the two reactants to form two new products

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

dry cell
contains dry substances and uses a chemical reaction to produce electrical energy; commonly used for portable devices such as a torch battery

E

early detection and predictive testing for adults
the testing of chromosomes for the presence of alleles that increase the probability of cancers forming

echolocation
the ability to use sound to navigate and hunt

ecological footprint
measure of the environmental impact of a person, community or country by calculating the amount of land and water needed to provide resources and absorb waste, especially carbon emissions

economic sustainability
practices that manage environmental, economic and social factors to support long-term economic growth and development today, without compromising this ability for future generations

economy
the supply of money and goods and services that are produced, distributed and consumed

ectoparasite
a parasite that lives on the host (e.g. a tick)

ectotherm
an animal that is unable to regulate its own body temperature

effector
a cell, tissue or organ that responds to a stimulus

elastomer
a long chain of polymers occasionally linked together like a ladder

electric charge
a property of subatomic particles (electrons and protons) that results in electric energy; electric charge can be positive or negative

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

electric current
the flow of electrical charge through a circuit

electrical conductor
a material through which charged particles are able to move

electrical insulator
a material that does not allow the movement of charged particles

electromagnetic wave
a transverse wave that transfers energy through space without any need for a medium

electron
a negatively charged particle that moves around in the space outside the nucleus

electron configuration
the arrangement of electrons of an atom, placed in electron shells centred on the nucleus

electron shells
the placement of electrons around an atom's nucleus; an atom may have one or more electron shells

electroreception
the ability to sense electric fields generated by other animals

electrostatic charge
an electric charge between two objects caused by a deficiency or excess of electrons (negative charges)

element
a pure substance made of only one type of atom

emission spectrum
the pattern of coloured lines of light that are seen through a spectroscope when an element is heated

endemic
always found in a specific location

endocrine system
a collection of glands that make and release hormones

endometrium
the lining of the uterus

endoparasite
a parasite that lives inside the host (e.g. a tapeworm)

endotherm
an animal that regulates its own body temperature

energy
the capacity to do work

energy efficiency
a measure of how much input energy is transformed, rather than lost (via sound or heat)

enhanced greenhouse effect
the additional effect that humans are having on the natural greenhouse effect due to the burning and release of fossil fuels

enriching
increasing the proportion of a specific component in a mixture

environmental sustainability
practices to maintain, manage and minimise damage to natural resources today so they are available for the future needs of generations

enzyme
a protein-based catalyst

epidemic
a widespread outbreak of an infectious disease that is typically isolated to a specific region

epididymis
a coiled tube behind the testes that carries sperm to the vas deferens

ethical framework
a structured system of principles and values that guides individuals and organisations in making decisions about right and wrong

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

eukaryotic
an organism with cells that contain a nucleus and membrane-bound organelles; protists, fungi, plants and animals have eukaryotic cells

eutrophication
excess nutrients in a body of water that can cause the rapid growth of algae (algal blooms) and damage to aquatic ecosystems

evolution
the process by which populations of organisms change over successive generations through variations in their genetic material

evolutionary relationship
the way in which two species or populations are related with respect to their evolutionary descent

external fertilisation
the union of male and female gametes outside the female reproductive tract

extinct
refers to when there are no living members of the species left

extrapolation
estimating unknown values from trends in known data

F

fallopian tubes
tubes that connect the ovaries to the uterus

fermentation
an anaerobic process of breaking down sugars

fertilisation
the union of male and female gametes

filament
the stalk or slender part of a stamen, which holds the anther, where pollen is produced

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

foetus
an unborn animal or human after the embryo stage; in humans, this is after 8 weeks of development

force
a push or pull that, if unbalanced, can cause a change in an object's motion or shape

fossilisation
the process of an organism becoming a fossil

fossil
the remains or traces of an organism that existed in the past

fragmentation
asexual reproduction in which an organism breaks into fragments, each capable of growing into a new individual

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

fuse
a switch or wire that stops the flow of current if it starts moving too fast

G

gamete
a reproductive cell (sperm in males and ova in females) that carries half the genetic information necessary for the formation of a new organism

gamma ray
a high-energy electromagnetic ray released as a part of radioactive decay; can be stopped by lead

gene
a segment of DNA that codes for a specific trait

gene cloning
the production of identical copies of a gene

gene editing
a method that allows scientists to make precise changes to an organism's DNA to alter its traits

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
a medical technique that involves altering the genes inside a person's cells to treat or prevent disease; it aims to correct or replace faulty genes with healthy ones to improve health outcomes

generator
a machine that uses the electromagnetic effect to separate charges and produce electricity

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

genetic disorder
a condition caused by abnormalities (mutations) in the DNA (genes); genetic disorders are inherited (passed from parent to child)

genetic drift
a random evolutionary mechanism that causes changes in allele frequencies within a population's gene pool over time

genetic engineering
the deliberate engineering of change in the DNA of an organism

genetic predisposition
an increased chance of developing a disease due to genetic (inherited) characteristics

genetic screening
the testing of populations or groups to identify individuals at risk of genetic disorders, even if they do not show symptoms

genetic technology
techniques that involve manipulating the genetic material (DNA) of organisms to change their characteristics or functions

genetic testing
testing that examines an individual's genetics to identify changes or mutations that may indicate a genetic disorder or an increased risk of developing certain diseases

genetically modified organism (GMO)
an organism that has had its DNA changed in a laboratory

genome
the complete set of genetic material present in an organism, including both coding and non-coding DNA

genotype
the combination of alleles for a particular trait

geothermal energy
energy that comes from heat beneath Earth's surface

geotropism
the growth or movement of a plant in the direction of gravity (positive geotropism) or against gravity (negative geotropism)

gestation
the length of time between fertilisation and birth

global warming potential (GWP)
a measure of how much impact a gas will have on atmospheric warming over a period of time compared to carbon dioxide

gonadotropin-releasing hormone (GnRH)
a hormone produced in the hypothalamus that plays a crucial role in regulating the reproductive system

greenhouse gas
a gas (carbon dioxide, water, methane) in the atmosphere that can absorb heat

groups
the vertical columns of the periodic table; elements in each group have the same number of electrons in their valence shell

gymnosperms
seed-producing plants that do not form flowers or fruits, and their seeds are exposed on the surface of cones

H

Haber–Bosch process
the method for the production of ammonia

half-life
the time it takes the radioactivity in a substance to decrease by half

haploid
containing one complete set of chromosomes (*n*), which is half the diploid number; gametes (sperm and egg cells) are haploid

heredity
the process by which traits and characteristics are passed from parents to offspring through genes

heterotrophic
an organism that consumes other organisms to obtain energy

heterozygous
having two different alleles for a particular trait; a carrier for a recessive trait

hibernation
an extended period of inactivity, typically in response to colder conditions

high-pressure system
regions where the air pressure is higher than surrounding areas

histamine
a chemical released by mast cells during allergic reactions and immune responses; causes blood vessels to dilate and become more permeable, leading to swelling, redness and itching

histone
a protein that helps package and organise DNA in the nucleus of eukaryotic cells

homeostasis
the process by which the body detects and responds to stimuli to ensure a stable internal state is maintained

homologous chromosome pairs
chromosome pairs – one inherited from each parent – that are similar in size, shape and genetic content

homologous structures
structures that are 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

hormone
a chemical messenger that travels through blood vessels to target cells

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 nitrogenous bases in the DNA helix

hydropower
energy produced by falling water that turns turbines to generate electricity

hydrotropism
the growth or movement of plant roots towards or away from moisture

hyperglycaemia
a condition resulting from too much glucose in the blood

hypoglycaemia
a condition resulting from too little glucose in the blood

hypothalamus
the region at the centre of the brain that produces hormones and regulates important body functions such as sleep, body temperature and heart rate

hypothesis
a proposed explanation for a prediction that can be tested

I

image
what is formed when light from an object is reflected by a mirror

immune
able to fight infection as a result of prior exposure

immune system
a system of organs and structures that protect an organism against disease

incidence
the number of new cases of a disease measured over a specific time

inconclusive
not leading to a definite conclusion or result

independent variable
a variable that is changed in an investigation

indicator
a substance that changes colour in the presence of an acid or a base

inert
a substance that does not react with other substances

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

infectious disease
a condition or disorder caused by pathogens such as bacteria, viruses and fungi

inference
a conclusion based on evidence and reasoning

inflammation
the body's protective response to injury, infection or harmful stimuli

infrasound
sounds that cannot be heard by humans, with frequencies usually below 20 Hz

inorganic compound
a chemical compound that does not have any carbon–hydrogen bonds

insulator
a substance that prevents the movement of thermal or electrical energy

internal fertilisation
the union of male and female gametes inside the female reproductive tract

interneuron
a nerve cell that links sensory and motor neurons; also known as a connector neuron

interphase
a phase of cell life where normal functioning occurs

interpolation
an estimation of a value within the original range of the data

intrusion
when upwelled waters do not reach the surface

inversely proportional relationship
a relationship between two variables in which the dependent variable decreases as the independent variable increases

investigative
able to be investigated through measurement and observation

ion
an atom that has either a net positive or negative electrical charge

ionic bond
a chemical bond formed from the electrostatic attraction between oppositely charged ions

ionic compound
a compound that is formed by ionic bonding; ionic compounds consist of both positively and negatively charged ions

ionisation
the process by which atoms become ions by losing or gaining electrons

iris
the coloured part of the eye that controls the dilation and shrinking of the pupil

isobar
a line drawn on a weather map that joins places of equal air pressure

isolated system
a system that does not allow matter or energy to enter or leave

isolation
the division of a population into two groups

isotopes
different forms of the same element that have a different atomic weight due to a different number of neutrons, but the same number of protons

J

joule (J)
the unit of energy; its symbol is J

K

karyotype
a way of representing a complete set of chromosomes, arranged in pairs, in order of decreasing size

kilowatt-hour
unit used by electricity companies to measure electricity usage; it is equal to the amount of energy used (in kilowatts) in one hour

kinetic energy
the energy an object or particle has due to its motion

kurtosis
indicates how much data resides in the tails (outliers) compared to a normal distribution

L

law of conservation of energy
a scientific rule that states that the total energy of a closed system and its surroundings is always constant and cannot be created or destroyed

law of reflection
when light is reflected off a surface, the angle of incidence will equal the angle of reflection

lens
a curved piece of transparent material

line graph
a graph used to display continuous data that is connected by a line; typically used to demonstrate trends in data

line of best fit
the line on a scatter graph that passes through, or nearly through, as many data points as possible to show any overall trends in the data

linear polymer
a long single chain 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

load
a device that transforms electric potential energy into other forms of energy such as heat or light

logbook
a book used to record all the details of experiments or research projects

longitudinal wave
a type of (sound) wave where the particles move in the direction of travel of the wave; also known as a compression wave

low-pressure system
regions where the air pressure is lower than surrounding areas

M

magnetoreception
the ability to sense Earth's magnetic fields

magnitude
the size or extent of something

mast cell
a type of white blood cell that plays a role in the inflammatory response; releases histamine, which causes capillary walls to become more permeable

maternal serum screening (MSS)
the genetic testing of fetal DNA found in the mother's blood

matter
anything that has space and volume; it is made up of atoms

mean
the average of a set of numbers calculated by adding the numbers and dividing by the total number of values

mechanical waves
waves that need a medium to propagate (transfer energy)

mechanoreceptor
a nerve cell that detects pressure or touch

median
the middle value in a sorted data set

medium
the matter that waves travel through

megafauna
large animals, typically extinct species that were significantly larger than modern-day relatives

meiosis
a specialised type of cell division that reduces the chromosome number by half, producing four genetically unique haploid gametes from a single diploid parent cell

memory cell
an immune cell produced in response to an infection; retains the memory of how to fight the pathogen

Mendelian inheritance
the inheritance patterns of traits controlled by single genes with two alleles, one dominant and one recessive

meniscus
the curve at the surface of a liquid in a container

menstruation
also known as a period; the process of the endometrial lining of the uterus breaking down and leaving the vagina

mesothelioma
an aggressive type of cancer that results from asbestos fibres sticking to the protective layer of the lungs

methodology
the overall approach to a scientific investigation

migrate
the movement of an animal from one region to another, typically in response to changing seasons

mineral
a naturally occurring inorganic substance with a definite chemical composition and crystalline structure

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

mode
the value that appears most frequently in a data set

molecular compound
a compound composed of two or more non-metal atoms held together by chemical bonds

molecule
a group of two or more atoms connected by chemical bonds; a molecule is the smallest unit of a substance that retains its properties

monatomic
an ion consisting of single, isolated atoms that are not bonded together

monogenic inheritance
the inheritance pattern in which a single gene determines traits

monogenic trait
a trait determined by one gene with two alleles

monohybrid cross
a genetic cross between two individuals that focuses on the inheritance of a single trait, controlled by one gene with two alleles

monomer
a small molecule that is capable of reacting with other similar molecules to form a long-chain molecule (polymer)

mortality
number of deaths

motor neuron
a nerve cell that carries a message from the central nervous system to a muscle cell; also known as an efferent neuron

mRNA
a molecule that carries the coding sequence for protein synthesis

mutagen
a chemical or physical agent that causes a change in genetic material such as DNA

mutation
a permanent change in a DNA sequence

myelin sheath
a fatty layer that covers the axon of a nerve cell

N

natural active immunity
the long-lasting immunity that develops when the immune system is naturally exposed to a pathogen, leading to the production of specific antibodies and memory cells

natural greenhouse effect
the natural warming of Earth due to water vapour and other gases being present in small amounts in the atmosphere and affecting Earth's radiation balance

natural passive immunity
the temporary immunity that occurs when a baby receives antibodies in breast milk or through the placenta from the mother

natural selection
the process by which traits that enhance survival and reproduction become more common in a population, while less advantageous traits diminish over generations

negative control
an individual test that checks that a negative result is possible in an experiment

negative feedback loop
a regulatory mechanism in which the stimulus causes a response that acts in the opposite direction to whatever is being regulated

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

neuron
a nerve cell

neurotransmitter
a chemical messenger that crosses the synapse between the axon of one neuron and the dendrite of another neuron

neutral
having a pH of 7, so neither an acid nor a base; an example is water

neutron
a neutral (no charge) subatomic particle in the nucleus of an atom

newborn screening
the testing of chromosomes in a baby's white blood cells for the presence of a genetic disease

newton
the unit used to measure force, symbol N

Newton's first law
an object remains at rest or in constant velocity unless acted on by a net unbalanced force; also known as the law of inertia

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

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

noble gases
gases with a full electron shell; noble gases are extremely stable and do not easily react with other elements

non-disjunction
an error in cell division (meiosis or mitosis), where chromosomes fail to separate properly, resulting in daughter cells with an abnormal number of chromosomes

non-infectious disease
a condition or disorder caused by environmental or genetic factors rather than pathogens

non-investigable
cannot be investigated through measurement and observation

non-specific immune response
the generalised response of the immune system to protect the body against all pathogens, rather than targeting a specific pathogen; also called the "innate immune response"

non-spuriousness
not false or fake

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

nuclear fission
when the nucleus of an atom splits into two or more smaller nuclei, with the release of energy

nuclear fusion
the process in which smaller nuclei come together and form a larger nucleus

nucleotide
the building block of DNA consisting of one deoxyribose sugar, one phosphate group and one nitrogenous base

nucleus
(chemistry) the small region at the centre of an atom that consists of the protons and neutrons; plural "nuclei"

nutrient
a compound that is required for the growth, repair and basic functions of a body; includes proteins, fats, carbohydrates, water, vitamins and minerals

nutritional deficiency
a condition caused by inadequate intake or absorption of nutrients, such as proteins, fats, vitamins and minerals

O

objective
without bias or prejudice

observations
facts or details based on actual sensory information

ochre
a natural clay earth pigment rich in iron oxide, commonly found in yellow, red and brown hues

octet
a group or set of eight

octet rule
where the valence shell of an electron has eight electrons

oestrogen
a reproductive hormone in females

offspring
an organism's young, or child

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

opaque
a substance that does not allow light to pass through

open-cut mining
a surface mining method that digs a large hole to extract minerals near the surface

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

optic nerve
the connection that sends the electrical signal to the brain to create the image; creates a blind spot where it meets with the retina due to the lack of light-sensitive cells

ore
a naturally occurring solid material from which metals or minerals can be extracted

organic compound
a chemical compound that has carbon–hydrogen bonds

organism
an individual living thing

outlier
a data point that does not fit with the rest of the data

ovum
(plural: ova) the reproductive egg

ovary
a female reproductive organ found in both animals and plants; it produces eggs (ova) in animals and ovules in plants

ovulation
the part of the menstrual cycle when an egg is released from the ovary

P

pandemic
a widespread outbreak of an infectious disease that is spread across multiple global regions

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

parthenogenesis
asexual reproduction in which an egg develops into a new individual without fertilisation

pathogen
a disease-causing agent such as bacteria, virus or fungi

pattern
when a set of data repeats in a predictable way

pedigree
a chart showing the phenotypes of an individual and their ancestors, usually over several generations; also known as a family tree diagram

peptide hormone
a protein-based hormone that is fast acting and relatively short-lived

periods
the horizontal rows of the periodic table; elements in each period have the same number of electron shells

peripheral nervous system
all the neurons (nerve cells) that function outside the brain and spinal cord

permafrost
ground that has been frozen since the last Ice Age; stores carbon

permeable
a barrier that allows fluids, gases or other substances to pass through it

pH scale
a scale that represents the acidity or basicity of a solution; $pH < 7$ indicates an acid, $pH > 7$ indicates a base, pH 7 indicates a neutral solution

phagocyte
an immune cell that surrounds, absorbs and destroys pathogens

phagocytosis
the process by which certain white blood cells engulf and destroy bacteria

phenotype
observable physical and physiological traits of an organism, resulting from the interaction between its genotype and environmental influences

photon
an elementary particle of electromagnetic radiation that acts as both a particle and a wave

photoreceptor
a cell in the eye that detects light

phototropism
the growth or movement of a plant towards or away from light

photovoltaic cells (pv cells)
solar cells that transform solar energy into electrical energy; also known as pv cells

phylogenetic tree
a branching tree-like diagram showing relationships between different taxonomic groups

pituitary gland
a small gland at the base of the brain that produces hormones

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

placenta
the organ that connects the developing foetus to its mother

pluripotent
a stem cell that can develop into nearly all cell types in an organism

pollination
the process in which pollen from the male reproductive plant structures is transferred to the female reproductive structure of a plant

pollution
the introduction of substances to the environment that can cause harm

polyatomic ion
an ion consisting of two or more atoms that have been bonded together

polygenic
inheritance patterns where multiple genes contribute to a single trait, resulting in a continuous range of phenotypes

polymer
a long-chain molecule formed by the joining of many smaller repeating molecules (monomers)

polymerisation
a chemical reaction where small molecules (monomers) combine to form a long-chain molecule (polymer)

positive control
an individual test that checks that a positive result is possible in an experiment

potential difference
the difference in electrical potential energy between two points of a circuit for each unit of charged particle; also known as voltage drop

poultice
a soft, moist mass of material, often made from herbs, plants or clay, that can be applied to the skin, typically to relieve pain, reduce inflammation or treat infections

power
the rate at which energy is transformed in a circuit

precision
the state of measurements being consistent and repeatable

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

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

primary data
data collected by the person writing the report

pro
an advantage where the outcomes are favourable

probe
a DNA or RNA fragment used to detect complementary sequences in a sample through hybridisation

procedure
a series of clear steps that are followed when conducting a scientific investigation; also called a method

product
a substance obtained at the end of a chemical reaction; written on the right side of a chemical equation

prokaryotic
a single-celled organism with no nucleus or membrane-bound organelles; bacteria and archaea are made up of a single prokaryotic cell

prostate gland
a walnut-sized structure surrounding the neck of the male bladder that blocks the flow of urine so sperm can move along the urethra

protein
a molecule made of long chains of amino acids, essential for the structure, function and regulation of body tissues and organs

proton
a positively charged subatomic particle in the nucleus of an atom

pseudoscience
incorrect beliefs that are mistakenly thought to be scientific

Punnett square
a graphical tool used in genetics to predict the possible genotypes and phenotypes resulting from a cross between two individuals

pupil
the black, circular opening that controls the amount of light entering the eye

Q

qualitative data
information that is descriptive and cannot be represented by numbers

quantitative data
information that can be counted or measured; numerical values

R

radioactive decay
the conversion of a radioactive isotope into its stable form, releasing energy in the form of radiation

radioisotope
an isotope (different versions of the same element due to differing atomic mass) that emits radiation due to an unstable nucleus

radionuclide
a radioactive isotope

random error
variability in a measurement in either direction by an unknown cause or causes

randomised
when people, objects or similar are selected at random

reactant
a substance used at the beginning of a chemical reaction; written on the left side of a chemical equation

reaction force
the force acting in the opposite direction to an initial force

reaction rate
how fast a reaction proceeds

receptor
a specialised cell that detects a stimulus or change in the normal functioning of the body

recessive allele
a gene variant that only expresses its trait when two copies are present

recessive gene
a gene that must be present on both chromosomes to be expressed

recessive trait
a characteristic that is only expressed in the phenotype when two identical alleles are inherited

recombinant DNA technology
a range of techniques that use enzymes to cut and join the DNA from different organisms

recycle
to turn waste into a new material

red shift
the shift in the frequency of light towards lower frequencies, or the red end of the spectrum, as the source of light and the observer move away from each other

reflex
an involuntary movement in response to a stimulus

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

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

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

refute
prove a statement to be false or incorrect using evidence

regression analysis
a statistical method used to predict how one variable (the dependent variable) changes when another variable (the independent variable) changes

relationship
an association between two or more variables; observed when a change in one variable causes a change in another

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
the same results and observations can be made under the same conditions and using the same method

reproducible
the ability to repeat and replicate a test exactly

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

resistor
a device that has opposition to an electric current

resource
any natural material that can be extracted and used

response
the action or change in behaviour or physiology that occurs as a result of a stimulus

retina
light-sensitive cells that convert light into electrical signals

retinal cell
a photoreceptor cell of the eye's retina

rhizome
a horizontal, underground stem that grows parallel to the soil surface; serves both as a storage organ and as a means of vegetative reproduction

risk assessment
the determination of quantitative or qualitative estimate of risk related to a well-defined situation and a recognised threat (also called hazard)

risk
the potential for harm

RNA
(ribonucleic acid) a single-stranded molecule essential for protein synthesis; contains the sugar ribose, unlike DNA which has deoxyribose

runner
specialised horizontal stems that grow along the ground's surface; they extend from the main plant and can produce new plants at their nodes

S

safety data sheet (SDS)
a document providing information about how to minimise the risk associated with the use, handling and storage of hazardous chemicals

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

Sankey diagram
a flow chart that represents movement or change in resources, such as the transfer or transformation of energy

satellite
any object that orbits a planet or a star

scalar quantity
quantity that has magnitude (size)

scatter graph
a graph used to represent continuous data; it consists of discrete data points

scattering of light
when light waves strike particles such as dust, gases or water droplets, causing them to deflect from their original path in different directions

scientific argument
an explanation based on evidence rather than belief or opinion

scientific scepticism
questioning the scientific basis of claims, theories or beliefs

scrotum
a sac-like structure that contains the testes

sebum
an oily secretion produced in the sebaceous glands of the skin

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

secondary data
data collected by someone else

selection pressures
environmental factors that affect an organism's ability to survive

selective gathering
the careful removal of specific plants or animals from a population to maintain ecological balance while allowing for resource use

self-pollination
when both gametes come from the same plant

semiconductor
a material that has properties between conductors and insulators; its conductivity increases by adding some impurities to it

seminal vesicles
a pair of small pouch-like structures that provide a sugary fluid that assists sperm to travel along the vas deferens

sensory neuron
a nerve cell that carries a message from a receptor to the central nervous system; also known as an afferent neuron

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

sex chromosome
a chromosome that determines the sex of an organism

sexual reproduction
the combination of genetic material from two parent organisms, resulting in offspring that are genetically unique

sexually dimorphic
describes species in which the male and female organisms look structurally different

shell diagram
a diagram that shows the number of electrons in each electron shell around a particular atomic nucleus

short circuit
a condition in an electrical circuit that allows the current to flow along an unintended path

silent mutation
a change in a DNA sequence that does not alter the amino acid sequence of a protein, typically having no impact on its structure or function

single displacement reaction
a reaction in which a more reactive element displaces a less reactive element on a molecule

sister chromatids
identical copies of a chromosome that are formed during DNA replication and are joined together at the centromere; they separate during cell division

social sustainability
practices that focus on inclusion, equity and just societies to ensure the wellbeing of current and future generations

solar energy
the energy from sunlight that can be converted into electrical or heat energy

solar radiation
radiant electromagnetic energy from the Sun

somatic cell
all types of cells in the body except for gametes (egg and sperm)

somatic nervous system
the part of the nervous system that controls the muscles attached to the skeletal system

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

speciation
the process that results in the formation of a new species

species
a group of organisms that can breed with each other in natural conditions to produce offspring that are viable (alive) and fertile (able to have children of their own)

specific immune response
the response of the immune system that targets specific pathogens using B cells and T cells; also called the "adaptive immune response"

spectroscope
a device that spreads out different wavelengths of light

spectrum
a chart or graph that shows the intensity of emitted light across different wavelengths

speed
the distance travelled per unit of time

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

sperm
the male gamete (sex cell)

spinal cord
the cylindrical bundle of nerve fibres and associated tissue which is enclosed in the vertebrae

spore
a tiny reproductive structure that, unlike a gamete, does not need to fuse with another cell to form a new organism

spreadsheet
a digital tool that allows you to organise, calculate and analyse data displayed in rows and columns

stamen
the male reproductive part of a flower, consisting of the anther and filament

standard deviation
measures how close the values in the data set are to the mean; a low standard deviation indicates data points are clustered tightly around the mean, while a high standard deviation means they are more dispersed

stellar fusion
is the process where light atomic nuclei fuse under extreme heat and pressure in stars, releasing energy

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

steroid hormone
a cholesterol-based hormone that is slower acting and relatively long-lived

stigma
the top of the carpel; this is where the pollen from the anther begins its journey to the ovary

stimulus
any information that the body receives that causes it to respond

stimulus–response model
a model that describes how an organism responds to a stimulus (change in their environment)

style
a slender, tube-like structure that connects the stigma to the ovary in the carpel

subsidence
the gradual caving in or sinking of an area of land

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

sustainability
to maintain, manage and minimise damage to resources so they are available for future generations, while meeting the needs of the present

synapse
a small gap between two neurons, across which nerve impulses are transmitted

synaptic terminal
the bulb-like structure at the end of an axon that transmits information (neurotransmitters) to the synapse; also called an axon terminal

synthesis
a reaction that involves building up compounds by combining simpler substances, usually elements

systematic error
a consistent and predictable difference in measurements

T

T cell
an immune cell that recognises and kills pathogens

target cell
a cell that has a receptor that matches a specific hormone

temporal relationship
the timing or order of events in relation to each other

test cross
a genetic cross used to determine the genotype of an individual with a dominant phenotype; requires a cross with an individual that is homozygous recessive for the trait

testis
(plural: testes) the male reproductive organ that produces sperm

testosterone
a male hormone involved in the reproductive system

the Doppler effect
the apparent change in the frequency of a wave when there is a relative motion between the source of the wave and the observer

thermoplastic polymer
a polymer that softens and forms new shapes when heated

thermoreceptor
a nerve cell that detects temperature

thermosetting polymer
a polymer that does not melt or change shape when heated

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

trace fossil
a geological record of biological activity, distinct from body fossils; includes footprints, burrows, nests, fossilised dung and bite marks

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

transformed
describes energy that has changed into a different form

transgenesis
the process of introducing a gene from one species into the DNA of another species, creating a genetically modified organism (GMO)

transgenic organism
an organism that has a gene from another organism inserted into its own chromosomes

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

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

transparent
a material or object that you can see through; allows light to pass through

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

trend
the general tendency of a set of data to move in a certain direction

trisomy
a genetic condition characterised by the presence of an extra chromosome in an individual's cells, resulting in a total of three copies of a particular chromosome instead of the usual two

tRNA
a molecule that carries amino acids

true value
the value that would be obtained if its measurement was free of errors

true-breeding
an organism known to be homozygous dominant or homozygous recessive

tuber
the swollen, fleshy storage organ of a plant that develops from underground stems; serves as a storage organ and a means of vegetative reproduction

turbine
a large wheel with angled sections called vanes, like a propeller, that is used to generate electricity

U

ultrasound
a high-frequency sound, with a frequency above the range humans can hear

unbiased
showing no prejudice for or against something

uncertainty
the range of possible values where the true measurement lies

underground mining
a method that creates tunnels to reach and extract deeper minerals

unicellular prokaryotic organism
a single-celled life form without a defined nucleus or membrane-bound organelles, including bacteria and archaea

univariate data
data about a single variable

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

uterus
an organ in the female reproductive system; where the foetus develops

V

vaccination
an injection of an inactive or artificial pathogen that results in the individual becoming immune to a particular disease

vagina
a female reproductive organ; a muscular tube connecting the outside of the female body to the cervix

valence electrons
the electrons in the valency shell of an atom

valence shell
the outermost electron shell of an atom

valency
the number of electrons an atom needs to lose, gain or share to have a full outer shell

valid
where a test investigates what it sets out to investigate

Van de Graaff generator
a machine that produces an electrostatic charge

vas deferens
the tube through which sperm travel from the epididymis to the prostate

vector
an organism that transmits a pathogen to a different species

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

vegetative reproduction
asexual reproduction in plants from vegetative parts like roots or stems; examples include runners, tubers and rhizomes

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

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

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

virtue ethics
an ethical framework focused on the character of the individual(s) making the decision

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

voltage
a measure of the amount of energy in joules given to a unit of charged particles passing through a battery

W

water cycle
the continuous movement of water on, above and below the surface of Earth

watt
unit of power; 1 watt is equal to 1 joule per second

wave
a disturbance that transfers energy through a medium or space without the transfer of matter

weaning
the gradual transition of a young mammal from a milk-based diet to solid food, reducing reliance on maternal milk

weather
the temperature, humidity, rainfall and wind on particular days at a particular place

wet cell
contains wet substances and uses a chemical reaction to produce electrical energy (e.g. a car battery)

white blood cell
an immune cell that destroys pathogens

X

X-linked dominant
an inheritance pattern in which a gene associated with a trait or disorder is located on the X chromosome, and only one copy of the gene is needed for the trait to be expressed; both males and females can be affected

X-linked recessive
an inheritance pattern in which the gene causing the trait or disorder is located on the X chromosome and two copies of the gene are required for females (XX) to express the trait; in contrast, males (XY) will express the trait if they inherit a single copy

Z

zoonotic
a disease that can be transferred between non-human animals and humans

zygote
the first diploid cell of a new organism that results from the union of two haploid gametes during fertilisation

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Periodic table

Key	
6	Atomic number
C	Chemical symbol
12.01	Atomic mass
Carbon	Name of element

Period \ Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 **H** 1.0 Hydrogen																	2 **He** 4.0 Helium
2	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
3	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
4	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
5	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
6	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
7	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

Series															
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		Non-metals	Other
Alkali metal	Actinide	Diatomic non-metal	Metalloid
Alkaline earth metal	Transition metal	Polyatomic non-metal	Unknown chemical properties
Lanthanide	Post-transition metal	Noble gas	

Notes

Notes

Notes

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